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Thorsten Blecker, Wolfgang Kersten and
Christian M. Ringle (Eds.)

Operational Excellence in Logistics and Supply Chains

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Prof. Dr. Thorsten Blecker
Prof. Dr. Dr. h. c. Wolfgang Kersten
Prof. Dr. Christian M. Ringle
(Editors)

Operational Excellence in Logistics and Supply Chains

Optimization Methods, Data-driven Approaches and Security Insights

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Preface

The HICL-Conference celebrates its 10th anniversary, indicating major interest in the research fields of supply chain management and logistics. Thanks to the large number of outstanding research contributions to this year's conference, the proceedings comprise of three volumes. They are dedicated to make recommendations for new approaches and solutions that enable companies to cope with current and future challenges in supply chains and logistics.

The contributions of the third volume of the 2015 conference focus on innovative models to optimize logistics and supply chains at an operational level. They address process efficiency and data-related aspects. Supply chain security insights are also given.

We would like to thank the international authors for making this volume possible. Their research papers significantly contribute to logistics and supply chain management research. This book would not exist without good organization and preparation. We would like to thank Niels Hackius and Irene Sudy for their efforts to prepare, structure, and finalize this book. We would also like to thank Pascal Freigang, Beverly Grafe, Julian Schäfer, and Henning Schöpper for their contributions to the print layout.

Hamburg, August 2015

Prof. Dr. Thorsten Blecker

Prof. Dr. Dr. h.c. Wolfgang Kersten

Prof. Dr. Christian M. Ringle

Table of Contents

I.
Optimized Logistics and Supply Chain Operations

Modelling Complex Planning Processes in Supply Chains

Martin Wallner, Uwe Brunner and Helmut Zsifkovits

Demand planning has become a key issue for the performance of supply chains. However, the right quantity is dependent on many factors. Besides market influences, like changing demands, there are also inner-company variables such as the availability of resources. Decision makers often lack a clear picture of what influences their decisions and perceive a state of complexity.
There are several theoretical models for managing complexity, but they are not designed to identify the complexity in demand planning. The aim of this paper is to establish a methodology for visualizing and reducing the complexity in the demand planning process.
The first result is a model for visualizing the complexity in the planning process. The model shows the factors which influence planned quantities in a chronological order, and, makes cause-effect relations regarding time, responsibility and system support visible.
The second result is a structured compilation of methods and tools to actively influence the complexity in the demand planning process. The identified approaches are either assigned to complexity design – reducing complexity by simplifying the supply chain – or complexity control – reducing complexity by decreasing the uncertainty in planning.

Keywords: Complexity Management, Demand Planning, Supply Chain Management, Visualizing Complexity

1 Complexity in Supply Chains

Within the last decades, markets for products and services have undergone profound changes. New product features and design variations have increased the variety of offers visible on traditional and electronic markets. Sophisticated technologies have driven the need for specialization and thus, the division of work. Supply chains have come to span more players in the processes of value creation, with a need for more coordination, and they have become more globally connected.

Links between businesses have changed from simple transactions to much more sophisticated collaborative relationships. Suppliers are becoming strategic partners who are fully integrated in their customers' development. Processes cross company borders and thus have to connect technology and people in multiple enterprises.

The reasons for the growing complexity of products, structures and processes are manifold. From a demand perspective, heterogeneous customer preferences, variety-seeking and transaction cost minimizing efforts drive the complexity of market offers. From a supply-side view, the trend towards more complexity is motivated by technology innovation, globalization, and the attempt of keeping new entrants out of the market.

We will not discuss whether a certain degree of variety is efficient or useful. The question whether there can be too much choice in buying or other decision processes is investigated by Iyengar (2011), among others. Here, we take the present complexity on markets, within and between enterprises as a fact.

The large and steadily increasing variety of product offers and the resulting complexity of organizational structures and processes pose strong challenges on the effective planning and control of supply chains.

The majority of businesses is suffering from the complexity, not only in terms of technical complexity of the products and the variety of products offered, but also in terms of internal processes, organizational structures and production facilities. As an example, a large-series manufacturer of high-tech products needs more than 40 different process chains to ensure the material supply to a production area.

This diversity is expensive and neither wanted nor documented in the process standards; it has simply grown over time. This results in production processes with different manufacturing technologies and orders, fluctuating production times, complex provisioning processes and sophisticated internal and external control requirements. Mastering the complexity of the supply and manufacturing processes is the key challenge to internal operations and supply chains. Due to its interdisciplinary nature, logistics in many cases has to deal with the effects of increased complexity, without being able to influence their causes directly.

Variant management is aiming to manage and control diversity in products and processes. This means to reduce the company's internal diversity which is a cost driver, while increasing external diversity which creates customer value. Variant-related costs are a significant portion of "complexity costs". The methods of variant management are aimed at prevention, control and reduction of diversity.

Complexity has monetary and non-monetary consequences on all processes, in all phases of the product lifecycle. The following table gives an overview of the effects of increased variety on development, procurement, manufacturing, sales and service processes. Some of these occur in the product market cycle (i.e. from product introduction to product phase-out), but also the effects in the pre-market and after-market phase have to be taken into account.

Higher product variety increases costs in all these phases. This increase often cannot be fully compensated via higher sales prices. So, there should be a methodological approach to all the planning and control processes of logistics in order to handle complexity, aiming to improve efficiency and eliminate waste of any kind.

Table 1 Effects of higher product variety on supply chain processes

	Before	Market Cycle	After
Development	Additional engineering drawings, BOMs, tests	Adaptation of variants due to engineering changes	Data cleaning
Procurement	Additional suppliers, selection processes	Reduced order quantities Loss of price reduction	Phase-out planning
Manufacturing	Additional tools Additional work schedules	More complex manufacturing control	Equipment/ tools disposal

	Before	Market Cycle	After
		Increased setup times Higher inventory levels (WIP) Quality control	
Sales	Staff training More sophisticated pricing	Higher inventory levels (finished goods) Higher frequency of errors in order management	Phase-out planning
Service	Service documentation Staff training	Lower customer satisfaction („Fix-it-right-first-time rate“)	Provision of spare parts over 5 to 10 years

2 Complexity Drivers in a Supply Chain

Regarding the need for a methodology to manage complexity in demand planning, certain complexity drivers within a supply chain lead to planning problems. In order to provide a more structured approach, the complexity drivers are divided into internal and external complexity drivers influencing the demand planning process.

Based on a literature research, the drivers were categorized after the aforementioned structure. This was done in case internal complexity drivers could be compared with structural complexity drivers (Denk/Pfneissl, 2009, p.22 and Kirchhof, 2003, p.62-64) and external complexity drivers could be transferred from economic trends and challenges (Brunner/Schweiger, 2014, p.308), which are connected to supply chain management.

For a common understanding of the complexity drivers and their influence on demand planning it is necessary to discuss them in detail. To support managers, this section also provides an evaluation of the complexity driver's relative influence.

2.1 Internal Complexity Drivers

Internal complexity drivers can directly be influenced from the company. The complexity roots in the various operations that support the business model. The most apparent internal drivers are outlined in the following table.

Table 2 Internal complexity drivers

Segment	Complexity driver
Product/Customer structure	Lot sizes Customer structure Production structure Brand policy

Segment	Complexity driver
Supplier structure	Number of suppliers Value added depth Supplier contracts
Organization	Supply chain responsibility Organizational structure Process structures

2.1.1 Product/Customer Structure

Lot sizes are extremely relevant for demand planning. Nearly every industrial enterprise tries to optimize lot sizes in production and along the supply chain and that causes a long-term goal conflict between production and sales managers. An integrated, but independent logistics department could try to balance the different objectives in their role as production planners. In addition to lot sizes, the customer structure itself influences the demand planning process. The more customers you have, the more orders you need; the smaller order sizes there are, the more complex is the demand planning process. This also interferes with the product structure, when standardized mass products could be planned more clearly than individualized products in a serial or single-item production (production structure). Moreover, the brand policy of a company could indirectly influence demand planning. If more brands need to succeed on the market, there is a wider range of products (materials/articles) – each requiring individual management.

2.1.2 Supplier Structure

Demand planning is not only focused on the customer side of the supply chain, it also correlates with supplier aspects. The more suppliers a company has, the more consideration must be given towards different delivery dates and differences in quality. Companies with a deeper value-added depth can more easily plan their production, because they merely have to coordinate internal suppliers and do not require a multitude of external suppliers for a lot of items, which must be purchased. Additionally, some standardized supplier contracts for material supply could give a company an opportunity to decrease the complexity in planning.

2.1.3 Organization

First it is important to know who is really responsible for the logistics processes. The main issue is, if there is a Supply Chain Manager with an overall responsibility for all logistics processes. Only an overall responsibility of the supply chain processes in a company could lead to excellence in supply chain and demand planning. In practice some companies have developed their former transport or logistics departments into real supply chain departments. For example, there are companies, in which the production department as part of the general supply chain reports to the supply chain department. This possibly represents the future of organizational integration. And this leads to optimized processes with an ideal process structure. However, no company can possibly perfect all processes, and, hence continuous improvement has to be implemented.

Table 3 External complexity drivers

Segment	Complexity driver
Market	Price fluctuations Demand fluctuations Urbanization
Optimization needs	Lead time variances in SC Stock level vs availability Appropriate IT for planning

2.2 External Complexity Drivers

External complexity drivers root in market dynamics and can only be indirectly influenced by a company. The table below contains the most apparent drivers.

2.2.1 Market

The market is the most important complexity area regarding the field of demand planning. Demand fluctuations are very common in economically and politically uncertain periods, the reasons for which are manifold and diverse. One such reason could be price fluctuations on the market itself. There are products which are more price sensitive than others. As an example from the field of logistics, the prices for diesel in recent years have shown that price fluctuation only has a minimum impact on the current

consumption for trucks and vehicles, because they are needed, and equivalent alternatives in terms of cost and availability were rare. Other examples show that there are products with more sensitive market reactions. And also other factors than price may lead to demand fluctuations. The construction industry provides yet a further example. If there is an economic crisis and the government must save money, public spending will decrease with a parallel strong impact on the construction business.
Urbanization as a global megatrend influences the demand situation. Future city centers will be places to live and work at the same time. This will have a big impact on supply strategies. Companies need to adapt their city logistics concepts.

2.2.2 Optimization Needs

The last subset of complexity drivers deals with the extended needs for optimization in the last years. Companies were forced to decrease their stock levels although the lead time variances in the supply of a company were still high. This happens especially due to high imports of products from countries with lower salary costs, mainly situated in Asia. A company therefore has to decide about the appropriate stock levels to be available on the market. Customers very easily intend to change the supplier or source.
The last aspect of external complexity is found in corporate IT systems. The main issue is to check, if the "appropriate" IT systems are used for the demand planning. There are a lot of systems available on the market, but not every system is ideal for planning. In business there are a lot of examples, in which complex planning situations are covered via an isolated Microsoft

Excel toolset. Excel in general could be an excellent tool, but not in the case of complex planning.

2.3 Evaluation of Influence

All these factors are generally important for a company, yet all companies are unique and therefore the complexity drivers must be evaluated by the respective management team. To see how strongly the complexity drivers could influence demand planning, an expert group has conducted a neutral evaluation to give managers an indication of their relative influence (see figure below).

Regarding internal complexity "Production structure", "Lot sizes", "Value-added depth" and "Customer structure" are the main complexity drivers. These factors are closely related to the product and the general business model of the enterprise in question.

For the external complexity "Price fluctuation", "Demand fluctuation", "Stock level vs availability" and "Appropriate IT for planning" are the main complexity drivers. These are factors which are mainly driven by the market and its uncertainty.

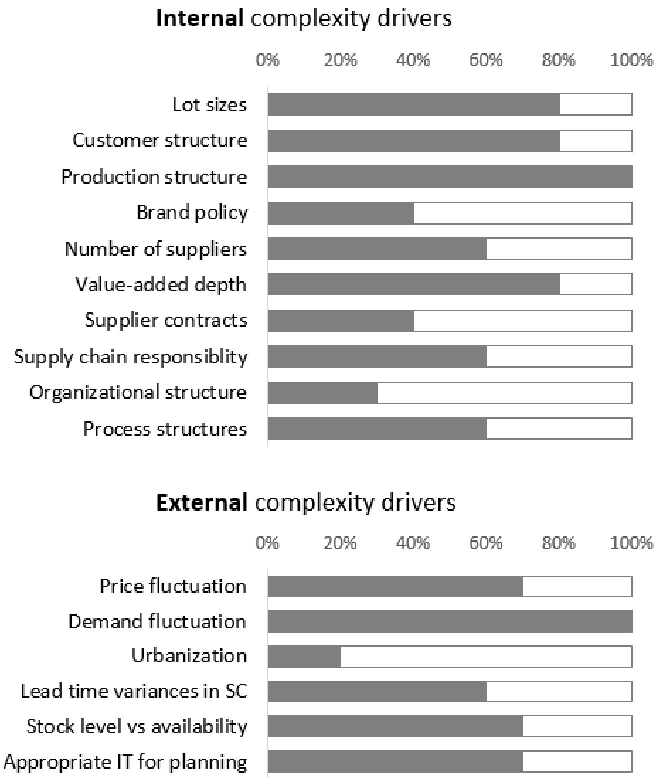

Figure 1 Evaluation of complexity drivers (relative influence)

Having clarified the root causes for complexity in demand planning processes the next chapter will provide a methodology to make this complexity visible, and consequently manageable.

3 Visualizing Complexity

Through visualization the complexity of a planning problem becomes understandable for the decision-making managers (Schwinghammer, 2011, p.112). Thus, gathering the required information to feed a model is often the first step in reducing the (perceived) complexity (Meyer, 2007, p.35). This chapter will explain the logic of building the model.

3.1 Methodology and Model

The model in figure 2 is designed to visualize the complexity in a demand planning process, but can identically be applied to other processes. The layout is based on the precedence diagram method (PDM). PDM connects activities and events in processes in chronological order and also reflects on the relationship of activities (Leutert, 2007, p.24-26). There could be arrows indicating variants to a path, for example.

In detail, the model shows the flow of decision-making processes. The vertical axis (from left to right) represents the chronology of the process split into planning phases (columns), each containing one or more decisions. The horizontal axis (from top to down) contains information that is relevant for decision-making.

The grid system enables the allocation of decisions to mutually exclusive planning phases. Decisions are either in sequence or happen simultaneously, there are no overlaps. The coordinates help reference identified potentials for improvement. The markers (e.g. "1") highlight the parts of the model that will be explained in detail.

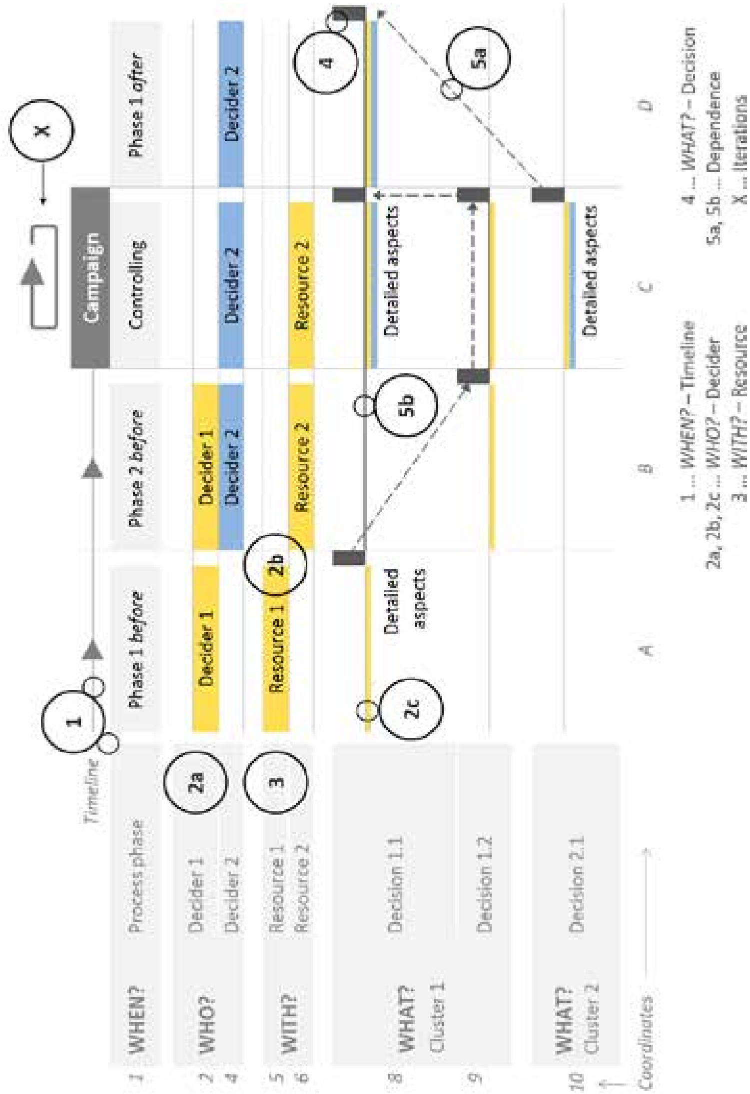

Figure 2 Visualizing complexity in demand planning

Besides PDM, the model also has strong influences from Systems Engineering, a methodology for (re-)designing systems in a project approach. In the following list selected recommendations are outlined (Geiger et al., 2009, p32-33):

- Analyze the system step-by-step (project management)
- Take care of formal logic (notation)
- Use appropriate tools (for modelling)
- Make system borders visible (e.g. between departments)
- Visualize only essential cause-effect relations
- Identify interplays and system patterns
- Consider subjectivity

A single phase (When?) contains one or more decisions (What?) that are taken in this phase. Besides the chronology of decisions the model also shows the decision-makers (Who?), relevant resources (With?) and the relationship of the decisions (Dependence).

The dependence visualizes two kinds of information. On the one hand, it shows the relationship of a decision to its predecessor(s) and its successor(s) by arrows, and, on the other hand, the decision's deadlines indicated by a change in the timeline of each decision (strokes change from dotted to full) become visible.

Table 4 contains a detailed description of the model's components and references the markers set in figure 2. The circle arrow highlighted with "X" indicates that this very phase has several iterations. This could be true for marketing campaigns with weekly controlling updates.

Table 4 Description of the model

	Examples	#	Model
When?	Point of time	1	Timeline
Who?	Person, Organizational Unit	2a	Horizontal Swim-lanes
		2b	Responsibility for resources (With?); color coding
		2c	Responsibility for decisions (What?); color coding
With?	Software, Tool, Key Fig-ure	3	Horizontal Swim-lanes
What?	Decisions	4	Decisions and de-tailed aspects
Dependence	Predecessor(s) and Suc-cessor(s), Deadlines	5a	Arrows
		5b	Deadlines; change in stroke style

3.2 Analysis

The structure of the model enables various possibilities for visual analysis. The visual identification of irregularities is the first step in managing complexity. The main levers are presented here.

3.2.1 Identification of Gaps

As presented in figure 3, there are two possible directions for identifying gaps: horizontal and vertical. Horizontal gaps (1) could reveal that a decider is not taking part in a certain decision, but then again in the following. Vertical gaps (2) could show if a phase misses resources or maybe uses too much.

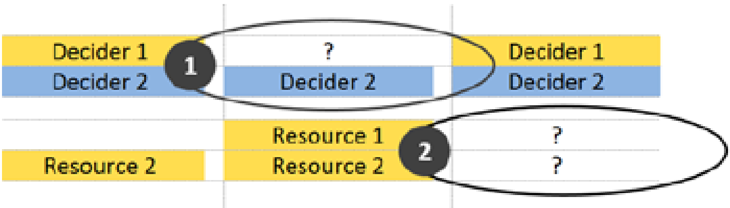

Figure 3 Identification of gaps

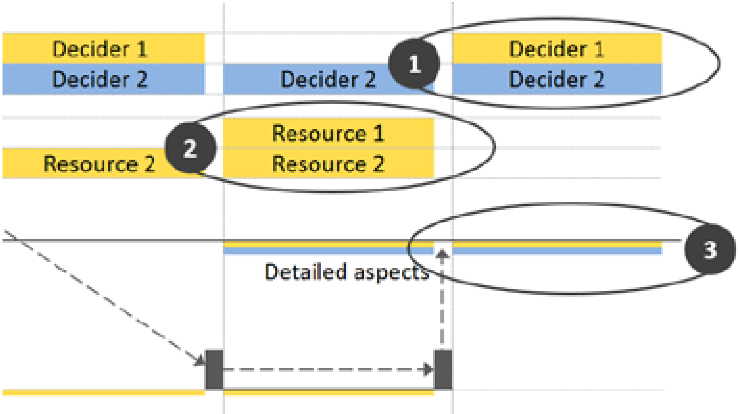

Figure 4 Identification of redundancies

3.2.2 Identification of Redundancies

Redundancies are another key aspect of visual analysis. The model shows (see figure 4) if a decision is over- or understaffed (1) and if a planning phase unnecessarily uses two resources of the same type (2). It also reveals inconsistencies between official responsibility and the role in decision-making (3).

3.2.3 Chronological Allocations

In figure 5 the arrows (1) indicate if decisions – considering their deadlines – can be moved to another phase; or even excluded.

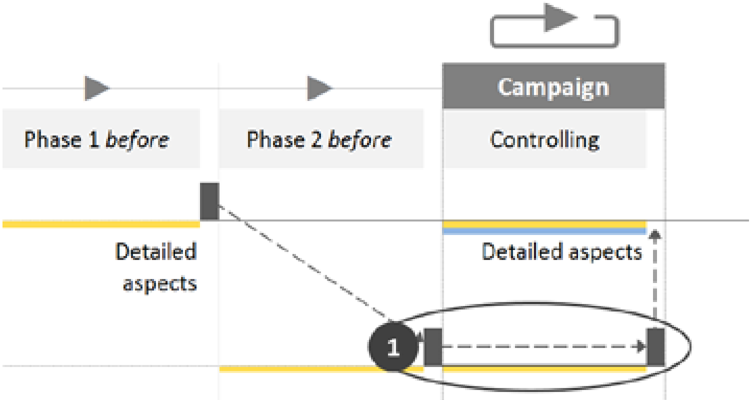

Figure 5 Chronological allocations

4 Methods to Reduce Complexity

This chapter provides methods to reduce complexity in a supply chain. The characteristics of complexity are plurality, variety, ambiguity and variability (see table 5). Additionally, the table identifies appropriate strategies to change or reduce complexity (Betge, 2006, p.80-81).

Table 5 Characteristics of complexity and appropriate strategies

Character-istic	Description	Strategy
Plurality	Number of system elements and relations	Dimensioning
Variety	Different types of system elements and relations	Differentiation/Adaption
Ambiguity	Different interpretations of system elements and relations	Specification
Variability	Frequency, strength and continuity of changes of system elements and relations	Stabilization

As a result of their focus, the strategies are either assigned to complexity design or complexity control (table 6). Complexity design leads to a substantial change in the supply chain, Complexity control aims for the most efficient way to manage it. The assignment is based on a doctoral thesis about managing complexity in the automotive industry (Maune, 2002, p.14-42). The methods will be explained in detail in the following two sections of this chapter.

Table 6 Methods to change/reduce complexity

Complexity design	Complexity control
(Plurality) Dimensioning (Variety) Differentiation	(Ambiguity) Specification (Variability) Stabilization
Product/value analysis	Project planning
Equal parts management	Changing demand
Classification and prioritization	IT as an enabler
Order penetration point	Logic of communication
Supply chain design	

4.1 Complexity Design

The goal of complexity design is to (re-)design the objects in a supply chain. In detail, the plurality and the variety of objects shall be reduced.

4.1.1 Product/Value Analysis

Value analysis is an effective method to reduce complexity in products or processes. Its goal is to improve the ratio of cost and function, defined as value. To gain a higher costumer value, either improve the function or reduce the costs (Arnolds et al., 2013, p.120-123). If there is a predefined level of maximum costs, the method enhances to Target Costing (Schröter, 2011, p.17). In the context of complexity the value of process steps is in scope. Failure to pass on information in an early phase may lead to unnecessary processing.

4.1.2 Equal Parts Management

Equal parts are components of a product, which are used in not only one product (individual parts), but in several (Thonemann, 2010, p.444). A higher usage of equal parts directly affects supply chain complexity; meaning less customized interfaces, templates, processes etc. Equal parts can be established through the integration of functions (Maune, 2002, p.24) – e.g. TV power adapters that can switch between 110 and 230 volts – or by (industry-wide) standardizations (Ehlers, 2006, p.140).

4.1.3 Classification and Prioritization

The classification or prioritization of products or processes – e.g. based on their value added – indicates if they have a proper level of complexity. Important methods are ABC analysis, for prioritizing objects from A to C (Zsifkovits, 2013, p.187), CONJOINT analysis, for evaluating multiple attributes of a product (Scholz, 2009, p.160), and Portfolio analysis, for clustering objects in two dimensions (Gärtner, 2013, p.253).

4.1.4 Order Penetration Point

The order penetration point (OPP) splits orders along their value chain regarding several aspects and therefore has direct impact on supply chain processes and their complexity. Two important aspects are the change from push- to pull-production and the change in optimization targets (Schönsleben, 2011, p.41-43). Everything upstream from the OPP will be pushed as lean as possible. The products can run through highly standardized production processes without considering the specific order. Downstream from the OPP the customers will pull individual products that meet their specific needs (e.g. a car with outsize rims); the processes have to be agile.

4.1.5 Supply Chain Design

Supply Chain Design (SCD) focuses on the (re-)design of supply chains in terms of efficiency and effectiveness (Hoppe, 2007, p.21). A simple map visualizing all stakeholders, resources and their associations could give valuable feedback on critical paths, potentials for IT and business models (Kummer et al., 2009, p.339). The display format and the level of detail depend on the desired outcome of the analysis.

4.2 Complexity Control

Complexity control aims for improving the planning and controlling of a supply chain. The main focus is on defining clear directions for communication to prevent or reduce ambiguity. Furthermore, it provides methods for avoiding temporal changes in planning objects.

4.2.1 Project Planning

Projects are time-limited and unique assignments (Burghardt, 2013, p.19). The planning characteristics and restrictions established on top-level are transferred to the associated work packages. The complexity is mainly driven by the interplay between different planning and control layers. Milestones are effective control mechanisms to address this complexity and should be planned according to the costs-by-cause principle (Schreckeneder, 2010, p.64).

4.2.2 Changing Demand

Little changes in demand can have unpredictable effects on the scaling of a supply chain. For example, if the forecast predicts a certain rise in sales all stakeholders involved could – dependent on their planning algorithms – order a different quantity (including safety stock). Multiplying this effect upstream the supply chain could lead to large swings in inventory. Because of its characteristic curve the effect is also known as Bullwhip Effect (Zsifkovits, 2013, p.91-93). Information policies and technologies can reduce the implied complexity (misunderstandings, misinterpretations, lack of data etc.). A smart way to ensure forecast data feed from the customer is to provide incentives for sharing – i.e. better payment conditions.

4.2.3 IT as an Enabler

Many modern business processes are exclusively enabled by the usage of information technology (IT). This leads to substantial business process reengineering, often referred to as Efficient Consumer Response (ECR) in the context of supply chain management (Corsten/Pötzl, 2002, p.7). ECR's main goal is to have common standards and processes for controlling and optimizing the supply chain (Kummer et al., 2009, p.341-342). By integrating big data from social media like Facebook or Google, forecasts can immediately be readjusted according to the latest sales data (Schmarzo, 2013, p.167). Faster data access and integration are a key issue in preventing and controlling complexity. The degree of integration depends on the performance requirements of the supply chain (Melzer-Ridinger, 2007, p.29).

4.2.4 Logic of Communication

The quality of shared information is one of the most significant factors of complexity. It is of essential importance that receiver's understanding and interpretation of information is equivalent to the sender's (Ostertag, 2008, p.49). This requires mandatory regulations. The SUCCESS rules of Hichert provide clear instructions for data structure and display (HICHERT FAISST, 05.05.2015). The rules are also relevant for the model in this paper, since every project regarding Complexity Management begins with the visualization of complexity.

5 Concluding remarks

The model for visualizing the complexity in demand planning processes was applied to an industrial company. This was done parallel to literature research and helped understanding practical implications.
The model improves employee understanding and supports innovation processes. Like mentioned before, the visualization of complexity is often the first step of reducing it. The employees have a common process structure available and that makes discussions about improvement a lot easier. A very important aspect is to have a systematic approach. The project should start by analyzing systemic interfaces at a top level and gradually

move to the details. This also supports understanding cause-effect-relations.

In future Knowledge Management could play an important role in complex processes, because they often require a lot of collaboration. Appropriate IT systems will enable people to share their ideas in an organized way and the system will also "remember" what happened in the past.

References

Arnolds, H., Heege, F., Röh, C., Tussing, W., 2013. Materialwirtschaft und Einkauf. 12th ed. Wiesbaden: Springer Gabler.

Betge, D., 2006. Koordination in Advanced Planning and Scheduling-Systemen. Wiesbaden: DUV/GVW.

Brunner, U., Schweiger, J., 2014. Logistik und Beschaffung. In: Heimerl, P., Tschandl, M. (Ed.), 2014. Controlling, Finanzierung, Produktion, Marketing (p.303-346). Wien: Facultas.

Burghardt, M., 2013. Einführung in Projektmanagement – Definition, Planung, Kontrolle, Abschluss. 6th ed. Erlangen: Publicis Publishing.

Corsten, D., Pötzl, J., 2002. ECR – Efficient Consumer Response. München/Wien: Carl Hanser.

Denk, R., Pfneissl, T., 2009. Komplexitätsmanagement. Wien: Linde.

Ehlers, U.-D., 2006. Standards are the Medium and not the Message. Zu Möglichkeiten und Grenzen der Standardisierung. In: Eder, F., Gastager, A., Hofmann, F. (Ed.), 2006. Qualität durch Standards (p.139-150). Münster: Waxmann.

Gärtner, M., 2010. Herausforderungen und Lösungswege bei der optimalen Umsetzung eines betrieblichen IT-Projektportfolios durch konsequentes Ressourcenmanagement. In: Ahlemann, F., Eckl, C. (Ed.), 2010. Strategisches Projektmanagement (p.249-268). Berlin/Heidelberg: Springer.

Geiger, I. K., Romano, R., Gubelmann, J., Badertscher, K., Pifko, C., 2009. Projektmanagement - Zertifizierung nach IPMA(3.0)-Ebenen D und C: Grundlagen und Kompetenzelemente, Methoden und Techniken mit zahlreichen Beispielen. 2nd ed. Zürich: Compendio Bildungsmedien AG.

HICHERT FAISST, 2015. International Business Communication Standards (IBCS) with SUCCESS. [online] HICHERT FAISST. Available at: <http://www.hichert.com/de/success.html> [Accessed 05 May 2015].

Hoppe, M., 2007. Absatz- und Bestandsplanung mit SAP APO. Bonn: Galileo Press.

Iyengar, S., 2011. The Art of Choosing. New York: Twelve.

Kirchhof, R., 2003. Ganzheitliches Komplexitätsmanagement: Grundlagen und Methodik des Umgangs mit Komplexität im Unternehmen. Wiesbaden: DUV.

Kummer, S. (Ed.) Grün, O., Jammernegg, W., 2009.Grundzüge der Beschaffung, Produktion und Logistik. 2nd ed. München: Pearson.

Leutert, R., 2007. Projektcontrolling mit Netzplantechnik. Hamburg: Diplomica.

Maune, G., 2002. Möglichkeiten des Komplexitätsmanagements für Automobilhersteller auf Basis IT-gestützter durchgängiger Systeme. Aachen: Shaker.

Melzer-Ridinger, R., 2007. Supply Chain Management – Prozess- und unternehmensübergreifendes Management von Qualität, Kosten und Liefertreue. München: Oldenbourg.

Meyer, C.M., 2007. Integration des Komplexitätsmanagements in den strategischen Führungsprozess der Logistik. Bern: Haupt.

Ostertag, R., 2008. Supply-Chain-Koordination im Auslauf in der Automobilindustrie – Koordinationsmodell auf Basis von Fortschrittszahlen zur dezentralen Planung bei zentraler Informationsbereitstellung. Wiesbaden: GWV.

Schmarzo, B., 2013. Big Data – Understanding how data powers big business. Indianapolis: Wiley.

Scholz, M., 2009. Die Conjoint-Analyse als Instrument zur Nutzenmessung in Produktempfehlungssystemen. Berlin: Logos.

Schönsleben, P., 2011. Integrales Logistikmanagement: Operations und Supply Chain Management innerhalb des Unternehmens und unternehmensübergreifen. 6th ed. Berlin/Heidelberg: Springer Gabler.

Schreckeneder, B. C., 2010. Projektcontrolling. 3rd ed. Freiburg: Haufe.

Schröter, N., 2011. Wertkettenmanagement – Target Costing und Prozesskostenrechnung. Hamburg: Diplomica.

Schwinghammer, W., 2011. Wertkettenmanagement – Target Costing und Prozesskostenrechnung. Hamburg: Diplomica.

Thonemann, U., 2010. Operations Management: Konzepte, Methoden und Anwendungen. München: Pearson.

Zsifkovits, H. E., 2013. Logistik. Konstanz/München: UVK.

The Total Landed Cost Concept Begging for Answers

Andreas Pumpe and Franz Vallée

The Total Landed Cost (TLC) often comprise a large share of the total international sourcing cost and thereby determine the cost-saving potential. Therefore, the TLC must become an integral part when making international supplier selection decisions to be able to make deliberate choices on a case-by-base base. The literature proposes a number of frameworks to evaluate the TLC, but the ordinary way has not been examined satisfactorily.

In this research, an online survey was conducted and the importance-performance analysis (IPA) was applied. IPA is an effective tool that simultaneously analyses quality attributes of the two dimensions performance and importance to identify areas needing improvement as well as areas of effective performance. The sample included 264 valid and usable respondents.

As a result, reasons for an overall performance in need of improvement are the accessibility of required information and the duration of the TLC evaluation process. Based on a comprehensive literature review, this is probably why TLC frameworks with sufficient detail to prompt effective decision-making are not present in research. The authors discuss the resulting, derived research needs to enable an appropriate TLC evaluation in international supplier selection decisions.

Keywords: Total Landed Cost, International Sourcing, Supplier Selection, Importance-performance Analysis

1 Introduction

Several researchers have mentioned that international sourcing is typically driven by cost considerations. Lower factor costs, fewer regulatory control and several other factors could lead to considerable savings (Trent and Roberts, 2010). However, the Total Landed Cost (TLC) often comprise a large share of the total international sourcing cost and complicate the profit picture (Zeng and Rossetti, 2003). In this study, TLC is seen as the "sum of all costs associated with obtaining a product, including acquisition planning, unit price, inbound cost of freight, duty and taxes, inspection and material handling for storage and retrieval" (Trent and Roberts, 2010, p.67). It also includes hidden costs; for example, uncertainty in supply is often accompanied by additional inventory (Young, et al., 2009). Therefore, TLC must become an integral part of every international sourcing analysis (Hausmann, et al., 2010; Kamann and van Nieulande, 2010; Trent and Roberts, 2010) to be able to make deliberate choices on a case-by-case base.

Different studies clearly show that companies often underestimate the true costs of international sourcing, with the consequence of yielding less than expected savings or in fact uneconomical results (Holweg, Reichhart and Hong, 2011; Schiele, Horn and Vos, 2011; Bygballe, Bø and Grønland, 2012). Accordingly, the TLC evaluation is particular important but unfortunately not costless. The evaluation requires employment of skilled and costly labor, information system support, etc. For this reason, an efficient procedure with a favorable ratio between effort and benefit is needed. The more complex and important the decision, the more effort has to be invested (Eisenführ, et al., 2010; Trent and Roberts, 2010).

Up to now, the TLC evaluation for international supplier selection decisions is unexplored and hence the focus of this research. The main research questions are the following:
How do companies do the evaluation of the Total Landed Cost to support international supplier selection decisions?
How is the perceived performance of the Total Landed Cost evaluation procedures?
This paper is organized in the following manner. The next section contains a review of existing literature relating to TLC in international sourcing. In section 3, a brief description of the importance-performance analysis method (IPA) is given, followed by a detailed description of the survey results in section 4. This paper concludes in chapter 5 by discussing the contribution of this study and questions that could be addressed in future research.

2 Literature Review

The following comprehensive literature review of TLC in international sourcing is structured according to the main phases in the supplier selection process: from the formulation of criteria, over the pre-selection, to the final choice among the preselected suppliers. The framework of Levy and Ellis (2006) and vom Brocke, et al. (2009) was applied.
A number of studies about the considered cost criteria as well as their proportion of the total international sourcing costs have been identified. For example, Young, et al. (2009) analyzed if the landed cost models are adequate in that they take into consideration all relevant costs. Ferrin and

Plank (2002) developed a comprehensive categorization of cost drivers, as a checklist to consider all possible cost factors when sourcing internationally. In contrast to this, Platts and Song (2010) focused on the amount of the costs. They found out that storage costs are on average 8.9%, transport is 5.7%, and inspection of the goods is 5.4% for sourcing from China. Further research has been carried out in this field but most of these studies are based on survey data from purchasing managers which may measure their expectations rather than actual costs (Platts and Song, 2010; Horn, Schiele and Werner, 2013). The TLC evaluation procedure is unknown, and a validation of these self-reported costs data did not take place. The number of cases is mostly too high, and/ or getting access to carry out detailed costing within companies is not possible.
Besides the formulation of the relevant cost criteria, a procedure for an appropriate assessing of the TLC is required to support the pre-selection and final supplier selection phase. Frameworks could meet this challenge; they describe a procedure in an abstracted, model-like way. They can be understood as normative references to manage the complexity and to be applicable in a wide range of individual cases (Stahlknecht and Hasenkamp, 2005; Wasson, 2006; Adaev, 2015). However, frameworks are not a standalone solution, because available methods are included (Balzert, 2005; Pernice, 2010; Ebel, 2012). Frameworks represent a structure intended to serve as a guide for solving a special problem, whereas methods are in general transferable, like the famous ABC analysis (Beller, 2009). Against the background of the research problem, the existing frameworks are divided into two groups: On the one hand, those frameworks that support the development of an individual TLC model with recommended methods, and, on the

other hand, those frameworks which provide a selection of the most appropriate methods.

Frameworks of the first group use, adapt and combine existing methods to develop a specific TLC model in a structured way. For example Rennemann (2007) developed a model for the automotive industry which used mathematical algorithms for a quantitative part and a scoring model for difficult-quantifiable elements. Further frameworks were developed by Zeng (2003), Weber, et al. (2010), Cagliano, et al. (2012), Johnson, Sawaya and Natarajarathinam (2013), which differ in the use case, level of detail, generalizability, underlying assumptions, and, of course, the applied methods. Nevertheless, the frameworks of the second group will show that not all methods are equally useful in every possible supplier selection situation. The specific industry in which a method has been empirically tested does not determine the usefulness of certain procedures. More generic, situational characteristics like the importance of the purchase are determinatives for the suitability of a certain method. However, these frameworks do not sufficiently address this contextual issue.

Frameworks of the second group are not developing a TLC model, but rather focus on the selection of the right method based on situative context factors. For example, the meta-model of Masi, Micheli and Cagno (2013) allows the choice of the most appropriate method in relation to a specific purchasing situation. A scoring model is the optimum method if the impact of the purchase on the project is low and the degree of difficulty in managing the purchase is high. Further approaches can be find by Boer, Labro and Morlacchi (2001), Weber and Wallenburg (2010), Arnolds, et al. (2013), Schuh (2014). These frameworks confirm the necessity to apply certain methods depending on the decision type. Nevertheless, these are just meta-models, without application guideline, method combination, recommended criteria, etc. Focus on TLC is also lacking. Besides this, the pre-selection phase has received far less attention from all researchers, whereby the quality of the supplier selection largely dependends on the quality of the previous step.

Nevertheless, the literature also proposes different transferable methods, which could be part of a TLC framework. They range from verbal and graphical methods, rating/ linear weighting methods (e.g. Janker, 2008), over standard cost allocations (e.g. Kumar, Andersson and Rehme, 2010) and classification approaches (e.g. Zeng and Rossetti, 2003), to mathematical algorithms (e.g. Rennemann, 2007), special accounting systems (Clemens, 1995), and different process costing methods (e.g. Meinke, 2007). These methods have different degrees of accuracy and complexity, since a higher level of accuracy generally implies greater complexity of the method.

In conclusion, several cost criteria, frameworks and methods have been proposed and tested, but the ordinary way and especially the perceived performance has not been examined satisfactorily. The TLC literature in international sourcing is prescriptive rather than descriptive. The next step is to conduct a survey where companies are asked concerning the TLC evaluation utilized when making international supplier selection decisions. In this research, the importance-performance analysis technique (IPA) is applied.

3 Methods

The IPA was introduced by Martilla and James (1977), originally developed for marketing purposes, and has now been applied in diverse research settings (Azzopardi and Nash, 2013), including e-business (Levenburg and Magal, 2005), supplier`s performance evaluation (Ho, et al., 2012), and risk assessment (López and Salmeron, 2012). IPA is an effective tool that simultaneously analyses quality attributes of the two dimensions performance and importance to identify areas needing improvement as well as areas of effective performance (Skok, Kophamel and Richardson, 2001). After obtaining the scores for each attribute, the attributes are plotted on the IPA grid (figure 1). The quadrant method splits the plots into four areas, which are identified as ‘Possible overkill’ (Q1), ‘Keep up good work’ (Q2), ‘Low Priority’ (Q3) and ‘Concentrate here’ (Q4).

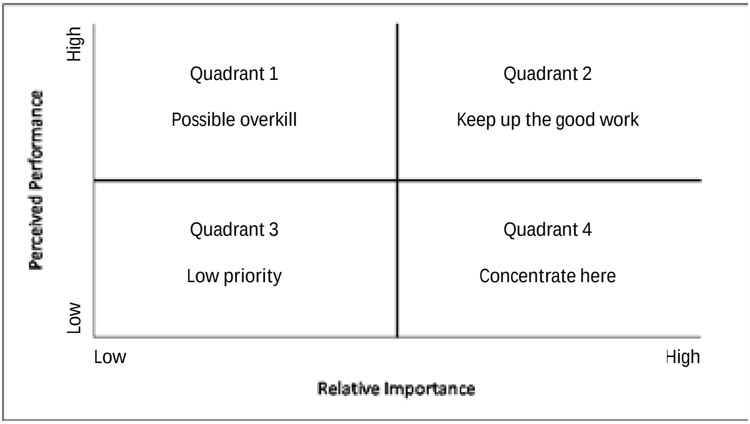

Figure 1 Importance-performance analysis grid

Quadrant 1 contains attributes that are insignificant strengths of the TLC evaluation procedure and suggests areas where resources could be withdrawn and better used elsewhere: 'possible overkill'. Quadrant 2 contains attributes that are strengths of the procedure and calls for 'keep up good work'. Attributes positioned in Quadrant 3 are not performing exceptionally well, but are considered to be relatively unimportant. They do not represent a threat to the TLC evaluation: 'low priority'. Attributes located in Quadrant 4 represent key challenges that require immediate corrective action and should be given highest priority: 'Concentrate here' (Bacon, 2003; Matzler, Sauerwein and Heischmidt, 2003). This research was based on the framework of Lai, Ivan Ka Wai and Hitchcock (2015) to ensure a reliable and valid way of research.

3.1 Questionnaire Design

This paper is applying the updated DeLone and McLean model for evaluating information systems' (IS) success as a framework to guide the identification of the critical attributes to be evaluated. It was selected because it is well validated and its six interrelated dimensions (figure 2) ensure a multi-dimensional identification of attributes. This model has been successfully applied in diverse research settings, including beyond the IS domain (Wang, 2008; Baraka, Baraka and EL-Gamily, 2013; Bossen, Jensen and Udsen, 2013).

The success of IS ('Net benefits') depend on the intervening variables ('Use' and 'User satisfaction'), which in turn depend on the quality of 'Information', 'System' and 'Service' (Eom, et al., 2012). The initially broad evaluation model was subsequently developed to focus on the relationship between the three quality dimensions and 'use' on the one side, and 'user satisfaction' on the other side (highlighted arrows in figure 2). In this work, the relevant dimensions of the DeLone and McLean IS success model can be applied to the TLC evaluation environment as follows: 'Information quality' is concerned with whether the data are relevant, complete, accurate, etc. 'System quality' addresses the performance in terms of functionality, flexibility, ease of use etc. 'Service quality' addresses the support of users (e.g. user training). 'User satisfaction' measures the level of acceptance by the users (DeLone and McLean, 2003, 2004).

Within this conceptual framework, specific attributes were identified from a comprehensive literature review concerning TLC in international sourcing. 830 identified articles have been reviewed to identify a comprehensive set of attributes, which have been clustered and afterwards mapped to the relevant dimension. Service quality attributes were not discussed.

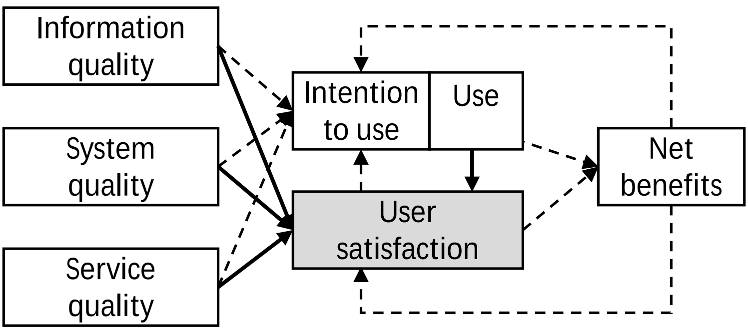

Figure 2 Updated IS Success Model (based on DeLone and McLean, 2003)

Due to survey length restrictions, a high level of abstraction rather than specific attributes is recommended (Oh, 2001; DeLone and McLean, 2003, 2004). The number of attributes was reduced to nine through expert interviews with purchasing and supply chain managers as well as logistics consultants. All interviewees had more than five years of work experience. Table 1 presents the complete list of relevant attributes.

Table 1 Questionnaire Attributes

Attribute		Brief description
Information quality		
1	Development of TLC	Cost development because internal (e.g. purchasing volume) and/ or external factors (e.g. oil price) change
2	Accessibility of cost information	Effort for data collection and data preparation
3	Up-to-dateness of cost information	Appropriate updating of evaluation base, surcharge rates etc.
4	Plausibility of TLC	Amount and composition of the costs can be understood
5	Documentation of TLC	Appropriate documentation of the results

Attribute		Brief description
System quality		
6	Flexibility of TLC evaluation	Easy adaptable evaluation e.g. change of Incoterm, transport mode
7	Transparency of TLC evaluation	Cost methods, assumptions etc. are sufficiently well-known
8	Quick TLC evaluation	Sufficient responsive decision support
9	Controlling of TLC	Comparison of actual and estimated results
Use		How frequently is the TLC evaluation for international supplier selection decisions used? for nearly every decision; for a few important decisions; for some selected decisions
User satisfaction		Overall perceived performance

The next step was to conduct an online survey. To avoid a parallel set of repetitive questions to measure performance and importance within the same questionnaire, a statistically inferred method based on correlation estimation was applied (indirect importance measurement). It reflects the causal relationships between the importance of the attributes and the overall performance (Gustafsson and Johnson, 2004; Matzler, et al., 2004). The questionnaire's length could be significantly curtailed to benefit from less fatigue and higher respondent involvement. Based on discussions by

Preston and Colman (2000) as well as Lai, Ivan Ka Wai and Hitchcock, (2015), a seven-point Likert scale, ranging from performance 'very bad' (1) to performance 'very good' (7), has been adopted.
Because of a cross-border Dutch/ German research project, a specialist with economics background and fluent language skills translated the German questionnaire into Dutch. The questionnaire was pre-tested in both countries and has been adapted to minimize the possibility of misunderstanding and misinterpretation.

3.2 Participants

Of the 264 valid and usable respondents, 201 (76.1%) were German and 63 (23.9%) were Dutch companies. The sampling frame used for the German part was a list of randomly selected enterprise representatives from purchasing and logistics/ supply chain management (Hoppenstedt database). 201 of 1,883 mailed surveys were completed, representing a response rate of 10.7%. In the Netherlands, 255 mailed surveys, one stand at the Business Meets Twente Exhibition, and the usage of two association newsletters (World Trade Center Twente, VNO NCW Midden) led to 63 completed surveys. The largest company size group was the large-enterprises (41.7%), as defined by EU law, while the smallest group was that of micro-enterprises (5.3%). Small-enterprises were represented by 51 (19.3%) and medium-enterprises by 89 surveys (33.7%). The mean international sourcing share by company size was between 21% and 27%. Approximately 70% of the respondents were manufacturing companies (155), whereby trading companies (69) had a substantially higher inter-national sourcing share, with

33.6% (SD = 34.6) in comparison to 19.5% (SD = 21.8). 188 respondents are involved in international sourcing and form the basis of this analysis.

3.3 Statistical Analysis

The data derived from the survey was systematically coded and analyzed using SPSS (Statistical Package for the Social Sciences) software. The perceived performance of the different attributes was obtained through the average ratings of the respondents, while correlation coefficients were used to implicitly measure the related relative importance. According to Matzler, Sauerwein and Heischmidt (2003) and Homburg and Klarmann (2012), the relative percentage importance (w_j) is determined as the ratio of the squared correlation coefficients of the attribute (r_{j2}) to the sum of the squared correlation coefficients of all attributes (j). This 'powerful' method has three main advantages: (1) relative simple and comprehensible; (2) high popularity; (3) no negative correlations and other implausible results (Homburg and Klarmann, 2012; Azzopardi and Nash, 2013; Sever, 2015).

Preliminary reviews of the data suggested that the distribution of it might not be normal (Kolmogorov-Smirnov method), and thus non-parametric correlation coefficients were used (Kendalls Tau). To verify construct validity of the questionnaire, an exploratory factor analysis with varimax rotation, eigenvalue exceeding 1, and factor loadings exceeding 0.5 was conducted. The test value of the Kaiser-Meyer-Olkin test was 0.904, and the p-value of the Bartlett`s test was zero (Lai, Ivan Ka Wai and Hitchcock, 2015). The questionnaire has also acceptable reliability with a value of

Cronbach`s alpha for each attribute greater than 0.60, except for 'Development of TLC' (1).

4 Results

4.1 Total Landed Cost Evaluation

Related to the first research question, a descriptive analysis concerning the TLC evaluation was conducted. 176 respondents answered the question when they evaluate the TLC for international supplier selection decisions: 50% for nearly every decision, 32% for a few important and 18% just for some selected decisions. Especially for geographically distant regions like China, more respondents evaluate the TLC for nearly every decision. In contrast, the frequency of use is independent of the Incoterm. It thus makes no difference if the delivery term is ex works, free on board, or any other. Furthermore, the scale of the TLC evaluation differs significantly. The respondents have been asked per TLC cost category if and how they evaluate them. The options have been exact evaluation, differentiated and lump sum surcharges, included in purchasing price and no evaluation. Surprisingly, several TLC elements are not considered by the respondents at all. As example, 29% do not consider costs for inspection and material handling for storage and retrieval, 36% storage costs, 29% capital commitment cost and even 41% administration costs. On the contrary, especially customs are mainly accurately calculated (41%). More than half of the respondents are not using any information system for TLC evaluation, which include integrated systems as well as application software. All in all this study has found out that the TLC evaluation is rarely used and the scope is often insufficient for international supplier selection decisions. In the following, the overall perceived performance of the respondents is analyzed.

4.2 Overall Performance

Based on the survey data, the mean and standard deviation of overall perceived performance was 4.5828 and 1.34. This value was obtained through the average rating of the respondents. Consequently, the respondents ranked the overall TLC evaluation between ‘mediocre’ and ‘rather well’, which indicates that room for improvement exists. It should be noted that a higher frequency of use let to a statistically significant (p=0.0005) higher overall performance. Experiences, standardized processes, and increased number of software system users could explain the better performance. In order to find out the reasons for an amendable overall performance of 4.5828, the performance and importance of the individual attributes are analyzed.

4.3 Importance-Performance Analysis Grid

The average performance ratings for the nine attributes ranged from a high of 5.1 to a low of 4.5. All attributes had standard deviations below 1.7 and a positive impact on the overall performance, with a significant level of correlation. The implicitly derived relative importance of the attributes ranges between 3% and 15%, which is described in the following section. The result of a factor analysis was that all attributes are performance factors (Matzler, et al., 2004; Homburg and Klarmann, 2012).

After obtaining the scores of importance and performance for each attribute, the nine attributes were plotted on the IPA grid (figure 3). The quadrant

method splits the plots into four areas by using the often applied ‘data-centered quadrants approach’, where the empirical mean values obtained from the data determine the cross-hair point of the IP matrix (Martilla and James, 1977; Sever, 2015). As already explained, the four quadrants are identified as ‘Possible overkill’ (Q1), ‘Keep up good work’ (Q2), ‘Low Priority’ (Q3) and ‘Concentrate here’ (Q4).
The matrix in figure 3 shows that four attributes were identified in the ‘keep up good work’ quadrant (Q2), indicating that these attributes were perceived to be very important, and at the same time were rated as having a high level of performance. These attributes are ‘Up-to-dateness of cost information’ (3), ‘Plausibility of TLC’ (4), ‘Flexibility of TLC evaluation’ (6) and ‘Transparency of TLC evaluation’ (7). Even though all of these attributes appear in the ‘keep up good work’ quadrant, it was shown that performance scores were not rated very highly (i.e., all are less than 6). Some of these attributes were also at a close distance to the performance axe, especially ‘Transparency of TLC evaluation’ (7). According to Bacon (2003) as well as Eskildsen and Kristensen (2006), borderline attributes are not to be interpreted in the same way as attributes that fall clearly within a quadrant. “Discontinuity in the inferred priority” has to be considered (Bacon, 2003, p.58). As a consequence, more efforts could be necessary to improve these attributes. The attributes ‘Development of TLC’ (1) as well as 'Controlling of TLC’ (9) fall within the ‘low priority’ quadrant (Q3). These attributes are not performing exceptionally well, but are considered to be relatively unimportant. The attribute in the upper left-hand quadrant (Q1) should command the lowest priority for improvement: ‘Documentation of TLC’ (5). Re-

sources could be withdrawn and better used elsewhere. Especially the attributes in quadrant 4 are considered problematic, because the TLC evaluation fails to satisfy the users` perceived level of performance in relative important areas. The attributes in this quadrant are 'Accessibility of cost information' (2) and 'Quick TLC evaluation' (8). These attributes require immediate action with highest priority.

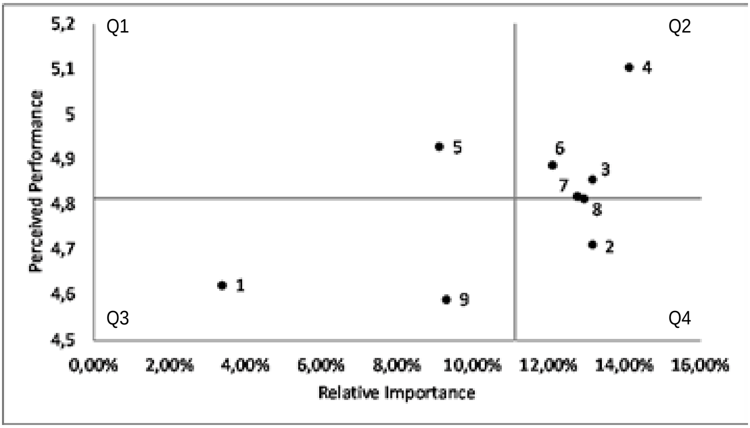

Figure 3 Importance-performance analysis grid

5 Conclusion

As international sourcing is an important business strategy, evaluating the TLC has to be seen as increasingly critical and important. The first contribution of this research was the result that just 50% of the respondents evaluate the TLC for nearly every international supplier selection decision. The fact that several TLC elements are not considered by the respondents makes matters worse. An IPA with a unique set of attributes has been developed to shed light on the reasons of an amendable overall performance. The IPA grid provided detailed insight into the importance and performance of the selected attributes, as areas of weakness were easily identified. To summarize, reasons for an amendable overall performance are especially the attributes 'Accessibility of cost information' and 'Quick TLC evaluation'.

The sample included 264 valid and usable respondents, of which 188 respondents are involved in international sourcing. This research involved German and Dutch enterprises representing multiple industries; however, it was geographically limited, which limits the generalizability of the research findings from the current study.

A comprehensive literature review identified several cost criteria, frameworks and methods, which have been proposed and tested. However, the review suggests that the TLC evaluation is not presented with sufficient detail to prompt effective decision-making. An appropriate framework has to differentiate between consecutive supplier selection phases, select and perhaps combine the situationally best fitting methods, and additionally guide the application of them. Therefore, the amendable TLC evaluation in practice is also due to insufficient frameworks in research.

For this reason, the TLC concept is begging for answers and it is hoped that this research will stimulate the development of an appropriate framework that overcomes the limitations. An important need for action has been identified to enable companies to choose the right supplier in an international context.

However, the applied IPA grid clearly sacrifice depth for breadth and convenience; it is unlikely to provide the detailed insights (Skok, Kophamel and Richardson, 2001). The IPA grid also rely on the respondent's perception of satisfaction and not on objective values. The inability to account for such metrics should be a recognized weakness. The indirect measures are also limited by the assumptions underlying the statistical procedure. Indeed, the IPA grid is used as a preliminary research to identify attributes requiring more detailed analysis to improve the TLC evaluation in international sourcing decisions.

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References

Adaev, K., 2015. Vorgehensmodell zur wandlungsfähigen integrierten Absatz-, Produktions- und Logistikplanung in Produktionsnetzwerken der Stahlverarbeitung. Dortmund: Verl. Praxiswissen.

Arnolds, H., Heege, F., Röh, C. and Tussing, W., 2013. Materialwirtschaft und Einkauf. Grundlagen - Spezialthemen - Übungen. 12th ed. Wiesbaden: Springer.

Azzopardi, E. and Nash, R., 2013. A critical evaluation of importance–performance analysis. Tourism Management, 35, pp. 222–233.

Bacon, D. R., 2003. A comparison of approaches to importance-performance analysis. International Journal of Marketing Research, 45(1), pp. 55–77.

Balzert, H., 2005. Lehrbuch Grundlagen der Informatik. 2nd ed. Heidelberg: Spektrum Akademischer Verlag.

Baraka, H. A., Baraka, H. A. and EL-Gamily, I. H., 2013. Assessing call centers' success: A validation of the DeLone and Mclean model for information system. Egyptian Informatics Journal, 14(2), pp. 99–108.

Beller, M., 2009. Entwicklung eines prozessorientierten Vorgehensmodells zur Fabrikplanung. Dortmund: Verl. Praxiswissen.

Boer, L. de, Labro, E. and Morlacchi, P., 2001. A review of methods supporting supplier selection. European Journal of Purchasing & Supply Chain Management, 7(2), pp. 75–98.

Bossen, C., Jensen, L. G. and Udsen, F. W., 2013. Evaluation of a comprehensive EHR based on the DeLone and McLean model for IS success: Approach, results, and success factors. International Journal of Medical Informatics, 82(10), pp. 940–953.

Bygballe, L. E., Bø, E. and Grønland, S. E., 2012. Managing international supply: The balance between total costs and customer service. Industrial Marketing Management, 41(3), pp. 394–401.

Cagliano, A. C., Marco, A. D., Rafele, C. and Arese, M., 2012. A decision-making approach for investigating the potential effects of near sourcing on supply chain. Strategic Outsourcing: An International Journal, 5(2), pp. 100–120.

Clemens, M., 1995. Entscheidungsorientierte Beschaffungskostenrechnung. Frankfurt am Main: Lang.

DeLone, W. H. and McLean, E. R., 2003. The DeLone and McLean Model of Information Systems Success: A Ten-Year Update. Journal of Management Information Systems, 19(4), pp. 9–30.

DeLone, W. H. and McLean, E. R., 2004. Measuring e-Commerce Success: Applying the DeLone & McLean Information Systems Success Model. International Journal of Electronic Commerce, 9(1), pp. 31–47.

Ebel, G., 2012. Vorgehensmodell für die Anforderungsanalysen der Baulogistik. Dortmund: Verl. Praxiswissen.

Eisenführ, F., Weber, M., Langer, T. and Eisenführ-Weber-Langer, 2010. Rationales Entscheiden. 5th ed. Berlin: Springer.

Eom, S., Ashill, N. J., Arbaugh, J. B. and Stapleton, J. L., 2012. The role of information technology in e-learning systems success. Human Systems Management, 31, pp. 147–163.

Eskildsen, J. K. and Kristensen, K., 2006. Enhancing importance-performance analysis. International Journal of Productivity and Performance Management, 55(1), pp. 40–60.

Ferrin, B. G. and Plank, R. E., 2002. Total Cost of Ownership Models: An exploratory study. Journal of Supply Chain Management, 38(2), pp. 18–29.

Gustafsson, A. and Johnson, M. D., 2004. Determining attribute importance in a service satisfaction model. Journal of Service Research, 7(2), pp. 124–141.

Hausmann, W. H., Lee, H. L., Napier, G. R. F., Thompson, A. and Zheng, Y., 2010. A process analysis of global trade management: an inductive approach. Journal of Supply Chain Management, 46(2), pp. 5–29.

Ho, L.-H., Feng, S.-Y., Lee, Y.-C. and Yen, T.-M., 2012. Using modified IPA to evaluate supplier's performance: Multiple regression analysis and DEMATEL approach. Expert Systems with Applications, 39(8), pp. 7102–7109.

Holweg, M., Reichhart, A. and Hong, E., 2011. On risk and cost in global sourcing. International Journal of Production Economics, 131(1), pp. 333–341.

Homburg, C. and Klarmann, M., 2012. Die indirekte Wichtigkeitsbestimmung im Rahmen von Kundenzufriedenheitsuntersuchungen: Probleme und Lösungsansätze. In: C. Homburg, ed. 2012. Kundenzufriedenheit. Konzepte, Methoden, Erfahrungen. 8th ed. Wiesbaden: Gabler, pp. 190–225.

Horn, P., Schiele, H. and Werner, W., 2013. The “ugly twins”: Failed low-wage-country sourcing projects and their expensive replacements. Journal of Purchasing and Supply Management, 19(1), pp. 27–38.

Janker, C. G., 2008. Multivariate Lieferantenbewertung. Empirisch gestützte Konzeption eines anforderungsgerechten Bewertungssystems. 2nd ed. Wiesbaden: Gabler Verlag / GWV Fachverlage GmbH Wiesbaden.

Johnson, M. D., Sawaya, W. J. and Natarajarathinam, M., 2013. A methodology for modelling comprehensive international procurement costs. International Journal of Production Research, 51(18), pp. 5549–5564.

Kamann, D.-J. and van Nieulande, V., 2010. A four-filter method for outsourcing to low-cost countries. Journal of Supply Chain Management, 46(2), pp. 64–79.

Kumar, N., Andersson, D. and Rehme, J., 2010. Logistics of low cost country sourcing. International Journal of Logistics Research and Applications, 13(2), pp. 143–160.

Lai, Ivan Ka Wai and Hitchcock, M., 2015. Importance–performance analysis in tourism: A framework for researchers. Tourism Management, 48, pp. 242–267.

Levenburg, N. M. and Magal, S. R., 2005. Applying Importance-Performance Analysis to evaluate E-Business strategies among small firms. E-service Journal, 3(3), pp. 29–48.

Levy, Y. and Ellis, T. J., 2006. Towards a framework of literature review process in support of information systems research. Proceedings of the 2006 Informing Science and IT Education Joint Conference, pp. 171–181.

López, C. and Salmeron, J. L., 2012. Risks Response Strategies for Supporting Practitioners Decision-Making in Software Projects. Procedia Technology, 5, pp. 437–444.

Martilla, J. A. and James, J. C., 1977. Importance-Performance Analysis. Journal of Marketing, 41(1), pp. 77–79.

Masi, D., Micheli, G. J. and Cagno, E., 2013. A meta-model for choosing a supplier selection technique within an EPC company. Journal of Purchasing and Supply Management, 19(1), pp. 5–15.

Matzler, K., Bailom, F., Hinterhuber, H. H., Renzl, B. and Pichler, J., 2004. The asymmetric relationship between attribute-level performance and overall customer satisfaction: a reconsideration of the importance–performance analysis. Industrial Marketing Management, 33(4), pp. 271–277.

Matzler, K., Sauerwein, E. and Heischmidt, K., 2003. Importance-performance analysis revisited: the role of the factor structure of customer satisfaction. The Service Industries Journal, 23(2), pp. 112–129.

Meinke, A., 2007. Cost oriented supply chain management and supply chain controlling. Combination and configuration of instruments. Aachen: Shaker Verl.

Oh, H., 2001. Revisiting importance–performance analysis. Tourism Management, 22(6), pp. 617–627.

Pernice, R., 2010. Vorgehensmodell für die Integration einer simulationsgestützten Entscheidungsassistenz in Logistiknetzen. Dortmund: Praxiswissen.

Platts, K. and Song, N., 2010. Overseas sourcing decisions – the total cost of sourcing from China. Supply Chain Management: An International Journal, 15(4), pp. 320–331.

Preston, C. C. and Colman, A. M., 2000. Optimal number of response categories in rating scales: reliability, validity, discriminating power, and respondent preferences. Acta Psychologica, 104(1), pp. 1–15.

Rennemann, T., 2007. Logistische Lieferantenauswahl in globalen Produktionsnetzwerken. Wiesbaden: DUV Deutscher Universitäts-Verlag.

Schiele, H., Horn, P. and Vos, B., 2011. Estimating cost-saving potential from international sourcing and other sourcing levers. International Journal of Physical Distribution & Logistics Management, 41(3), pp. 315–336.

Schuh, G., 2014. Einkaufsmanagement. Handbuch Produktion und Management 7. 2nd ed. Berlin, Heidelberg: Springer.

Sever, I., 2015. Importance-performance analysis: A valid management tool? Tourism Management, 48, pp. 43–53.

Skok, W., Kophamel, A. and Richardson, I., 2001. Diagnosing information systems success: importance–performance maps in the health club industry. Information & Management, 38(7), pp. 409–419.

Stahlknecht, P. and Hasenkamp, U., 2005. Einführung in die Wirtschaftsinformatik. 11th ed. Berlin: Springer-Verlag.

Trent, R. J. and Roberts, L. R., 2010. Managing global supply and risk. Best practices, concepts, and strategies. Fort Lauderdale, Fla: J. Ross Pub.

Vom Brocke, J., Simons, A., Niehaves, B., Riemer, K. and Plattfaut, R. C. A., 2009. Reconstructing the giant: On the importance of rigour in documenting the literature search process. Proceeding of the 17th European Conference on Informations Systems, pp. 2206–2217.

Wang, Y.-S., 2008. Assessing e-commerce systems success: a respecification and validation of the DeLone and McLean model of IS success. Information Systems Journal, 18(5), pp. 529–557.

Wasson, C. S., 2006. System analysis, design, and development. Concepts, principles, and practices. Hoboken, N.J: Wiley-Interscience.

Weber, J. and Wallenburg, C. M., 2010. Logistik- und Supply Chain Controlling. 6th ed. Stuttgart: Schäffer-Poeschel.

Weber, M., Hiete, M., Lauer, L. and Rentz, O., 2010. Low cost country sourcing and its effects on the total cost of ownership structure for a medical devices manufacturer. Journal of Purchasing and Supply Management, 16(1), pp. 4–16.

Young, R. R., Swan, P. F., Thomchick, E. A. and Ruamsook, K., 2009. Extending landed cost models to improve offshore sourcing decisions. International Journal of Physical Distribution & Logistics Management, 39(4), pp. 320–335.

Zeng, A. Z. and Rossetti, C., 2003. Developing a framework for evaluating the logistics costs in global sourcing processes: An implementation and insights. International Journal of Physical Distribution & Logistics Management, 33(9), pp. 785–803.

A New Product Driven System Concept for the Replenishment Process

Najlae Alfathi, Abdelouahid Lyhyaoui and Abdelfettah Sedqui

The product driven system improves the reactivity and flexibility of production systems. However, these requirements cannot be achieved without an availability of quality and quantity of raw materials; as a result, the optimization of raw material replenishment system is essential.
We present in this paper, the use of product driven system concept for the replenishment process.
The integration of infotronic technology makes the product smart and able to communicate with its environment, so the product "being smart" decides the appropriate time for its replenishment.
The modeling of this proposal is performed by the Business Process Model Notation "BPMN", having regard to the capacity of this tool to model at the same time, the process of making decision of replenishment by product and the treatment, and the follow-up of the order by the procurement department, as well as the exchange of information between the two collaborators, product and procurement department.
To validate the modeling of the replenishment process, an experimental application is simulated by "*activiti modeler*"; as a result the stock out rate and the overstocking are minimized.
The replenishment triggered by the product performs the role of the product driven system for the control of production.

Keywords: Product Driven System, Smart Product, Infotronic Technology, BPMN (Business Process Model and Notation)

1 Introduction

The growing competition between industrial companies and the emergence of information and communication technologies have made the appearance of mass customization concept. This concept leads to a high diversity of products and production processes, which requires reactive and flexible piloting systems to better satisfy customers and ensure the sustainability of companies.

The systems of piloting and decision-making have evolved from a centralized architecture, where all decisions are taken by the superior level of the system, to a distributed control architecture that relies on the principle of distribution of all decisions, also it consider that each inferior level has a controller which is autonomous and cooperate with all the other levels. Hence its flexibility and its relative tolerance to disturbance.

While the centralized architecture provides a robust and stable piloting, distributed architecture guarantees flexibility and responsiveness of the piloting system. The hybridization of these two approaches gave birth in 2003 (Morel, 2003) the paradigm of product driven system.

The concept of product driven system takes into account the capabilities of the product to play an active role to synchronize the exchange between various company processes. This synchronization requires knowledge of accurate data in real-time, it requires integration of infotronic technology, which is carrier of data.

After the use of this concept in projects relating to the management of the rescheduling of product (Noyel, 2015), hospital logistics (Huet, 2011), industrial processes in enterprises (Elhouazi, 2009). We propose in this paper a replenishment system triggered by product to ensure a robust, flexible and reactive procurement system.

2 Literature Review

2.1 Product Driven System

The product driven system concept considers that the product is the main actor in decision making and the exchange of data in real time with other business processes. In the literature the researchers gave several definitions and characteristics to the concept. While authors introduced the concept as a derivative of the Holonic Manufacturing Systems (HMS), which the originality is to combine the centralized decisions on a priori means horizons to long term, with decentralized or distributed decisions make at the execution on short- term horizons (Elhouazi, 2009). Other authors in addition to the definition of the concept as a hybridization of two piloting approaches, they recalled the product capabilities, to play an active role of synchronization of exchanges between different enterprise systems (Noyel, 2012).

Of all the different definitions cited in the literature, one can define a product driven system, as a piloting architecture considering the product as an intelligent entity capable to communicate with its environment and make decisions that affect its flow.

2.2 Smart Product

The product seen like well by the production system, and as provider of information and services by the management system, ensures consistency between physical and information flows (Gouyon, 2009).
Several studies have provided definitions of this concept and have detailed these features. We find in (Cardin, 2013), and (Gouyon, 2009) the definitions of products intelligence levels, since the consideration of the product as active during production leads to impart technical intelligence capabilities to the product. These capabilities are:

1. owning a unique identifier
2. be able to communicate with its environment
3. be able to store its data
4. deploy a language to display its characteristics, its production requirements...
5. be able to provide or participate in a decision on its future.

Based on these five capacities, they are two technical product intelligence levels:

- Product with level 1 intelligence is able to communicate it state (form, composition, location, and key criteria). This level 1 is oriented to the product information's, it covers items from 1 to 3 described above;
- Product with a level of intelligence 2 is able not only to communicate it condition, but also to influence the decisions that are taken against it. This second level is oriented to the decision; it covers items 1 to 5 described above.

The Simplest structure of a smart product consists of the product itself during the manufacturing process and a base associated, such as a pallet carrying this product. It is the whole product + basic information which is the product oriented (Cardin, 2013).
In general, there is no stable definition, of the concept of product "smart / active ". So, we must define the aspects of intelligence and interaction with the environment.

2.3 Infotronic Technology

The intelligence characteristic associated with the product, to ensure a piloting by product, is feasible by integrating infotronic technology carried by the product to store and manages data.
There are several types of infotronic technology from the barcode to active RFID. These types differ in the informational functions that each technology can guarantee, which influence on the level of intelligence of the product.
Several studies in the literature have conducted a comparison of the features offered by the infotronic technology. The studies of (Gaudreau, 2009) compared the informational functions that can guarantee each type of infotronic technology. They conclude that the smart sensor technology ensures at the same time identification of an element, information transport, the localization of a given element, the data acquisition, their processing and analysis and the decisions and reactions. While other studies (Thierry, 2009) presented the active RFID as a technology provides to the product a single identification and a processing capacity, localization and the decision making.

3 Replenishment Trigged by Product

We propose in this paper a driven product system at the raw material replenishment.

By integrating infotronic technology that makes the smart product capable of making it own decisions, the product triggers its supply by sending a request to the responsible of procurement. The request sent contains the amount of product to be procured and the time not to exceed.

As every procurement process, we consider three threshold of storage for each product reference. The green threshold is the maximum amount of product that must be stocked; the yellow line is the replenishment point, while the red line is the safety stock.

We present a mapping of the visual monitoring of stock status at Figure 1.

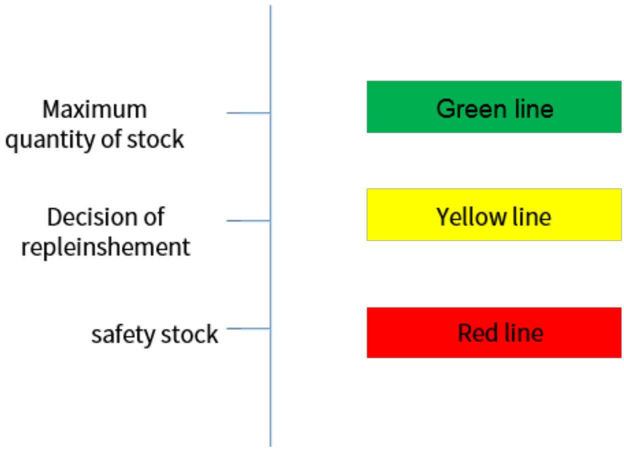


Figure 1 Storage threshold

The objective of the proposed solution is to avoid a stock out or a over-stocking, thereby the monitoring of the stock state is essential.

3.1 Replenishment Stages Triggered by Product

3.1.1 Send the Request

The products on stock communicate and count each other, the moment when the quantity of remaining products in stock is equal to the yellow line, one of the smart products sends to the Smartphone, Tablet or Computer (NFC standard) of the responsible of procurement a replenishment demand including the quantity and the time not to exceed.

3.1.2 Receipt and Processing of the Request

At the receipt of the product request, the procurement department sends a command including the amount and time previously defined by the smart product.

3.1.3 End of the Deadline

At the end of this period two cases are possible:
First case: If the requested amount is received before the deadline, in which case the replenishment process started with the request of the smart product is completed
Second case: The smart product awaits the arrival of the requested amount since the red threshold is not reached.

3.1.4 Red Threshold Reached

The red threshold corresponds to the safety stock identified for each reference; this threshold is achieved because the delivery period is exceeding by the supplier. If this threshold is reached the product triggers and sends a warning to procurement responsible for the latter warns the supplier or search the requested quantity from other suppliers.

4 Modeling of the Proposal

For the system design, we present a methodology to validate the specifications set of a technological system. The figure 2 shows the steps of this process. The modeling step should be preceded by a study and selection of the most suitable tool to satisfy the criteria that the resulting model must meet.

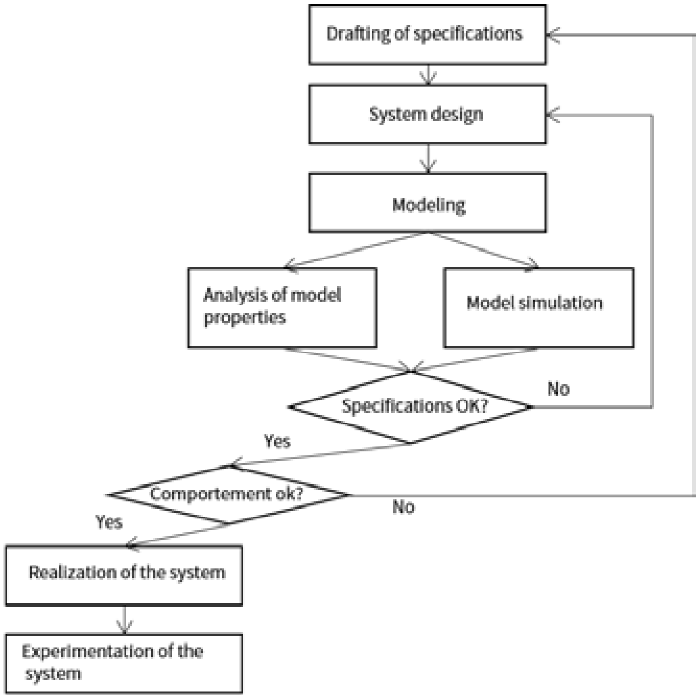


Figure 2 Method to validate process specifications

To validate our solution specifications, we have to model the interactions between the smart product and procurement department, the different flow control points, the execution of a condition or the passage from a spot to another, at end the points of synchronization between the process of requesting product by the smart product, and the treatment of the request by the procurement department.

(Verane, 2006) provides a comparison of several modeling tools according to their performance criteria. According to (Verane, 2006) the tool that meets most of these criteria and which can model the interactions between the processes is the “Busines Process Model and notation” BPMN.

4.1 Busines Process Model and Notation

BPMN provides a standardized representation of the process flow for business analysts, who produce the first draft, technical staff, which implements the technology solution running the process, and the business users that manage and control the processes.
BPMN 2.0 is the latest and advanced version of BPMN, thus we model according this version. In the notation BPMN2.0 there are four categories of diagrams:

— orchestration diagram (process private and public process)
— collaboration diagram
— choreography diagram
— conversation diagram

In table 1 we present the different criteria which every type of diagram can meet.

Table 1 Criteria answered by different types of diagrams

Diagram/criteria	Description of process	interaction between process	identify the actors of process
process private	Yes	No	Yes
public process	No	Yes	No
collaboration diagram	Yes	Yes	Yes
choreography diagram	No	No	No
conversation diagram	No	Yes	No

In our case, we'll use a collaboration diagram because it allows to model:

— decision making process by the smart product,
— receiving and treatment process of the request at the procurement department.
— various data exchange and interactions between two collaborators,
— different synchronization points between the two processes.

4.2 BPMN Deployment Software

There are many BPMN modeling software, the table 2 shows some software that implement BPMN 2.0.

Table 2 BPMN Deployment Software

Software	Definition
Oryx Modeling Platform	Oryx is a web-based, extensible modeling platform, licensed under open source terms.
Activiti BPM Platform	Activiti is a light-weight workflow and Business Process Management (BPM) Platform targeted at business people, developers and system admins. Its core is a super-fast and rock-solid BPMN 2 process engine for Java. It's open-source and distributed under the Apache license.

In this paper we will use "Activiti Modeler" because of its compatibility with BPMN 2.0.

4.3 Modeling of the Proposal

After modeling our process with “Activiti Modeler”, we give the result presented in the figure 3.

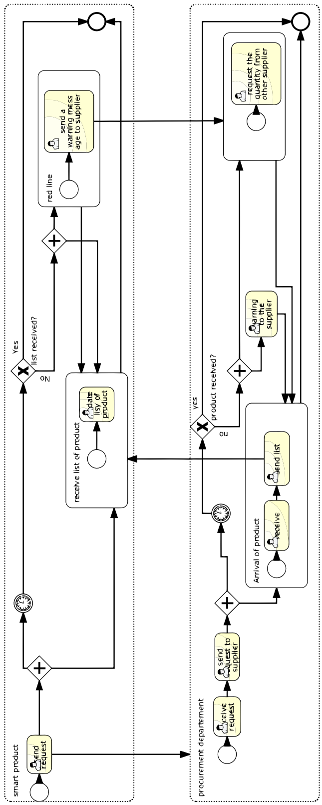


Figure 3 Modeling of new replenishment system performed by Ac

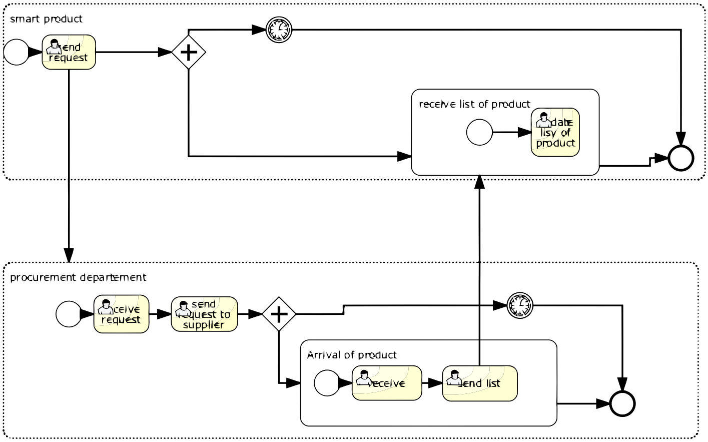


Figure 4 The model of the Case 1

To validate the proposal model, we simulate three scenarios by “Activiti Explorer”,

1. Case 1: we receive the amount requested on or before the deadline. The figure 4 presents the model of this case.
2. Case 2: we receive the products after the deadline and before reaching the red line. We find in the figure 5 the modeling of the second case.
3. Case 3: we reach the red line before the arrival of the requested products. In this case the model presented in the Figure 1 is the executed model.

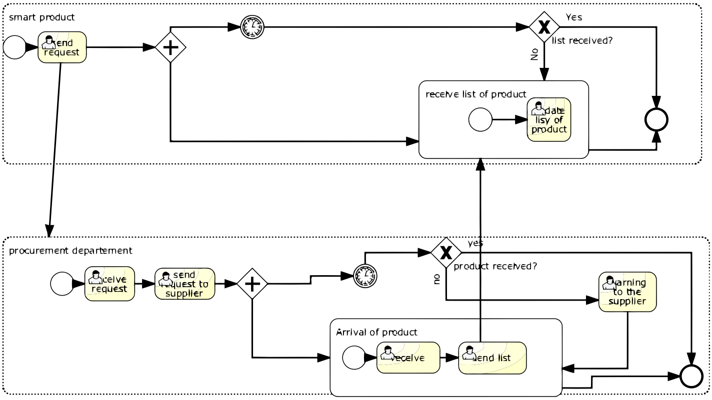


Figure 5 The model of the second case

4.4 Results

4.4.1 A Proactive and Reactive Procurement Process

The decision making of procurement at the moment when the quantity of remaining products in stock is equal to the yellow line, make the procurement process more reactive, which reduces the possibilities of stock out to reach the red line. Thus, the proposed solution makes it possible optimization of stock out rate.

4.4.2 An Advanced Monitoring of the Quantities of Products in Stock

The smart products of each reference of product's control the outgoing quantities from the stock and the received quantities. So at any time the product know the level of its stock and have to never exceed the red (safety stock) and green (overstocking) thresholds.

5 Conclusion

The mass customization requires a reactive and flexible piloting system. In this context we proposed an improvement of the procurement process to optimize the out stock rate and the overstocking. Therefore, increasing the reactivity and flexibility of the production piloting system. The use of the concept of product driven system for the improvement of other processes such as delivery will make the companies more intelligent and efficient.

References

Morel, G., Panetto, H., Zaremba, M., & Mayer, F. (2003). Manufacturing enterprise control and management system engineering paradigms and open issues. Annual Reviews in Control, 199-209.

Noyel, M. Thomas, A.Thomas, P. Charpentier, P. 2015 dynamic rescheduling in a product driven system concept. JPI Days 2015 Intelligent Products 17-18 March 2015 Valenciennes France

Huet, J. 2011. Proposal of a methodology for reengineering Of the product driven system of manufacturers systems: Application of the drug circuit of a hospital. Engineering Sciences. Universit_e Blaise Pascal - Clermont-Ferrand II, 2011.

Elhouzi, H. Methodological approach for the integration of Driven product system in an environment just- a- time. Engineering Sciences. Universite Henri Poincare - Nancy I, 2008. Frensh.

Noyel,M.,Thomas, P, Thomas, A. Beaupretre, B. 2012. Back industrial experience on the choice of a Information technology scope by products. Internationale Conférence of Modelling. Optimisation et SIMulation - MOSIM'12 From 06 to 08 June 2012 – Bordeaux.

Gouyon, D. Michael, D. 2009.Towards the implementation of a monitored system by product using networks wireless sensors. Journal of Europeen automated Systemes, Hermes.

Cardin,O. Castagna,P. Chové, E.2013. Use of an observer for piloting the Product driven system.Journal of Europeen automated Systemes, Hermes.

Gaudreai, E. Agard, B. Trepanier,M. Baptiste,P. 2005. Responsive piloting of production systems using intelligent sensors. 6e international Congrès of industrial Engineering – 7-10 june2005 – Besançon.

Thierry,C. Thomas,A. Bel, G.2008.Simulation of the system piloting by product. hal-00341856, version 1 - 26 Nov 2008.

Vérane , H.2006. Integrated logistics process trade in the supply chain application case to groupspharmaceutical and cosmetic. Mining School of Alb

Material Requirements Planning under Phase-out Conditions

Regina Wagner and Thorsten Blecker

In today's production environment with shortened product lifecycles, phase-outs, i.e. product elimination from production, become regular events. Badly planned phase-outs lead to high remaining stock levels after end of production, causing immense sunk costs. Previously performed 26 interviews revealed that this is a major challenge in current production (Grussenmeyer and Blecker, 2014; Grussenmeyer, Gencay and Blecker, 2014). Therefore, the objective of this paper is to develop a material requirements planning focusing on remaining stock induced costs during phase-out to plan optimal phase-out quantity and phase-out date. The research is conceptually driven and proposes an example of the methodology.

Keywords: Phase-Out, Product Elimination, Production Planning and Control, Remaining Stock Costs

1 Introduction

Shortened product life cycles are significant current trends of supply networks (Bakker, Wang, Huisman and den Hollander, 2014, p.10). They lead to frequent product changes in order to satisfy customer's demand (Slamanig, 2011, p.46).

Enabling successful product's ramp-ups requires production capacities availability. Since 80% of the new products are symmetrical replacements (Saunders and Jobber, 1988), companies use the old generation's production plant as well for the replacement's manufacturing, implying an equipment change. Thus, the old product needs to be eliminated in order to release the demanded production capacity (Vyas, 1993, p.68). Product elimination implementations mostly are realized as phase-outs (Avlonitis, 1983; Mitchell, Taylor and Tanyel, 1998; Baker and Hart, 2007), and their success depends on phase-out's process quality (Prigge, 2008). The need of having good phase-out processes is also described by practitioners (Holzhäuer and Riepl, 1996, p.49). Still, very few research deals with phase-out and its processes.

Phase-out can be described in a four-stage process, starting after product elimination decision-making. The two main stages are planning and implementation, framed by definition and finalization, describing the actual dealing with phase-out in the production department.

To successfully produce products, and therefore, as well to phase-out products, companies use production planning and control (PPC). Adopting this, especially the material requirements planning is a key issue in phase-out planning for not having any remaining stock after end of production

(Holtsch, 2009; Hertrampf, 2012). To appropriately plan material requirements, this publication presents a methodology to estimate remaining stock costs.

The outline of this publication is as follows. After reviewing literature in chapter 2, equations to calculate remaining stock costs are elaborated in chapter 3. The following chapter 4 presents a phase-out example to demonstrate the methodology's functionalities. Chapter 5 summarizes the results.

2 Literature Review

Eliminating products from the company's portfolio is considered as an uninspiring and depressing task (Eckles, 1971, p.72) Nevertheless, in today's competitive environment, it is becoming more and more important (Prigge, 2008, p.100). After elimination decision-making, the implementation strategy needs to be determined (Avlonitis, Hart and Tzokas, 2000, p.54). From marketing point of view, five options are available, namely drop immediately, phase-out immediately, phase-out slowly, sell-out and drop from standard and re-introduce as special strategies (Baker and Hart, 2007, p.478).

2.1 Product Phase-Out

From a production point of view, only the phase-out strategies are interesting to investigate due to several reasons. The drop immediately strategy implies a direct machine stop, without any potential for improvement. The sell-out and drop strategy only induce marketing activities. In cases of plant sale, production does not change, while when product's rights are sold by ending production, a phase-out takes place. The situation is similar to the drop strategy. Even though the product might be re-introduced as a special after its normal end of production, it necessarily has to be phased-out before. Thus, this paper deals with the planned phase-out of a product.

In literature, product phase-out definitions are not clear. Apart from the fact that many authors use the term without defining it before (e.g. Inness, 1994; Holzhäuer and Riepl, 1996; Aurich, Naab and Barbian, 2005; Kotler and Armstrong, 2010) other definitions only include the production reduction from full capacity run to end of production (e.g. Kirsch and Buchholz, 2008; Ostertag, 2008; Scholz-Reiter, Baumbach and Krohne, 2008; Elbert, 2011) without considering any planning. Therefore, we define the product phase-out as "process, enabling companies to eliminate a product. The phase-out is subsequent to the phase-out decision and starts with the planning. The phase-out ends with the finalization after the end of production" (adopted from Grussenmeyer and Blecker, 2014, p.185).

Several authors assume a correlation between the market's decline phase and product phase-out (e.g. Aurich and Naab, 2006; Hertrampf, Nickel and Nyhuis, 2010) even though Avlonitis (1990, pp.55–60) detected that products are eliminated irrespective of their position in the product life cycle. Consequently, a phase-out may also take place at any time during the product's life.

2.2 Planning and Controlling Product Phase-Outs

Holtsch (2009, pp.54–60) described that previous publications do not deal with phase-out PPC. He then developed an 8-phase phase-out reference process intending to give industry a guideline to plan and control phase-out (Figure 1).

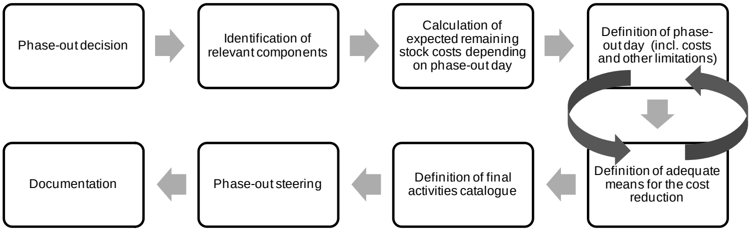


Figure 1 Phase-out Control Process; Source: Holtsch (2009, p.62)

The phase-out PPC process presented by Holtsch is limited to phase-out induced remaining stock costs without referring to any further phase-out aspects. In addition, he does not follow any of the existing PPC models (e.g. Hornung, 1996; Hackstein, 1989; Lödding, 2005; Schuh, 2006) which he analyzed in his work. Holtsch (2009, p.111) only adds four activities to production plan generation and one function to make-or-buy decision-making to the Aachener PPS Modell (Aachen PPC Model Hornung 1996).

In his first process stage – phase-out decision-making – he aggregates requirements of different stakeholders without giving any elimination decision-making model on how to decide to phase-out, and without referring to any product elimination literature. For the second process stage – component identification – he develops a phase-out cube, with the three dimensions (ranging from N via O to P) phase-out coefficient, normative range of stock and normative stock value (as described in Holtsch (2009, p.74)). The cube's axes seem to have different relevance (e.g. NPO = neutral / OPN = dispositive adoption / PNO = phase-out relevant), where the phase-out coefficient is the main influence factor, but no justification is given.

The third process stage is to calculate the expected remaining stock costs (inventory multiplied by unit costs) for all product components. This formula does not include multi-variant phase-outs where there might not only be one optimum phase-out day. At this stage, only unit costs are considered, i.e. remaining stock handling costs are entirely neglected. Furthermore, the amount of items or parts expected to become remaining stock is considered as input variable, obliging the companies themselves to develop calculation models. Process stages four and five summate all part's costs during phase-out (inventory costs, remaining stock costs, process costs, as well as income or losses from remaining stocks options) in addition to general phase-out management costs. In the sixths process stage, all options are then balanced to obtain the maximum profit. Process stage seven, i.e. phase-out control, is described as standard control loop without detailing any methodologies applicable. The author also describes how to perform multi phase-outs (subsequent or parallel) by adopting the control loop, but he does not include multi phase-outs into his planning process (Holtsch, 2009, pp.61–109). Therefore, it is necessary to develop a phase-out PPC model complying with specific phase-out objectives.
To close the first part of this gap, a methodology how to really calculate the expected remaining stock at end of production and its induced costs is presented in the following chapter.

3 Expected Remaining Stock

Material requirements planning can follow stochastic, deterministic and heuristic approaches. In general, stochastic models are applied for high volume, low cost products, while deterministic models are used for high costs, low volume products. New products or products with unknown demand are calculated with heuristic models; which are therefore not relevant for phase-out. All models include decisions on production and inventory quantities and the identification of relevant costs, e.g. variable production costs, setup costs, and inventory costs. Similar to standard production planning, a phase-out plan is created in a rolling horizon fashion, to be updated after implementing the first decisions. The revised plan minimizes demand forecast and production uncertainties (Graves, 2001, p.730). Production planning figures are non-negative integers ($\in\mathbb{N}_0$).

The first planning step is to determine the amount of lots for every part j to be purchased during phase-out for producing all phase-out items i following the standard deterministic approach. The result then needs to be compared to existing contract limitations, e.g. lot sizes, which lacks in existing literature. For example. Hertrampf (2012) only reduces lot sizes by incorporating risk costs and Holtsch (2009) does not consider lot size limitations.

$$aPL_{jt} = \begin{cases} \left\lceil \dfrac{\sum_{i=1}^{I} ar_{ij} \cdot \left\lceil \frac{n_{it}}{LS_{it}} \right\rceil \cdot LS_{it} - s_{jt-1} + sp_{jt}}{PLS_{jt}} \right\rceil & if \quad n_{it} > 0 \\ 0 & else \end{cases} \quad (1)$$

$$ar_{ij}, PLS_{jt} > 0$$

$$\forall i \in I, j \in J, t \in T$$

ao_{it}	amount of items i ordered in period t [pcs]
aPL_{jt}	amount of procurement lots of part j in period t [u/m]
ar_{ij}	amount of part j required for item i [pcs/pcs]
LS_{it}	production lot size of item i in period t [pcs/(u/m)]
n_{it}	need of item i in period t [pcs], i.e. $ao_{it} - s_{it-1}$ [pcs]
PLS_{jt}	procurement lot size of part j in period t [pcs/(u/m)]
$Q_j(\tau)$	repair parts order quantity [pcs]
sp_{jt}	spare parts need of part j in period t [pcs] (equation (2))
s_{it-1}	stock of item i at the beginning of period t [pcs]
s_{jt-1}	stock of part j at the beginning of period t [pcs]

subject to

$$Q_j(\tau) = \sum_{t=1}^{T} sp_{jt} \quad \forall j \in J \quad (2)$$

To determine the spare parts order quantity $Q_j(\tau)$ and the spare parts need sp_{jt}, please consult the publication of Sahyouni et al (2010, p.794) who present a deterministic optimization model.

Equation (1) calculates the ceiling of the necessary procurement lots of part j, i.e. the smallest integer greater or equal to the equation. The equation combines information of the quantity bill of materials with the existing demand subtracted by items i on stock. The division by the procurement lot size directly links the calculated need to procurement limitations. It is necessary to summate over all items i to obtain the parts' need for all phase-out items. For any situation where the amount of orders can already be covered by the stock on hand, the procurement lot size decreases to zero. Multiplying the amount of procurement lots with the lot size gives the stock level of part j, as given in equation (3).

$$s_{jt} = aPL_{jt} \cdot PLS_{jt} + s_{jt-1} \quad \forall j \in J, t \in T \tag{3}$$

aPL_{jt}	amount of procurement lots of part j in period t [u/m] (eq. (1))
PLS_{jt}	procurement lot size of part j in period t [pcs/(u/m)]
s_{jt}	stock of part j at end of period t [pcs]
s_{jt-1}	stock of part j at the beginning of period t [pcs]

The amount of stock serves to calculate the amount of lots that can be produced, taking now into account the given production lot size which is determined by the company and its suppliers. To do so, equation (4) divides the not-blocked stock of part j by the amount of parts j required to produce one item i and by the production lot size (part consumption). To not obtain half lots, the largest integer less than or equal to the equation is calculated (floor calculation), thus differing from the ceiling calculation in equation (1). The company needs enough parts procurement lots to produce (=

rounding up), leading to a limited amount of item's production lots (= rounding).

$$aL_{ijt} = \left\lfloor \frac{s_{jt} - sp_{jt}}{LS_{it} \cdot ar_{ij}} \right\rfloor \quad \forall i \in I, j \in J, t \in T \tag{4}$$

$$ar_{ij}, LS_{it} > 0 \quad \forall i \in I, j \in J, t \in T$$

aL_{ijt} amount of production lots of item i in period t with given part j [u/m]

ar_{ij} amount of part j required for item i [pcs/pcs]

LS_{it} production lot size of item i in period t [pcs/(u/m)]

s_{jt} stock of part j at end of period t [pcs] (eq. (3))

sp_{jt} spare parts need of part j in period t [pcs] (eq. (2))

Since all different parts j have different procurement lot sizes and different consumptions per item i, equation (4) will provide several solutions for the amount of production lots for item i and period t; one value for every part j. To include all parts j given in the bill of materials to produce item i only the smallest number of lots as calculated in equation (5) may be produced with the given stock of materials. The necessary calculation is formulated in equation (5).

$$aLm_{it} = \min_{\rightarrow j \in J} \{aL_{ijt}\} \quad \forall i \in I, t \in T \tag{5}$$

aL_{ijt} amount of production lots of item i in period t with given part j [u/m] (eq. (4))

aLm_{it} minimum amount of production lots for item i in period t [u/m]

The expected item's i remaining stock needs to be calculated despite the fact that the calculation started with the initial amount of orders, due the rounding procedures in equation (1) and (4) leading to additional items i produced, that cannot be sold. Equation (6) calculates the item's i remaining stock, i.e. maximum amount of items i available at the end of period t (from stock or production), considering production and procurement lot size constraints leveraged by the amount of items ordered. When the time period t corresponds to the time between phase-out beginning and end of production, the amount of production lots times the production lot size is the phase-out quantity.

$$RS_{it} = aLm_{it} \cdot LS_{it} + s_{it-1} - ao_{it} \quad \forall i \in I, t \in T \tag{6}$$

aLm_{it} minimum amount of production lots of item i in period t [u/m] (eq. (5))

ao_{it} amount of items i ordered in period t [pcs]

LS_{it} production lot size of item i in period t [pcs/m/u]

s_{it-1} stock of item i at the beginning of period t (t-1) [pcs]

RS_{it} remaining stock of item i at the end of period t [pcs]

In addition to the item's i remaining stock, the remaining stock amount of every part j is a set of stock balance constraints that equate the supply of all parts j in a period with its demand for producing item i. In any period t, a certain amount of parts is ordered, while others are already stocked. The available parts are then consumed to produce the item or to store them as spare parts. Due to the fact that normally more parts are procured than sold, stock remains (equation (7)).

$$RS_{jt} = s_{jt-1} - sp_{jt} + aPL_{jt} \cdot PLS_{jt} - \sum_{i=1}^{I} aLm_{it} \cdot ar_{ij} \cdot LS_{it} \quad \forall j \in J, t \in T \tag{7}$$

aLm_{it}	minimum amount of production lots for item i in period t [u/m] (eq. (5))
aPL_{jt}	amount of procurement lots of part j in period t [u/m] (eq. (1))
ar_{ij}	amount of part j required for item i [pcs/pcs]
I	number of phase-out items using part j
LS_{it}	production lot size of item i in period t [pcs/(u/m)]
PLS_{jt}	procurement lot size of part j in period t [pcs/(u/m)]
RS_{jt}	amount of remaining stocks of part j at the end of period t [pcs]
s_{jt-1}	stock of part j at the beginning of period t [pcs]
sp_{jt}	spare parts need of part j in period t [pcs] (eq. (2))

The calculated remaining stock from equation (7) is multiplied with the sum of the unit price per part j (i.e. the purchase price) and the remaining stock costs (equation (8)). The latter costs depend on the chosen remaining stock handling option chosen for part j (e.g. sale, recycle, or scrap). For sale situations where some income is generated, the cost is negative to reduce the expected remaining stock costs.

$$ecRS_{jt} = \begin{cases} RS_{jt}(pu_{jt} + cRS_{jt}) & if \quad RS_{jt} > 0 \quad \forall j \in J, t \in T \\ 0 & else \end{cases} \tag{8}$$

Source: Adopted from Hertrampf (2012, p.37)

cRS_{jt}	unit costs for the remaining stock handling option according to the existing remaining stock option of part j (Holtsch, 2009, p.95) [€/pcs]
$ecRS_{jt}$	expected remaining stock costs for remaining stock of part j at the end of period t [€]
pu_{jt}	unit price per part j in period t [€/pcs]
RS_{jt}	amount of remaining stocks of part j at the end of period t [pcs] (equation (7))

At this point it is reasonable to estimate a valuation at the part's replacement costs for pu_{jt}, for two reasons. First, following the first-in-first-out (FIFO) principle will in many situations reduce previous period's stock (s_{jt-1}) to zero. Second, planning periods should be relatively short so the difference between procurement costs of two subsequent periods is neglectible. For an entirely exact calculation, the procurement costs need to be discounted together with the storage costs that emerged by that date depending on the time every part j was bought (also not specified by Hertrampf (2012)).

The phase-out coefficient represents the usage degree of one part j in the phase-out item i and in other items l (Holtsch, 2009, p.74). A coefficient of less than one indicates a further use of part j in other items l and that any part's remaining stock can be "sold" to another product, thus, generating a revenue the the unit price to eliminate the part from calculation $pu_{jt} = -cRS_{jt}$. Those parts j do not create any loss for the remaining stock costs calculation. Equation (9) shows the phase-out coefficient.

$$cPO_j = \sum_{t=1}^{T} \frac{\sum_{i=1}^{I}(ar_{ij} \cdot ao_{it})}{\left(\sum_{l=1}^{L} ar_{lj} \cdot ao_{lt} + \sum_{i=1}^{I} ar_{ij} \cdot ao_{it}\right)} \quad \forall j \in J \qquad (9)$$

$$ar_{lj}, ar_{ij} > 0 \quad \forall i \in I, j \in J, l \in L, t \in T$$

Source: Holtsch (2009, p.74)

ao_{it}	amount of phase-out items i ordered in period t [pcs]
ao_{lt}	amount of orders of alternative item l in period t [pcs]
ar_{ij}	amount of part j required for item i [pcs/pcs]
ar_{lj}	amount of part j required for item l [pcs/pcs]
cPO_j	phase-out coefficient of part j [0;1]
I	number of phase-out items i
L	number of alternative use in other items l
T	number of time periods until end of planning horizon

Parts j that might be used in next generation versions of item i might also be sold in future, which is not considered in equation (9). In those cases the expected remaining stock handling option would be storage and positive revenue after item's i end of production at the level of the unit price per part j. Similar to calculating the part's remaining stock costs in equation (8) also the remaining stock costs of the surplus items is calculated in equation (10), following an identical assumption. It is highly likely that companies sell remaining stock to at least obtain a lower-than-normal revenue (i.e. negative cRS_{it}), such as IBM who in 1998 generated a loss of $1 billion due to excess PC inventory at their dealers which were sold at low special offer prices (Bulkeley, 1999).

$$ecRS_{it} = \begin{cases} RS_{it}(cp_{it} + cRS_{it}) & if \quad RS_{it} > 0 \quad \forall i \in I, t \in T \\ 0 & else \end{cases} \tag{10}$$

Source: Adopted from Hertrampf (2012, p.37)

cp_{it} unit cost of production for item i in period t [€/pcs] (in general: material procurement costs, manufacturing costs and related overhead)

cRS_{it} unit costs for the remaining stock handling option of item i [€/pcs]

$ecRS_{it}$ expected remaining stock costs for remaining stock of item i at the end of period t [€]

RS_{it} amount of remaining stock of item i at the end of period t [pcs] (eq. (6))

Equation (11) gives the total expected remaining stock costs for all parts j and the phase-out item i for every period t over the planning horizon of T periods until end of production.

Concluding, equations (1) to (11) calculate the company's total remaining stock costs at the end of any period with a given amount of orders. For situations with only one phase-out item, the index i becomes 1.

$$tcRS_t = \sum_{i=1}^{I} ecRS_{it} + \sum_{j=1}^{J} ecRS_{jt} \quad \forall t \in T \tag{11}$$

$ecRS_{it}$	expected remaining stock costs for remaining stock of item i at the end of period t [€] (equation (10))
$ecRS_{jt}$	expected remaining stock costs for remaining stock of part j at the end of period t [€] (equation (8))
I	number of phase-out items
J	number of parts
$tcRS_t$	total remaining stock costs of all parts in period t [€]
T	number of time periods

4 Phase-out Example

To better understand the equations described above, this chapter offers an example to calculate remaining stock costs for one phase-out item i consisting of five parts j (j1-j5). Production lot sizes is LS_{it} = 45, and s_{it-1} = 50 items are already on stock. Let us assume the following further values:

Table 1 Input Variables for Phase-Out Example

Input variable	i1	i2	i3	i4	i5
ar_{ij}	1	2	3	4	5
PLS_{jt}	50	40	28	20	10
pu_{jt}	3	2	58	17	31
cRS_{jt}	10	10	10	10	10
s_{jt-1}	5	4	3	2	50

Table 2 Amount of Items Ordered in Periods t1-t6

	t1	t2	t3	t4	t5	t6
ao_{it}	75	10	25	54	43	77

Table 3 Amount of Items Ordered in Periods t7-t12

	t7	t8	t9	t10	t11	t12
ao_{it}	90	100	12	23	97	49

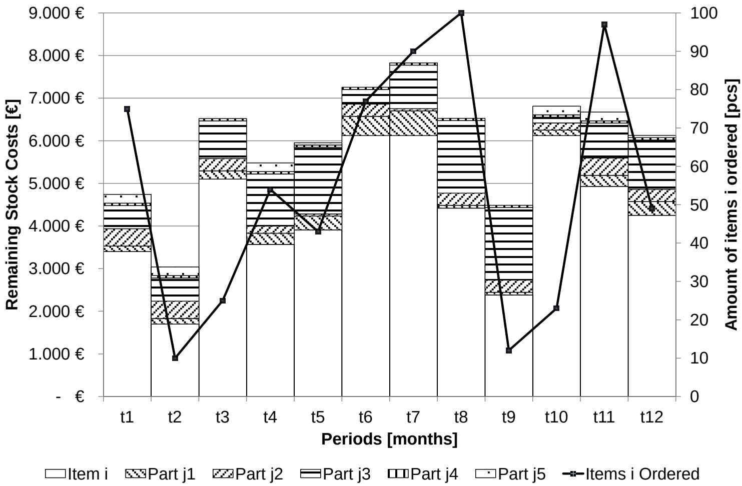


Figure 2 Expected Remaining Stock Costs per Period

Figure 2 shows a sample calculation of the expected remaining stock costs over 12 periods of the phase-out item i.

As given in the formulas above the remaining stock costs depends on the demand, the procurement and production lot sizes, the inventory at hand, as well as costs for remaining stock handling and procurement / production unit costs.

In the given example the company will need to pay ca. €6.000 of remaining stock costs at the end of period t12, consisting out of €4.200 for handling the remaining stock of the item itself and €1.800 for handling the parts' remaining stock.

Figure 2 clearly shows that remaining stock costs differ strongly from period to period. The lowest amount may be achieved at the end of period t2;

the highest amount needs to be paid at the end of period t7. The latter costs are more than twice times period t2 costs.

5 Summary and Conclusions

This research introduces a methodology to calculate expected remaining stock costs at end of production as add-on to material requirements planning within PPC. After a brief literature review, eleven equations are presented which serve to calculate first, the expected remaining stock quantity, and second, resulting costs. An example shows the methodology's functionalities.

This paper closes the gap in research by addressing the missing link of quantity and cost calculation in remaining stock investigations. By now, only costs were analyzed, expecting remaining stock quantity as given input.

Using the presented equations supports companies first of all in knowing the expected remaining stock costs level. In a further step companies may now decide basing on the new information to take different means for reducing the expected stock. One option is to end production earlier, i.e. to not meet the entire demand. In the example, period t2 is the month with least remaining stock costs. Yet, the company most probably will need to offer a penalty payment or a replacement product to the customer. This makes choosing period t2 less likely, but period t9 could then become interesting. But a further aspect changing the situation is that at the end no remaining stock of the item itself will be available (it is not reasonable to scrap remaining stock and pay penalty for unmet demand at the same time), so only the parts' remaining stock will be regarded, which would shift it to period t10 in the given example. Yet, also the amount to be paid for not meeting the demand needs to be considered, which consists of penalty costs and lost profit.

Alternatively, companies might try to reduce item's stock by selling them to a lower (cost-covering) price and to reduce part's stock by reducing procurement lot sizes where possible. Calculating appropriate lot size amounts is presented in Hertrampf's (2012) publication.

The next steps in research are therefore to include unmet demand (lost sales) and additional production runs to consume remaining parts into the methodology. Then, companies are enabled to thoroughly decide which remaining stock reduction measure is the most appropriate for their given situation.

References

Aurich, J.C. and Naab, C., 2006. Organization of the run-out phase in production projects. Production Engineering, XIII(1), pp.153–156.

Aurich, J.C., Naab, C. and Barbian, P., 2005. Systematisierung des Serienauslaufs in der Produktion. Zeitschrift für wirtschaftlichen Fabrikbetrieb, 100(5), pp.257–260.

Avlonitis, G.J., 1983. The product-elimination decision and strategies. Industrial Marketing Management, 12(1), pp.31–43.

Avlonitis, G.J., 1990. 'Project Dropstrat': product elimination and the product life cycle concept. European Journal of Marketing, 24(9), pp.55–67.

Avlonitis, G.J., Hart, S.J. and Tzokas, N.X., 2000. An analysis of product deletion scenarios. Journal of Product Innovation Management, 17(1), pp.41–56.

Baker, M.J. and Hart, S., 2007. Product elimination. In: Product strategy and management, 2nd ed. Harlow u.a.: FT Prentice Hall, pp.440–525.

Bakker, C., Wang, F., Huisman, J. and den Hollander, M., 2014. Products that go round: exploring product life extension through design. Journal of Cleaner Production, 69, pp.10–16.

Bulkeley, W.M.B.S.R. of T.W.S., 1999. IBM discloses PC pretax loss of nearly $1 billion last year. The Wall Street journal. 25 Mar.

Eckles, R.W., 1971. Product line deletion and simplification: tough but necessary decisions. Business Horizons, 14(5), pp.71–74.

Elbert, N., 2011. Auslaufmanagement in der Logistik - Untersuchung der Pfadabhängigkeit im Produktlebenszyklus am Beispiel der Automobilindustrie. Veszprém, Ungarn.

Graves, S.C., 2001. Manufacturing planning and control. In: P.M. Pardalos and M.G.C. Resende, eds., Handbook of applied optimization. New York, N.Y: Oxford University Press, pp.728–746.

Grussenmeyer, R. and Blecker, T., 2014. Aligning Product Phase-Out with New Product Development. In: Grubbström, R.W.;Hinterhuber, H.H., (Eds): PrePrints, Volume 1. 18th International Working Seminar on Production Economics. Innsbruck, Austria, pp.183–194.

Grussenmeyer, R., Gencay, S. and Blecker, T., 2014. Production Phase-out During Plant Shutdown. Procedia CIRP, 19, pp.111–116.

Hackstein, R., 1989. Produktionsplanung und -Steuerung (PPS): Ein Handbuch für die Betriebspraxis. Düsseldorf: VDI.

Hertrampf, F., 2012. Auslaufmanagement in Produktionsnetzen. Berichte aus dem IPH. Garbsen, Germany: PZH.

Hertrampf, F., Nickel, R. and Nyhuis, P., 2010. Efficient phase-out planning by alignment of lot sizes in supply chains. In: Proceedings. 43rd CIRP International Conference on Manufacturing Systems. Wien, pp.860–867.

Holtsch, P., 2009. Planung und Steuerung von Produktionsausläufen in der Elektronikindustrie. Berichte aus dem IPH. Garbsen: PZH, Produktionstechn. Zentrum.

Holzhäuer, R. and Riepl, K., 1996. Der 'geordnete' Produktauslauf. IO Management, 65(4), pp.49–50.

Hornung, V., 1996. Aachener PPS-Modell: Das Aufgabenmodell. 4th ed. Sonderdruck 6/94. Aachen: Forschungsinstitut für Rationalisierung (FIR).

Inness, J.G., 1994. Achieving successful product change: a handbook. Financial times. London, UK: Pitman.

Kirsch, T. and Buchholz, W., 2008. An- und Auslaufmanagement - logistische Herausforderungen am Anfang und Ende des Produktlebenszyklus. Industrie Management, 24(3), pp.45–48.

Kotler, P. and Armstrong, G.M., 2010. Principles of marketing. 13th ed. Upper Saddle River, N.J: Pearson Education.

Lödding, H., 2005. Verfahren der Fertigungssteuerung: Grundlagen, Beschreibung, Konfiguration. Berlin: Springer.

Mitchell, M., Taylor, R. and Tanyel, F., 1998. Product elimination decisions: a comparison of American and British manufacturing firms. International Journal of Commerce and Management, 8(1), pp.8–27.

Ostertag, R., 2008. Supply-Chain-Koordination im Auslauf in der Automobilindustrie. Wiesbaden: Gabler.

Prigge, J.-K., 2008. Gestaltung und Auswirkungen von Produkteliminationen im Business-to-Business-Umfeld: eine empirische Betrachtung aus Anbieter- und Kundensicht. Wiesbaden: Gabler.

Sahyouni, K., Savaskan, R.C. and Daskin, M.S., 2010. The effect of lifetime buys on warranty repair operations. Journal of the Operational Research Society, 61(5), pp.790–803.

Saunders, J. and Jobber, D., 1988. An exploratory study of the management of product replacement. Journal of Marketing Management, 3(3), pp.344–351.

Scholz-Reiter, B., Baumbach, B. and Krohne, F., 2008. Integriertes Auslaufmanagement - Anforderungen an ein zielorientiertes Kennzahlensystem zur effizienten Durchführung von Produktausläufen. Industrie Management, 24(5), pp.74–78.

Schuh, G. ed., 2006. Produktionsplanung und -Steuerung: Grundlagen, Gestaltung und Konzepte. Berlin: Springer.

Slamanig, M., 2011. Produktwechsel als Problem im Konzept der Mass Customization: theoretische Überlegungen und empirische Befunde. Wiesbaden: Gabler.

Vyas, N.M., 1993. Industrial Product Elimination Decisions: Some Complex Issues. European Journal of Marketing, 27(4), pp.58–76.

Approach for Complexity Management in Variant-rich Product Development

Wolfgang Vogel and Rainer Lasch

During the last years, companies in high-technology marketplaces were confronted with technology innovations, dynamic markets, changing customer requirements and uncertainty. Manufacturing companies can't escape these trends. To cope with these trends, companies try to develop new product variants, which lead to increased complexity. Product development is characterized by different factors such as product, product portfolio and the development process. Complexity management in product development is a strategic issue for companies to be competitive. A systematic literature review was performed to identify and analyze the existing approaches for complexity management in all fields. Based on this, a new approach for managing complexity in variant-rich product development was developed. It encourages the reader to manage product development's complexity. In this approach, complexity is systematically analyzed and evaluated to create conditions for a target oriented managing and controlling of complexity in product development.

Keywords: Complexity, Complexity Management, Approach, Product Development

1 Introduction

Developing and producing individual and complex products for diversified marketplaces at minimum cost is the challenge of the 21st century. Within the last decades, complexity in the company has increased continuously in many industries (Schuh, Arnoscht and Rudolf, 2010, p.1928; Lübke, 2007, pp.2-4; Krause, Franke and Gausemeier, 2007, pp.3-4; ElMaraghy, et al., 2012, p.797). Companies in high-technology marketplaces are confronted with technology innovation, dynamic environmental conditions, changing customer requirements, market globalization and uncertainty. These are trends that manufacturing companies can´t escape (Miragliotta, Perona and Portioli-Staudacher, 2002, p.382; Gerschberger, et al., 2012, p.1016). In today's highly competitive environment it is fundamental for a company's success to bring new products to the market quickly and with customized settings (Augusto Cauchick Miguel, 2007, p.617; Lübke, 2007, pp.2-3). As a reaction, the companies are present in the market with a diversified product portfolio (Haumann, et al., 2012, p.107; ElMaraghy and ElMaraghy, 2014, pp.1-2). Product development is one of the most complex and nontransparent tasks and uncertain processes in the company (Bick and Drexl-Wittbecker, 2008, p.20; Davila, 2000, p.386; Specht and Beckmann, 1996, p.25-26). Product development process is confronted with several complexity factors such as demand variety, uncertain objectives, environmental dynamics, high time pressure and restricted resources (Wildemann, 2012, p.202). Dehnen (2004, pp.33-35) argues that complexity in product development comes generally from a variety of internal and external sources, called complexity drivers. Complexity drivers describe a system's complexity and help to evaluate and handle it. Complexity management is a strategic issue for companies to be competitive (Miragliotta, Perona and Portioli-Staudacher, 2002, p.383).

The purpose of this paper is to present a praxis-oriented approach for managing complexity in variant-rich product development. The approach was developed based on literature and encourages the reader to manage product development's complexity. Section 2 gives a literature overview about complexity management, their properties, requirements and objectives. Furthermore, an overview of existing complexity management approaches in different fields is presented. As a result of the existing complexity management approaches, a new approach for complexity management in variant-rich product development is described in section 3 and is applied on a recent development project in the automotive industry. Section 4 and 5 conclude the paper and close the research gap with implications for future research.

2 Literature Review

2.1 Complexity Management

The origin of the term complexity comes from the Latin word "complexus", which means "entwined, twisted together" (Miragliotty, Perona and Portioli-Staudacher, 2002, p.383). Based on systems theory, complexity is characterized by the amount and diversity of a system's elements, the amount and type of dependencies and the variation of the elements and their dependencies over time (Kersten, 2011, p.15). Thus, complex systems are characterized by the variety of their states (Schuh, 2005, pp.34-35).

Generally in literature, increasing complexity is related to increasing costs (Meyer, 2007, p.94). For example, modifications in product design or process are responsible for product or process variety and generate additional costs. Furthermore, such modifications may have unpredictable effects on the whole development process (Aggeri and Segrestin, 2007, p.38).
Managing a system's complexity requires an optimum fit between internal and external complexity. Managing complexity comprises designing the necessary variety, handling variety-increasing factors, reducing variety and controlling complex systems (Schuh, 2005, pp.34-35). Generally, complexity management has several objectives. In literature, the main objectives are reducing, mastering and avoiding complexity (Wildemann, 2012, p.69; Lasch and Gießmann, 2009a, p.198; Schuh and Schwenk, 2001, pp.32-40; Kaiser, 1995, p.102). Wildemann (2012, p.69) defines these objectives as the three main strategies for complexity management. In addition to the three complexity strategies, Krause, Franke and Gausemeier (2007, pp.15-16) argue that complexity identification, complexity evaluation and the determination of the optimum complexity degree are also important objectives for complexity management and to improve transparency.
Complexity management requires approaches for understanding, simplification, transformation and evaluation of complexity (Hünerberg and Mann, 2009, p.3). A successful complexity management approach enables a balance between external market's complexity and internal company's complexity (Rosemann, 1998, p.61; Kaiser, 1995, p.17). Therefore, it is necessary to implement complexity management in company's management process as an integrated concept (Kersten, 2011, pp.17-18).

Product development is mainly characterized by three categories: product, product portfolio and product development process. Based on these categories, the complexity drivers product complexity, product portfolio complexity and process complexity are derived. Complexity drivers are factors or indicators, which influence a system's complexity (Puhl, 1999, p.31; Perona and Miragliotta, 2004, p.104). Thus, managing complexity in product development requires a detailed complexity analysis in these categories (Dehnen, 2004, p.9). Beyond the mentioned categories, Ponn and Lindemann (2008, p.7) argue that the applied methods and instruments in product development are also important aspects.

Product complexity is characterized by product design, the number of elements or materials and their interdependencies as well as the dynamics of products activity. Product activity consists of the rate at which new products are introduced or existing products are changed (Edersheim and Wilson, 1992, pp.27-33; Kirchhof, 2003, p.40). Product portfolio complexity is determined by the product range or the variant range, the number of their elements and the dynamics of product portfolio's variability (Kirchhof, 2003, p.40; Lübke, 2007, p.173; Schoeller, 2009, p.50). Process complexity is mainly characterized by process design, process dynamics and multidimensional target expectation. Process design contains of the number of direct and indirect process steps, their interdependencies, the design of process interfaces, the level of difficulty as well as the controllability and consistency of each step. Process dynamics refer to the rate at which processes or product design and operational parameters are changing. Operational parameters could be tolerances (Edersheim and Wilson, 1992, pp.28-34;

Klabunde, 2003, p.8; Kirchhof, 2003, p.40). Furthermore, process complexity describes the multidimensional demand for a structural coordination between different interfaces (Dehnen, 2004, p.34). According to complexity management's objectives and product development's characteristics, the requirements for a complexity management approach in variant-rich product development must be defined. In literature, several requirements for a complexity management approach exist. According to Lasch and Gießmann (2009a, pp.203-206), we defined eleven main requirements and assigned them to the following three main categories:

- Structural: Recurring cycle, modular structure.
- Functional: Practicability and transparency, identifying the complexity problem, methods for complexity management, application of key figures, approach for capability planning.
- Cause related: Identifying complexity drivers, identifying complexity drivers' interdependencies, evaluation of complexity drivers, evaluation of complexity (degree).

2.2 Research Methodology and Results

This paper's purpose is to develop a praxis-oriented approach for managing complexity in variant-rich product development. Before developing a new approach, existing literature must be identified, analyzed and evaluated. For this literature review, we determined two research questions:

RQ1: What different approaches currently exist in scientific literature?

RQ2: What structure and focuses do the existing approaches have?

The first step in conducting a literature research is to define the right search terms based on the research questions. In literature, the terms "approach", "model", "method", "concept", "procedure" and "framework" are often used synonymously for describing a complexity management approach. Thus, all terms were used for this literature research. Furthermore, to extend the results and to prevent the elimination of important articles, the research was performed in English and German by using the following six databases, specialized in science and economics: Emerald, ScienceDirect, IEEE Xplore, Google Scholar, GENIOS/WISO and SpringerLink. No restrictions were made regarding the research period. The researched literature sources were synthesized based on the aforementioned research questions. This resulted in forty-seven relevant approaches in the time period between 1992 and 2014 (see Table 1 and 2). Fifty-seven percent of the existing approaches are focused on general in manufacturing companies. The remaining forty-three percent are separated in other fields such as product development (6.1 percent), procurement (2.0 percent), production (10.2 percent), logistics (4.1 percent), internal supply chain (16.3 percent) and distribution (4.1 percent). Only three approaches are focused on product development. In the next step, the identified approaches are analyzed and described according to their structure and targets (see Table 1 and 2). Furthermore, the existing approaches are evaluated based on the described requirements to identify deficits (see Table 3 and 4). The evaluation is based on the following three criteria:

¾ Fulfilled (+ +): Content and precise methods are described
¾ Partial fulfilled (+): Content are described without precise methods
¾ Not fulfilled (-): Content and methods are not described

Table 1 Overview about existing approaches (Part 1)

Explanation for focus:

- G General in manufacturing companies
- PD Product Development
- PC Procurement
- PR Production
- L Logistics
- SC Internal Supply Chain
- D Distribution

Explanation for evaluation criteria:

- ++ fulfilled
- + partial fulfilled
- - not fulfilled

Author(s)	Focus	Approach's structure: Complexity analysis	Complexity evaluation	Determine complexity strategy	Determine complexity instruments	Complexity planning	Implement complexity management	Complexity controlling	Target: Product complexity	Process complexity	Product protfolio complexity
Grossmann (1992)	G	●			●		●		-	-	-
Wildemann (1995)	PR			●	●				-	-	-
Fricker (1996)	G	●	●						-	-	-
Warnecke and Puhl (1997)	G	●	●	●					-	+	-
Bliss (1998)	G			●					++	-	-
Bohne (1998)	G	●	●	●				●	-	-	-
Rosemann (1998)	G			●					-	-	-
Puhl (1999)	G	●				●		●	-	+	-
Wildemann (1999)	PC			●					-	-	-
Bliss (2000)	G			●					++	-	-
Westphal (2000)	L			●					-	-	-
Miragliotta, Perona and Portioli-Staudacher (2002)	G	●	●	●	●				-	-	-
Kim and Wilemon (2003)	PD		●	●			●		-	-	-
Kirchhof (2003)	G	●				●			-	-	-
Dehnen (2004)	PD			●					++	++	++
Hanenkamp (2004)	PR			●		●	●	●	+	+	-
Meier and Hanenkamp (2004)	SC	●		●	●				-	-	-
Perona and Miragliotta (2004)	PR, L	●		●					-	-	-
Blecker, Kersten and Meyer (2005)	G	●	●						-	-	-
Geimer (2005)	SC	●		●			●		-	-	-
Geimer and Schulze (2005)	SC	●		●			●	●	-	-	-
Anderson et al. (2006)	G	●	●	●					-	-	-
Greitemeyer and Ulrich (2006)	G	●		●		●		●	+	+	-
Denk (2007)	G	●		●					-	-	-

Table 2 Overview about existing approaches (Part 2)

Explanation for focus:

G General in manufacturing companies
PD Product Development
PC Procurement
PR Production
L Logistics
SC Internal Supply Chain
D Distribution

Explanation for evaluation criteria:

++ fulfilled
\+ partial fulfilled
\- not fulfilled

		Approach's structure							Target		
Author(s)	**Focus**	Complexity analysis	Complexity evaluation	Determine complexity strategy	Determine complexity instruments	Complexity planning	Implement complexity management	Complexity controlling	Product complexity	Process complexity	Product protfolio complexity
Marti (2007)	G		●	●					++	-	-
Meyer (2007)	D	●		●				●	-	-	-
Bick and Drexl-Wittbecker (2008)	G			●					++	++	-
Schuh et al. (2008)	G	●							++	-	-
Denk and Pfneissl (2009)	G	●		●					-	-	-
Lasch and Gießmann (2009b)	G	●	●	●		●	●	●	+	+	+
Lindemann, Maurer and Braun (2009)	PD	●		●					+	-	-
Blockus (2010)	G	●		●		●		●	-	-	-
Warnecke (2010)	G	●	●	●					-	-	-
Isik (2011)	SC	●	●	●				●	-	-	-
Kersten (2011)	SC	●	●	●					-	-	-
Schawel and Billing (2011)	G	●		●					-	-	-
Fabig and Haasper (2012)	G	●		●	●		●		+	-	+
Koch (2012)	G	●	●	●					-	-	-
Lammers (2012)	D	●	●		●				-	-	-
Aelker, Bauernhansl and Ehm (2013)	SC	●	●	●					-	-	-
Boyksen and Kotlik (2013)	G	●		●					-	-	-
Jäger et al. (2013)	PR, SC	●	●	●	●				-	-	-
Meier and Bojarski (2013)	G	●	●						++	++	-
Serdarasan (2013)	SC	●	●	●	●				-	-	-
Grimm, Schuller and Wilhelmer (2014)	G	●		●	●		●	●	-	-	-
Schöttl et al. (2014)	PR	●	●		●				-	+	-
Wassmus (2014)	G	●		●			●	●	++	-	-

Table 3 Overview about existing approaches (Part 3)

Explanation for evaluation criteria:

++ fulfilled
+ partial fulfilled
- not fulfilled

Author(s)	Recurring cycle	Modular structure	Practicability	Transparency	Identifying the complexity problem	Methods for complexity management	Application of key figures	Approach for capability planning	Identification of complexity drivers	Complexity drivers' interdependencies	Evaluation of complexity drivers	Evaluation of complexity (degree)
Grossmann (1992)	-	-	++	+	++	++	+	-	-	-	-	-
Wildemann (1995)	-	++	-	-	-	++	-	-	-	-	-	++
Fricker (1996)	-	-	+	++	++	++	-	-	+	-	-	-
Warnecke and Puhl (1997)	++	+	++	+	-	++	-	-	++	-	++	++
Bliss (1998)	++	-	++	+	-	++	-	-	-	-	-	+
Bohne (1998)	+	-	+	++	+	++	-	-	-	-	-	-
Rosemann (1998)	-	-	+	-	-	++	-	-	-	-	-	-
Puhl (1999)	++	++	++	++	+	++	+	-	+	+	+	++
Wildemann (1999)	-	-	++	-	-	++	-	-	-	-	-	-
Bliss (2000)	++	-	++	+	-	++	-	-	-	-	-	+
Westphal (2000)	-	-	-	-	-	++	-	-	-	-	-	-
Miragliotta, Perona and Portioli-Staudacher (2002)	+	-	+	++	-	-	-	-	+	+	-	+
Kim and Wilemon (2003)	+	-	+	++	+	-	+	-	+	-	+	-
Kirchhof (2003)	+	+	-	++	-	+	-	-	++	++	+	-
Dehnen (2004)	-	+	+	-	-	+	-	-	-	-	-	+
Hanenkamp (2004)	+	+	-	++	-	+	-	-	++	++	+	-
Meier and Hanenkamp (2004)	++	+	++	+	-	++	-	-	++	-	++	-
Perona and Miragliotta (2004)	-	-	+	++	-	-	-	-	-	-	-	-
Blecker, Kersten and Meyer (2005)	+	+	++	++	-	-	-	-	++	++	-	-
Geimer (2005)	-	-	-	++	+	++	-	-	+	-	-	-
Geimer and Schulze (2005)	-	-	+	++	+	++	-	-	+	-	-	-
Anderson et al. (2006)	-	-	-	+	-	-	-	-	-	-	-	-
Greitemeyer and Ulrich (2006)	-	-	+	++	-	-	+	-	-	-	-	+
Denk (2007)	-	+	-	++	-	-	-	-	-	-	-	-

Table 4 Overview about existing approaches (Part 4)

Explanation for evaluation criteria:

++ fulfilled
\+ partial fulfilled
\- not fulfilled

Author(s)	Recurring cycle	Modular structure	Practicability	Transparency	Identifying the complexity problem	Methods for complexity management	Application of key figures	Approach for capability planning	Identification of complexity drivers	Complexity drivers' interdependencies	Evaluation of complexity drivers	Evaluation of complexity (degree)
Marti (2007)	-	-	++	++	-	+	-	-	-	-	-	+
Meyer (2007)	++	++	++	++	-	++	+	-	++	++	+	-
Bick and Drexl-Wittbecker (2008)	-	-	+	+	+	+	-	-	-	-	-	-
Schuh et al. (2008)	-	+	-	+	+	-	-	-	-	-	-	-
Denk and Pfneissl (2009)	-	+	-	++	-	-	-	-	-	-	-	-
Lasch and Gießmann (2009b)	++	-	+	-	+	++	+	-	++	++	+	+
Lindemann, Maurer and Braun (2009)	-	-	-	+	+	+	-	-	-	-	-	-
Blockus (2010)	-	-	+	++	-	+	+	-	-	-	-	-
Warnecke (2010)	-	-	+	+	-	+	-	-	-	-	-	+
Isik (2011)	-	-	+	++	+	-	-	-	+	+	-	-
Kersten (2011)	-	-	+	+	-	+	-	-	++	+	-	-
Schawel and Billing (2011)	-	-	+	++	-	++	-	-	++	++	+	-
Fabig and Haasper (2012)	+	-	-	-	-	+	-	-	-	-	-	-
Koch (2012)	-	-	-	+	-	-	-	-	-	-	-	-
Lammers (2012)	-	-	+	++	+	++	-	-	++	++	++	-
Aelker, Bauernhansl and Ehm (2013)	-	-	-	+	-	-	-	-	+	-	-	+
Boyksen and Kotlik (2013)	++	-	+	+	-	-	-	-	+	-	+	+
Jäger et al. (2013)	+	-	-	+	-	-	+	-	+	-	-	+
Meier and Bojarski (2013)	+	+	+	++	-	+	-	-	-	-	-	-
Serdarasan (2013)	++	+	-	+	-	-	-	-	+	-	-	+
Grimm, Schuller and Wilhelmer (2014)	+	-	+	+	+	-	-	-	+	-	-	-
Schöttl et al. (2014)	-	-	+	+	++	+	-	-	+	-	++	-
Wassmus (2014)	++	+	-	+	-	+	-	-	-	-	-	-

In the first step, the structure and the targets of all identified approaches are analyzed to identify commonalities and differences. Based on this analysis, seven stages of complexity management can be identified and were applied in literature: complexity analysis (N: 36; 77%), complexity evaluation (N: 19; 40%), determination of complexity strategies (N: 38; 81%), determination of appropriate complexity instruments (N: 10; 21%), complexity planning (N: 6; 13%), complexity management's implementation (N: 9; 19%) and complexity controlling (N: 11; 23%). The most applied stages are determination of complexity strategies, complexity analysis and evaluation. Thus, these stages are very important. However, there is no approach, which consists of all stages.

Complexity management in product development is determined by product complexity, process complexity and product portfolio complexity. This is the reason why we analyzed the literature according to these categories. Most of the existing approaches have no explicit target or focus. Only one approach exists with a focus on all mentioned complexity categories.

In the next step, the identified approaches are evaluated based on the defined eleven main requirements. As a result, there is no approach, which fulfills all requirements in total or partial. The evaluation criteria practicability (N: 31; 66%), transparency (N: 40; 85%) and methods for complexity management (N: 31; 66%) are the most fulfilled or partially fulfilled requirements. Thus, the existing approaches are mostly focused on these criteria. They can be defined as the approach's objectives.

In summary, an approach which consists of all stages and categories and fulfills all requirements in total or partially does not exist yet. With our complexity management approach we cover this research gap.

3 Complexity Management in Variant-rich Product Development

In our literature review, we identified seven stages, which were applied for complexity management in the company.

Product development is characterized by variety, dynamics, complex and nontransparent tasks and uncertain processes (Wildemann, 2012, p.202; Bick and Drexl-Wittbecker, 2008, p.20; Davila, 2000, p.386; Specht and Beckmann, 1996, pp.25-26). This leads to an increasing risk in product development (Specht and Beckmann, 1996, p.25). For risk management, four stages are described in literature: analysis, evaluation, regulation and controlling of risks (Ahrendts and Marton, 2008, p.14; Schawel and Billing, 2011, p.165). Complexity and risk are closely connected because of their characteristics (Specht and Beckmann, 1996, pp.25-26). Thus, risk management's four stages can also be applied for complexity management.

Considering product development's characteristics, we developed a four stages complexity management approach for variant-rich product development based on the existing literature and the risk management strategies (see Figure 1). The approach is focused on product development's three main dimensions product complexity, product portfolio complexity and process complexity (Dehnen, 2004, p.9) and comprises the seven stages. The approach is designed as a recurring cycle with a modular structure to fulfill the structural requirements of a complexity management approach. Furthermore, different methods and tools for complexity management are described to gain practicability.

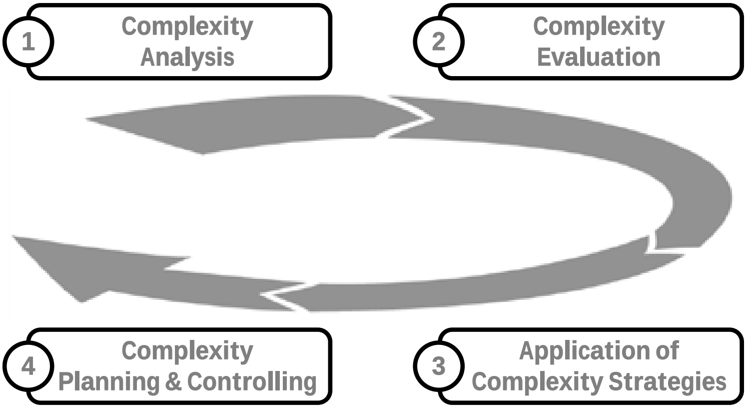


Figure 1 Four stage complexity management approach

The new approach was applied on a recent development project in the automotive industry to verify the scientific results. Cars are probably the most complex mass-produced industrial products in the market, because they combine many different parts, components, technologies and functions. The development process takes between three to four years and involves hundreds of engineers, technicians and partners (Moisdon and Weil, 1996, cited in Aggeri and Segrestin, 2007, p.38). In the last years, automotive companies increased their product portfolio successively to gain market shares and to be competitive. Complex products such as cars consist not only of mechanical and electrical parts and components but also of software, control modules and human-machine interfaces (ElMaraghy, et al., 2012, p.793), which influence each other and lead to an increasing complexity.

3.1 Complexity Analysis

Complexity in a project, especially in product development, requires a detailed complexity analysis (Warnecke, 2010, p.640) to increase transparency and to fulfill the functional requirements (see chapter 2.1). The first step is to formulate and distinguish the tangible problem and to derive the demand for action (Grossmann, 1992, p.209; Fricker, 1996, p.113; Schöttl, et al., 2013, p.258). Hauschildt (1977, p.127) argues that problem complexity is related to a problem's structure, its parts and uncertainty. For analyzing the complexity problem, Schöttl, et al. (2013, p.258) use individual questionnaires. The second step is to identify and analyze the complexity drivers. Complexity driver's analysis and understanding is the basis for developing a clear strategy for managing complexity (Serdarasan, 2013, p.533). In literature, several approaches for complexity driver's identification exist. The most applied approaches are expert interviews, process or systems analysis and influence analysis. In the third step, product variants are analyzed in detail to identify product's commonalities and differences and to identify the main attributes, which characterize a product variant. Variant's analysis and the main attributes are the basis for generating a variant derivation matrix in terms of an effective variant management (Nurcahya, 2009, pp.59-68). Variants are products with a high proportion of identical components in the categories geometry, material or technology (Lingnau, 1994, p.24). DIN 199 (1977 cited in Schwenk-Willi, 2001, pp.22-23) defines variants as objects with similar form or function and a high proportion of identical groups or components.

In our case study, the investigated object was the powertrain of a car. To identify the complexity problem in the product development department, we used expert interviews and questionnaires. The result was that the product portfolio increased in the last years continuously to gain market shares. However, the available budget and the development time for projects are decreasing successively. Another problem is that the variants are characterized by different complexity levels. Thus, the management is faced to develop an increased powertrain product portfolio in less time with the same or less input and resources.

For a detailed problem and complexity analysis, the powertrain was abstracted to a product model (see Figure 2) (Nurcahya, 2009, pp.59-62). The product model is an abstraction of a real product and contains all relevant elements or modules for product's characterization (Nurcahya, 2009, pp.54-61). This model is the basis for complexity driver's identification, analysis and evaluation. In our case study, the product model of a powertrain is divided into five main modules (engine, induction system, fuel injection system, exhaust system and drivetrain) and contains forty-eight relevant elements (turbocharger, injection valve, catalytic converter, etc.).

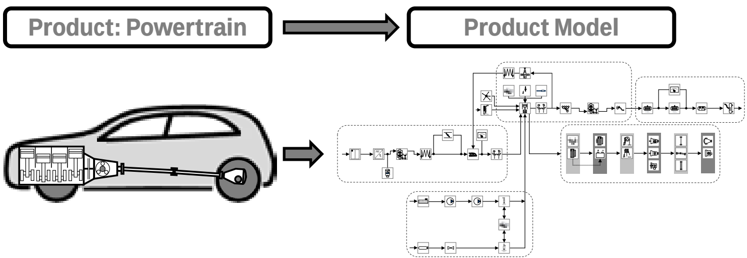


Figure 2 Powertrain product model

Next, the complexity drivers were identified and analyzed by using different approaches in the three categories product, product portfolio and process.

¾ Product: Literature, expert interviews, questionnaires, workshop, influence analysis.

¾ Product portfolio: Expert interviews, workshops, variant tree

¾ Process: Process analysis, expert interviews, workshops

In the third step, the product portfolio is analyzed to identify commonalities and differences. Based on product and complexity driver's analysis, the main attributes, which characterize a product variant, were defined.
Product portfolio can be divided in reference variants, product variants, product groups and product families. The reference variant is the most complex variant within a product family and the basis for variant's derivation. Product variants are derived from reference variants and clustered within the product family. A product group consists of several product families. Within a product family, the variants are similar with respect to specified criteria (Nurcahya, 2009, pp.52-55). Next, all reference and product variants within a product family are compared according to their characteristics to identify commonalities and differences (Nurcahya, 2009, pp.66-67). Nurcahya developed a matrix for variants' comparison. The matrix shows, which variants have the same characteristics and can be derived from another.
In our case study, a powertrain variant can be described by twenty different attributes (e.g. engine; transmission; time to market; etc.). Within the attributes, different product variants exist (e.g. 3.0l, 2.5l or 2.0l engine; auto-

matic or manual transmission; etc.). According to product complexity, development effort and time to market, the most complex and expensive product in the product portfolio, launched first in market is the reference variant, called lead. Product variants which can be derived from a lead-variant are called derivates. According to their complexity, development effort and time to market, derivates can be further separated in different sizes such as large, middle and small. As a result of this classification, a product portfolio can be clustered into four different groups: lead, derivate large, derivate middle and derivate small. Based on the described attributes, we analyzed and evaluated the product portfolio to identify commonalities and differences. Furthermore, we clustered the variants according to the product classification and developed a derivation matrix with expert's cooperation. Basically, the derivation matrix is similar to an influence matrix and shows, which variant can be derived from another. Figure 3 shows a derivation matrix for the main attributes "engine" (3.0l, 2.5l or 2.0l) and "transmission" (automatic or manual) and an example for clustering a product portfolio consisting of five variants with different market launches. With the derivation matrix, the powertrain portfolio can be analyzed and clustered into the four different groups. In the example, the reference variant, called lead variant (L), is the powertrain with a 3.0l engine and an automatic transmission. The lead is the most complex variant, launched first in the market at the time of T0. All other variants are derivates from the lead with different sizes and launched after T0.

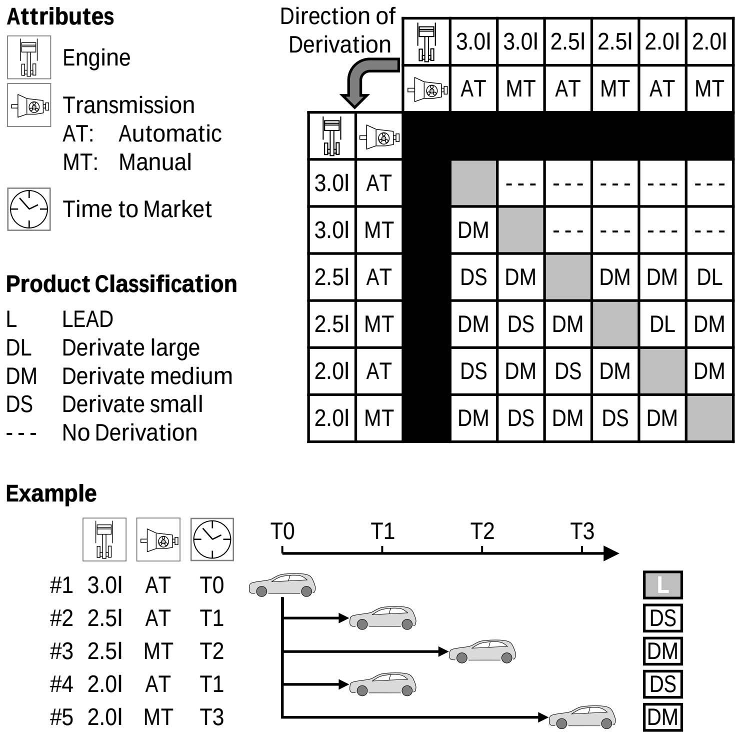


Figure 3 Derivation matrix and example

3.2 Complexity Evaluation

The second stage of our complexity approach comprises the complexity evaluation in the three categories product, product portfolio and process. The objective of evaluation in general is to emphasize commonalities and differences between relating object's properties (Kieser and Kubicek, 1983, p.174). Beyond, complexity evaluation is the basis for application of the right complexity strategy in the next stage of our approach.
Complexity management's objective is to achieve a company's optimum complexity degree, where internal and external complexity are equal (Schuh, 2005, p.43; Boyksen and Kotlik, 2013, p.49; Reiß, 1993, pp.133-134). In product development, internal complexity is characterized by product, product portfolio and process complexity (Dehnen, 2004, pp.33-35). External complexity is characterized by environmental, demand and competitive complexity (Dehnen, 2004, pp.33-35). Thus, company's optimum complexity degree can be achieved by evaluating and managing internal complexity. According to systems theory, a system's complexity degree is characterized by the amount of elements, their dependencies and the amount of system's conditions, so called variety (Curran, Elliger and Rüdiger, 2008, p.162; Malik, 2002, p.186). Malik (2002, p.186) argues that complexity can be quantified by variety. In literature, no uniform definition and measuring scale for a complexity degree exists. Höge (1995, pp.31-32), Greitemeyer and Ulrich (2006, p.8) state that the optimum complexity degree and measuring scale must be planned company-specific according to each company's strategy. To achieve a company's optimum complexity, internal complexity must be analyzed and evaluated. In our case study, we developed

three complexity indices on the basis of variety to evaluate product development's internal complexity in the categories product, process and product portfolio. According to Kieser and Kubicek, the objective is to compare different development projects in the categories to identify complexity trends over time.

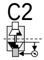
3.2.1 Product Complexity Index (PDCI)

ElMaraghy and ElMaraghy (2014, p.5) described a product complexity index to characterize a product and to measure, how complex a product is. The measurement is based on variety. According to ElMaraghy and ElMaraghy, we also developed a PDCI, based on the product and the difference of variety ($\Delta\ Cn$) within the identified product complexity driver's categories. In our evaluation, the complexity drivers were weighted according to development effort, costs and time (WF_{Cn}), because some drivers are more complex than others. The most complex drivers have the weighting factor 1.0. The weighting factors of other drivers are defined in comparison to the most complex driver.

The PDCI is formulated as the weighted average of variety difference in all product complexity driver's categories (Cn). N is the maximum amount of product complexity driver's categories and n is the category's number.

$$PDCI = \frac{\sum_{\mathrm{n}=1}^{N}(\Delta Cn * WF_{Cn})}{N} \tag{1}$$

The PDCI represents the percentage increase or decrease of development effort or costs, in comparison to the basis. Figure 4 shows an example for calculating a PDCI of two powertrain development projects. Project #1 is already completed while project #2 is currently developed. For comparison, we use seven complexity driver's categories (C1-C7): engine (C1), turbocharger (C2), valve controlling (C3), fuel injection system (C4), ignition system (C5), catalytic converter (C6) and transmission (C7). In the first step, the variety in the categories C1-C7 is identified for project #1 and #2. Next, the differences of variety ($\triangle\ Cn$) between project #1 and #2 are calculated, using project #1 as the basis. Then, the PDCI is calculated percentual considering different weighting factors. As a result, the new project #2 has a complexity increase of forty percent in comparison to project #1. In category two (C2) the variety of turbochargers in project #1 and #2 is identified. The finished project #1 had one turbocharger and the current project #2 has two different turbochargers. The difference ($\triangle\ Cn$) between project #2 and #1 is one. The basis is project #1, thus the variety in project #2 increased by 100 percent. The categories turbocharger (C2) and valve controlling (C3) have a weighting factor of 1.0, because they are the most complex drivers.

	Product Complexity Driver's Categories Cn						
	C1 	C2 	C3 	C4 	C5 	C6 	C7 
Variety in Cn Project #1	2	1	1	2	1	2	1
Variety in Cn Project #2	2	2	3	1	1	1	2
$\triangle\ Cn_{\text{Project\#1 à \#2}}$	0%	+100%	+200%	-50%	0%	-50%	+100%
Weighting factor WF_{Cn}	0.8	1.0	1.0	0.6	0.7	0.9	0.6

PDCI: +40%

Figure 4 Example PDCI

3.2.2 Process Complexity Index (PRCI)

In literature, no process complexity index exists. Thus, we developed a PRCI analogously to PDCI. PRCI is based on the development process and the difference of variety within the identified process complexity driver's categories ($\triangle\, PrCn$). The complexity drivers were also weighted according to development effort and time (WF_{PrCn}). The PRCI is formulated as follows:

$$PRCI = \frac{\sum_{\mathrm{n}=1}^{N}(\Delta \mathrm{Pr}Cn * WF_{PrCn})}{N} \tag{2}$$

Figure 5 shows an example for calculating a PRCI of two powertrain development projects. In this case, the process complexity drivers are the amount of different process steps (PrC1) and their conjunctions (PrC2) and the amount of interfaces to other subsections within the value chain (PrC3). The PRCI is calculated analogously to PDCI. As a result, the development process of project #2 has a complexity increase of twenty-six percent in comparison to project #1.

	Process Complexity Driver‘s Categories PrCn		
	PrC1	PrC2	PrC3
Variety in PrCn Project #1	6	2	5
Variety in PrCn Project #2	7	3	6
$\triangle$ PrCn$_{\text{Project\#1 à \#2}}$	+17%	+50%	+20%
Weighting factor WF$_{PrCn}$	0.7	1.0	0.8

PRCI: +26%

Figure 5 Example PRCI

3.2.3 Product Portfolio Complexity Index (PPCI)

Product portfolio complexity is another important part when evaluating product development's complexity. However, in literature no index for measuring product portfolio complexity exists. Based on product attributes (e.g. engine or transmission), product classification (e.g. lead or derivates) and derivation matrix, the product portfolio can be analyzed and clustered into different groups (leads and derivates) according to their characteristics. Next, the groups with equal product classifications are evaluated by the assignment of weighting factors. The weighting factors are also defined according to development effort, costs and time and represent single efforts. The lead variant is the most complex and expensive variant with the highest single effort and has the weighting factor 1.0. The weighting factors of the derivates (large, medium and small) are defined in comparison to the lead variant.

The PPCI is calculated by summing up the weighting factors ($WF_{Variant\ n}$), which were assigned to all variants in the product portfolio. N is the total amount of product variants in the product portfolio and n is the product variant's number. PPCI's unit are effort points (EP).

$$PPCI = \sum_{n=1}^{N} WF_{Variant\ n} \quad (3)$$

PPCI facilitates product portfolio's standardization to one measured value under consideration of product and process complexity and provides an overview about complexity in the product portfolio. Furthermore, PPCI describes the total effort, which is dedicated to develop a specific product portfolio. To quantify product portfolio complexity in our case study,

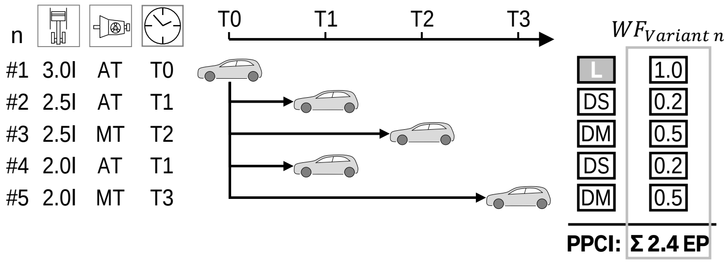


Figure 6 Example PPCI

we developed four weighting factors for our product classifications according to their complexity, development time and effort. The Lead-variant is the most complex variant in the portfolio and has the highest factor 1.0. The Derivates have weaker factors. Figure 6 shows an example for calculating the PPCI for a product portfolio with five powertrains.

In the next step, the product's development effort is identified and evaluated over product's launch time. The PPCI and the evaluated product portfolio are the basis for calculation. Therefore, the development efforts over time for the different product classifications (Lead or Derivate) were described. In our case study, the development efforts of a Lead-variant was separated consistently over a period of three years. The time period is determined by the company's experts. They divide the development efforts in different periods according to their development plan. The development efforts for our derivates were specified analogously. However, the periods were one year for small and two years for medium and large derivates. For calculation of the total development effort in a period, the particular efforts were summed up. Figure 7 shows an example for calculating the development effort over time for a product portfolio consisting of five powertrains.

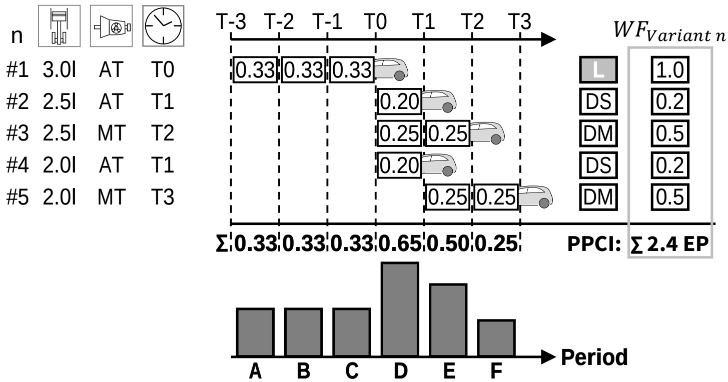


Figure 7 Calculating project's development effort over time

It can be seen that the maximum is achieved in period D because of the amount of variants, which were developed simultaneously. Furthermore, the PPCI can also be calculated as a number, called effort points.

3.3 Application of Complexity Strategies

In the third stage, the complexity strategies are presented for a company's complexity optimization. In literature, a vast number of different single approaches for managing complexity are described (Gießmann, 2010, pp.57-70). However, there is no specific instruction which approaches are the most effective for managing a specific complexity problem. An approach's application depends on the particular situation and must be planned company-specific. Generally, the approaches can be divided in four categories according to their focus: product, product portfolio, process and organization (Gießmann, 2010, pp.57-70).

Table 5 Applied single approaches for complexity management

Focus	Approaches	Reduction	Mastering	Avoidance
Product	Modular concept	✓✓✓	✓✓	✓
	Modular system	✓✓✓	✓✓	✓
	Standardization	✓✓✓	✓	✓✓
	Using same parts	✓✓✓	✓	✓✓
	Platform concept	✓✓✓	✓✓	✓
	Differential construction	✓✓✓	✓✓	✓
	Integral construction	✓✓✓	✓✓	✓
Product portfolio	Packaging	✓✓✓	✓✓	
	Reducing product range	✓✓✓		✓✓
	Reducing of customers	✓✓✓		
Process	Postponement concept	✓✓✓	✓✓	✓
	Standardization of	✓✓✓		✓✓
	Modularity of processes	✓✓✓	✓✓	✓
Organization	Delayering	✓✓✓		
	Empowerment	✓✓✓		

✓✓✓Priority 1 ✓✓Priority 2 ✓Priority 3

The approaches were mainly used for complexity reduction, mastering and avoidance. Table 5 presents an overview about the different approaches and their main purposes. The basis for Table 5 was our literature analysis. In our research project we applied different single approaches for complexity reduction, mastering and avoidance in the categories product, product portfolio and process. The effects resulting of an approach's application are evaluated with our three indices to identify the approach's effectivity. The Figures 8-10 show three examples from our research project. In the first example (Figure 8), we use product standardization to reduce the variety in the categories turbocharger (C2) and valve controlling (C3) in project #2.

PDCI	Product Complexity Driver's Categories Cn						
Product standardization in C2 and C3	C1	C2	C3	C4	C5	C6	C7
Variety in Cn Project #1	2	1	1	2	1	2	1
Variety in Cn Project #2	2	~~2~~ **1**	~~3~~ **2**	1	1	1	2
△ $Cn_{Project\#1\ à\ \#2}$	0%	0%	+100%	-50%	0%	-50%	+100%

PDCI: +~~40~~% è +12% Complexity Reduction

Figure 8 Application of product standardization

PRCI	Process Complexity Driver's Categories PrCn		
Process standardization and modularization in PrC1	PrC1	PrC2	PrC3
Variety in PrCn Project #1	6	2	5
Variety in PrCn Project #2	~~7~~ **5**	3	6
△ $PrCn_{Project\#1\ à\ \#2}$	-17%	+50%	+20%

PRCI: +~~26~~% è +18% Complexity Reduction

Figure 9 Application of process standardization and modularization

After product standardization the current development project has one turbocharger and two valve controlling systems. Thus, the PDCI was reduced from forty to twelve percent.

Next, process standardization and modularization was applied in category PrC1 (see Figure 9). Different process steps were standardized and modularized to reduce the number from seven process steps to five. The PRCI was reduced from twenty-six percent to eighteen percent.

In the third example, we reduced product portfolio's complexity, development efforts and costs by reducing the product range (see Figure 10). Based on a cost-benefit analysis, company's experts decided to remove the variants #3 and #4 with weighting factors of 0.5 and 0.2 from the portfolio. The

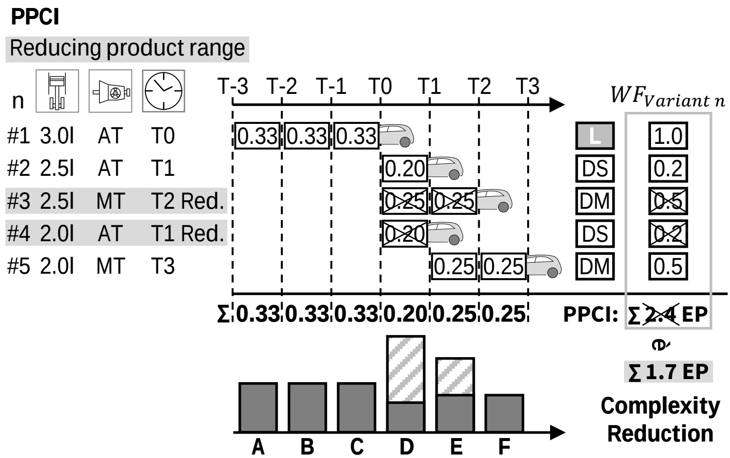


Figure 10 Application of reducing product range

PPCI was decreased from 2.4 to 1.7 effort points. In period D and E, the development effort also decreased from 0.65 EP (period D) and 0.5 EP (period E) to 0.20 EP (period D) and 0.25 EP (period E).

3.4 Complexity Planning and Controlling

Complexity planning and controlling are important elements for a target oriented complexity management. They provide a leverage point for an active complexity adjustment and help the company to prevent costs (Kirchhof, 2003, pp.166-167). Company's capacity planning contains of planning of resources (Schuh, Millarg and Göransson, 1998, p.49) and is an important factor for company's competitiveness (Krüger and Homp, 1997, p.10). Furthermore, it is the basis for complexity controlling (Jania, 2004, p.16). Resources can be separated in tangible (e.g. equipment, facility) and intangible (e.g. technology, image) resources (Hungenberg, 2001, p.116). To reduce costs and time, it is necessary to apply the resources effectively. In product development, resources have a particular relevance, because the amount of available resources is restricted. Based on our research, product development's complexity has a high influence on the required resources and their planning. A detailed complexity planning increases transparency and enables the management to simulate different development scenarios to identify the optimum.

Complexity costs can be separated into direct and indirect costs. Direct costs consist of continuous (e.g. costs for serial supervision) and nonrecurring costs (e.g. test vehicle, test engine). Indirect costs are costs which generate no benefit growth (e.g. costs for increasing product range have no benefit because of product cannibalization) (Gießmann, 2010, p.39).

In our research project, we developed a complexity planning model based on literature and the results of complexity analysis and evaluation. The complexity indices are particularly important for this.

Kersten, Lammers and Skirde (2012, pp.28-30) developed a complexity vector with two dimensions for complexity driver's visualization and operationalization. The dimensions describe different points of view regarding complexity's occurrence and can be weighted. Different complexity drivers can be visualized in the vector space and thereby they can be compared with each other. The visualization can be used as a starting point for different strategies in complexity management. According to Kersten, Lammers and Skride, we developed a complexity vector $\overrightarrow{CI}$ with the two dimensions product (PDCI) and process complexity index (PRCI). The two dimensions have the same weighting.

$$\overrightarrow{CI} = \begin{pmatrix} PDCI \\ PRCI \end{pmatrix} \tag{4}$$

Vector $\overrightarrow{CI}$ is visualized in the vector space. The vector's length $\left|\overrightarrow{CI}\right|$ represents development's project complexity. The distance between two complexity vectors describes the proportion for complexity reduction. The distance is calculated with Pythagoras' theorem.

$$\left|\overrightarrow{CI_{12}}\right| = \sqrt{(PDCI_1 - PDCI_2)^2 + (PRCI_1 - PRCI_2)^2} \tag{5}$$

In the first step of our complexity evaluation, we identified a $PDCI_1$ with forty percent and a $PRCI_1$ with twenty-six percent (see chapter 3.2) and generated the vector $\overrightarrow{CI_1}$ (see Figure 9). After complexity evaluation, we applied different single approaches to reduce the complexity indices (see chapter 3.3). $PDCI_2$ (twelve percent) and $PRCI_2$ (eighteen percent) are the basis of vector $\overrightarrow{CI_2}$. The distance between $\overrightarrow{CI_1}$ and $\overrightarrow{CI_2}$ is the proportion of complexity reduction. In our case study, the application of different single sources resulted in a complexity reduction of twenty-nine percent in total. For complexity planning, the length of $\overrightarrow{CI_2}$ is important, because it is directly associated to development project's complexity, development efforts and the amount of required resources (see Figure 11). Thus, the amount of required resources is directly proportional to the length of $\overrightarrow{CI_2}$ and the PPCI. The length of $\overrightarrow{CI_2}$ is twenty-two percent, thus the amount of resources in the periods A until F is also increased by this percentage.

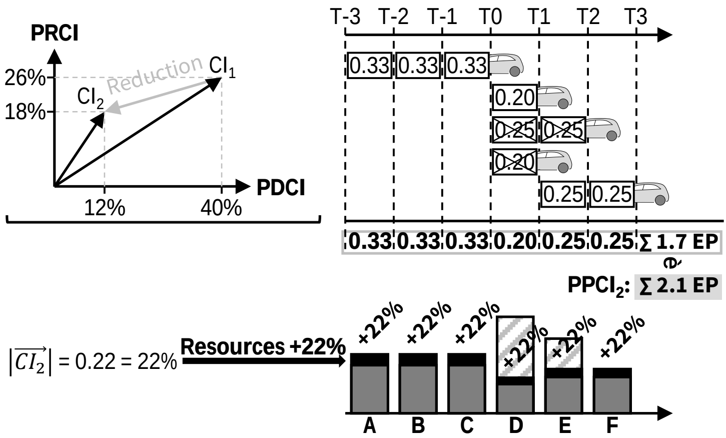


Figure 11 Complexity vector's influence on development effort

For calculating the precise amount of required resources (e.g. test vehicles), we determined a resource factor (RF) based on process analysis, expert interviews and workshops (e.g. 7 test vehicles per effort point). The resource factor represents the amount of resources which are required for a specific development effort. With the resource factor, the development efforts (EP) in each period can be translated in a precise amount of required resources. In Figure 12 we calculated the amount of test vehicles in period A based on the amount of effort points in period A and the RF for test vehicles. Calculation is based on Figure 11. This procedure was used analogously to develop cost factors for calculating development costs.

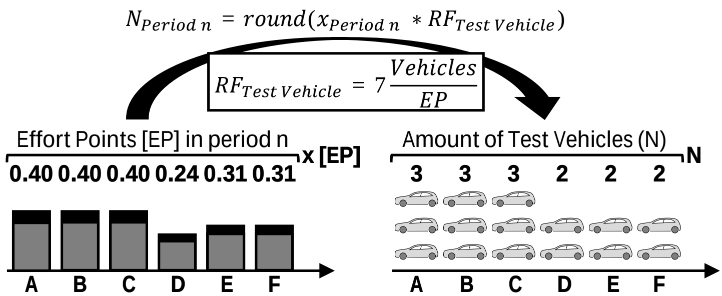


Figure 12 Calculating required resources based on resource factor

In product development, complexity controlling enables the management to compare the actual development efforts or costs of different projects with the planned values to identify weakness, potentials, and to influence company's development activities. The objective is to develop a complexity controlling system to fulfill this requirements and to provide a methodically principle (Jania, 2004, pp.15-17). For complexity controlling, key performance indicators (KPI) were used to gain transparency and to apply specific strategies in product development. KPI in different projects or function levels can be compared with reference values to identify discrepancy and increasing complexity (Gleich and Klein, 2013, pp.49-53). Furthermore, KPI are used to achieve company's objectives and are defined company specific (Kersten, 2011, p.17). KPI can be defined by comparison of costs and benefits (Gleich and Klein, 2013, p.53). Based on Kersten, Gleich and Klein, we developed project KPI ($KPI_{Project\ n}$) by comparing the applied amount of resources ($N_{Resources\ Project\ n}$) and project's PPCI. KPI are compared with reference values to identify discrepancies.

$$KPI_{Project\ n} = \frac{N_{Resources\ Project\ n}}{PPCI_{Project\ n}} \tag{6}$$

Figure 13 shows an example with two projects (A, B) in period A. The projects have different PPCIs, but the amount of applied resources (test vehicle) is equal. To compare the projects, the project KPIs for A and B are determined and compared with the reference value. In our case study, the reference is the resource factor for test vehicle. As comparison's result, project A is more efficient than project B ($KPI_{Project\ A} < KPI_{Project\ B}$). However, both projects show differences according to the reference. If the reasons for the differences are unclear, a further complexity analysis in stage one can be started. With this method, other KPIs can be developed analogously, such as for test engines or development costs.

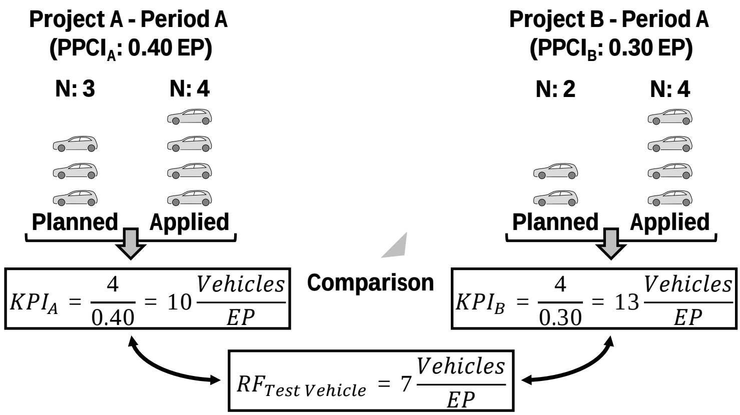


Figure 13 Calculating KPIs and comparison with planned values

4 Results and Discussion

The result of this paper is a four stage praxis-oriented approach for managing complexity in variant-rich product development. The approach was developed based on a detailed literature analysis and applied on a recent development project in the automotive industry. This paper describes the objectives and requirements of complexity management approaches and characterizes product development by three categories: product, product portfolio and process. Based on these categories, the complexity drivers are derived and described. For this research paper, we determined two research questions, which will be answered in the following manner. Before developing a new approach, the existing literature must be identified, analyzed and evaluated systematically. The identified approaches are analyzed according to their structure and focuses. In literature forty-seven complexity management approaches exist. However, an approach which fulfills all requirements in total or partially does not exist yet.

In summary, our approach applies all steps and categories and fulfills all requirements in total (see Table 6). In all stages we described different methods, which can be applied easily by the user. The new approach consists of a modular structure and a recurring cycle. The approach is focused on the three categories product, product portfolio and process and enables a detailed complexity analysis by identifying the complexity problem, the complexity drivers and their interdependencies (see chapter 3.1). After complexity analysis, complexity is evaluated and optimized by applying different complexity single approaches (see chapter 3.2 and 3.3). In the last stage, we developed an approach for capability and resource planning as well as complexity controlling by application of key figures (KPIs).

Table 6 Evaluation of our new complexity management approach

Approach's structure							Target			Evaluation criteria											
Complexity analysis	Complexity evaluation	Determine complexity strategy	Determine complexity instruments	Complexity planning	Implement complexity management	Complexity controlling	Product complexity	Process complexity	Product protfolio complexity	Recurring cycle	Modular structure	Practicability	Transparency	Identifying the complexity problem	Methods for complexity management	Application of key figures	Approach for capability planning	Identification of complexity drivers	Complexity drivers' interdependencies	Evaluation of complexity drivers	Evaluation of complexity (degree)
●	●	●	●	●	●	●	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++

5 Conclusion

This paper's purpose was to close the research gap by analyzing existing literature and developing a praxis-oriented complexity management approach for variant-rich product development. In literature, such an approach does not exist yet. The existing approaches are focused on specific issues and do not fulfill all requirements in total or partial. This paper covers this literature gap. It provides a four stage complexity management approach and encourages the reader to manage product development's complexity. The approach was first applied in the automotive industry and verified in toy industry. Future research may include other sectors.

References

Aelker, J., Bauernhansl, T. and Ehm, H., 2013. Managing complexity in supply chains: A discussion of current approaches on the example of the semiconductor industry. Procedia CIRP, 7, pp.79-84.

Aggeri, F. and Segrestin, B., 2007. Innovation and project development: an impossible equation? Lessons from an innovative automobile project development. R&D Management, 37(1), pp.37-47.

Ahrendts, F. and Marton, A., 2008. IT-Risikomanagement leben: Wirkungsvolle Umsetzung für Projekte in der Softwareentwicklung. Berlin: Springer Verlag.

Anderson, B., Hagen, C., Reifel, J. and Stettler, E., 2006. Complexity: customization's evil twin. Strategy & Leadership, 34(5), pp.19-27.

Augusto Cauchick Miguel, P., 2007. Innovative new product development: a study of selected QFD case studies. The TQM Magazine, 19(6), pp.617-625.

Bick, W. and Drexl-Wittbecker, S., 2008. Komplexität reduzieren: Konzept, Methode, Praxis. Stuttgart: LOG_X Verlag.

Blecker, T., Kersten, W. and Meyer, C., 2005. Development of an Approach for Analyzing Supply Chain Complexity, Hamburg University of Technology. Available at: <http://mpra.ub.uni-muenchen.de/5284/1/MPRA_paper_5284.pdf> [Accessed 18 March 2015].

Bliss, C. A., 1998. Komplexitätsreduktion und Komplexitätsbeherrschung bei der Schmitz-Anhänger Fahrzeugbau-Gesellschaft mbH. In: D. Adam, ed. 1998. Komplexitätsmanagement: Schriften zur Unternehmensführung. Wiesbaden: Gabler Verlag. pp.145-168.

Bliss, C. A., 2000. Management von Komplexität: Ein integrierter, systemtheoretischer Ansatz zur Komplexitätsreduktion. Wiesbaden: Betriebswirtschaftlicher Verlag.

Blockus, M.O., 2010. Komplexität in Dienstleistungsunternehmen: Komplexitätsformen, Kosten- und Nutzenwirkungen, empirische Befunde und Managementimplikationen. Wiesbaden: Gabler Verlag.

Bohne, F., 1998. Komplexitätskostenmanagement in der Automobilindustrie: Identifizierung und Gestaltung vielfaltsinduzierter Kosten. Wiesbaden: Gabler Verlag.

Boyksen, M. and Kotlik, L., 2013. Komplexitätscontrolling: Komplexität erkennen, bewerten und optimieren. Controller Magazin, November/Dezember 2013, pp.48-52.

Curran, C.S., Elliger, C. and Rüdiger, S., 2008. Komplexitätsmanagement: Wann ist viel schon zu viel?. Nachrichten aus der Chemie, 56(2), pp.160-162.

Davila, T., 2000. An empirical study on the drivers of management control systems' design in new product development. Accounting, Organizations and Society, 25, pp.383-409.

Dehnen, K., 2004. Strategisches Komplexitätsmanagement in der Produktentwicklung. Hamburg: Verlag Dr. Kovac.

Denk, R., 2007. Die 5α des Komplexitätsmanagements. CFO aktuell, February, pp.19-22.

Denk, R. and Pfneissl, T., 2009. Komplexitätsmanagement. Wien: Linde Verlag.

Edersheim, E. H. and Wilson, J., 1992. Complexity at Consumer Goods Companies: Naming and Taming the Beast. Journal of Cost Management, 6(36), pp.26-36.

ElMaraghy, W. H., ElMaraghy, H. A., Tomiyama, T. and Monostori, L., 2012. Complexity in engineering design and manufacturing. CIRP Annals - Manufacturing Technology, 61, pp.793-814.

ElMaraghy, H. A. and ElMaraghy, W. H., 2014. Variety, Complexity and Value Creation. In: M. F. Zaeh, ed. 2014. Enabling Manufacturing Competitiveness and Economic Sustainability: Proceedings of the 5th International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2013). Cham: Springer Verlag. pp.1-7.

Fabig, C. and Haasper, A., 2012. Komplexitätsmanagement im 21. Jahrhundert. In: C. Fabig, A. Haasper, eds. 2012. Complexigence: Komplexität verstehen und aktiv managen. Norderstedt: Books on Demand. pp.7-26.

Fricker, A. R., 1996. Eine Methodik zur Modellierung, Analyse und Gestaltung komplexer Produktionsstrukturen. Aachen: Verlag der Augustinus Buchhandlung.

Geimer, H., 2005. Komplexitätsmanagement globaler Supply Chains. HDM Praxis für Wirtschaftsinformatik, 42, pp.38-46.

Geimer, H. and Schulze, F., 2005. Die Beherrschung der Komplexität. Jahrbuch der Logistik, 19, pp.98-102.

Gerschberger, M., Engelhardt-Nowitzki, C., Kummer, S. and Staberhofer, F., 2012. A model to determine complexity in supply networks. Journal of Manufacturing Technology Management, 23(8), pp.1015-1037.

Gießmann, M., 2010. Komplexitätsmanagement in der Logistik - Kausalanalytische Untersuchung zum Einfluss der Beschaffungskomplexität auf den Logistikerfolg. Lohmar: Josef Eul Verlag.

Gleich, R. and Klein, A., 2013. Komplexitätscontrolling: Komplexität verstehen und beherrschen. Freiburg: Haufe Verlag.

Greitemeyer, J. and Ulrich, T., 2006. Komplexitätsmanagement im Mittelstand. Scope, April, pp.8-9.

Grimm, R., Schuller, M. and Wilhelmer, R., 2014. Portfoliomanagement in Unternehmen: Leitfaden für Manager und Investoren. Wiesbaden: Springer Gabler.

Grossmann, C., 1992. Komplexitätsbewältigung im Management: Anleitungen, integrierte Methodik und Anwendungsbeispiele. St. Gallen: Verlag GCN.

Hanenkamp, N., 2004. Entwicklung des Geschäftsprozesses Komplexitätsmanagement in der kundenindividuellen Serienfertigung: Ein Beitrag zum Informationsmanagement in mehrdimensional modellierten Produktionssystemen. Aachen: Shaker Verlag.

Haumann, M., Westermann, H.H., Seifert, S. and Butzer, S., 2012. Managing complexity - A methodology, exemplified by the industrial sector of remanufacturing. In: M. Björkman, ed. 2012. Proceedings of the 5th International Swedish Production Symposium SPS 12. Linköping: The Swedish Production Academy. pp.107-114.

Hauschildt, J., 1977. Entscheidungsziele: Zielbildung in innovativen Entscheidungsprozessen - theoretische Ansätze und empirische Prüfung. Tübingen: Mohr Verlag.

Höge, R., 1995. Organisatorische Segmentierung: Ein Instrument zur Komplexitätshandhabung. Wiesbaden: Deutscher Universitäts Verlag.

Hungenberg, H., 2001. Strategisches Management in Unternehmen: Ziele, Prozesse, Verfahren. 2nd ed. Wiesbaden: Gabler Verlag.

Hünerberg, R. and Mann, A., 2009. Komplexität und Ressourceneinsatz als Herausforderungen an die Unternehmensführung. In: R. Hünerberg and A. Mann, eds. 2009. Ganzheitliche Unternehmensführung in dynamischen Märkten. Wiesbaden: Gabler Verlag. pp. 1-14.

Isik, F., 2011. Complexity in Supply Chains: A New Approach to Quantitative Measurement of the Supply-Chain-Complexity. In: P. Li, ed. 2011. Supply Chain Management. Shanghai: InTech. pp. 417-432.

Jania, T., 2004. Änderungsmanagement auf Basis eines integrierten Prozess- und Produktdatenmodells mit dem Ziel einer durchgängigen Komplexitätsbewertung. Available at: <http://digital.ub.uni-paderborn.de/hs/content/titleinfo/3567> [Accessed 1 March 2015].

Jäger, J. M., Kluth, A., Sauer, M. and Schatz, A., 2013. Komplexitätsbewirtschaftung: Die neue Managementdisziplin in Produktion und Supply Chain. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, 108(5), pp.341-343.

Kaiser, A., 1995. Integriertes Variantenmanagement mit Hilfe der Prozesskostenrechnung. Hallstadt: Rosch-Buch.

Kersten, W., 2011. Je komplexer, desto teurer und risikoreicher. io management, September/October, pp.14-19.

Kersten, W., Lammers, T. and Skirde, H., 2012. Komplexitätsanalyse von Distributionssystemen. Available at: <https://www.bvl.de/files/ 441/481/Sachbericht_16164.pdf > [Accessed 10 March 2015].

Kieser, A. and Kubicek, H., 1983. Organisation. 2nd ed. Berlin: De Gruyter.

Kim, J. and Wilemon, D., 2003. Sources and assessment of Complexity in NPD projects. R&D Management, 33(1), pp.15-30.

Kirchhof, R., 2003. Ganzheitliches Komplexitätsmanagment: Grundlagen und Methodik des Umgangs mit Komplexität im Unternehmen. Wiesbaden: Deutscher Universitäts-Verlag.

Klabunde, S., 2003. Wissensmanagement in der integrierten Produkt- und Prozessgestaltung: Best-Practice-Modelle zum Management von Meta-Wissen. Wiesbaden: Deutscher Universitäts-Verlag.

Koch, D., 2012. Wissensmanagement und der Umgang mit Komplexität. In: C. Fabig, A. Haasper, eds. 2012. Complexigence: Komplexität verstehen und aktiv managen. Norderstedt: Books on Demand. pp.40-61.

Krause, F.L., Franke, H.J. and Gausemeier, J., 2007. Innovationspotenziale in der Produktentwicklung. München: Carl Hanser Verlag.

Krüger, W. and Homp, C., 1997. Kernkompetenz-Management: Steigerung von Flexibilität und Schlagkraft im Wettbewerb. Wiesbaden: Gabler Verlag.

Lammers, T., 2012. Komplexitätsmanagement für Distributionssysteme. Lohmar: Josef Eul Verlag.

Lasch, R. and Gießmann, M., 2009a. Ganzheitliche Ansätze zum Komplexitätsmanagement - eine kritische Würdigung aus Sicht der Beschaffungslogisitk. In: R. Bogaschewsky, et al., eds. 2009. Supply Management Research: Aktuelle Forschungsergebnisse 2008. Wiesbaden: Gabler Verlag. pp.194-231.

Lasch, R. and Gießmann, M., 2009b. Qualitäts- und Komplexitätsmanagement: Parallelitäten und Interaktionen zweier Managementdisziplinen. In: R. Hünerberg and A. Mann, eds. 2009. Ganzheitliche Unternehmensführung in dynamischen Märkten. Wiesbaden: Gabler Verlag. pp.93-124.

Lindemann, U., Maurer, M. and Braun, T., 2009. Structural Complexity Management: An Approach for the Field of Product Design. Berlin: Springer Verlag.

Lingnau, V., 1994. Variantenmanagement: Produktionsplanung im Rahmen einer Produktdifferenzierungsstrategie. Berlin: Erich Schmidt Verlag.

Lübke, E., 2007. Lebenszyklusorientiertes Produktstrukturmanagement: Eine theoretische Untersuchung. München: Transfer-Centrum-Verlag.

Malik, F., 2002. Strategie des Managements komplexer Systeme: Ein Beitrag zur Management-Kybernetik evolutionärer Systeme. 7th ed. Bern: Haupt Verlag.

Marti, M., 2007. Complexity Management: Optimizing Architecture of Industrial Products. Wiesbaden: Deutscher Universitäts-Verlag.

Meier, B. and Bojarski, S., 2013. Ganzheitliches Modell zur Bewältigung vielfaltsinduzierter Komplexität. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, 108(7-8), pp.547-551.

Meier, H. and Hanenkamp, N., 2004. Komplexitätsmanagement in der Supply Chain. In: A. Busch and W. Dangelmaier, eds. 2004. Integriertes Supply Chain Management: Theorie und Praxis effektiver unternehmensübergreifender Geschäftsprozesse. 2nd ed. Wiesbaden: Gabler Verlag. pp.111-130.

Meyer, C. M., 2007. Integration des Komplexitätsmanagements in den strategischen Führungsprozess der Logistik. Bern: Haupt Verlag.

Miragliotta, G., Perona, M. and Portioli-Staudacher, A., 2002. Complexity Management in the Supply Chain: Theoretical Model and Empirical Investigation in the Italian Household Appliance Industry. In: S. Seuring, ed. 2002. Cost Management in Supply Chains. Berlin: Springer Verlag. pp.381-397.

Nurcahya, E. Z., 2009. Ein Produktdatenmodell für das rechnerunterstützte Variantenmanagement. Aachen: Shaker Verlag.

Perona, M. and Miragliotta, G., 2004. Complexity management and supply chain performance assessment: A field study and a conceptual framework. International Journal of Production Economics, 90, pp.103-115.

Ponn, J. and Lindemann, U., 2008. Konzeptentwicklung und Gestaltung technischer Produkte: Optimierte Produkte - systematisch von Anforderungen zu Konzepten. Berlin: Springer Verlag.

Puhl, H., 1999. Komplexitätsmanagement: Konzept zur ganzheitlichen Erfassung, Planung und Regelung der Komplexität in Unternehmensprozessen. Kaiserslautern: Foto-Repro-Druck.

Reiß, M., 1993. Komplexitätsmanagement (I). In: G. Sieben and A. Woll, eds. 1993. WISU - Das Wirtschaftsstudium. Düsseldorf: Werner & Lange Verlag, pp.132-137.

Rosemann, M., 1998. Die Komplexitätsfalle. Logistik Heute, 20(9), pp.60-62.

Schawel, C. and Billing, F., 2011. Top 100 Management Tools: Das wichtigste Buch eines Managers. Wiesbaden: Gabler Verlag.

Schoeller, N., 2009. Internationales Komplexitätsmanagement am Beispiel der Automobilindustrie, RWTH Aachen University. Available at: < http://publications.rwth-aachen.de/record/51376/files/ Schoeller_Nicolas.pdf> [Accessed 23 March 2015].

Schöttl, F., Herrmann, N., Maurer, M. and Lindemann, U., 2014. Systematic Procedure for Handling Complexity in the Automotive Production. In: M. F. Zaeh, ed. 2014. Enabling Manufacturing Competitiveness and Economic Sustainability. Heidelberg: Springer Verlag. pp.255-260.

Schuh, G., 2005. Produktkomplexität managen: Strategien, Methoden, Tools. München: Carl Hanser Verlag.

Schuh, G., Millarg, K. and Göransson, A., 1998. Virtuelle Fabrik: Neue Marktchancen durch dynamische Netzwerke. München: Carl Hanser Verlag.

Schuh, G. and Schwenk, U., 2001. Produktkomplexität managen - Strategien, Methoden, Tools. München: Carl Hanser Verlag.

Schuh, G., Arnoscht, J. and Rudolf, S., 2010. Integrated Development of Modular Product Platform. In: D. Kocaoglu, T. Anderson and T. Daim, eds. 2010. Proceedings of International Center for Management of Engineering and Technology PICMET. Portland: IEEE. pp.1928-1940.

Schuh, G., Monostroi, L., Csáji, B. C. and Döring, S., 2008. Complexity-based modeling of reconfigurable collaborations in production industry. CIRP Annals - Manufacturing Technology, 57, pp.445-450.

Schwenk-Willi, U., 2001. Integriertes Komplexitätsmanagement: Anleitung und Methodik für die produzierende Industrie auf Basis einer typologischen Untersuchung. Bamberg: Difo Druck.

Serdarasan, S., 2013. A review of supply chain complexity drivers. Computers & Industrial Engineering, 66, pp.533-540.

Specht, G. and Beckmann, C., 1996. F&E-Management: Kompetenz im Innovationsmanagement. Stuttgart: Schäffer-Poeschel Verlag.

Warnecke, G., 2010. Komplexität: mit Kompetenz bewältigen, mit Technik beherrschen. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, 105(7-8), pp.639-641.

Warnecke, G. and Puhl, H., 1997. Komplexitätsmanagement: Mit Systemdenken zur Beherrschung der Komplexität. wt Werkstattstechnik, 87, pp.359-363.

Wassmus, A., 2014. Serviceorientierung als Erfolgsfaktor und Komplexitätstreiber beim Angebot hybrider Produkte. Wiesbaden: Springer Gabler.

Westphal, J. R., 2000. Komplexitätsmanagement in der Produktionslogistik, Technische Universität Dresden. Available at: <http://tu-dreden.de/die_tu_dresden/fakultaeten/vkw/iwv/diskuss/2000_4_diskusbtr_ivw.pdf> [Accessed 14 March 2015].

Wildemann, H., 1995. Komplexitätsmanagement in der Fabrikorganisation. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, 90(1-2), pp.21-26.

Wildemann, H., 1999. Ansätze für Einsparpotentiale. Logistik Heute, 21(4), pp.64-67.

Wildemann, H., 2012. Komplexitätsmanagement in Vertrieb, Beschaffung, Produkt, Entwicklung und Produktion. München: Transfer-Centrum-Verlag.

Identifying Main Drivers on Inventory using Regression Analysis

Steffi Hoppenheit and Willibald A. Günthner

Inventory management is essential for satisfying customer demands and reducing logistics costs. Extensive material portfolios, balancing inventory costs versus customer service levels as well as fluctuating demand are factors that influence inventory levels. Inventory management is often considered as inventory reduction; quick reduction activities are carried out without knowing the exact root causes of non-target inventory levels. A sustainable and comprehensive approach could be, to consider those factors which have a strong impact on inventory and to use this information for further inventory optimization activities. This paper therefore gives an answer to the question, how to systematically identify main drivers on inventory, using multiple linear regression analysis and how to quantify their impact considering company-specific data and structures. The described approach is applied in a case study at a company in the commercial vehicle industry. Data sets from different locations are analyzed and compared. It will be shown in a methodical way that few factors have a strong linear influence on inventory level and differ depending on the characteristics of the respective location. Companies can thereby analyze main drivers on inventories e.g. per location, region, sales channel or company-wide, depending on the chosen data set. The results can be used to identify root-causes for non-target inventory levels and form the basis for company-specific inventory optimization activities.

Keywords: Inventory Management, Regression Analysis, Main Drivers, Root Cause Analysis

1 Introduction

Inventory management is a large research field with high practical relevance. It includes many functions, such as demand planning, inventory controlling and inventory planning. It determines all decision-related facts which have an influence on inventory level (Pfohl, 2000). Inventory optimization refers to the reduction of stock in warehouses, production and the entire supply chain while ensuring high material availability (ten Hompel and Weidenblut, 2011). Furthermore, it is a cross-sectional function that optimizes inventory and material flow within all functional areas. Inventory management also includes integration and coordination functions, since upstream and downstream processes are coordinated (Stadtler, 2002). Many approaches describe how to calculate inventory levels, with the aim of meeting customer demand with minimal inventory costs and stock out costs, also called inventory trade-off. In order to achieve defined inventory strategies, targets and handling this trade-off, it is important to understand pre-defined parameters and factors which influence stock level.

Many approaches addressing, how to identify main drivers on inventory exist in literature. Also qualitative factors and parameters are mentioned that affect inventory to a large extent. However, the interaction of all factors and their effect on inventory level have not been analyzed and quantified in an integral approach. In particular, it is possible that parameters, which have not been considered for optimization activities have a major impact on inventory. Company specific structures and organizational set-ups might also affect inventory at a certain stage.

In order to proactively avoid non-target inventory levels, it is essential to identify the root causes of the non-target inventory level. These root causes may appear along the entire supply chain and within different departments. Non-target inventory levels might be generated actively by wrong planning decisions, parameter settings and human influences or indirectly through interactions with other parameters. As a result, non-target inventory levels may arise without knowing which parameter, decision or set-up has the biggest influence on inventory. This problem is neither sufficiently considered by practical approaches nor by theoretical methods.

This paper therefore presents an approach to identify those factors that influence inventory the most and have led to non-target inventory levels in the past. We will present a method to analyze whether categorical and metric factors have the same impact on inventory or how a potential difference may be quantified. In addition, we will examine whether different plant structures and characteristics have an effect on the main drivers on inventory. The approach presented in this paper was undertaken, based on real data provided by a company in the commercial vehicle industry. For this purpose, we formulate the following research questions:

1. How can main drivers on inventory be identified in an analytical way?
2. How can main drivers' impact on inventory level be quantified?
3. How can company-specific structures be considered in determining main drivers on inventory?

The remainder of the paper is structured as follows: Section two provides an overview of standard definitions and current approaches to inventory driver's analysis. In section three, we describe how potential influencing factors were collected and classified, based on literature research. Section four describes a method for analyzing the collected drivers on inventory using multiple linear regression analysis. The analysis results are outlined in section five. Section six contains an interpretation of the results and section seven concludes the paper.

2 Literature Review

Inventory levels are affected by a large number of factors. These factors may be internal or external and appear along the supply chain. Demeter and Golini (2013) consider this aspect and cluster drivers on inventory into four categories: Market factors, internal operations, supply chain characteristics and business strategy. Cachon and Fisher (2000), Lee, Padmanabhan and Whang (1997) as well as Lee, So and Tang (2000) described information sharing within and between companies as vital for efficient inventory management. However, they also analyze that external information sharing using computer-based technologies such as collaborative planning and forecasting or vendor-managed inventory can reduce supply chain costs up to 35%. Information flow between participants within the supply chain has been identified as a driver on inventory: Van Ackere, Larsen and Morecroft (1993) run a simulation study to quantify this impact. Companies also pushing inventory holding responsibilities to suppliers in order to reduce capital lockup and own stocking expenses (Fazel, 1997). The impact of outsourcing of inventory was shown by Kakabadse and Kakabadse (2002): Based on a survey applied by Cranfield School of Management this driver was identified. D'Aveni and Ravenscraft (1994) stated that inventories can be better managed applying internal rather than external communication and coordination. In addition, long lead-times due to long distances, lead to higher inventory levels (Golini and Kalchschmidt, 2011; Kouvelis and Gutierrez, 1997). Long distances between customers and suppliers, especially in global supply chains, lead to an increase in inventories to guarantee flexibility and variability (Golini and Kalchschmidt, 2015; Stratton and Warburton, 2006). Lieberman, Helper and Demeester (1999) analyzed this correlation using standard inventory models as well as empirical studies. Inventory levels also depend on material costs. Beamon (1998) showed that inventory costs increase if material costs exceed other logistics costs. This approach is based on Porters correlation analysis between material costs and market characteristics (e.g. suppliers' number and bargaining power) (Porter, 1980). Furthermore, the customer order penetration point, or decoupling point, has a huge impact on inventory levels (Olhager, 2003; Naylor, Naim and Berry, 1999). Naylor, Naim and Berry (1999) differentiated between the different inventory types, such as buy-to-order (suppliers stock), make-to-order (raw and semi-finished stock), assemble-to-order (WIP stock), make-to-stock (finished goods stock) and ship-to-stock (customers stock). Depending on the inventory policy, a decoupling point can be set (Naylor, Naim and Berry, 1999). Olhager (2003) explained that WIP stock and risk of obsolete stock can be reduced, setting the decoupling point close to the beginning of a supply chain. A forward shifted decoupling point increases WIP stock because of forecast-based materials (Olhager, 2003). Demeter and Matyusz (2011) ran an empirical study in the manufacturing industry on the correlation between decoupling points and inventory levels. According to their study, assemble-to-order companies have lower input inventories and WIP inventories compared to make-to-order companies are showing higher input inventories and make-to-stock companies with higher finished goods inventories. Moreover, they also showed how the type of production process impacts inventory levels. Companies organized in job-shops show higher WIP stock, compared to companies with dedicated lines. Companies with cellular layout show no empirical trend of higher inventories (Demeter and Matyusz, 2011).

Literature review shows that inventory levels may be affected by a large number of factors, such as communication, production processes, and lot sizes. Those factors are included and combined in the aforementioned approaches, may correlate with each other, and are in different causal loops with respect to inventory management. They do not have the same level of impact on inventory. The impact may be linear and/or non-linear. Production leveling activities potentially explain inventory levels at a higher stage than purchasing volumes. The level of impact plays an important role in terms of inventory optimization: The higher a factor's impact on inventory, the greater the opportunity to control inventory by adjusting the factor under consideration of its interaction with other parameters. Depending on the factors considered in the supply chain, the factor-specific impact on inventory may vary. This leads to the following hypothesis:

Factors influence inventory level with a different intensity and in an either direct or indirect way.

Therefore, a more efficient way to control inventory could be to preventively avoid high inventory levels by optimizing the main drivers with regard to their correlation with other material planning parameters. There are many opinions and approaches with respect to which factors influence inventory the most, however, an analytical analysis is missing, considering the described approaches without a pre-selection. Analyzing all potential drivers on inventory in an analytical way allows an objective identification of the main drivers. Adjusting factors showing a heavy linear impact should also affect the amount of inventory and lead to smaller differences between actual and target inventory levels. These drivers may differ between companies and industrial sectors. It is therefore essential to identify the influencing factors on inventory on a company-specific basis and optimize them continuously. This allows a proactive inventory control and management. The identified main drivers on inventory can accordingly be used as variables within optimization models.

In order to substantiate this research gap, an analytical procedure will be developed in the following.

3 Collection and Classification of Potential Drivers on Inventory

Many potential factors influencing inventory were collected through literature research. The identified factors can be found on different levels within a company and are connected to different processes. Since each factor's influence should be connected to the causal part within the supply chain, a factor structuring according to the various parts of the supply chain was chosen. The SCOR model is one way to structure the factors (SCOR, 2015). SCOR aims to analyze and configure supply chain processes according to the following supply chain segments: Source (S), Make (M), Deliver (D) and Plan (P). A structuring based on SCOR allows the factors to be allocated to the segment in the supply chain where they appear. They affect inventory in both the short and long run. Some factors can easily be quantified, others are human or strategic factors, such as communication and coordination, which can hardly be quantified. In order to better derive at actions for improvement regarding inventory management, the identified factors were classified. Such a classification allows differentiation, amongst others between quantifiable and non-quantifiable factors. Factors can be divided into categorical or metric scales (see Table 1). To quantify the influence of factors with the greatest effect on inventory, metric data is needed in order to apply arithmetical operations.

In total, 111 internal and external factors, split into 58 metric and 53 categorical factors, were gathered.

Now, the question is how to identify the main drivers on inventory. There are many methods for analyzing the predominant influencing factors. To identify the main drivers on inventory, we use multiple linear regression analysis. Compared to other methods, it is a clear mathematical approach to objectively describe the dependency between one target variable and one or several independent variables based on empirical data. All of the collected factors can be combined with each other in order to determine the strongest influence on inventory. Moreover, categorical factors can also be analyzed using this mathematical method. Using this approach, qualitative factors such as communication, standards or processes collected during the literature research can also be included in the analysis as a coded variable. As a last step, all identified main drivers on inventory must not correlate with each other, so a correlation matrix needs to be analyzed.

Table 1 Excerpt of factor structuring based on SCOR

Factor	S	M	D	P	Categori-cal	Met-rical
Order quantity	x					x
Deliveries from suppliers	x					x
Product mix				x		x
Prime material		x				x
Delivery qty. to customer			x			x
Deliveries to customer			x			x
Delivery performance	x	x				x

4 Data Based Analysis using Multiple Linear Regression Analysis

Multiple linear regression analysis is often deployed as part of a general regression analysis. Multiple indicates that more than one describing variable is analyzed, linear means the focus is on linear relationships between the describing variables and the target variable.

In this case, the target variable is inventory, the describing variables are all of the aforementioned 111 collected factors. For these 111 factors, the multiple linear regression analysis is applied in order to identify the combination of factors having the strongest influence on inventory.

The theoretical test run was as follows:

- Describing factors: 111 collected factors (e.g. minimum order quantity, lot size, communication, etc. with either semi-annual mean values, cumulated absolute values or binary-coded variables)
- Target value: Inventory level
- Scope of study: 6 months of arithmetic mean of describing factors
- Dimension of area of study: Quantity of collected describing factors
- Test run: Linear, logarithmic and squared model

The describing values refer to the collected factors. The area of study contains the average values of all describing factors to explain the target value which is the inventory level. The dimension of the scope of the study is defined through all collected factors which impact on the target value shall be identified. A linear model is chosen in order to identify the target values' linear dependency on the describing factors. A linear model reveals the direct impact on the expected target value if describing values are changed.

To identify the impact of variables which influence inventory, five statistical key figures with the following ranges are used (for a detailed description of the below mentioned key figures, please refer to Backhaus et al. (2011), Hornig, Hatzinger and Nagel (2011) and to Crawley (2007)):

- the adjusted R squared (R^2) with adj. $R^2 \geq 0.7$,
- the F-test and/or p-value with $p < 0.001$,
- the normal probability plot (Q-Q plots),
- the AIC (An Information Criterion), with the AIC as small as possible, and
- the variance inflation factor (VIF), with VIF close to 1.

Real data from a company in the commercial vehicle industry was used for the regression analysis and to accomplish the described test runs. Materials (e.g. their inventory levels) and factors (e.g. their levels per material) from three different production locations of commercial vehicle companies in the USA, France and the Czech Republic were analyzed. Each location has a different characteristic within the supply chain. Table 2 shows the attributes and location specifications:

Table 2 Plant characteristics

	USA	Czech Republic	France
Product portfolio (number of variants)	High	Middle	Low
Sales channels	OE, OES, ICO, IAM, Reman	OE, OES, ICO, IAM	ICO
Location structure	Production, Distribution	Production	Production
Manufacturing penetration	High	Low	Medium
Inventory space (x) [m^2]	x > 10,000	2000 < x ≤ 10,000	1,000 < x ≤ 2,000
Analyzed part numbers	18,017	4,846	8,137

In Table 2, the abbreviations get the following definitions: OE thereby describes Original Equipment Manufacturer, OES represents Original Equipment Manufacturer Service, ICO refers to Intercompany, IAM is the abbreviation for Independent Aftermarket and Reman represents Remanufacturing.

Analyzing different locations with different characteristics allows us to obtain a more complete picture of potential drivers on inventory and to check whether influencing factors vary depending on location. In total, data was collected for 31,000 materials.

The analyzed material types were finished goods, semi-finished goods, raw materials and spare parts. For each factor, data was taken from an enterprise resource planning (ERP) system as well as from a product lifecycle management database (PLM database) on a part number level. Due to data availability issues and data quality, values for only 46 metric factors (e.g. safety stock, lead time, throughput time, etc.) and 10 categorical factors (standards, structures, organizational impacts, etc.) for all 31,000 materials were collected. For this reason, not all 111 factors and their combinations could be modeled using regression analysis.

Before modeling all factors, it is helpful to plot the data in a scatter plot. A linear trend of the data might indicate a linear dependency between the dependent and describing variables. If no linear trend is visible, it is possible to transform the variables. In our models, we used linear, logarithmic and squared transformation. Figure 1 shows two plots of the linear dependency. Each dot represents one material – the y-axis represents the dependent variable (average inventory) and the x-axis represents the describing

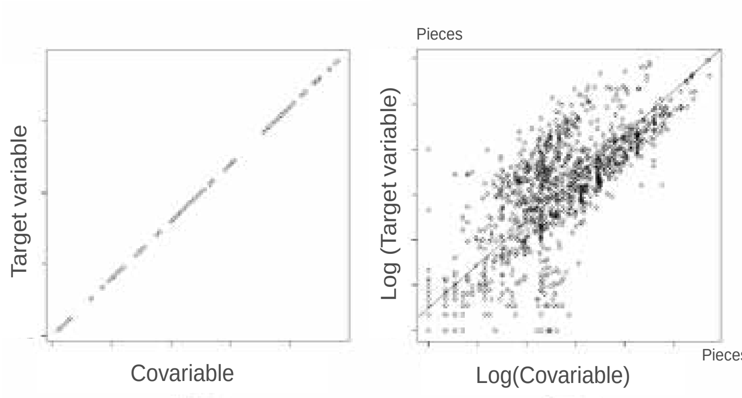


Figure 1 Optimal and transformed data plot showing linear trend

variable (in this example, order size). The two plots can be described as follows: The optimal linear dependency (left plot) and the real data based plot (co-variable order quantity), but logarithmically plotted (right plot).

Transforming the data set, in this case using the logarithm transformation, provides the opportunity to summarize the data set and analyze trends.

The influence of only one factor on inventory was analyzed, as was the influence of combinations of factors. In order to include all factors in the model, the forward selection technique was applied: Variables are included sequentially in the regression model, if they lead to an increase of the expected target value. In a first step, only two factors were combined with each other, followed by the combination of three factors, four factors, etc. Altogether, nearly one billion test runs were analyzed in order to determine the factor combination with the greatest influence on inventory with respect to different model transformations (lin, log, sqrt). The aforementioned test runs yield to the following regression models:

Linear

$$\hat{Y} = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k \tag{1}$$

Logarithmic

$$\mathrm{Log}(\hat{Y}) = \alpha + \beta_1 \log(X_1) + \beta_2 \log(X_2) + \cdots + \beta_k \log(X_k) \tag{2}$$

and root

$$\mathrm{Sqrt}(\hat{Y}) = \alpha + \beta_1 \,\mathrm{sqrt}(X_1) + \beta_2 \,\mathrm{sqrt}(X_2) + \cdots + \beta_k \,\mathrm{sqrt}(X_k) \tag{3}$$

With

$$\hat{\hat{Y}} \ldots expected\ values\ of\ Y$$

$$\alpha, \beta_1, \ldots, \beta_k \ldots\ Regression\ Coefficient$$

$$X_1, \ldots X_k \ldots Covariables$$

$$1 \leq k \leq 56$$

Each data set yields one linear, logarithmic and root regression equation and provides a mathematical expectation for the inventory level $\hat{Y}$.

5 Results

The combination of multiple factors, considering different data transformation can be seen in Table 5: Depending on the factor combination, the inventory's linear dependency varies. This excerpt only shows those models having an adjusted R^2 higher than 0.9, a p-value smaller than 0.001, also all other aforementioned statistical key figures are fulfilled. No concrete threshold values are defined for adjusted R^2 values in the literature. According to Groß (2010) guidelines, an adjusted R^2 of greater than 0.7 can be interpreted as relatively high, whereby an adjusted R^2 value of less than 0.3 is considered less suitable. An adjusted R^2 between 0.3 and 0.7 describes a linear connection between the depending and describing variable, however according to Groß (2010), more describing should be added in order to analyze changes in the linear connection.

The "x" in a row indicates those factors which combination has a high linear influence on inventory. This linear influence is indicated through the statistical criteria described above. Each row stands for one regression equation that describes a strong linear dependency between the marked factors ("x" $\triangleq X_k$) and inventory (inventory $\triangleq$ Y). It is evident that some factors appear in more regression equations than others. As all combinations listed in Figure 2 describe a high linear influence on inventory, the main drivers can be indicated as those appearing in many regression equations with more than 10 x's per column. This implies that identified main drivers do not have one bijective beta factor, as they appear in different regression equations. The regression equations for the first and fourth row are as follows:

$$\hat{Y} = -65.7 + 2.5X_1 + 38.3X_2 + 3.2X_3 \quad (4)$$

$$\hat{Y} = -0.92 + 2.5X_1 + 38.5X_2 - 0.2X_3 + 3.2\,X_4 \quad (5)$$

With

$$X_1 \ldots Procurred\ Quantity$$
$$X_2 \ldots Product\ Variety$$
$$X_3 \ldots Preferred\ Materials$$
$$X_4 \ldots deliveries\ from\ supplier$$

Figure 2 does only show an excerpt of 10 factors analyzed applying a linear model.

Furthermore, four graphical plots were analyzed, if they fulfilled the requirements to consider the respective factor as the main driver on inventory. Figure 3 shows the plots representing the example of the factor batch.

Factors combined	Observations	Adjusted R^2	p-value	Safety stock	Procurred qty	Min Order qty	Backlog	Deliveries from supplier	Delivery qty	Delivered qty customer	Amount Customer	Product variety	Preferred material	...
				0	13	0	5	11	12	9	15	20	17	0
3	7175	0.992	2,18E-25		x							x	x	
	5229	0.992	4,35E-21		x			x				x		
	5163	0.992	1,73E-75		x			x					x	
4	5163	0.992	7,43E-21		x			x				x	x	
	4332	0.993	7,82E-22		x							x	x	
	3310	0.999	3,10E-143		x			x				x		
5	3300	0.999	7,53E-191		x			x				x	x	
	3089	0.994	3,38E-195		x			x				x	x	
	2296	0.812	8,88E-08					x	x		x		x	
6	2104	0.999	8,88E-08		x			x				x	x	
	1483	0.874	4,08E-82		x			x			x	x		
	1483	0.881	1,59E-204		x			x			x		x	
7	1465	0.883	6,14E-110		x				x		x	x	x	
	1465	0.882	1,24E-124					x	x		x	x	x	
	1402	0.886	6,65E-117						x	x	x	x	x	
8	1246	0.881	6,27E-203		x				x		x	x	x	
	1207	0.885	1,31E-85						x	x	x	x	x	
	1160	0.880	4,59E-53						x	x	x	x	x	
9	1066	0.832	6,47E-78				x		x	x	x	x	x	
	1036	0.902	3,47E-46				x		x	x	x	x		
	1036	0.902	4,47E-168				x		x	x	x	x		
10	522	0.857	5,21E-03						x	x	x		x	
	505	0.890	8,38E-61				x		x	x	x	x		
	375	0.895	2,20E-202				x			x	x	x		

Figure 2 Excerpt of regression results per factors combination

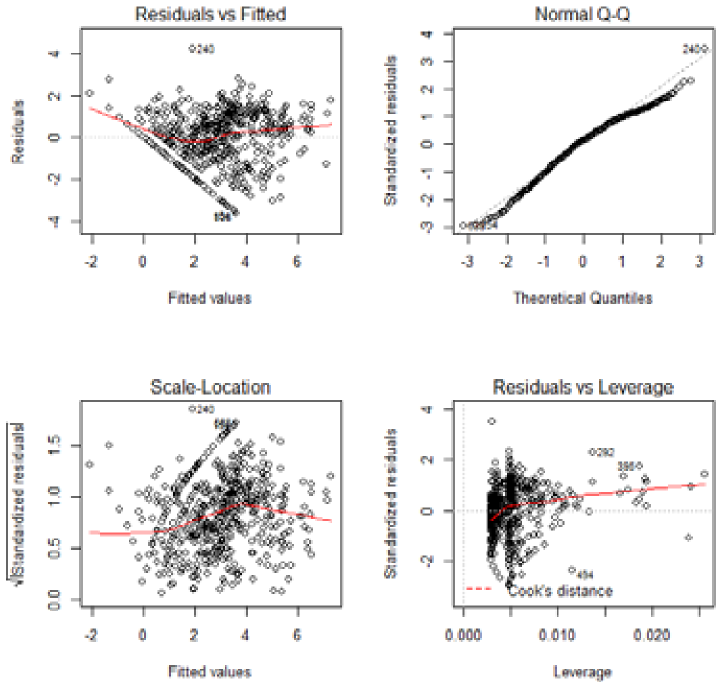


Figure 3 Excerpt of four graphical plots for driver batch

The picture on the top left plots the residuals versus the fitted values. If the residuals' spread (solid line) differs significantly from the dotted line, the linear relation will not be explained sufficiently. The top right picture shows the residuals normal distribution: This is a precondition for applying linear regression, otherwise the F-test will not be valid. Significant discrepancies between the normal distribution (dotted line) and the data points show an unreliable model. The third plot at the bottom left uses the same data as the first plot to analyze the scale location. Crawley (2007, pp.402) states: "If there was a problem, such as the variance increasing with the mean, then the points would be distributed inside a triangular shape, with the scatter of the residuals increasing as the fitted values increase." The fourth plot at the bottom right reveals the influence of data points. If one data point is outside the so called Cook's Distance, a strong impact on the model can be interpreted (Groß, 2010). If those data points are taken out of the model, a different linear model might result.

The regression analysis was applied to each location data set as well, as to the whole data set (USA plant + France plant + Czech plant). Table 3 shows the main drivers per data set:

Table 3 Main drivers on inventory per different data set

Czech Republic	France	USA	All Locations
Order quantity from supplier	Order quantity from supplier	Order quantity from supplier	Order quantity from supplier
Replenishment time	Batch	Product portfolio	Product portfolio

Czech Republic	France	USA	All Locations
Number of suppliers' shipments	Customer delivery performance	Number of prime materials	Number of prime materials
Quantity issued to customer	Quantity issued to customer	Quality related stock	Internal delivery performance
	Number of shipments to customer	Number of shipments to customer	Number of shipments to customer
	Customer delivery quantity	Customer delivery quantity	Customer delivery quantity
		Number of suppliers' shipments	

The difference in the number of main drivers on inventory per location is related to the number of x's per column, as shown in the excerpt in Figure 2.

This allows a comparison of the plants' specifications with the set-up of an entire network. According to Table 3, the factors showing the greatest linear influence on inventory, taking into consideration the whole data set and structured according to Table 1 into Source, Make, Deliver, Plan, are as follows:

- Order quantity (S): The average order quantity of a material. This factor takes every order of a material into account, and calculates an average, based on these individual amounts.
- Product Portfolio (P): Product assortment depth. Describes how many components belong to the same "product family".
- Number of shipments to customer (D): Total number of customer deliveries. The total number of deliveries of a material to the end customers, in a specific time period.
- Customer delivery quantity (D): The average quantity of a component delivered to the customer.
- Internal delivery performance (S, M): This factor calculates the internal delivery performance level, also referred to as "ICO delivery performance".
- Prime material (M): Proportion of use of products from the same product family. The percentage of usage of a component with respect to materials from the same product family.

6 Interpretation of Results

The previously listed research questions were answered: The main drivers on inventory were identified analytically, quantified and company-specifically analyzed, using multiple linear regression analysis. Furthermore, the analysis supports the aforementioned hypothesis: Only a few factors explain inventory level to a great extent. The identified factors may vary depending on industry, material portfolio, data quality, fixed period, etc. However, multiple linear regression analysis can be used to identify the main drivers on inventory on a company-specific basis and among others explain their level of influence on inventory through the adjusted R^2.

The six main drivers appear at different stages along the supply chain. Earlier studies focused on optimizing specific inventory related areas within the supply chain, e.g. only procurement parameters, or based their approach on empirical studies, without quantifying the drivers' impact on inventory and correlation with other factors. Assigning the main drivers on inventory for Source, Make, Deliver or Plan, the results of this study reveal that inventory management has to consider all parts of the supply chain, since they interact with one another throughout the course of the supply chain without correlating with each other. In addition to other aforementioned literature approaches, also qualitative factors were analyzed, using coded variables. They were not identified as main drivers on inventory in the application of this data set. However, multiple linear regression analysis allows for their consideration.

Figure 3 shows further statistical criteria which have to be fulfilled: If the normal distribution of residuals is not given, a factor will automatically be excluded as main driver. However, combining it with other factors it may lead to a normal distribution of the residuals and improve the model. It is thereby possible to consider drivers on inventory that might have been deleted because of data issues. All identified main drivers on inventory fulfill these requirements: There are no main drivers present, outside the Cook's Distance, the residuals fit the expected values and data points are not spread in a triangular form.

Depending on the plant's characteristic, the factors show a different linear influence on inventory. Many identified factors can be explained by these characteristics. The Czech plant, for example, is distinguished by high replenishment times, because suppliers are situated far away from the plant. This also leads to higher order quantities from suppliers in order to guarantee that customer demand is met. The identified main drivers "Order quantity from supplier", "Replenishment time" and "number of suppliers' shipments" affect inventory at the Czech plant due to the procurement structure. The opposite situation can be found at the French plant: there are long delivery times from the plant to the customers due to long shipping distances. The identified outbound-related main drivers on inventory, such as "quantity issued to customer", "number of shipments to customer", "customer delivery performance" and "delivered quantity to customer" can thus be attributed to the French plant's distribution network.

The USA plant has a high product portfolio and high focus on product variants, which explains the strong linear influence arising from the "product portfolio" and "number of prime materials" factors. Due to the USA plant's geographical location, there are long delivery distances both from suppliers and to the customers. The other identified main drivers on inventory therefore also affect the procurement and distribution part of the USA plant's supply chain. Overall, the identified main drivers on inventory on a plant level can be attributed to the plant's structure, or supply chain set-up. Furthermore, factors that cannot be directly related to this structure or organizational set-up, provide transparency about other effects on inventory which might not have been realized in the past. In addition, the regression analysis revealed that main drivers on inventory vary, depending on the plant's location and structure and need to be identified separately.

7 Conclusion and Further Steps

The regression analysis is based on historical data, thus the identified drivers explain inventory levels in the past. A more efficient way to plan inventory could be, to use these results in order to proactively control the inventory level. These factors relate to inventory in a linear way, their optimization will therefore automatically affect the inventory level. Varying these factors continually reduces the risk of creating a non-target inventory level. An improvement measure within the scope of inventory management depends on the kind of factor and may be a defined standard process or a calculation method. The derivation of actions for reacting to inventory level deviations as well as for preventing such deviations in the future is a next step in completing this systematic approach.

Among other aspects, factors were structured according to their appearance within the supply chain (see Table 2). The findings in this study support this type of structuring, since the identified main drivers appear at different points along the supply chain. Based on these results, improvement measures can be focused on the relevant department as a clear allocation to the appropriate supply chain part.

In addition, analyzing the data set on a location-wide basis allows identification of the location-specific main drivers on inventory and allows for taking location-specific issues into account. Furthermore, analyzing all data sets at once provides an overall picture of the main drivers on inventory within the network of a company and helps create a common understanding as to where the biggest potentials for inventory optimization measures exist in the supply chain.

One next step is to include the valuation class per material and inventory level in the regression analysis. It shall be shown whether "Source" factors have a stronger impact on raw material inventory levels than on e.g. finished goods inventory levels.

As market and other external factors change over the time, the main drivers on inventory may vary. One next step is therefore to define a regulatory framework where responsibilities and regularities are described. This would allow an inventory improvement process that considers the actual internal and external situation within the supply chain.

References

Backhaus, K., Erichson, B. Wulff, P. and Weiber, R., 2011. Multivariate Analysemethoden. Eine anwendungsorientierte Einführung. 13th ed. Berlin [u.a.]: Springer.

Beamon, B. M., 1998. Supply chain design and analysis. International Journal of Production Economics, 55(3), pp. 281–294.

Bruce, M., Daly, L. and Towers, N., 2004. Lean or agile: A solution for supply chain management in the textiles and clothing industry? International Journal of Operations & Production Management, 24(2), pp. 151–170.

Cachon, G. P. and Fisher, M., 2000. Supply Chain Inventory Management and the Value of Shared Information. Management Science, 46(8), pp. 1032–1048.

Cachon, G. P. and Olivares, M., 2010. Drivers of Finished-Goods Inventory in the U.S. Automobile Industry. Management Science, 56(1), pp. 202–216.

Cagliano, R., Caniato, F. and Spina, G., 2004. Lean, Agile and traditional supply: how do they impact manufacturing performance? Journal of Purchasing and Supply Management, 10(4-5), pp. 151–164.

Callioni, G., Montgros, X. d., Slagmulder, R., van Wassenhove, Luk N. and Wright, L., 2005. Inventory-driven costs. Harvard Business Review, 83(3), pp. 135–141.

Crawley, M. J., 2007. The R book. Chichester, England, Hoboken, N.J.: Wiley.

D'Aveni,.A. and Ravenscraft,D.J.,1994.Economies of integration versus bureaucracy costs: does vertical integration improve performance? Academy of Management Journal 37(5), pp.1167–1206.

Demeter, K. and Matyusz, Z., 2011. The impact of lean practices on inventory turnover. International Journal of Production Economics, 133(1), pp. 154–163.

Demeter, K. and Golini,R., 2013. Inventory configurations and drivers: An international study of assembling industries. International Journal of Production Economics, 157(2014), pp. 62-73.

Fazel, F., 1997. A comparative analysis of inventory costs of JIT and EOQ purchasing. International Journal of Physical Distribution & Logistics Management, 27(8), pp. 496–504.

Golini, R. and Kalchschmidt, M., 2011. Moderating the impact of global sourcing on inventories through supply chain management. International Journal of Production Economics, 133(1), pp. 86–94.

Golini, R. and Kalchschmidt, M., 2015. Managing inventories in global sourcing contexts: A contingency perspective. International Journal of Production Economics, 165, pp. 64–78.

Groß, J., 2010. Grundlegende Statistik mit R. Eine anwendungsorientierte Einführung in die Verwendung der Statistik Software R. Wiesbaden: Vieweg + Teubner.

Hompel ten, M. and Heidenblut, V., 2011. Taschenlexikon Logistik. Abkürzungen, Definitionen und Erläuterungen der wichtigsten Begriffe aus Materialfluss und Logistik. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg.

Hornik, K., Hatzinger, R. and Nagel, H., 2011. R. Einführung durch angewandte Statistik. München: Pearson Studium ein Imprint der Pearson Education.

Kakabadse, A. and Kakabadse, N., 2002. Trends in Outsourcing. European Management Journal, 20(2), pp. 189–198.

Kouvelis, P. and Gutierrez, G.J., 1997. The newsvendor problem in a global market: optimal centralized and decentralized control policies for a two-market stochastic inventory system. Management Science, 43, pp. 571–585.

Lee, H. L., Padmanabhan, V. and Whang, S., 1997. Information Distortion in a Supply Chain: The Bullwhip Effect. Management Science, 43(4), pp. 546–558.

Lieberman, M. B., Helper, S. and Demeester, L., 1999. The empirical determinants of inventory levels in high-volume manufacturing. Production and Operations Management, 8(1), pp. 44–55.

Naylor, J. B., Naim, M. M. and Berry, D., 1999. Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain. International Journal of Production Economics, 62(1-2), pp. 107–118.

Olhager, J., 2003. Strategic positioning of the order penetration point. International Journal of Production Economics, 85(3), pp. 319–329.

Pfohl, H.-C., 2010. Logistiksysteme. Betriebswirtschaftliche Grundlagen. 8th ed. Berlin, Heidelberg: Springer.

Porter, M.E., 1980. Competitive strategy. New York: Free Press.

SCOR, 2015. APICS Supply Chain Council. Available at: www.supply-chain.org [Accessed 23.06.2015].

Stadtler, H., 2002. Supply Chain Management - An Overview. In: H. Stadtler, and C. Kilger, eds. 2002. Supply chain management and advanced planning. Concepts, Models, Software and Case Studies. 2nd ed. Berlin, Heidelberg [u.a.]: Springer.

Stadtler, H. and Kilger, C., eds., 2002. Supply chain management and advanced planning. Concepts, Models, Software and Case Studies. 2nd ed. Berlin, Heidelberg [u.a.]: Springer.

Stratton, R. and Warburton,R.D.H., 2006. Managing the trade-off implications of global supply. International Journal of Production Economics 103(2), pp. 667–679.

Investigation of Scheduling Techniques for Uncertain Conditions

Taiba Zahid, Mathias Kühn, Michael Völker and Thorsten Schmidt

The traditional methods and techniques employed in operational management seem unable to provide solutions that can be actually practiced. This insufficiency is caused by the uncertainties and delays which are faced in practice. The potential causes of these uncertainties are usually internal (inadequate resources, faults and breakdowns) and external (material shortfall or low quality) environment. These realizations have forced researchers in the past decade to find stable solutions which have ability to remain insensitive to these disturbances and provide solutions which can be practiced.

The present study investigates the methods adopted to provide such flexible and robust solutions. The aim is to identify and categorize the methodologies in this non-deterministic field and compare their performance with the static ones. In addition to that, a detail analysis of techniques proposed in the literature is delivered, which implies their limitations, assumptions and applications areas in scheduling.

Keywords: Scheduling, Uncertainty, Robustness, Stochastic

1. Introduction

The global trend towards product customization and diversification led to new requirements in production planning and control. With the consequent increasing of product complexity and variety, combined with shorter product life cycles, the uncertainty of the planning data and the frequency of disturbances increases. These fluctuations further complicate the scheduling problem which is already categorized as a NP-hard problem (Lee, 2003). Another consequence of individualization is higher product cost. To offer these products at no extra cost for the customer, improvement in planning and control is necessary. According to a recent study reported by Pekny (2005) an effective planning and scheduling system leads to a decrease in process costs as well as an increase in process throughout, implying an improvement of about 5% to 15%.

Due to increased uncertainties and disruptions along with a rise of production costs, the interest of methods for effective scheduling methods increases. In order to make the plans effective and applicable, these fluctuations at various levels of operations management need consideration at initial decision phases.

In the past decade, various researches have been conducted focusing on non-deterministic strategic analysis. We do not claim to provide an all-inclusive literature on this rapidly expanding research area, but the focus is to equip reader with a methodological investigation. This investigation summarizes the taxonomy of modelling strategies proposed in scheduling and operations management in the context of various types of fluctuations.

2. Classification of Uncertainty

The conviction of uncertainty about future is the notion known with certainty. As Hurley (1996) argued "Why is that such a vast amount of research is being conducted and financial and intellectual resources being wasted generating useless solutions to unrealistic problems?" There can be multiple causes of a disturbance with various effects resulting in the direct or indirect addition of non-value quantities. The structure of decision making typically observed in operations management (as described follows) represents a hierarchical structure characterized by distinct management requirements and thus, may exhibit peculiar reasons of disturbances.

Strategic Level: This level comprises of decisions at the earliest stage, meant for longer time horizons at managerial level. The decisions made at this level are mainly concerned with business planning. The examples can be selection of factory site, suppliers, client handlings and order collection etc.

Tactical Level: This level aims for long to midterm planning decisions. Processes are actually defined at this level and guidelines are composed. The example decisions at this stage can be budget allocation, inventory and resource distribution etc.

Operational Level: Detailed management of activities and resource allocation at production floor level is the target of operational level. This involves daily and weekly planning and management of processes.

Naturally, cause and effects of disturbances at each decision level will vary. The differentiation among these uncertainties regarding hierarchy of such decision levels helps decision makers to concentrate on specific disturbances and to model uncertainties at each specific level. Landegham and

Vanmaele (2002) summarized sources of fluctuations and their influence at each decision level in the context of demand chain planning. The final effect of disturbances although is the same i.e. a negative addition in the overall objective value of the company. However various the causes of these disturbances should be considered separately at each decision level. For example, the cause of an activity delay at operational level can be machine breakdown but the same effect of activity delay can happen due to delay in material supply at tactical level. Thus, while scheduling at operational level, decision makers need to be concerned more with the scenario of machine break down. Table 1 summarizes possible sources of uncertainty of a disturbance and their influence on various decision making levels. For example, the source of an activity delay can be caused by a delay in material supply. Although, this will affect the whole project to be delayed and will effect activities at all decision levels, but it will influence the decision making process at tactical level the most since as previously explained, this level is concerned with resource and inventory allocation decisions.

Table 1 Influence of plausible sources of disturbances on various decision making levels

Disturbance	Plausible Sources	Operational	Tactical	Strategic
Activity Delay	Machine Breakdown	High	Medium	Zero
	Resource unavailability	High	Low	Zero
	Delay in material supply	Zero	High	Medium
	Labor strike	Low	Low	High
	Limited Resources	Medium	High	Zero
Low Quality Product	Supply material error	Zero	Medium	High
	Production negligence	High	Low	Zero
	Process inefficiency	Zero	High	Medium

Disturbance	Plausible Sources	Operational	Tactical	Strategic
Cost Over-shoot	Inflation in material rates	Zero	Null	High
	Resource cost Inflation	Zero	High	Low
	Order delay	High	High	Zero
Demand Fluctuation	Customer Requirements	Zero	Medium	High

Various criteria for classification of uncertainties have been proposed by researchers in order to separately identify them for modelling purposes. Subrahmanyam, Pekny and Reklaitis (1994) divided them into short term and long term uncertainties. Short term uncertainties basically comprised of shorter planning horizons and need to be dealt with on daily basis. Long term uncertainties regarded disturbances effecting decisions at strategic level such as demand fluctuations and inflation rate.

Yadegari (2013) in his work summarized the uncertainties into three types based on their frequency of occurrence named as periodic (P), sporadic (S) and unique/random (R). Periodic ones occur at regular intervals while unique occur rarely and are related with disaster management. Sporadic are the ones which occur due to the faults and errors in production planning which can be of humans as well as of machines.

In regards with supply chain problems, Geary, Childerhouse, and Towill, (2002) segregated uncertainty into process, demand, supply and control. Process uncertainties referred to the estimation of processing times for different activities. These disturbances were mainly related with the internal capacity of company to meet due dates. Fluctuations regarding delays and errors in external resources such as machinery and material were included in supply while demand uncertainties represented difference in end market demand and the orders placed by the customer. Control uncertainties spanned entire network and observed the disturbances during the entire feedback loop and information flow such as material shortage, machine breakdown, order variation and process inadequacy.

3. Modeling Strategies for Scheduling under Uncertainty

Based on these various categorizations, a number of solution strategies have been proposed for such non-deterministic scheduling strategies. Since the problems in this area are declared as NP-hard (Alcaraz, Maroto & Ruiz, 2003), researchers have focused to provide computationally effec-tive solutions. The hierarchical tree of these strategies was created after thorough investigation of literature in this area and can be visualized in figure 1. This was done in order to facilitate reader in providing a compre-hensive overview of the scattered numerous modelling strategies for this NP-Hard problem.

Broadly classifying, strategies proposed in the literature can be categorized into two major groups of proactive and reactive techniques.

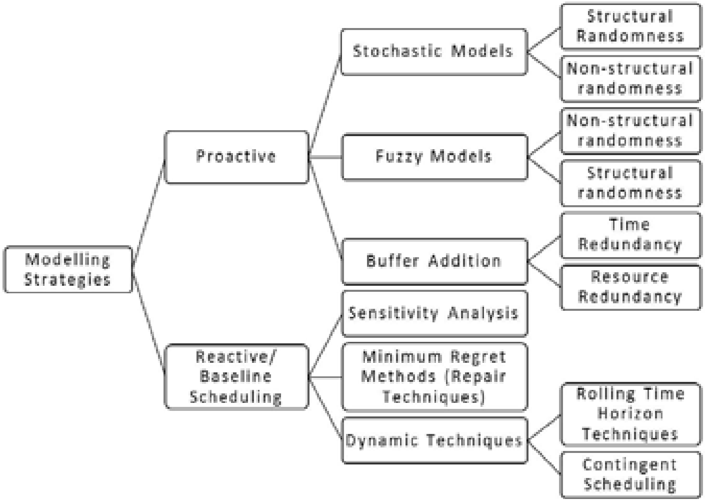


Figure 1 Taxonomy of Non-deterministic Modelling Strategies

3.1 Reactive Techniques

Reactive techniques are based on stabilizing the base line schedule in case of disturbances. A base line schedule based on deterministic information is formulized and in case of any external disruption, reactive heuristics react in such a way so as to repair the base line schedule in order to minimize the difference between base line and new schedule (minimum regret based methods). Since this technique do not requires rescheduling, the computation cost for repairing is low but results in poor results in many cases. Since reactive scheduling tend to repair the base line schedule and minimize its differences from the base line schedule, it will be more beneficial in the cases where disturbances are human based or in cases where activities can be crashed at the expense of cost, hence in short can be summarized as manageable.

Another variation of reactive scheduling is dynamic scheduling which is further divided into two sub-strategies. As the name suggests, dynamic strategies tend to start with a feasible baseline schedule that tends to change with time to cope with disturbances caused by uncertain situations. One way is to create a feasible schedule that spans a time horizon of a year and then implement it monthly while changing the schedule of next month/time period according to the feedback of first period/month. This is known as rolling time horizon while contingent scheduling relies on creating multiple baseline schedules and shifting from one to another in case of fluctuations.

Contingent scheduling is basically a combination of reactive and proactive techniques. It focuses more towards providing flexibility rather than robustness by creating various scheduling options and adjusting the plan after realization of any disruption. This technique relies on the assumption that in a production environment, one comes across with unexpected but anticipated disruptions. Drummond, Bresina and Swanson (1994) presented way of just in case scheduling in this domain. In case of each anticipated disturbance, the schedule breaks and reschedules the rest of the activities to accommodate disturbance. Another recommendation in developing multiple baseline schedules was proposed by Billaut and Roubellat (1996). They recommended creation of groups for every renewable resource and to consider all the possible options for schedules. This was done in the hope of switching from one schedule to other in case of uncertain event. But the approach was applied on a small job shop problem and once

the problem is extended even to medium sized problems having two or more renewable resources, the number of possible options will increase to a large amount making it difficult to adopt this method.
Sensitivity analysis is mainly characterized as a post optimal tool. It mainly focuses on what-if questions from the production floor for example what is the effect of a certain parameter on optimal schedule or which data sets do not have an impact on base line schedule. Researchers mostly perform these tests on a polynomial solvable scheduling problem and then gather this data for larger scale NP-Hard problems. Hall and Posner (2004) described a detailed systematic study on the literature found on sensitivity analysis for scheduling problems. They proposed that robustness of a schedule can be improved by change of selection method for robust schedule. Apart from focusing on the best objective function value, attention should be given in selecting the schedule from the pool of near optimal schedules, which is least sensitive to external disruptions.

3.2 Proactive Techniques

Proactive techniques have been further classified into sub categories. The most popular one are stochastic techniques. Pinedo (2005) provided an overview of stochastic scheduling problems. Stochastic techniques tend to capture the uncertainties which occur periodically in the system. They require knowledge from the past and based upon this knowledge, it develops probability curves for disturbances. The quality of the solution depends upon these curves. Herroelen and Leus (2004) have given a comprehensive overview of project scheduling techniques used under uncertainty. The study mainly focuses stochastic models.

Another class of proactive scheduling is fuzzy based scheduling. These fuzzy variables are used when imprecision is observed in place of uncertainty. Mostly in case of project durations, when there is possibility of different activity durations, researchers tend to use fuzzy variables that make use of membership functions rather than probability curves. It allows managers to consider multiple possible scenarios rather than single one.

State-of-the-art literature widely discusses robust scheduling in the context of proactive strategies. But the numerous definitions and criteria of robustness have been defined which makes it difficult and rather confusing for the readers to actually state its taxonomy.

Many researchers have defined robustness in context of flexibility and quality and most of these definitions are published in machine scheduling area. Davenport and Beck (2000) defined robustness as "schedule that is able to absorb some level of unexpected events without rescheduling". Kouvelis, Daniels and Vairaktarakis (2000) depicted robustness as "the determination of a schedule whose performance (compared to associated optimal schedule) is relatively insensitive to the potential realization of job processing times."

Besides robustness measures, terms like quality robustness, solution robustness or stability of robustness and flexibility are often used while describing this proactive technique. In general, term quality robustness is used where sensitivity of the schedule performance is tested regarding target function while stability or solution robustness refers to the insensitivity of the schedule with respect to objective function. Robust results are not the optimal results. Many ideas have been presented to control degree of conservatism searching for the optimal one.

Through these various definitions, it can be concluded that robustness actually defines the strength or ability of a proactive schedule to be realized successfully in case of uncertainties. Hence, it is suitable to consider it in structural randomness (paper title: robust optimization of uncertain logistics networks) which can be modelled as either a possibility (fuzzy modelling) or a probability (stochastic models) depending on the data available. As a conclusion, if input data has been analyzed well enough to assign probability functions with knowledge based data, then stochastic models can be constructed, otherwise, fuzzy models are suggested to be more accurate for linguistic variables.

4. Scope of the Study

As noticeable, literature presents various approaches for optimized or feasible solutions with different solution strategies. Among all of the solution approaches (despite considering reactive or proactive strategies) metaheuristics special genetic algorithm seems to be the most popular choice for obtaining optimal results.

However up to the knowledge, no such specific criterion has been suggested, nor any systematic study has been conducted that can help decision managers for practical applications of these techniques. The literature lacks in providing comparison of solution strategies with respect to the production environments and their layouts such as job shop or assembly lines production systems.

Moreover, problem datasets which have been utilized for evaluation vary which makes it difficult to compare the efficiency of provided techniques.

Also, datasets are based on different assumptions which make these datasets suitable for limited production examples.

The current investigation provides state-of-the-art literature review in the light of following research questions:

— What are the most widely proposed solution techniques for various modelling strategies?
— Which types of uncertainties are considered?
— Comparison of data sets (limitations and application)
— Solution strategies w.r.t production layout

5. Literature Investigation

In the recent decade, a wide range of research is being carried out in the area of operations and research management for finding practical solutions for scheduling. In the following sub sections, a literature review of such methods has been provided in reference to the research questions described in section 4. Additionally, an analysis of various datasets used for benchmarking is performed to identify their limitations and applications in the industry.

5.1 Literature Review

As described in section 3, a wide spread of modelling and solution strategies is exhibited in the area of non-deterministic scheduling practices. Table 2 provides a comparison of notable researches in this area.

In Table 3, an investigation of some recent works was made on objective functions, typically being considered in the area of operations management. It was realized that most of the works focused on makespan minimization to test their respective proposed strategies. This trend is widely seen because of the fact that as a regular objective function, the quality of proposed algorithm can be better evaluated through benchmarking and sensitivity analysis. In comparison, research work that adopts time/cost trade-off as an objective is more suitable for production layouts where crashing of an activity is directly proportional to the increase in cost, mostly measured by resource utilization. Such trade-offs strategies should be evaluated through case studies.

Table 2 Literature review

Author (Year)	Type S,R,P	Model Scheme	Solving Plan	Dataset	Level	Layout	Comments
Lambrachts, O. & Herroelen, W (2007)	S	Proactive	Heuristics/ Buffer	PSPLib	Operational	RCPSP	Expert based knowledge heuristics, lacking evaluation
Sireesha, V. & Ravishankar, N (2010)	S	Fuzzy Estimation	CPM	None Specified	General	None Specified	Only precedence constraint, Construction projects suited
Yaghounzadeh, H. & Roghanian, E (2014)	S, R	Fuzzy Estimation	CCM (Critical Chain Method)	Case Study	Strategic	Construction Projects	Random durations based on expert knowledge, Position based buffers
Perez, M. and Kuhl, M.E. (2014)	General	Stochastic PERT	Simulation optimization	None Specified	Generalized	None Specified	Optimization via simulator framework

Author (Year)	Type S,R,P	Model Scheme	Solving Plan	Dataset	Level	Layout	Comments
Ramkumar, R., Tamilarasi, A., & Devi, T (2011)	S	Fuzzy Inference Model	Priority heuristics	None Specified	Tactical	Job Shop Scheduling	Due dates and customer preferences assign via priorities
Grey, J.R. (2007)	P	Stochastic Task Insertion	Time redundancy	RanGen	Strategic/ Tactical	None Specified	Modification of Extreme Buffer Sizing approach by probability distribution
Helen, R. & Sumathi, R (2013)	S	Fuzzy Modelling	CPM with crashing	None	Operational	None specified	TCTP assuming decrease of activity duration with increased cost
Petrovic, S., Fayad, C. & Petrovic, D. (2007)	S	Fuzzy PERT	Sensitivity analysis, heuristics	None	Operational	Job Shop	Knowledge based heuristics for PERT, Analysing impact of an activity delay on project makespan

Author (Year)	Type S,R,P	Model Scheme	Solving Plan	Dataset	Level	Layout	Comments
Van de Vonder, S., Ballestin, F., Demeulemeester, E. & Herroelen, W (2006)	S	Dynamic/ Contingent	Priori heuristics	PSP-Lib	Operational	RCPSP	Minimum deviation from baseline schedule, Multiple schedules creation for each disturbance, Computationally intractable
Cheng, J., Fowler, J. & Kempf, K (2012)	S	Stochastic task Durations	Simulated Annealing/Monte-Carlo	PSP-Lib	Operational	Product Layout/ MMRCPSP	Simulation based makespan optimization, Normally distributed task durations
Hong, T.P., Yu, K.M. & Huang, C.M. (1998)	S	Fuzzy Membership functions	Priority Heuristics	None	Operational	Job Shop Scheduling	Variable activity durations with Fuzzy priority rules

Author (Year)	Type S,R,P	Model Scheme	Solving Plan	Dataset	Level	Layout	Comments
Archer, S., Armacost, R.L. & Armacost, J.P.(2009)	P	Stochastic Task Insertion	Repair heuristics	None	Strategic/ Tactical	RCPSP	Left/Right shift scheduling heuristics, Proposing partial buffer addition CPM analysis tool
Fallah, M., Ashtiani, B. Aryanezhad, M. (2010)	S	Buffer sizing	CCM lognormal distribution	None	Operational	None Specified	Project & Feeding buffers assigned in proportion with risk scale of tasks
Lee, D.E. (2003)	S	Stochastic Modelling	Monte-Carlo Simulation	RanGen	General	Constrained Schedule	Computational effort reduced via reducing non-deterministic variables

Author (Year)	Type S,R,P	Model Scheme	Solving Plan	Dataset	Level	Layout	Comments
Umang, N., Erera, A.L. and Bierlaire, M. (2002)	S	Robust (Scenario Creation)	Local neighbourhood search	None	Operational	Single Machine Sched uling	Minimization of difference between optimal and robust solution, using CPLEX
Rodríguez, I.G., Puente, J., Varela, R. & Vela, C.R. (2008)	S	Fuzzy Modelling	Post-optimal analysis	Benchmark	Generalized	JobShop Sched uling	Hybrid approach with GA, compared with benchmark jobshop instances
Gomes, M.C., Póvoa, A.P.B. & Novais, A.Q. (2013)	P	Reactive	Modelling & heuristics	Case Study Mould making	Tactical (Order variation)	Make-to-order Type	LP model,proposed for predictive-reactive scheduling for fresh orders

Table 3 Literature analysis in regards with objective function

Author (Year)	Objective	Layout	Solving Scheme	Comments
Gerchak, Y. (2000)	Single, Minimum Penalty Cost	Not Defined	Stochastic/ Linear preserving transformation	Task duration proportional to Production cost, Limited application
Gutjahr, C. and Wegner, S.E. (2000)	Time/Cost trade off problem	None specified, suitable for single resource constrained scheduling problems for example flow lines	Stochastic Optimization, Heuristic Branch & Bound method	Comparison of various scenarios for cost efficient scheduling
Atli, O. and Kahraman, C. (2012)	Single, Makespan minimization	None Specified, RCPSP , suitable for construction projects	Fuzzy Activity Durations, Tabu search algorithm with priority heuristics	Knowledge based estimates of activity's durations
Chen, R.M., Wub, C.L., Wang, C.M. and Lo, S.T. (2010)	Minimal makespan	RCPSP	Particle Swarm Optimization	Deterministic Variables, Random selection of parameters for PSO is applied to escape local optima

Author (Year)	Objective	Layout	Solving Scheme	Comments
Afshar-Nadjafi, B., Karimi, H., Rahimi, A. and Khalili, S. (2013)	Single, Makespan Minimization	MSRCPSP, Process layout	Heuristics with differential evolution	Deterministic variables, Differential evolution based on stochastic optimization proves to provide comparative results for Patterson's test sets
Andreica, A. and Chira, C. (2014)	Single, Makespan minimization	MMRCPSP, Generalized	Genetic Algorithm	Two loop optimization for two decision variables i.e. mode selection & deterministic start time of tasks
Coelho, J. and Vanhoucke, M. (2011)	Single, Makespan minimization	MMRCPSP, Generalized	SAT (Boolean) Solver	Utilizes SAT solver for mode assignment problem which resembles branch and bound algorithm, deterministic, limited usage due to computational complexity by increased decision variables

5.2 Dataset Comparison

To test one's solution strategy, a few benchmark data sets have been proposed in literature. These datasets libraries are created through project generators having some fixed defined parameters. Most widely used library for benchmarking is PSPLib based on ProGen. However, there are certain limitations of network instances created via ProGen that limits its usage for practical applications. A new dataset library i.e. MMLib created by RanGen has recently become more popular as benchmarking. A detail comparison between these datasets can be studied in table 4. Renewable (R), Non-renewable (NR) and human (H) resources are categorized for input details of various datasets.

Each dataset has some parameters that make it suitable for particular applications. For example, it was realized that among all, only NSPLib provides the option of personal scheduling which makes it suitable for applications where managing human resources is of foremost priority. Moreover, every production layout has specific type of input data available. Hence, a choice has to be made in selection of a particular dataset for testing purposes. However, state-of-the-art literature provides no means of comparison among these various problem generators, which makes it difficult from users point of view to decide which particular dataset would be the most suitable in a particular layout with available data information.

For the problem of job shop scheduling or for a make-to-order type environment, some special instances have been proposed by researchers. The most commonly used are Fischer & Thompson instances. A detailed comparison of these instances particularly created for such environment can be found in (Behnke and Geiger, 2012). Following observations were made after comparing these various datasets:

- It can be perceived from gathered information that so far, there is a lack of project generators that combines personal scheduling required for special shift plans for resources and network scheduling.
- The area concerning multi-project environment requires more attention. The dataset libraries available use the concept of dummy activity for combining multiple projects that can only be applied when every project has the same start point.
- The concept of multiple modes is directed in two ways. One is multi-skilled, where an activity can be performed with different resources defined as mode options. However, datasets with alternative paths for activities (i.e. variable precedence constraints) has not been investigated so far.

Table 4 Comparison of Available Datasets

Dataset Library	PG	Creator	Availability PG	Res Typ	MMA	MMS	Tasks limit	MP	Comments
MMLIB, RG300	RanGen	Demeulemeester, E., Vanhoucke, M. & Herroelen, W. (2003)	Yes	R	No	Yes	150 (max)	No	Two different libraries available,single & multimode options
PSPLib	ProGen (PSPLib)	Kolisch, R. and Sprecher, A. (1996)	No	R, NR	No	Yes	120 (max)	No	Generator not available, available dataset library with benchmarks, most widely used
Multi-project Instances	Multi-Project Generator	Browning, T.R. & Yassine, A.A. (2010)	No	R	No	No	Not limited	Yes	To study the effect of individual projects in muti-project networks

Dataset Library	PG	Creator	Availability PG	ResTyp	MMA	MMS	Tasks limit	MP	Comments
Boctor's data set	RanGen	Boctor, F.F. (1993)	No	R	No	Yes	100 (max)	No	Resource strength is very low provided almost no resource limits
Patterson's test set	Customized	Patterson, J. (1984)	No	R	No	No	50 (max)	No	Multi-resource problems by Patterson for exact heuristics comparison
User Defined	P2 Engine	Demeulemeester, E. & Vanhoucke, M. (2012)	Yes, Limited	R, NR	No	No	Not limited	No	Several criteria available for defining network complexity

6. Conclusion & Future Recommendations

The current study indicates that as competitiveness at technological, qualitative and cost level acts as the main driving force, research in the area of operations management aims towards providing flexible solutions; insensitive to disruptions. The main disturbances considered in the state-of-the-art literature are activity durations and addition of tasks and are mostly dealt at operational level. The area of research, which considers the effect of possible external contributors to disturbances e.g. quality of supplies, environment and customer’s demands, seems void. Moreover, it was seen that literature on periodic task insertion uncertainties prefers the utilization of reactive techniques over proactive techniques. For examining the quality of solutions, various benchmarks based on different project generators are available. However, the link between theories and industrial practices was found to be missing. Benchmarks available suggest no measures on dealing with personal scheduling problem within the context of manufacturing environment. A separate dataset named as NSPLib, specifically deals with staff scheduling problem.

Future studies in the working group of facility planning under the chair of logistics engineering at Technical University of Dresden are to be extended in a direction that provides measures to model these solutions for industrial practices. Research is being conducted for agent based optimization and robust solutions. The facility planning team focuses on implementation of efficient scheduling schemes which involve inventory management, resource allocation and plant planning. This requires the extension of resource scheduling problem (typically personal scheduling) in parallel with production requirements. Additionally, proposal of techniques for quantitative measure of external disturbances would be beneficial in order to have better practical solutions.

References

Afshar-Nadjafi, B., Karimi, H., Rahimi, A. and Khalili, S., 2013. Project scheduling with limited resources using an efficient differential evolution algorithm. Journal of King Saud University - Engineering Sciences, 27(2), pp.176–184.

Alcaraz, J., Maroto, C. and Ruiz, R., 2003, Solving the multi-mode resource constrained project scheduling problem with genetic algorithms. Journal of Operational Research Society, 54(6), pp.614-626.

Andreica, A. and Chira, C., 2014. Best-Order Crossover in an Evolutionary Approach to Multi-Mode Resource-Constrained Project Scheduling. International Journal of Computer Information Systems and Industrial Management Applications, 6, pp.364-372.

Archer, S., Armacost, R.L. and Armacost, J.P., 2009. Implementing a Repair Heuristic for Unplanned Work in Resource Constrained Project Schedules Using Base SAS® and SAS® PROC CPM, University of Central Florida, Orlando, FL.

Atli, O. and Kahrahman, C., 2012. Fuzzy resource constrained project scheduling using Tabu-search. International Journal of Intelligent Systems, 27(10), pp.873-907.

Behnke, D. and Geiger, M.J., 2012. Test Instances for the Flexible Job Shop Scheduling Problem with Work Centers. Research Report, Logistics Management Department, Helmut-Schmidt-University, Hamburg.

Billauta, J.D. and Roubellat, F., 1996. Characterization of a set of schedules in a multiple resource context. Journal of Decision Systems, 5(1-2), pp.95-109.

Boctor, F.F., 1993. Heuristics for scheduling projects with resource restrictions and several resource-duration modes. International Journal of Production Research, 31(11), pp.2547-2558.

Browning, T.R. and Yassine, A.A., 2010. A random generator of resource constrained multi-project network problems. Journal of Scheduling, 13(2), pp.143-161.

Chen, R.M., Wub, C.L., Wang, C.M. and Lo, S.T., 2010. Using novel particle swarm optimization scheme to solve resource-constrained scheduling problem in PSPLIB. Expert Systems with Applications,37(3), pp.1899–1910.

Cheng. J., Fowler, J. and Kempf, K., 2012. Simulation based multi-mode resource constrained project scheduling for semiconductor equipment installation and qualification. In: Simulation Conference (WSC), Proceedings of the 2012 Winter, Berlin, Germany, 9-12 December 2012. IEEE.

Coelho, J. and Vanhoucke, M., 2011. Multi-mode resource-constrained project scheduling using RCPSP and SAT solvers. European Journal of Operational Research, 213(1),pp.73–82.

Davenport, A.J. and Beck, J.C., 2000. A survey of techniques for scheduling with uncertainty. [online] Available at: <http://www.eil.utoronto.ca/profiles/chris/gz/uncertainty-survey> [Accessed 20 May 2015].

Demeulemeester, E., Vanhoucke, M. and Herroelen, W., 2003. RanGen: A Random Network Generator for Activity-on-the-Node Networks. Journal of Scheduling, 6(1), pp.17-38.

Demeulemeester, E. and Vanhoucke, M., 2012. P2 Engine. [online] Available at: < http://www.p2engine.com/> [Accessed 20 June 2015].

Drummond, M., Bresina, J.L. and Swanson, K., 1994. Just in-case scheduling. In: AAAI (Association for the Advancement of Artificial Intellingence), Proceedings of the 12th National Conference on Artificial Intelligence, Seattle, Washington, July 31-August 4 1994, AAAI Press.

Fallah, M., Ashtiani, B. and Aryanezhad, M., 2010. Critical Chain Project Scheduling: Utilizing uncertainty for buffer sizing. International Journal of Research and Reviews in Applied Sciences, 3(3), pp.280-289.

Geary, S., Childerhouse, P. and Towill, D.R., 2002. Uncertainty and the seamless supplychain. Supplychain Management Review, 6(4), pp.52-60.

Gerchak, Y., 2000. On the allocation of uncertainty-reduction effort to minimize total variability. IIE Transactions, 32(5), pp.403-407.

Gomes, M.C., Póvoa, A.P.B. and Novais, A.Q., 2013. A discrete time reactive scheduling model for new order insertion in job shop, make-to-order industries. International Journal of Production Research, 48(24), pp.7395-7422.

Grey, J.R., 2007. Buffer techniques for stochastic resource constrained project scheduling with stochastic insertion problems. Ph. D. University of Central Florida.

Gutjahr, C. and Wegner, S.E., 2000. A stochastic branch and bound approach to activity crashing in project management. INFORMS Journal on Computing, 12(2), pp.125-135.

Helen, R. and Sumathi, R., 2014. Time-Cost Trade-Off Problem Using Type-2 Trapezoidal Fuzzy Numbers. International Journal of Mathematical Trends and Technology, 10, pp.51-59.

Herroelen, W. and Leus, R., 2004. Robust and reactive project scheduling: A review and classification of procedures. International Journal of Production Research, 42(8), pp.1599-1620.

Hong, T.P., Yu, K.M. and Huang, C.M., 1998. LPT Scheduling on Fuzzy tasks with triangular membership functions. In: Knowledge-Based Intelligent Electronic Systems, 1998. Proceedings KES '98. Second International Conference, 3, pp.109-115. Adelaide, South Africa, 21-23 April 1998, IEEE.

Hurley, S.F., 1996. Letter: OR- based scheduling information- an issue of quality in research. Production Planning & Control: The management of Operations, 7(3), p.339.

Kolisch, R. and Sprecher, A., 1996. PSPLIB - A project scheduling library. European Journal of Operational Research, 96, pp.205-216.

Kouvelis, P., Daniels R.L. and Vairaktarakis, G., 2000. Robust scheduling of a two-machine flow shop with uncertain processing times, IIE Transactions, 32(5), pp.421-432.

Lambrachts, O., Demeulemeester, E. and Herroelen. W., 2007. Proactive and reactive techniques for RCSP with uncertain resource availabilities. Department of Information Science & Decision Management, Katholieke Universiteit Leuven.

Landeghem, V.H. and Vanmaele, H., 2002. Robust planning: a new paradigm for demand chain planning, Journal of Operations Management, 20, pp.769-783.

Lee, D.E., 2003. Probability of project scheduling using stochastic project scheduling simulation, Ph. D. Illionis Intitute of Technology.

Nicholas G. H. and Posner, M.E., 2004. Sensitivity Analysis for Scheduling Problems. Journal of Scheduling, 7(1), pp.49-83.

Patterson, J., 1984. A comparison of exact procedures for solving the multiple constrained resource project scheduling problem. Management Science, 30, pp.854–867.

Pekny, J.F., 2005. A Brief Guide to Purchasing an Advanced Planning and Scheduling (APS) System. Advanced Process Combinatorics Inc, Kent, UK.

Perez, M. and Kuhl, M.E., 2014. Simulation based optimization approach for stochastic resource constrained project scheduling. In: Y. Guan and H. Liao, eds, Proceedings of the 2014 Industrial and Systems Engineering Research Conference, Montreal, Canada, May 31-June 3, 2014.

Petrovic, S., Fayad, C. and Petrovic, D., 2007. Sensitivity analysis of a fuzzy multi-objective scheduling problem. International Journal of Production Research, 46 (12), pp.3327-3344.

Pinedo, M.L., 2005, Scheduling: Theory, Algorithms, and Systems, NewYork: Springer.

Ramkumar, R., Tamilarasi, A. and Devi, T., 2011. Multiple criteria job shop schedule using fuzzy logic control for multiple machines multiple jobs. International Journal of Computer Theory and Engineering, 3(2), pp.282-286.

Rodríguez, I.G., Puente, J., Varela, R. and Vela, C.R., 2008. Lateness minimization with Tabu search for job shop scheduling problem with sequence dependent setup times. Journal of Intelligent Manufacturing, 24(4), pp.741-754.

Sireesha, V. and Ravishankar, N., 2010. A new approach to find project characteristics and multiple possible critical paths in a fuzzy project network, International Journal of Engineering Science & Technology, 2(4), pp.600-609.

Subrahmanyam, S., Pekny, J.F. and Reklaitis, G.V., 1994. Design of batch chemical plants under market uncertainty. Industrial and Engineering Chemistry Research, 33(11), pp.2688-2701.

Umang, N., Erera, A.L. and Bierlaire, M., 2002. The robust single machine scheduling problem with uncertain release and processing times. Journal of Combinatorial Optimization , 6(1), pp.17-33.

Van de Vonder, S., Ballestín, F., Demeulemeester, E. and Herroelen, W., 2007. Heuristic procedures for reactive project scheduling. Computers & Industrial Engineering, 52(1), pp.11-28.

Vanhoucke, M. and Maenhout, B., 2005. NSPLib – A nurse scheduling problem library: a tool to evaluate (meta-)heuristic procedures. In: Brailsford, S. and Harper, P., Operational Research for Health Policy: Making Better Decisions, Proceedings for the 31st Annual Meeting of the working group on Operations Research Applied to Health Services, pp.151-165.

Yadegari, J., 2013. Graphical decomposition approach for robust scheduling. Masters Dissertation,Technische Universität Dresden, Germany.

Yaghounzadeh H. and Roghanian. E., 2014. A quantitative model for measuring the project by fuzzy approach (Case study: Construction of water treatment plant). International Journal of Engineering Research, 3(1), pp.34-39.

Review of Comprehensive Approaches in Optimizing AGV Systems

Isidro Ramos Torres, Luis Felipe Romero Dessens, José Luis Martínez Flores and Elías Olivares Benítez

This paper shows how researchers have focused their optimization studies in AGVs design and control optimization. This article discusses comprehensive approaches identified in other research papers. The four features examined were: focus-problem, solution methodology, manufacturing environment, and metrics. The five different optimization environments recognized and used to explore the AGV's performance were: facilities design, production planning, scheduling of machines, manufacturing system and design-control. Based on statistical tools, trends are identified in integrated approaches and maps of the conditions of the approach and solution methodologies.

Keywords: Material Distribution, Comprehensive Approach, Operational Control, AGV System

1 Introduction

Material Handling (MH) is a set of activities that has important implications on the performance of a manufacturing plant, warehouse, distribution centres, and container terminals. MH is composed of activities of distribution, storage, packaging and Control of materials (ASME; IMMS, 1985).Tompkins, et al., (2003) highlight the importance of MH, which represents between 30% up to 75% of the cost of manufacturing a product, MH utilizes around 25% of the total staff, uses up to 55% of the total space and uses up to 87% of the time of all activities.

Materials distribution (MD) is considered a relevant source of opportunities that provides important challenges to industry (Anbuudayasankar, et al., 2014). The dynamic conditions of the technological environment and competitiveness in the industry have added new elements to the problems mainly derived from the application of new technologies such as: the electronic data exchange (EDI), Global Positioning System (GPS), Geographic Information System (GIS), Intelligent vehicles-Systems of roads (IVHS) (Psaraftis, 1995).

The technological innovation in AGVs (Automatic Guided Vehicles), AGCs (Automatic Guided Cars) and hybrids Fork Lift Truck systems has been growing since year 2005 (Vis, 2006). It has made available increasingly autonomous vehicles equipped with better communication, liaison and information processing systems. These increased capacities facilitate dynamic operation of problems of AGVs in MD (Psaraftis, 1995). The MD using AGVs has additional features to the classical problem of distribution VRP (Vehicle Routing Problem), mainly derived from a dimensional scale; among these features are included: the possibility of collisions of AGVs, the need for routes design, for determining the frequency of travels, and for design of load capacity, among others (Qiu, et al., 2002).

The ways to address MD problems also evolve given the greater demands of the competitive environment and the innovation in the aforementioned technologies. The evolution of research approaches in this field changed in several areas, in some with more advances than others. This research is limited to 49 articles published in the last ten years related to the optimization of AGVs systems in different manufacturing environments. Also, this paper characterises the used approaches in design and control AGVs systems in MD through the identification of 4 features: Approach, Solution Methodology, Manufacturing System and Metrics. The incidence of various comprehensive approaches and their relationship with the other attributes are explored as the main issue here.

This article is organized in sections as follows: Section 1 describes the model used for the literature characterisation, Section 2 shows the main approaches characteristics found in the literature, Section 3 contains a discussion of the statistic results and summary of single and comprehensive approaches and finally, Section 4 presents the study conclusions.

2 Characterisation Model

The Problems about optimizing design and control of AGVs systems are related with operational and tactical decisions (Vis, 2006). Often these decisions are taken to solve different problems and are treated jointly since they have an interactive relationship. Sequenced or simultaneous treatments with one or more matching objectives of tactical/operational problems are referred here as comprehensive approaches.

Each item of literature was characterized in a binary table of occurrences recorded in the form of the attributes: 1) Specific types of problems treated, 2) solution methods, 3) manufacturing environment and 4) metrics. The first attribute element contains the focus of each article, which is the element that identifies and groups the revised papers.

The occurrence proportions of each element's attributes were obtained, and Pareto charts were used to identify usage trends. Once grouped, proportions for each approach were calculated.

3 Identification of Simple and Comprehensive Approaches

Four types of problems associated to the Design and Control of AGVs systems were found in this review: designing AGVs systems, controlling AGVs systems, Scheduling of Machines, Production planning and Design of Facilities, all in a given manufacturing environment. The Comprehensive approaches are graphically represented by intersections as shown Figure 1.

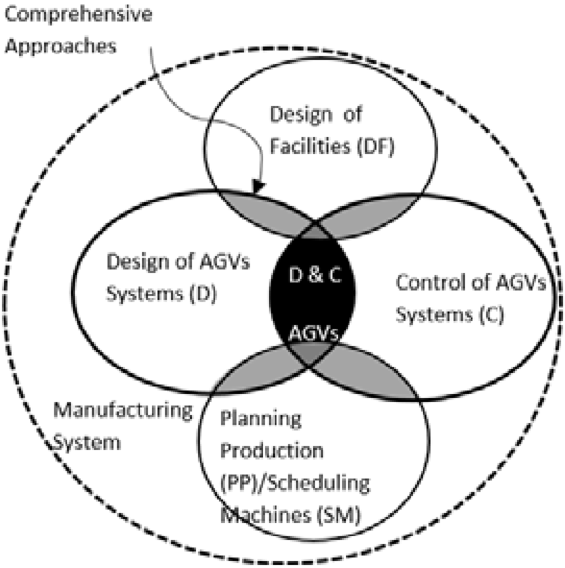


Figure 1 Associated problems to the Design and Control of AGVs systems (source: own contribution)

The literature characterization allowed the identification of comprehensive approaches as shown in Figure 1; the comprehensive approaches are:

C-D: Control and Design of AGVs systems,

C-DF: Control of AGVs systems and Facilities Design,

C-D-FD: Control and Design of AGVs systems and Design of facilities,

C-FD: Control of AGVs and Design of facilities,

C-PP: Control of AGVs systems and Production Planning,

C-MS: Control of AGVs systems and Scheduling of Machines, D-FD: Design of AGVs and Design of Facilities,

D-PP: Design of AGVs systems and Production Planning.

Figure 2 shows the comprehensive approaches that were found and their classification as tactical and/or operational problems in a cross table.

Operational problems	Tactical problems			
	AGVs Systems Design (**D**)	Facilities Design (**FD**)	Production Planning (**PP**)	
AGVs systems Control (**C**)	**C-D**	**C-FD**	**C-PP**	**C-MS**
Machines Scheduling (**MS**)	Not found	Out of interest range		
	D-FD			
	D-PP		**D-PP**	

Figure 2 Comprehensive approaches found (source: own contribution)

4 Essential Features of Approaches of Papers

This section describes the single and integrative approaches identified in the literature and their relationship with solution methodologies.

4.1 Single Approaches

4.1.1 AGVs Systems Control

The AGVs systems design includes problems of: routes design, traffic management, determination of Pick-up and Drop-off points (P/D), number and location of points, fleet size determination, idle points number and location, battery management and fault management. AGVs control issues can contain activities such as: dispatching of loads, route choice and AGVs scheduling (Vis, 2006).

4.1.2 AGVs Dispatching

Dispatching can be done in two ways: 1) Assign the AGV charge (WorkCentre-initiated) or 2) Assign an available AGV load (Vehicle-initiated) (Vis, 2006). The WorkCentre-initiated for the study of dispatching is used by Bin Md Fauadi, et al. (2013), in addition they investigate the effect of multi-loads using an integer programming model. Moreover Confessore et al. (2013), treat the dispatching strategy vehicle-initiated using a minimum cost flow network model and obtain solutions by linear programming and heuristics.

4.1.3 AGVs Scheduling and Routing

Lin, et al., (2006) analysed the Scheduling and routing of AGVs using an evolutionary algorithm called i-awGa. Aized, (2009) studies the impact of the route flexibility using Petri nets.

4.1.4 AGVs scheduling and routing dynamic features

Some researchers added elements of the AGVs dynamics such as traffic conflicts and route flexibility. Strategies to avoid these difficulties are different, some use mathematical models through heuristic and meta-heuristic algorithms and/or with exact solutions. Duinkerken, et al. (2006), studied the scheduling and free of conflicts short route allocation problem. Also, Strap, et al. (2007) solved this problem by mixed integer programming. Kesen & Baykoc (2007) dealt with the allocation problem under a Just in Time (JIT) philosophy where bi-directional route flow was allowed. Nishi, et al., (2009) raise the problem of routing using a timed Petri nets model whose solution is optimized by heuristics. Nishi & Tanaka, (2012) use a Petri net model combined with evasion of conflict rules.

Ghasemzadeh, et al. (2009) addresses the free bi-directional conflict in a network topology problem proposing a heuristic algorithm. Liu & Kulatunga (2007) studies the same case using a Simulated Annealing (SA) and an ant colony optimization (ACO) algorithm; Likewise Udhayakumar & Kumanan (2010) propose a GA and ACO algorithm to optimize workload balance, minimising transportation time and maximising the AGVs use. In order to avoid traffic conflicts, Chiew & Qin (2009) address the problem on a large scale by proposing a concurrent bi-tonic algorithm. Other research predicts possible collisions, such is the case of Nishi, et al. (2007), which added a sequence of re-routing and predicts the probability of collisions through Markov Chains. Fazlollahtabar & Mahdavi-Amiri, (2013) add the uncertainty of machines, operators and products in a genetic algorithm controlled by fuzzy logic.

Real-time data allows greater dynamism in the decisions under this environment. Nishi, et al., (2006) dealt with the problem of routing under an environment of real time requirements (dynamics). The developed algorithm is based on mathematical programming in a strategy of parallel computing.

4.2 Comprehensive Approaches of Papers

4.2.1 Design & Control of AGVs systems (D-C)

The design and control of AGVs systems have a mutual relationship due to the effect of the decisions of one over the other and their effect on the overall system performance (Vis, 2006). This interaction makes it necessary to use integrative approaches, not only between design and control problems but also with other collateral problems.

4.2.2 Scheduling and Routing

Xidias & Azariadis, (2011) studied the sequencing and routing of autonomous vehicles considering the restrictions of space available for movements, which suggests a bounded surface genetic algorithm.

4.2.3 Forming Tandems and Independent Zones

Tandem formation consists of partition in materials demand areas. This suggests the circuit formation with non-overlapping routes which allow material transfer points. Tandem formation is a form of establishing control through the design of circuits and P/D points and that the vehicles are commonly exclusive for each tandem.

In this review numerous approaches based on tandems and independent zones were found, such is the case of Shalaby, et al. (2006) who present a two-way route tandem formation approach in which a binary programming and a probabilistic model are combined to estimate the amount of empty travel. Ho & Liao (2009) propose the formation of zones of load sharing and dynamic control whose objective is to determine the amount and area size of each zone; it uses procedures of partition and Simulated Annealing algorithm (SA). ElMekkawy & Liu (2009) dealt with the same case by adding the problem of AGVs programming using two-way route tandems, used a mimetic algorithm Genetic Algorithm (GA) and local search. Rezapour, et al. (2011) designed Tandems and assign bi-directional paths to unique vehicles: the solution model proposed integrates (SA) and tabu search (TS).

Multiple load strategy is used by Kim & Chung (2007) in addition to the approach by Tandems and sequencing of AGVs using Traveling Sales Problem (TSP) and Markov chains.

Definition of independent zones differs slightly from the tandems, since a zone does not use material transfer points. This criterion is used by Namita, et al. (2011), who proposed the partition of exclusive areas of demand to avoid traffic conflicts. The proposal is based on heuristic rules that include a simulation model. Zheng, et al. (2013) proposed the formation of non-exclusive areas, which was conducted by simulation test bench.

In an effort to design a system of AGVs and evaluate control, Kahraman, et al. (2008) dealt with the problem viewing the load capacity of the AGVs.

The proposed model evaluates performance through Markov Chains to avoid the uncertainties of the AGVs operation.

4.2.4 Control of AGVs Systems & Scheduling Machines (C-MS)

Integration of programming AGVs and machines is a very common approach in AGVs system optimization. The synchronization of both activities has been found to allow the manufacturing system to work better.
In this review we found similar approaches with a diversity of solution proposals. The most common is the use of genetic algorithms, such is the case of Kumar, et al., (2011), which proposes a GA integrated into a computer system. Jerald, et al., (2006) propose an Adapted GA (AGA). Reddy & Rao, (2006) create a GA hybrid with ordering non-named (NSGA-II). In a multi-objective study, Chen, (2008) proposes a (MOGA) Mimetic algorithm that considers operation machining times, balancing workload of machining and ability of inheritance (MEFI) is used in a multi-agent approach. Erol, et al., (2012) used artificial intelligence to generate solutions in real-time.

4.2.5 Control AGVs & Production Planning (C-PP)

When manufacturing system elements operate asynchronously, to obtain an adequate operation is more complicated. The synchronization strategy is used for production planning, machine programming sequences and material handling activities. Fazlollahtabar et al., (2010) propose a mathematical programming model which considers demand fluctuations and restrictions of machines integrated to AGVs programming. Using mixed integer programming Khayat, et al., (2006) developed a production and dispatching model of AGVs programming. Nishi, et al. (2011) addressed the same problem adding free of conflict traffic and bi-directional ways routing using a mixed integer programming model.

Sequencing of AGVs and production scheduling is integrated by Udhayakumar & Kumanan, (2012), using a model based on ACO and PSO; their algorithm considers the number of AGVs empty returns. Tuma, et al., (2013) used Buffers flags and a genetic algorithm model (AGA + TS) for production and AGVs programming. They considered the demand variability as a stochastic element. The model is optimized using Response Surface Methodology (RSM).

4.2.6 Design AGVs Systems & Design of Facilities (D-FD)

The inside distribution formation and determination of each tandem is an issue addressed by Salehipour & Aloha, (2014) using an integer programming mixed model. Gamberi, et al. (2009) approached the buffers space required model (ILFA) and used the Hillier's rules based on a linear programming model. Ventura & Rieksts, (2007) focused in a dynamical approach to locate idle points in the P/D. A non-linear integer programming model was proposed to solve this approach.

4.2.7 Control of AGVs Systems & Facilities Design (C-FD)

Some elements of the facilities design were found in an integrated way, they are: the P/D point's location, idle/ dwell and supply sources as well as the inside tandems layout. The following subsections show the description of the integration of Facilities Design into AGVs control systems problems.

4.2.8 P/D (Pick-up and Drop-off Points)

Lee & Srisawat, (2006) investigated the effect of heuristic rules in the dispatching and P/D location points, under a strategy of multiple-load using simulation models. Also Asef-Vasiri, et al. (2007) integrated the determination of routes and P/D location points, on one-way circuits that uses heuristics and binary integer programming for neighbourhood search. The route planning is also treated by Nishi & Maeno, (2010) modeled by Petri nets decomposition with several independently created subnets to locate the delivery places for each subnet. The algorithm for the shortest path has a time penalty function.

4.2.9 Location of Idle/dwell (I/D) AGVs Points

Location of the (I/D) points is treated in Ventura & Rieksts (2009) by integrating the dynamic programming routing in a model restricted by AGVs time availability.

5 Statistical Results

To determine the approach trends and their relationship degree, the papers were examined to identify their manufacturing environment, solution methods and used metrics, using counting techniques, Pareto charts and proportion estimates $\hat{p}$.

5.1 Statistics of Single Approaches

Tables 1, 2 and 3 show the estimated incidence rate $\hat{p}$ of individual approaches, manufacturing systems, solution methods and metrics, respectively. Table 1 shows that studies dealing with AGVs Control issues (individual and integrated) have a use proportion of at least 80%. Also FMS environments are used in 85% of cases, as shown in table 2. Table 3 shows that solution methods have a more homogeneous proportion use. However, the most recurring methods are integer programming, heuristics, genetic algorithms (including evolutionary) and simulation.

Table 1 Incidence ratio for single approaches

Approach	Frequency	$\hat{\mathbf{p}}$	$\pm\mathbf{int}\ (\mathbf{95}\%)$
C	44	0.898	0.085
D	19	0.388	0.136
MS	9	0.184	0.108
FD	8	0.163	0.103
PP	6	0.122	0.092

* Frequencies are not mutually exclusive

**Sample size n=49

Table 2 Incidence ratio for manufacturing systems

Manufacturing system	Frequency	$\hat{\mathbf{p}}$	$\pm\mathbf{int}\ (\mathbf{95}\%)$
FMS	42	0.857	0.098
Job Shop	29	0.592	0.138
Flow Shop	23	0.469	0.140

* Frequencies are not mutually exclusive

**Sample size n=49

Table 3 Incidence ratio for Solution methods

Method	Frequency	$\hat{\mathbf{p}}$	$\pm\mathbf{int}(\mathbf{95}\%)$
Int. Programing	17	0.347	0.133
Heuristics	15	0.306	0.129
Genetic Algorithm	13	0.265	0.124
Simulation	13	0.265	0.124
Regression/Doe	6	0.122	0.092
Petri Nets	5	0.102	0.085
Tabu Search	5	0.102	0.085
Dyn. Programing	3	0.061	0.067
Flow nets	3	0.061	0.067
Annealing Simul.	3	0.061	0.067
Ant Colony (ACO)	3	0.061	0.067
Fuzzy logic	3	0.061	0.067
Markov Chains	2	0.041	0.056
Correlation	2	0.041	0.056
Particle (PSO)	1	0.02	0.039
Parallel Comp	1	0.02	0.039

* Frequencies are not mutually exclusive, **Sample size n=49

5.2 Trends of Single Approaches

Figure 3, shows that the most commonly integrative approaches used are: C, D-C, MS-C, and C-PP. This is not surprising since in terms of absolute frequencies, at least 80% of the articles address independent or combined control problems.

Flexible manufacturing systems (FMS) and Job Shop (JS) are a main trend. FMS is used almost twice as often as any other system approached (see Figure 4). The solution methods used are homogeneous, however; we can identify four methods: integer programming (Int-Pr), heuristics (HE), genetic algorithms (GA) and simulation (see Figure 5).

Figure 6 shows the proportion of use of the metrics, which shows a greater uniformity than the use of the solution methods, however we can identify metrics whose use frequencies can be twice as much as the rest of the metrics, and these are: time of computational processing, makespan and time/distance travelled.

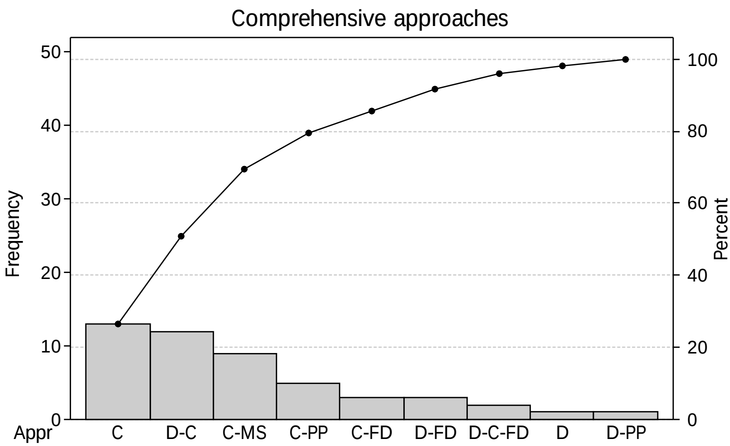


Figure 3 Pareto chart for comprehensive approaches (source: own contribution)

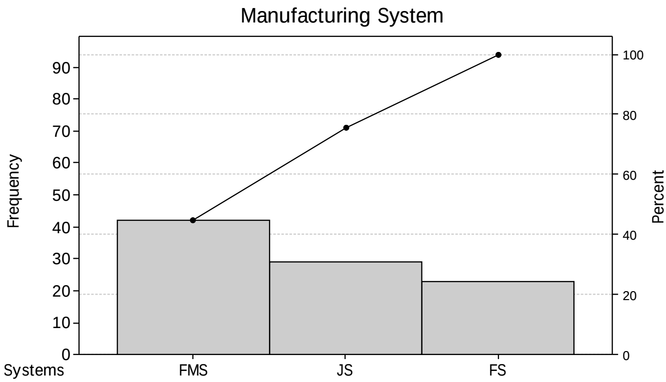


Figure 4 Pareto chart for Manufacturing systems (source: own contribution)

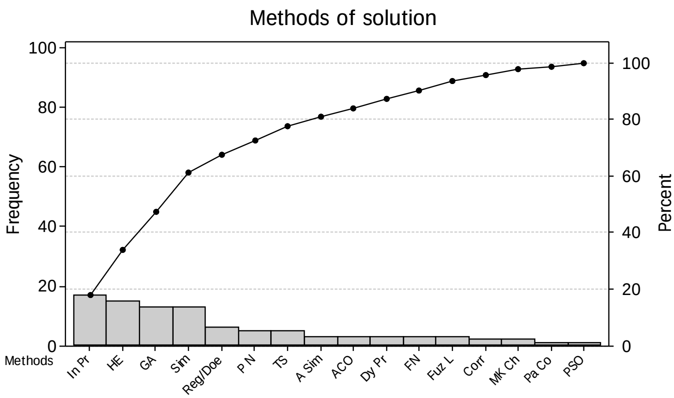


Figure 5 Pareto chart for Methods of solution (source: own contribution)

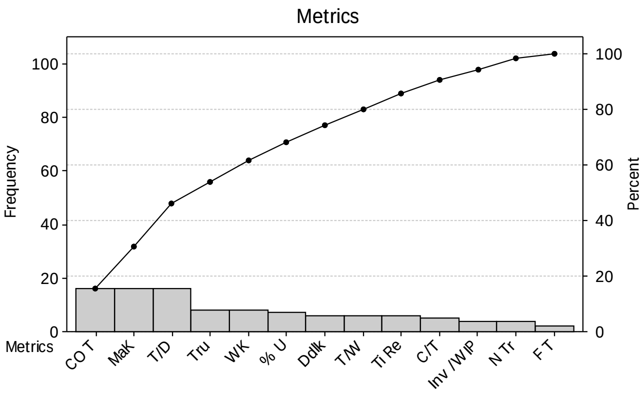


Figure 6 Pareto chart for Metrics (source: own contribution)

5.3 Trends of Comprehensive Approaches

As shown in table 5, FMS has the greatest relative occurrence in approaches that include control problems (C, C-FD, D-C-FD, C- MS, C-PP) except in D-FD and C-MS. The trend toward Job-Shop (JS) and Flow-Shop (FS) is higher in the D-FD approach.

Table 5 Relative ratios for manufacturing systems

Comprehensive Approach	FMS	JS	FS
C	0.8462	0.6154	0.4615
C-FD	1.0000	0.3333	0.0000
D	1.0000	1.0000	1.0000
D-FD	0.6667	1.0000	1.0000
D-C	0.9167	0.9167	0.8333
D-C-FD	1.0000	0.5000	0.5000
MS-C	0.7778	0.2222	0.1111
PP-C	0.8000	0.2000	0.0000
PP-D	1.0000	1.0000	1.0000

Approach	Solution Methods															
	Integer Programing	Dynamic Programing	Flow Nets	Petri Nets	Heuristics	Genetic Algorithm	Tabu Search	Simulation	Simulated Annealing	ACO*	PSO**	Parallel Computing	Markov Chains	Correlation	Regression/ Doe	Fuzzy Logic
C	0.23	0.00	0.08	0.31	0.38	0.15	0.00	0.31	0.08	0.15	0.00	0.00	0.08	0.00	0.23	0.00
C-FD	0.33	0.33	0.00	0.00	0.67	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
D-FD	1.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D-C	0.42	0.00	0.08	0.00	0.33	0.17	0.17	0.50	0.08	0.00	0.00	0.08	0.08	0.08	0.08	0.00
D-C-FD																
	0.50	0.00	0.00	0.00	0.50	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MS- C	0.11	0.11	0.11	0.00	0.22	0.89	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
PP C	0.60	0.20	0.00	0.20	0.00	0.20	0.20	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.20	0.00
PP D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00

*Ant Colony Optimization

**Particle Swarm Optimization

Table 7 Relative ratios for Metrics

Comp Approach	Metrics												
	MaKespan	% Utilization	Work balance	Time/Wait	Time Response	Time- distance travelled	No. Travels	Throughput rate	No. Deadlocks	Cost/Travel	Inventory -WIP	Flow Time	Computing Time
C	0.15	0.23	0.08	0.23	0.15	0.38	0.08	0.31	0.23	0.08	0.08	0.08	0.38
C-FD	0.00	0.00	0.33	0.00	0.33	0.33	0.00	0.33	0.00	0.00	0.33	0.33	0.67
D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00
D-FD	0.00	0.33	0.33	0.33	0.33	0.33	0.00	0.00	0.00	0.33	0.00	0.00	0.33
D-C	0.08	0.08	0.33	0.00	0.08	0.42	0.17	0.17	0.25	0.00	0.00	0.00	0.33
D-C-FD	0.00	0.50	0.00	0.00	0.50	0.50	0.50	0.00	0.00	0.50	0.00	0.00	1.00
C-SM	0.89	0.11	0.11	0.11	0.00	0.11	0.00	0.00	0.00	0.22	0.00	0.00	0.22
C-PP	1.00	0.00	0.00	0.20	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D-PP	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00

6 Conclusions

This paper was conducted to learn about the state of the art regarding the orientation of the approaches of researchers associated to operational control of AGVs in the last ten years. It is useful to know the integration degree of approaches and advances in the use of solution methods to visualize the different approaches to develop an improved method to solve a similar problem.

For the above, forty nine papers reviewed related to AGVs design and control systems were characterized by four factors: approach, manufacturing environments, solution methods, and metrics used as a performance evaluation for AGV proposed system models. Six comprehensive approaches were identified: 1) machine scheduling -control (C-MS), 2) production planning- AGVs design (D-PP), 3) production planning- AGVs control (C-PP), 4) AGVs design-facilities design (FD-D), 5) AGVs control-facilities design (C-FD), 6) AGVs design-AGVs control-facilities design (D-C-FD).

From general statistics:

— The most frequently four integrative approaches used were identified: C, D-C, C-SM and C-PP.
— At least 80% of the papers are related to control problems.
— The FMS and JS are above 70% of manufacturing environments focus.
— Solution methods that show increased frequency of use are: Integer programming, heuristics, genetic algorithms and simulation (in the range of 15% - 19% each one).

— The most commonly used metrics are: Computational processing time, makespan time/ travelled distance and whose frequencies of use very similar (around 18% each one).

From relative statistical information (inside comprehensive approaches):

— In C-MS approach, genetic algorithms are used as solution method in almost 9 of 10 cases.

— Approaches C-PP and C-MS tends to use makespan (100% and 89% respectively) as a performance metric.

It can be said that this indicates that researches are currently oriented towards issues of AGVs control systems and that classical methodologies such as (integer and dynamic programming, and flow networks), adaptable heuristic and meta-heuristics algorithms and simulation models prevail.

The computational processing time used for information and processing technologies, is still the most important performance variable. The proposed solution methods usually are compared against other models depending on performance variables, such as processing time of AGVs system and/or methodology performance.

Some trends of integrated approaches are very strong, as in the AGVs control and machines scheduling approach (C-MS), which are used at a high 89% rate of occurrence. Genetic algorithms and makespan are among the most mentioned. The makespan use is also very recurrent in the focus of AGVs control of and production planning (C-PP).

The dynamic elements found in the characterization of integrative approaches were not considered in the purpose of this paper. Nevertheless, studying this subject carefully to find out if there is any relationship between this dynamic elements and the attributes described in this work would be interesting.

References

Aized, T., 2009. Modelling and performance maximization of an integrated automated guided vehicle system using coloured Petri net and response surface methods. Computers & Industrial Engineering, Issue 57, pp. 822-831.

Anbuudayasankar, S. P., Ganesh, K. & Mohapatra, S., 2014. Models for practical Routing Problems in Logistics: design eand Practice. Switzerland: Springer.

Asef-Vasiri, A., Laporte, G. & Ortiz, R., 2007. Exact and Heuristic pprocedures for material handling circular flow design path. European Journal of Operational Research, Issue 176, pp. 707-726.

Asef-Vaziri, A. & Goetschalckx, M., 2008. Dual track and segmented single track bidirectional loop guidepath layout for AGV system. Europeran Journal of Operational Research, Issue 186, pp. 972-989.

ASME, (American Society of Mechanical Engineers); IMMS, (International Material Management Society);. (1985). Materials Handling Handbook (2da ed.). (R. A. Kulwiec, Ed.) Wiley.

Badakhshian, M., Sulaiman, S. B. & Ariffin, M. K. A., 2012. Performanceoptimization of simultaneous machine and automated guided vehicle sheduling using fuzzy logic controller based genetic algorithm. International Journal of Physical Sciences, 7(9), pp. 1461-1471.

Bin Md Fauadi, M. H. F., Yahaya, S. H. & Murata, T., 2013. Intelligent Combinatorial Auctions of Decentralized Task Assignment for AGV With Multiple Loading Capacity. IEEJ Transactions on electrical and electronic Engineering, Issue 8, pp. 371-379.

Chen. J.-H., 2008. Multi-objective Memetic Approach for Flexible Process Sequencing Problems. Atlanta,Georgia,USA., ACM, pp. 2123-2128.

Chiew, K. & Qin, S., 2009. Shedulling and Routing of AMOs in an Intelligent Transport System. IEEE Transactions on Intelligent Transportation Systems, 10(3), pp. 547-552.

Confessore, G., Fabiano. M. & Liota, G., 2013. A network flow based heuristic approach for optimizing AGV movements. Journal Intelligent Manufacturing, Issue 24, pp. 405-419.

Corréa, A. I., Lavengevin, A. & Rousseau, L.-m., 2007. Scheduling and routing of Automated guided vehicles: A hybrid approach. computers & Operations Reserach, Issue 34, pp. 1688-1707.

Duinkerken, M. B., Ottjes, J. A. & Lodewijjks, G., 2006. Comparison of Routing Strategies for AGV Systems using Simulation. Delf, The Netherlands, IEEE, pp. 1523-1530.

ElMekkawy, T. Y. & Liu, S., 2009. A new memetic algorithm for optimizing the partioning problem of tandem AGV systems. International Journal Production Economics, Issue 118, pp. 508-520.

Erol, R., Sahim, C., Baykasoglu, A. & Kaplanoglu, V., 2012. A multi-agent based approach to dynamic scheduling of machines and automated guided in manufacturing systems. Applioed Soft Computing, Issue 12, pp. 1720-1732.

Fazlollahtabar, H. & Mahdavi-Amiri, N., 2013. Producer´s behavior analisys in an uncertain bicriteria AGV-based flexible jobshop manifacturing systems with expert system. international Journal of manufacturing Technology, Issue 65, pp. 1605-1618.

Fazlollahtabar, H., Rezaie, B. & Kalantari, H., 2010. Matemátical programing approach to optimize material flow in an AGV-based flexible jobshop manufacturin system with performance analysis. Internationtal Journla of Advenaced manufacturing Technology, Issue 51, pp. 1149-1158.

Fazlollahtabar, H. & Saidi-Mehrabad, M., 2015. Methodologies to Optimize Automated Guided Vehicle Sheduling and Routing problems: A Review Study. Journal of Intelligent and Robotic Systems, Issue 77, pp. 525-545.

Gamberi, M., Manzini, R. & Regattieri, A., 2009. A new approach for the automatic analysis and control of material handling systems: integrated layout flow analysis (ILFA). Internationa Journal of manufacturing Technology, Issue 41, pp. 156-167.

Gebennini, E. et al., 2008. A simulation based approach for suporting automated guided vehicles AGVs systems design. Miami FL, IEEE, pp. 2156-2163.

Gen, M. & Lin, L., 2014. Multiobjetive evolutionary algorithms for manufacturing sheduling problems: state-of-the-art survey. Journal of Intelligent Manufacturing, Issue 25, pp. 849-866.

Ghasemzadeh, H., Behrangi, E. & Azgomi, M. A., 2009. Conflict-free schedilling and routing of aotomated guided vehicles in mesh topologies. Robotics and Autonomous System, Issue 57, pp. 738-748.

Guan, X. & Dai, X., 2009. Deadlock-free multi-atribute dispatching method for AGV systems. International Jorunal of Manufacturing technology, Issue 45, pp. 603-615.

Ho, Y.-C. & Liao, T.-W., 2009. Zone design and control for vehicle collision prevention and load balancing in a zone control AGV system. Computers & Industrial Engineering, Issue 56, pp. 417-432.

Jerald, J., Asokan, P. & Rani, A. D. C., 2006. Simultaneous scheduling of parts and automated guided vehicles in an FMS Enviroment using adaptative genetic algoritm. International Journal Advanced Manufacturing Technology, Issue 29, pp. 584-589.

Ji, M. & Xia, J., 2010. Analisys of vehicle requeriments in a general automated guided vehicle system based trasnportation system. Computers & industrial engineering, Issue 59, pp. 544-551.

Kahraman, A. F., Gosavi, A. & Oty, K. J., 2008. Stochastic Modeling of an Automated Guided Vehicle System With One Vehicle and a Close-Loop Path. IEE Transactions on Automation Science and Engineering. 5(3), pp. 504-518.

Kesen, S. E. & Baykoç, Ö. F., 2007. Simulation of automated guided vehicle (AGV) System based on Just-in-time (JIT) philosophy in a job-shop enviroment. Simulation Modeling Practice and Theory, Issue 15, pp. 272-284.

Khayat, G. E., Langevin, A. & Riopel, D., 2006. Integrated production and material handling scheduling using mathematical programing and constraint programing. European Journal of Operational Research, Issue 175, pp. 1818-1832.

Kim, K. S. & Chung, B. D., 2007. Design for a tandem AGV system with two-load AGVs. Computers & Indistrial Engineering, Volume 53, pp. 247-251.

Kumar, S. M., Janadhana, R. & Rao, C. P., 2011. Simultaneous scheduling of vehicles in an FMS enviroment with alternative routing. International Journal Advenced Manufacturing Tecnology, Issue 53, pp. 339-321.

Lacomme, P., Larabi, M. & Tchernev, N., 2013. Job-Shop based framework for simultaneous shceduling of machines and automated guided vehícles. International Journal Economics, Issue 143, pp. 24-34.

Lee, J. & Srisawat, T., 2006. Effec of manufacturing system constructs on pick-up and drop-off strategies of multiple-load AGVs. International Journal of Production Research, 15 February, 44(4), pp. 653-673.

Lin, L., Shinn, S. W., Gen, M. & Hwang, H., 2006. Network model and effective evolutionary approach for AGV dispatching in manufacturing system. Journal of Intelligent manufacturing, Issue 17, p.: 465–477.

Liu, D. K. & Kulatunga, A. K., 2007. Simultáneous Planning and Scheduling for Multi-Autonomous Vehicles. In: K. P. Dahal, K. C. Tan & P. I. Cowling, eds. Evolutionay Scheduling. Heidelberg: Springer-Verlag, pp. 437-464.

Meyers, F. E., 2010. Manufacturing Facilities Design and material Handling. New Jersey: Pearson.

Namita, S., Sarngadharan, P. V. & Prabir, K. P., 2011. AGV scheduling for automated material distribution: a case study. Journal of Intelligent Manufacturing, Volume 22, pp. 219-228.

Nishi, T. & Maeno, R., 2010. Petri Net Decomposition Approach to Optimization of Route planning problems for AGVs Systems. IEEE Transactions on Automation Science and Engineering, July, 7(3), pp. 523-537.

Nishi, T., Ando, M. & Konishi, M., 2006. Experimental Studies on a local resheduling procedurte for dynamic routing of autonomous decentrelized AGV systems. Robotics and Computer-Integrated manufacturing, Issue 22, pp. 154-165.

Nishi, T., Hiranaka, Y. & Grossmann, I. E., 2011. A bilevel descomposition algorithm for simultaneus production sheduling and conflict-free routing for automated guided vehicles. Computers & Operations Research, Volume 38, pp. 876-888.

Nishi, T., Morinaka, S. & Konishi, M., 2007. A distributed routing method for AGVs under motion delay disturbance. Robotics and Computer-Integrated Manufacturing, Volume 23, pp. 517-532.

Nishi, T., Shimatani, K. & Inuiguchi, M., 2009. Decomposition of Petri nets and Lagrangian relazation for solving routing problems for AGVs. International Journal of Production Research, 47(14), pp. 3957-3977.

Nishi, T. & Tanaka, Y., 2012. Petri Net Decomposition Approach for Dispatching and Conflict-Free routing of Bidirectional Automated Guided Vehicle Systems. IEEE Transactions on Systems, Man and Cybernetics- Part A: Systems and Humans, 42(5), pp. 1230-1243.

Qiu, L., Hsu, W.-J., Huang, S.-Y. & Wang, H., 2002. Scheduling and routing algorithms for AGVs: a survey. International Journal Production Research, 40(3), pp. 745-760.

Reddy, B. S. P. & Rao, C. S. P., 2006. A hobrid multi-objetive GA for simultaneous sheduling of machines and AGVs in FMS. International Journal Advanced Manufacturing Technology, Volume 31, pp. 602-613.

Rezapour, S., Zanjirani-Farahani, R. & Miandoabchi, E., 2011. A machine-to-loop assignment and layout design metodology for tandem AGV systems with single-load vehicles. International journal of Production Research, 49(12), pp. 3605-3633.

Rogers, L. K., 2011. Automatic Guided Vehicles. Mdern Materials handling, September.pp. 36-39.

Salehipour, A. & Sepehri, M. M., 2014. Optimal locations of workstations in tandem atomated-guided vehicle systems. International Journal of Advanced Manufacturing Technology, Issue 72, pp. 1429-1432.

Sedehi, S. M. & Farahani, Z. R., 2009. An integrated approach to determine the block layout, AGV flow path and the location of pick-up delivery points in single-loop system. International Journal of production Research, 47(11), pp. 30141-3061.

Shalaby, M. A., El Mekkawy, T. Y. & Fahmy, S. A., 2006. Zones formation algorithm in tandem AGV systems: a comparative study. International Journal of production Research, Frebruary, 44(3), pp. 505-521.

Tompkins, J. A. et al., 2003. Facilities Planning. New York: Willey.

Trebilcock, B., 2011. What is an AGV?. Modern Material Handling, Junio.pp. 22-28.

Tuma, C. C., Morandin, O. J. & Caridá, V. F., 2013. Minimizing the makespan for the problem of reactive production scheduling in a FMS with AGVs using a new structure of chromosome in a hybrid GA with TS. Cagliari, IEEE, pp. 1-6.

Udhayakumar, P. & Kumanan, S., 2010. Task Sheduling of in FMS Using Non-traditional Optimization Techniques. International Journal Simulation Model, pp. 28-39.

Udhayakumar, P. & Kumanan, S., 2012. Integrated scheduling of flexible manufacturing system using avolutiionary algorithms. International journal on manufacturing Technology, Issue 61, pp. 621-635.

Ventura, J. A. & Rieksts, B. Q., 2009. Optimal location of dewell points in a single loop AGV system with time restriction on vehicle availability. Production, Manufacturing and Losgistics, Issue 192, pp. 93-104.

Vis, I. F., 2006. Survey of research in the design and control aof automated guided vehicle systems. European Journal of Operational Research, Issue 170, pp. 677-709.

Xidias, E. K. & Azariadis, P. N., 2011. Mission design for a group of autonomous guided vehicles. Robotics and Autonomous Systems, Issue 59, pp. 34-43.

Zeng, C., Tang, J. & Yan, C., 2014. Sceduling of no buffer job shop with blocking constrains and automated guided vehicles. Applied Soft Computing, Issue 24, pp. 1033-1046.

Zheng, H., Tang, D., Gu, W. & Dai, M., 2013. Distributed control of multi-AGV system based on regional control model. Production Engineering Research and Development, Issue 7, pp. 433-441.

Freight Transport Modelling of Container Hinterland Supply Chains

Verena Flitsch and Katrin Brümmerstedt

Macroeconomic freight transport models serve as decision support for transport policy development. To evaluate infrastructure investments or policy measures these tools need to capture the underlying complexity of freight transport networks in a sufficient way. Recent developments in this field outline possibilities to combine aggregated and disaggregated approaches in freight transport modelling in order to integrate more realistic freight agent behaviour. In contrast to aggregated models, disaggregated approaches are able to simulate the decision behaviour on the micro-level of an individual decision maker.

In maritime container supply chains liner carriers or their brokers/agents and freight forwarders face a variety of interconnected logistical choices such as carrier, port, mode, route, shipment, or inventory choice. Modelling at least parts of these choices in disaggregated way could be of high value for adequate maritime hinterland policy development.

This paper provides both an overview of present freight transport models with and without a logistics step and applied methods to study maritime supply chain freight agents' behaviour. A summarizing framework for behavioural freight transport modelling in maritime container supply chains is introduced. Finally, the framework is applied to a container freight transport model under development.

Keywords: Freight Transport Modelling, Maritime Container Supply Chain, Choice Modelling

1 Introduction

Simulating present and forecasting future freight transport flows with macro-economic freight transport models serves as a strategic decision support for infrastructure investments or the evaluation of new policy measures. These models need to capture the underlying complexity of the examined freight transport networks at least in parts to present an accurate as-is situation. Recent developments outline possibilities to combine aggregated and disaggregated approaches in freight transport modelling. The objective is to obtain a more realistic representation of freight flows and underlying freight agent behaviour. In contrast to aggregated models, disaggregated approaches are able to simulate the decision behaviour on the micro-level of an individual decision maker (or rather firm level).

In maritime hinterland supply chains various decision makers interact (see figure 1). The market power has shifted from shippers being responsible for organising maritime and hinterland transport to liner carriers and freight forwarders. For instance, 60 percent of all liner carrier freight loaded or unloaded in German ports is controlled by sea freight forwarders (DSLV, 2015). Fransoo and Lee (2010) identify that in the Asia-Europe container trade even around 70% is contracted with carriers through freight forwarders. Notteboom (2008) agrees by asserting that on the European continent merchant haulage has the higher market share with approximately 70-90% of landside sea container transports. Thus, it can be assumed that 30-40 percent of German container hinterland transport is controlled by liner carriers/their agents and shippers with own transport departments, and 60-70 percent of German container hinterland transport is controlled by sea freight forwarders.

Economic choice situations in this environment are multifaceted and vary in terms of dependency, or frequency. Typical choices involve carrier and port choice but also mode and route choice. Decisions also vary in regard to one-time strategic or repetitive operational perspectives. In order to analyse these decisions different modelling and analysing methods are available. It can be argued that choices are too much simplified in order to apply rational method. The decision problem is not structured in a process-oriented way and connected situations are limited to a single decision. Considering this, one might also criticize that research stops prior to transferring new insights from the micro-level to macro-economic decision support tools.

This paper provides both an overview of present freight transport models with and without a logistics step and applied methods to study maritime supply chain freight agents' behaviour. Aim is to introduce a summarizing framework for behavioural freight transport modelling in maritime container supply chains. Finally, the concept is applied to a container hinterland transport model under development.

The paper is organised as follows. First, a literature review of present macro-economic freight transport models is performed. This is followed by a critical review of choice research in maritime supply chains. Second, a framework for container hinterland freight transport modelling is derived. Third, the framework is conceptually applied to a container freight transport model under development. Finally, the paper concludes with a discussion section.

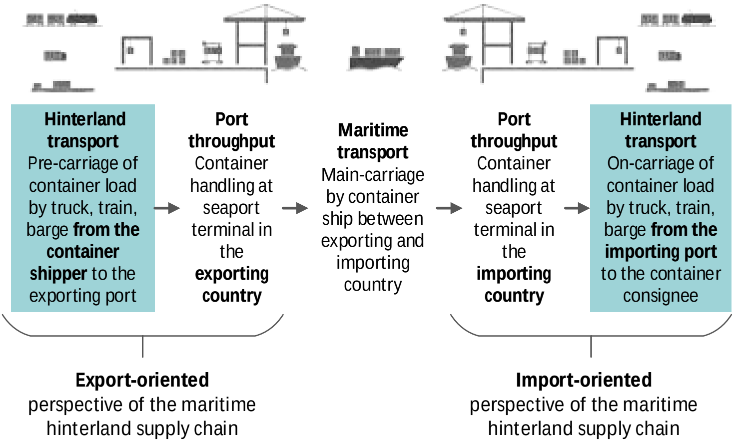


Figure 1 Maritime container supply chain

2 Literature Review

The literature review is twofold. Initially, it draws the attention to selection and classification of macro-economic freight transport models. Then, choices in maritime container supply chain research are reviewed.

2.1 Selection of Macro-Economic Freight Transport Models

Previous reviews on macro-economic freight transport models by de Jong et al. (2013), Tavasszy et al. (2012), Chow et al. (2010), Abdelwahab (1998), and on urban and metropolitan freight transportation by Taniguchi et al. (2014), Zhou and Dai (2012) guide the selection of models and classification criteria. Besides, the authors performed a review of scientific articles on freight transport models and identified 111 articles published from 1970 to February 2015. These articles were scanned concerning new model developments.

Worldwide there are various transport models or separate (sub-) modules in operation. Developers are either academics and/or work for public organisations or private industries. As a result, model details can be confidential and are not published rigorously. Thus, selecting established and recent regional and national macro-economic freight transport models for this review requires some limitations:

— Sub-modules are not extra highlighted, e.g. models on mode and shipment choice.
— Only models developed between 2005 and 2015 or earlier models which are named in previous reviews are chosen.
— Freight transport models listed in past reviews and journal articles are only selected if information on classification criteria is regarded to be sufficient.

Finally, 14 macro-economic freight transport models are selected for review.

2.2 Classification of Macro-Economic Freight Transport Models

Figure 2 summarizes the 14 different macro-economic freight transport models according to the following classification criteria: client, geographical study area, years of development, modes, number of zones, number of commodities, modelling steps (generation G, distribution D, modal split M, logistics L, assignment A), perspective (aggregated A, disaggregated D), and software.

Clients of the macro-economic freight model developers are national transport authorities or the European Commission. The study area mainly corresponds to the authority's' geographical area of responsibility or interest.

The basic model takes at least one to two years to develop but this period may be extended to up to five years depending on the model's features. All 14 models consider the modes road and rail, nine models add inland waterway, and seven models integrate sea, compared to six models including air. SCENES and SMILE+ contain all available transport modes including pipeline.

The number of geographical zones varies from 69 in BASGOED to 3101 in the NGVM. The average number of zones is about 650. The number of commodities ranges from five to 542 with 10 as the most frequent.

The modelling steps differ but except WFTM all follow in essence the classical 4-step approach which was originally developed for passenger transport. Building on this, several models replace the modal split step with a logistics step or add an additional logistics step between modal split and assignment.

Logistical choices diverge and may comprise shipment size choice, port choice, distribution centre choice, mode choice, vehicle type choice, or inventory choice. De Jong and Ben-Akiva (2007) refer to the number of legs in the transport chain, the use of terminals, and the mode used for each leg (including choice of vehicle/vessel type and loading unit) as 'transport chain choice'.

	1 ADA model for Flanders	2 BASGOED	3 German MFTM	4 GORM	5 SISD	6 NEMO	7 NGVM
Client	Flemish Ministry	Dutch Ministry	Basic funding of DLR	Swedish Admin.	Italian Ministry	Norwegian authorities	Swiss authorities
Study area	Flanders, Brussels, Belgium	The Netherlands	Germany	Denmark, Sweden	Italy	Norway	Switzerland
Years	2009-2010	2010-2011	Unclear	2008	2004	2004-2009	2009-2011
Modes	Road, rail, inland waterway, sea, air	Road, rail, inland waterway	Road, rail, inland waterway	Road, rail	Road, rail	Road, rail, sea, air	Road, rail
Zones	332	69	Unclear	296+	267	536	3101
Commodities	9	10	20	Unclear	5	32	118
Steps	G, D, L, A	G, D, M, A	G, D, M, A	Unclear	G, D, M, A	G, D, L, A	G, D, L, A
Perspective	ADA	A	AD	ADA	Unclear	ADA	ADA
Software	Own programm	Own programm	Visum	Unclear	Unclear	Own programm	Excel, Muuli, Visum

	8 SAMGODS	9 SCENES	10 SMILE+	11 TRANS-TOOLS	12 TREMOVE	13 UK Trans-Pennine	14 WFTM
Client	National authority	European Commission	Dutch Ministry	European Commission	European Commission	EU, UK department	Walloon region
Study area	Sweden	Europe	The Netherlands	Europe	EU + 8	UK	Belgium, Europe
Years	2004-2009	Unclear	1998-2005	2005-2009	1997-1998; 2002-2004	Prior to 2001	2006
Modes	Road, rail, sea, air	Road, rail, inland waterway, sea, pipeline	Road, rail, inland waterway, sea, pipeline	Road, rail, inland waterway, sea	Road, rail, inland waterway, air	Road, rail, inland waterway, sea, air	Road, rail, inland waterway
Zones	464	261+	117	1737	265	152	850+
Commodities	35	Unclear	542	10	Unclear	9	10
Steps	G, D, L, A	G, D, M, A	G, D, M, L, A	G, D, M, L, A	G, D, M, A	G, D, M, A	M, A
Perspective	ADA	AD	Unclear	AD	AD	ADA	Unclear
Software	Own programm	Unclear	Own programm	Various	Gams	Unclear	Nodus

Figure 2 Overview of macro-economic freight transport models

The majority of models show a disaggregated perspective. Especially, ADA models are established. In principal, aggregation refers to zone-to-zone flows and disaggregation to firm-to-firm flows. But the term disaggregation also relates to the conversion of shipment flows into vehicle flows, or the split of commodity groups into single commodities. ADA is applied by the ADA model for Flanders, SAMGODS, the NGVM and others.

Modelling steps and perspective are the logic behind the freight transport flow simulation. To integrate modelling steps and logic into geographical simulation different software tools are in available. Own programs are used frequently but also commercial freight transport modelling software like Visum and Nodus are deployed. Besides, commercial transport modelling software may be extended by own programs in external environments.

2.3 Choices in Maritime Container Supply Chain Research

Economics is about the choices individuals make, and micro-economics is the branch of economics that studies choice making (Krugman and Wells, 2013). Mathematical models as simplified representations of reality support this social research field heavily.

The root of choice modelling and analysis lies in two different decision theories. Descriptive decision theory concentrates on the psychology of individuals. It is also named empirical or behavioural decision theory and answers questions related to ‘what people do’. It is concerned with people's beliefs and preferences as they are, not as they should be (Kahneman and Tversky, 1984). Central research themes concentrate on how human choices derivate from rules of rationality. In contrast, normative or rational decision theory focusses on minimizing costs and maximizing benefits. It is concerned with the nature of rationality and the logic of decision making (Kahneman and Tversky, 1984). Rational decision theory answers questions related to 'what people should do'. Especially after the findings of Kahneman and Tversky (1979) a rethinking of normative models of rational choice for analysing decision making under risk took place.

Today, rational choice models may be adapted to capture differences in decision weights and preferences of decision makers. Durbach and Stewart (2012) distinguish between analyses based on: probabilities, decision weights, explicit risk attributes, fuzzy numbers, and scenarios. To bridge the gap between micro-economic research and model application in the maritime transport business, the following questions guide the upcoming literature review:

— What is the decision problem?
— Who is the decision maker?
— Which main method is used for data collection?
— Which main method is used for decision modelling and data analysis?

95 journal articles published between 1973 and 2014 are identified.

2.3.1 Decision problem

Dominant decision problem in maritime supply chain research is port choice (55 publications), followed by liner carrier choice (18 publications) and mode choice (six publications). Table 1 gives an overview of all articles and the decision problems. Starting point in theory is a well-structured decision problem.

Table 1 Overview of decision problems in maritime supply chain research

Decision problem	References
Port choice (55)	Anderson et al., 2009; Bird and Bland, 1988; Bird, 1988; Brooks and Schellinck, 2013; Chang et al., 2008; Chou, 2007, 2009; Chou et al., 2010; Chou, 2010; de Langen, 2007; Ffrench, 1979; Fleming and Hayuth, 1994; Foster, 1978; Garcia-Alonso and Sanchez-Soriano, 2009; Guy and Urli, 2006; Ha, 2003; Itoh et al., 2002; Kim, 2013; Lam and Dai, 2012; Lee et al., 2010; Lirn et al., 2003; Lirn et al., 2004; Loon Ching Tang et al., 2011; Magala and Sammons, 2008; Malchow and Kanafani, 2001; Malchow and Kanafani, 2004; Mangan et al., 2002; McCalla, 1994; Murphy et al., 1992; Murphy and Daley, 1994; Ng, 2006; Nir et al., 2003; Notteboom, 2011; Saeed, 2009; Sanchez et al., 2011; Seo and Ha, 2010; Song, 2004; Starr, 1994; Steven and Corsi, 2012; Tavasszy et al., 2011; Tongzon and Heng, 2005; Tongzon and Sawant, 2007; Tongzon, 2009; Tran, 2011; Ugboma et al., 2004; Ugboma et al., 2007; Ugboma et al., 2006; van Asperen and Dekker, 2013; Veldman et al., 2011; Veldman and Bückmann, 2003; Wiegmans et al., 2008; Willingale, 1981; Yeo et al., 2014; Yeo et al., 2011; Yuen et al., 2012
Carrier choice (liner, 18)	Brooks, 1984; Brooks, 1985; Brooks, 1990, 1995; Chen et al., 2010; Chou and Liang, 2001; Collision, 1984; D'Este, 1992; Gibson et al., 1993; Kannan, 2010; Kannan et al., 2011; Kent et al., 1999; Lobo, 2010; Lu, 2003b; Nind et al., 2007; Pedersen and Gray, 1998; Saldanha et al., 2009; Wen and Huang, 2007

Decision problem	References
Mode choice (6)	Brooks et al., 2012; Feo et al., 2011; Feo-Valero et al., 2011; Reis, 2014; Winston, 1981; Wong et al., 2008
Other (16)	Carrier choice (liner), port choice: D'Este and Meyrick, 1992; Murphy et al., 1991; Slack, 1985; Tiwari et al., 2003; Freight transportation choice (land): Mangan et al., 2001; McGinnis, 1979; Wang et al., 2014; Freight transportation choice (maritime): Talley and Ng, 2013; Talley, 2014; Thai, 2008; Carrier choice (land): Bardi, 1973; Murphy et al., 1997; Carrier choice (liner, air): Matear and Gray, 1993; Carrier choice (liner, land), mode choice: Meixell and Norbis, 2008; Logistics service choice: Lu, 2000; Maritime firm choice: Lu, 2003a

In practice, port and/or carrier choice problems are difficult to construct in a chronological and independent way due to, e.g. longer-term agreements, preferences of shippers, or different product life cycle stages (Flitsch and Jahn, 2014). Only three sources start their analysis by visually structuring the decision problem first. Mangan et al. (2002) highlight port choice as decision making 'process model'. Brooks (1990) introduce a 'decision flow diagram' named as ocean carrier selection model, and Brooks (1984) display the decision process in liner carrier choice as ‘decision tree’.

2.3.2 Decision Maker

Historically, the shipper was the main decision maker in maritime supply chains. With 17 publications it is still a highly researched area starting with

Bardi (1973) up to van Asperen and Dekker (2013). In addition, the shipper's agents carriers with 16 publications (Yeo et al., 2014; Willingale, 1981), carriers and freight forwarders with 14 publications (Chen et al., 2010; Brooks, 1984), and freight forwarders with 9 publications (Reis, 2014; Bird and Bland, 1988) are important research objects.

In 11 articles also shipments serve as a proxy for the group of all decision makers (Steven and Corsi, 2012; Winston, 1981). This refers to a revealed preference context where analysis of past choice and historical data takes place.

Other decision makers are named as carrier-shipper (Lobo, 2010), carrier-freight forwarder-shipper (Brooks and Schellinck, 2013), carrier-shipper-port (Talley, 2014), or as other actors and combinations (Sanchez et al., 2011).

2.3.3 Data Collection

Either no empirical data is collected or a questionnaire survey is conducted. Gathering statements of decision makers with (semi-) structured questionnaires is by far the most widespread main empirical data collection method with 37 papers, for instance see Brooks and Schellinck (2013) or Foster (1978).

15 articles concentrate on interviews for getting data (Yuen et al., 2012; Willingale, 1981), five current publications use discrete choice experiments (Brooks et al., 2012; Feo et al., 2011; Feo-Valero et al., 2011; Nind et al., 2007; Wen and Huang, 2007).

Kannan et al. (2011) and Kannan (2010) organize focus groups. No empirical data collection takes place in 36 papers (see Reis, 2014; Ffrench, 1979).

2.3.4 Decision Modelling and Data Analysis

Table 2 lists the main methods for decision modelling and data analysis applied in maritime supply chain research. Statistical analysis (descriptive, inferential) directed towards the identification of main decision attributes is applied in 37 publications. Theoretical contributions are made in 18 papers. Discrete choice models are of relevance in 16 articles. Additionally, the Analytical hierarchy process (AHP) is a popular analysis method applied in 8 publications.

Prior to 2003 research concentrated mainly on decision attribute identification and weighting with descriptive statistical analysis methods. Since 2003 further application of identified decision criteria and preference weights takes place, e.g. to estimate market share changes of carriers (Wen and Huang, 2007; Tiwari et al., 2003), to derive a demand function for traffic forecasting (Veldman and Bückmann, 2003), to formulate a optimization programming model for the port choice of shippers (Chou, 2009), or a combined fuzzy MCDA / optimization programming model (Chou et al., 2010), and to propose a web-based decision support system for port selection (Lam and Dai, 2012).

Table 2 Overview of main method for data analysis in maritime supply chain research

Decision problem	References
Statistical analysis (descriptive, inferential)	Bardi, 1973; Brooks, 1984; Brooks, 1985; Brooks, 1990, 1995; Brooks and Schellinck, 2013; Chang et al., 2008; Chen et al., 2010; de Langen, 2007; D'Este and Meyrick, 1992; Foster, 1978; Gibson et al., 1993; Ha, 2003; Kent et al., 1999; Kim, 2013; Lee et al., 2010; Lobo, 2010; Lu, 2000, 2003a, 2003b; Mangan et al., 2002; Matear and Gray, 1993; McGinnis, 1979; Murphy et al., 1991; Murphy et al., 1992; Murphy and Daley, 1994; Murphy et al., 1997; Ng, 2006; Pedersen and Gray, 1998; Saeed, 2009; Sanchez et al., 2011; Slack, 1985; Thai, 2008; Tongzon, 2009; Ugboma et al., 2004; Ugboma et al., 2007; Yeo et al., 2011
Theoretical	Chou, 2007, 2009; Chou et al., 2010; Chou, 2010; Chou and Liang, 2001; Ffrench, 1979; Loon Ching Tang et al., 2011; Magala and Sammons, 2008; Notteboom, 2011; Seo and Ha, 2010; Talley and Ng, 2013; Talley, 2014; Tavasszy et al., 2011; Tongzon and Heng, 2005; Tongzon and Sawant, 2007; Tran, 2011; Wang et al., 2014; Yeo et al., 2014
Discrete choice	Anderson et al., 2009; Brooks et al., 2012; Feo et al., 2011; Feo-Valero et al., 2011; Garcia-Alonso and Sanchez-Soriano, 2009; Itoh et al., 2002; Malchow and Kanafani, 2001; Malchow and Kanafani, 2004; Nind et al., 2007; Nir et al., 2003; Steven and Corsi, 2012; Tiwari et al., 2003; Veldman et al., 2011; Veldman and Bückmann, 2003; Wen and Huang, 2007; Winston, 1981

Decision problem	References
Analytical hierarchy process	Kannan, 2010; Kannan et al., 2011; Lirn et al., 2003; Lirn et al., 2004; Song, 2004; Ugboma et al., 2006; Wong et al., 2008; Yuen et al., 2012
Other	Descriptive analysis: Bird, 1988; D'Este, 1992; Wiegmans et al., 2008; Willingale, 1981; Simulation: Guy and Urli, 2006; Reis, 2014; Saldanha et al., 2009; van Asperen and Dekker, 2013; Literature review: Mangan et al., 2001; Meixell and Norbis, 2008; Market analysis: McCalla, 1994; Starr, 1994; Case study analysis: Collision, 1984; Conceputal analysis: Lam and Dai, 2012; Content analysis: Bird and Bland, 1988; Spatial analysis: Fleming and Hayuth, 1994

3 Framework for container hinterland freight transport modelling

It can be stressed that a long experience in passenger transport modelling in academia is a good starting point for modelling freight transport flows. Modelling practices are transferred. However, freight transport is far more complex than passenger transport. Decision makers and their power to act vary due to contractual and non-contractual relationships, e.g. freight forwarders may chose a port corresponding to a shipper's preference or because they have long-term volume agreements with liner carriers departing from that port. Transported goods differ in volume, urgency, or value. Empty loading units and vehicles require capacity, too. Further, container hinterland transport and mainland transport face different risks; say ship delays are not in the forwarders sphere of influence. In summary, it is possible to transfer passenger modelling practices to container hinterland supply chains. But realistic models of the as-is situation need to be capable to consider at least parts of the system's complexity.

The main research objective is to determine (1) how decision problems in container hinterland supply chains can be structured according to decision maker and freight category, (2) how identified decision problems may be modelled and analysed, (3) how to apply the results in a freight transport model under development and, (4) how the final freight transport model output may be validated.

By taking the literature review of both macro-economic freight transport models and choices in maritime container supply chain research into account, a simple framework for container hinterland freight transport modelling is proposed (see figure 3).

	STRUCTURE	**MODEL & ANALYSE**	**APPLY**	**VALIDATE**
Methods	Business process modelling	Discrete choice	Value functions	Sensitivity analysis
	Soft system methodology	Analytical hierarchy process	Preference weights	Case study
	System dynamics ...	...	...	...

Figure 3 Framework for container hinterland freight transport modelling

3.1 Structure

Graphical representation of decision situations is an accepted method for problem structuring and segmentation of decision makers.
As highlighted previously, three publications in supply chain choice research start their analysis by visually structuring the decision problem first. Mangan et al. (2002) depict a process model, Brooks (1990) introduces a decision flow diagram, and Brooks (1984) applies a decision tree.
Apart from this, the business process modelling method is selected in several PhD dissertations in maritime logistics research. Advantage is that not only choice dependencies but also decision makers can be visualised. Wolff (2014) models different business processes in empty container logistics. Will (2011) concentrates on RFID implementation to maritime container logistics and transshipment process optimisation. Zuesongdham (2010) models a reference process for project and heavy-lift cargo. Schwarz (2006) simplifies process models in tri-modal hinterland transport chains.
Other advanced problem structuring methods have been developed pragmatically and are own research fields in operations research (Mingers and Rosenhead 2004). Potential drawback is that in contrast to business process modelling decision makers in maritime supply chains are usually not acquainted to methods like soft system methodology, or system dynamics. This could hinder empirical data collection.

3.2 Model & Analyse

After reviewing the literature on methods to model and analyse choices in maritime container supply chain research, the acceptance of discrete choice models and the AHP in empirical research became apparent. Especially, after 2003 research moved further than identifying significant decision attributes to calculating preference weightings of rational decision makers.

The AHP is rooted in multi criteria decision analysis (MCDA) which is a subdiscipline of OR. Main idea is to aid subjective decision making by integrating objective measurement with value judgement (Belton and Stewart, 2002). The AHP is a structured MCDM technique for organizing and analysing complex decisions quantitatively based on qualitative human judgment (pairwise comparison of choice attributes). It supports the identification of the relative value of a previously identified choice attribute set in hierarchical order to reach a final decision.

By contrast, discrete choice models calculate choice probabilities derived from utility maximizing behaviour of the decision maker. Different models (e.g. the most popular multinomial logit MNL) start their analysis with an underlying rational decision process displayed in a functional form - the utility function consisting of a value function and an error term. Key thoughts are that the decision maker tries to maximize the individual value function, makes trade-offs between attributes and that an error term captures all other influences.

3.3 Apply

Results of the AHP are absolute values of preference weights for single decision attributes which can be ranked accordingly. Previously AHP helped to explore the relative importance of factors that determine container port competitiveness and to rank them (Yuen et al., 2012), to examine predominant factors for port choice (Ugboma et al., 2006), or to assist ocean container carriers in benchmarking their service quality (Kannan, 2010).

The outcomes of discrete choice analysis are preference estimates of the choice attributes and corresponding probability weights of two or more choice alternatives. Both help to predict future choice behaviour. Ben-Akiva and Lerman (1985) introduced the method to travel demand analysis. Today, discrete choice analysis assists to model the modal choice between door-to-door road transport and short sea shipping (Feo et al., 2011), to establish a demand function for container port services (Veldman et al., 2011), or to estimate market shares of freight agents (Wen and Huang, 2007; Tiwari et al., 2003). Additionally, discrete choice analysis may result in dedicated cost functions for transport flows which also include a quantification of qualitative choice criteria (see most comprehensive values of time and values of reliability for shippers and freight forwarders determined by de Jong et al. in 2014).

3.4 Validate

Sensitivity analysis and case studies supported by historical data analysis are possible methods to validate container hinterland freight transport model outputs. Changes in variable levels on output impact may be examined to adjust the model design in an iterative way. A prevailing risk is that data to validate the model cannot be or has not been collected by the researcher/others or that access to historical data is denied (confident, or no interest to share).

4 Application of the Framework to a Container Freight Transport Model

Client of the macro-economic container freight transport model under development is the Ministry of Science and Research of the City of Hamburg. Study area is the regional, national and international hinterland area of the Port of Hamburg. For the base model a two year development period with start in 2014 is anticipated. All modes of relevance for container hinterland transport are considered, thus, road, rail and inland waterway. The classical 4-stage model of transport modelling (generation, distribution, modal split, assignment) is enlarged by transferring the modal split choice into a combination of supply chain choices under the umbrella term 'logistics choice'. The previously proposed framework for behavioural freight transport modelling sets in here. Figure 4 displays the methods which are considered for application based on the previous framework.

Main parts of the model's logic are supported by the software environment Visum but the disaggregation logic of the followed ADA perspective is programmed externally. These external calculations are passed back to Visum for final simulation of freight transport flows onto the geographical road, rail and inland waterway network.

Input data consisting of structural data, transport networks, and production/distribution/consumption figures is enlarged by the generated decision process models of the maritime hinterland supply chain. The process models are essential for modelling and analysing freight agents' preferences in different maritime hinterland supply chains with discrete choice models. Altogether, the steps 'structure' and 'model & analyse' are key for

integrating behavioural differences of freight agents container hinterland transport flows.
The model's output comprises transport matrices and network loads. In order to validate the quality case studies with freight agents enable the researcher to compare results with historical data.
On the one hand, further research relates to base model extension. On the other hand, model application stimulates further research, exemplary, in the domain of transport forecasts and scenario analysis, location and potential analysis, environment and safety analysis as well as infrastructure and policy measure planning.

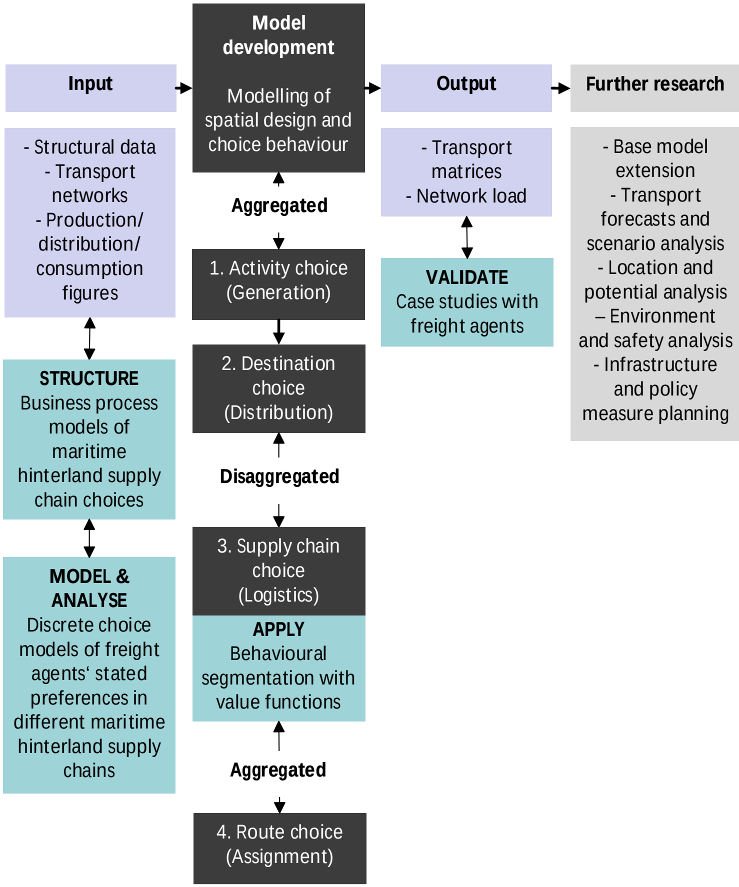


Figure 4 Conceptual representation of the container freight transport model

5 Discussion and Conclusion

Compared to the sophistication of passenger transport models, their underlying decision logic and supporting practices, freight transport models lag behind. This paper does not strive for radical innovations but for stressing the importance to combine established methods in a structured way. Apart from high demands on mathematical choice models to consider uncertainty, risk and decision power other issues complicate research progress. Getting data access is one major hindrance in the logistics environment and collecting the data can be costly. If decision makers do not understand why or how to supply their input for freight transport modelling projects the validity of realistic transport flows is likely to be low.

To conclude, this paper provides an overview of both recent freight transport models, and on accepted methods for choice analysis in maritime supply chain research. As a next step the researchers have the opportunity to use and evaluate the framework while working on the container transport freight model under development. By this, research would not stop prior to transferring new insights from the micro-level to macro-economic decision support tools.

References

Abdelwahab, W.M., 1998. Elasticities of mode choice probabilities and market elasticities of demand. Transportation Research Part E: Logistics and Transportation Review 34 (4), 257–266.

Anderson, C.M., Opaluch, J.J., Grigalunas, T.A., 2009. The Demand for Import Services at US Container Ports. Maritime Economics & Logistics 11 (2), 156–185.

Bardi, E.J., 1973. Carrier Selection From One Mode. Transportation Journal 13 (1), 23–29.

Belton, V., Stewart, T.J., 2002. Multiple criteria decision analysis: An integrated approach. Kluwer Academic Publishers, Boston.

Ben-Akiva, M.E., Lerman, S.R., 1985. Discrete choice analysis: Theory and application to travel demand. MIT Press, Cambridge, Mass.

Bird, J., Bland, G., 1988. Freight forwarders speak: the Perception of Route Competition via Seaports in the European Communities Research Project.Part 1. Maritime Policy & Management 15 (1), 35–55. 10.1080/03088838800000042.

Bird, J., 1988. Freight forwarders speak: the Perception of Route Competition via Seaports in the European Communities Research Project.Part 2. Maritime Policy & Management 15 (2), 107–125.

Brooks, M.R., 1984. An alternative theoretical approach to the evaluation of liner shipping. Part 1: Situational factors. Maritime policy and management 11 (1), 35–43.

Brooks, M.R., 1985. An alternative theoretical approach to the evaluation of liner shipping Part II. Choice criteria. Maritime Policy & Management 12 (2), 145–155.

Brooks, M.R., 1990. Ocean carrier selection criteria in a new environment. The logistics and transportation review 26 (4), 339–355.

Brooks, M.R., 1995. Understanding the ocean container market - A seven country study. Maritime policy and management 22 (1), 39–50.

Brooks, M.R., Puckett, S.M., Hensher, D.A., Sammons, A., 2012. Understanding mode choice decisions: A study of Australian freight shippers. Maritime Economics & Logistics 14 (3), 274–299.

Brooks, M.R., Schellinck, T., 2013. Measuring port effectiveness in user service delivery: What really determines users' evaluations of port service delivery? Research in Transportation Business & Management 8, 87–96.

Chang, Y.-T., Lee, S.-Y., Tongzon, J.L., 2008. Port selection factors by shipping lines: Different perspectives between trunk liners and feeder service providers. Marine policy 32 (6), 877–886.

Chen, K.-K., Wang, J.-S., Chu, C.-W., Chiu, Rong-Her, 2010. Improving service performance for an international container shipping company using index approach: A method and applications. Journal of Marine Science and Technology 18 (5), 759–770.

Chou, C.-C., 2007. A fuzzy MCDM method for solving marine transshipment container port selection problems. Applied Mathematics and Computation 186 (1), 435–444.

Chou, C.-C., 2009. An Empirical Study on Port Choice Behaviors of Shippers in a Multiple-Port Region. Marine Technology Society journal 43 (3), 71–77.

Chou, C.-C., Kuo, F.-T., Gou, R.-H., Tsai, C.-L., Wong, C.-P., Tsou, M.-C., 2010. Application of a combined fuzzy multiple criteria decision making and optimization programming model to the container transportation demand split. Optimisation Methods & Applications in Decision-Making Processes 10 (4), 1080–1086.

Chou, C.-C., 2010. Application of FMCDM model to selecting the hub location in the marine transportation: A case study in southeastern Asia. Mathematical and Computer Modelling 51 (5), 791–802.

Chou, T.-Y., Liang, G.-S., 2001. Application of a fuzzy multi-criteria decision-making model for shipping company performance evaluation. Maritime Policy & Management 28 (4), 375–392.

Chow, J.J., Yang, C., Regan, A., 2010. State-of-the art of freight forecast modeling: lessons learned and the road ahead. Transportation 37 (6), 1011-1030.

Collision, F.M., 1984. North to Alaska: Marketing in the Pacific Northwest-Central Alaska liner trade. Maritime policy and management 11 (2), 99–112.

de Jong, G., Ben-Akiva, M., 2007. A micro-simulation model of shipment size and transport chain choice. Transportation Research Part B 41 (9), 950–965. 10.1016/j.trb.2007.05.002.

de Jong, G., Kouwenhoven, M., Bates, J., Koster, P., Verhoef, E., Tavasszy, L., Warffemius, P., 2014. New SP-values of time and reliability for freight transport in the Netherlands. Transportation Research Part E: Logistics and Transportation Review 64 (0), 71–87. 10.1016/j.tre.2014.01.008.

de Jong, G., Vierth, I., Tavasszy, L., Ben-Akiva, M., 2013. Recent developments in national and international freight transport models within Europe. Transportation 40 (2), 347–371. 10.1007/s11116-012-9422-9.

de Langen, P., 2007. Port competition and selection in contestable hinterlands; the case of Austria. European Journal of Transport and Infrastructure Research 7 (1), 1–14.

D'Este, G.M., Meyrick, S., 1992. Carrier selection in a RO/RO ferry trade Part 1. Decision factors and attitudes. Maritime Policy & Management 19 (2), 115–126.

D'Este, G.M., 1992. Carrier selection in a RO/RO ferry trade Part 2. Conceptual framework for the decision process. Maritime Policy & Management 19 (2), 127–138.

DSLV, 2015. Zahlen, Daten, Fakten aus Spedition und Logistik.

Durbach, I.N., Stewart, T.J., 2012. Modeling uncertainty in multi-criteria decision analysis. European journal of operational research 223 (1), 1–14.

Feo, M., Espino, R., García, L., 2011. An stated preference analysis of Spanish freight forwarders modal choice on the south-west Europe Motorway of the Sea. Urban transport initiatives 18 (1), 60–67.

Feo-Valero, M., García-Menéndez, L., Sáez-Carramolino, L., Furió-Pruñonosa, S., 2011. The importance of the inland leg of containerised maritime shipments: An analysis of modal choice determinants in Spain. Transportation Research Part E: Logistics and Transportation Review 47 (4), 446–460.

Ffrench, R.A., 1979. Competition among selected eastern Canadian ports for foreign cargoes. Maritime Policy & Management 6 (1), 5–13.

Fleming, D.K., Hayuth, Y., 1994. Spatial characteristics of transportation hubs: centrality and intermediacy. Journal of Transport Geography 2 (1), 3–18.

Flitsch, V., Jahn, C., 2014. Maritime supply chain choices by freight forwarders in container shipping, in: IAME Conference 2014. IAME Conference 2014, Norfolk, USA. July 15-17, pp. 1–24.

Foster, T., 1978. Ports: What shippers should look for. Distribution Worldwide 77 (1), 40–48.

Fransoo, J.C., Lee, C.-Y., 2010. Ocean Container Transport: An Underestimated and Critical Link in Global Supply Chain Performance. Unknown.

Garcia-Alonso, L., Sanchez-Soriano, J., 2009. Port selection from a hinterland perspective. Maritime Economics & Logistics 11 (3), 260–269.

Gibson, B.J., Sink, H.L., Mundy, R.A., 1993. Shipper-Carrier Relationships and Carrier Selection Criteria. The logistics and transportation review 29 (4), 371–382.

Guy, E., Urli, B., 2006. Port selection and multicriteria analysis: An application to the Montreal-New York alternative. Maritime Economics & Logistics 8 (2), 169–186.

Ha, M.-S., 2003. A comparison of service quality at major container ports: implications for Korean ports. Journal of Transport Geography 11 (2), 131–137.

Itoh, H., Tiwari, P., Doi, M., 2002. An analysis of cargo transportation behaviour in Kita Kanto (Japan). International journal of transport economics 29 (3), 319–336.

Jahn, C., Flitsch, V., 2012. Improving truck arrival information at North Range container terminals, in: Pioneering Supply Chain Design - A Comprehensive Insight into Emerging Trends, Technologies and Applications. Eul Verlag, Lohmar, pp. 115–130.

Kahneman, D., Tversky, A., 1979. Prospect theory: An analysis of decision under risk. Econometrica 47 (2), 263–291.

Kahneman, D., Tversky, A., 1984. Choices, values, and frames. American Psychologist 39 (4), 341–350. 10.1037/0003-066X.39.4.341.

Kannan, V., 2010. Benchmarking the service quality of ocean container carriers using AHP. Benchmarking 17 (5), 637–656.

Kannan, V., Bose, S.K., Kannan, N.G., 2011. An evaluation of ocean container carrier selection criteria: an Indian shipper's perspective. Management research review 34 (7), 754–773.

Kent, J.L., Parker, R.S., Parker, R., 1999. International containership carrier selection criteria: Shippers-carriers differences. International Journal of Physical Distribution & Logistics Management 29 (5-6), 398–408.

Kim, J.-Y., 2013. Port user typology and representations of port choice behavior: A Q-methodological study. Maritime Economics & Logistics 16 (2), 165–187.

Krugman, P.R., Wells, R., 2013. Economics, 3rd ed. Worth Publishers, New York, NY.

Lam, J.S.L., Dai, J., 2012. A decision support system for port selection. Transportation Planning and Technology 35 (4), 509–524.

Lee, S.-Y., Chang, Y.-T., Lee, P.T.-W., 2010. Container Port Selection Factors: Heterogeneity Among Major Market Players., 8(2), 73–90. Journal of International Logistics and Trade 8 (2), 73–90.

Lirn, T.-c., Thanopoulou, H.A., Beresford, A.K.C., 2003. Transhipment Port Selection and Decision-making Behaviour: Analysing the Taiwanese Case. International Journal of Logistics Research and Applications 6 (4), 229–244.

Lirn, T.C., Thanopoulou, H.A., Beynon, M.J., Beresford, A.K.C., 2004. An Application of AHP on Transhipment Port Selection: A Global Perspective. Marit Econ Logist 6 (1), 70–91.

Lobo, A., 2010. Assessing the service quality of container shipping lines in the international supply chain network - shippers' perspective. International journal of value chain management 4 (3), 256–267.

Loon Ching Tang, Low, J.M.W., Shao Wei Lam, 2011. Understanding port choice behavior: A network perspective. Networks and spatial economics 11 (1), 65–82.

Lu, C.-s., 2000. Logistics services in Taiwanese maritime firms. Transportation Research Part E: Logistics and Transportation Review 36 (2), 79–96.

Lu, C.-s., 2003a. An Evaluation of Service Attributes in a Partnering Relationship between Maritime Firms and Shippers in Taiwan. Transportation journal 42 (5), 5–16.

Lu, C.-s., 2003b. The impact of carrier service attributes on shipper-carrier partnering relationships: a shipper's perspective. Transportation research / E 39 (5), 399.

Magala, M., Sammons, A., 2008. A New Approach to Port Choice Modelling. Maritime Economics & Logistics 10 (1), 9–34.

Malchow, M., Kanafani, A., 2001. A disaggregate analysis of factors influencing port selection. Maritime policy and management 28 (3), 265–278.

Malchow, M.B., Kanafani, A., 2004. A disaggregate analysis of port selection. Transportation research 40 (4), 317–338.

Mangan, J., Lalwani, C., Gardner, B., 2001. Identifying Relevant Variables and Modelling the Choice Process in Freight Transportation. Maritime Economics & Logistics (3), 278–297.

Mangan, J., Lalwani, C., Gardner, B., 2002. Modelling port/ferry choice in RoRo freight transportation. International Journal of Transport Management 1 (1), 15–28.

Matear, S., Gray, R., 1993. Factors Influencing Freight Service Choice for Shippers and Freight Suppliers. International Journal of Physical Distribution & Logistics Management 23 (2), 25–35.

McCalla, R.J., 1994. Canadian container ports: how have they fared? How will they do? Maritime Policy & Management 21 (3), 207–217.

McGinnis, M.A., 1979. Shipper Attitudes Toward Freight Transportation Choice: A Factor Analytic Study. International Journal of Physical Distribution & Logistics Management 10 (1), 25–34.

Meixell, M.J., Norbis, M., 2008. A review of the transportation mode choice and carrier selection literature. The international journal of logistics management 19 (2), 183–211.

Murphy, P.R., Daley, J.M., Dalenberg, D.R., 1991. Selecting Links and Nodes in International Transportation: An Intermediary's Perspective. Transportation Journal (American Society of Transportation & Logistics Inc) 31 (2), 33–40.

Murphy, P.R., Daley, J.M., Dalenberg, D.R., 1992. Port selection criteria: An application of a transportation research framework. The logistics and transportation review 28 (3), 237–255.

Murphy, P.R., Daley, J.M., 1994. A comparative analysis of port selection factors. Transportation journal 34 (1), 15–21.

Murphy, P.R., Daley, J.M., Hall, P.K., 1997. Carrier selection: Do shippers and carriers agree, or not? Transportation Research Part E: Logistics and Transportation Review 33 (1), 67–72.

Ng, K.Y., 2006. Assessing the Attractiveness of Ports in the North European Container Transhipment Market: An Agenda for Future Research in Port Competition. Maritime Economics & Logistics 8 (3), 234–250.

Nind, D., McAtamney, M., Matear, S., 2007. Industrial service design in the Asia-Pacific shipping industry: A strategic paradox? International journal of logistics systems and management 3 (4), 419–428.

Nir, A.-S., Lin, K., Liang, G.-S., 2003. Port choice behaviour-from the perspective of the shipper. Maritime policy and management 30 (2), 165–174.

Notteboom, T., 2011. An application of multi-criteria analysis to the location of a container hub port in South Africa. Maritime policy and management 38 (1), 51–80.

Notteboom, T.E., 2008. Bundling of Freight Flows and Hinterland Network Development, in: Priemus, H., Konings, J.W., Nijkamp, P. (Eds.), The future of intermodal freight transport: operations, design and policy. Edward Elgar, Cheltenham, pp. 66–88.

Pedersen, E.L., Gray, R., 1998. The transport selection criteria of Norwegian exporters. International Journal of Physical Distribution & Logistics Management 28 (2-3), 108–120.

Reis, V., 2014. Analysis of mode choice variables in short-distance intermodal freight transport using an agent-based model. Transportation Research Part A: Policy and Practice 61, 100–120.

Saeed, N., 2009. An analysis of carriers' selection criteria when choosing container terminals in Pakistan. Maritime Economics & Logistics 11 (3), 270–288.

Saldanha, J.P., Tyworth, J.E., Swan, P.F., Russell, D.M., 2009. Cutting logistics costs with ocean carrier selection. Journal of business logistics 30 (2), 175–195.

Sanchez, R.J., Ng, Adolf K Y, Garcia-Alonso, L., 2011. Port Selection Factors and Attractiveness: The Service Providers' Perspective. Transportation journal 50 (2), 141–162.

Schwarz, F., 2006. Modellierung und Analyse trimodaler Transportketten für Seehafenhinterlandverkehre. Univ., Diss.--Dortmund, 2006. Verl. Praxiswissen, Dortmund.

Seo, J.-S., Ha, Y.-S., 2010. The Role of Port Size and Incentives in the Choice of Location by Port Users: A Game-Theoretic Approach. The Asian Journal of Shipping and Logistics 26 (1), 49–65.

Slack, B., 1985. Containerization, inter-port competition, and port selection. Maritime policy and management 12 (4), 293–303.

Song, D.-W., 2004. A competitive analysis of Chinese container ports using the analytic hierarchy process. Maritime Economics & Logistics 6 (1), 34–52.

Starr, J.T., 1994. The mid-Atlantic load centre: Baltimore or Hampton Roads? Maritime Policy & Management 21 (3), 219–227.

Steven, A.B., Corsi, T.M., 2012. Choosing a port: An analysis of containerized imports into the US. Transportation Research Part E: Logistics and Transportation Review 48 (4), 881–895.

Talley, W.K., Ng, M., 2013. Maritime transport chain choice by carriers, ports and shippers. International journal of production economics 142 (2), 311–316.

Talley, W.K., 2014. Maritime transport chains: carrier, port and shipper choice effects. Sixteenth internationalworkingseminaronproductioneconomics, Innsbruck, 2010 151 (0), 174–179.

Taniguchi, E., Thompson, R.G., Yamada, T., 2014. Recent Trends and Innovations in Modelling City Logistics. Transportation: Can we do more with less resources? – 16th Meeting of the Euro Working Group on Transportation – Porto 2013 125 (0), 4–14.

Tavasszy, L., Minderhoud, M., Perrin, J.-F., Notteboom, T., 2011. A strategic network choice model for global container flows: specification, estimation and application. Journal of Transport Geography 19 (6), 1163–1172.

Tavasszy, L.A., Ruijgrok, K., Davydenko, I., 2012. Incorporating Logistics in Freight Transport Demand Models: State-of-the-Art and Research Opportunities. Transport reviews 32 (2), 203–219.

Thai, V.V., 2008. Service quality in maritime transport: Conceptual model and empirical evidence. Asia Pacific journal of marketing and logistics 20 (4), 493–518.

Tiwari, P., Itoh, H., Doi, M., 2003. Shippers' port and carrier selection behaviour in China: A discrete choice analysis. Maritime Economics & Logistics 5 (1), 23–39.

Tongzon, J., Heng, W., 2005. Port privatization, efficiency and competitiveness: Some empirical evidence from container ports (terminals). Transportation research. Part B: methodological 39 (5), 405–424.

Tongzon, J.L., Sawant, L., 2007. Port choice in a competitive environment: From the shipping lines' perspective. Applied economics 39 (4/6), 477–492.

Tongzon, J.L., 2009. Port choice and freight forwarders. Transportation research / E 45 (1), 186–195.

Tran, N.K., 2011. Studying port selection on liner routes: An approach from logistics perspective. Container Transport Operations 32 (1), 39–53.

Ugboma, C., Ibe, C., Ogwude, I.C., 2004. Service quality measurements in ports of a developing economy: Nigerian ports survey. Managing service quality 14 (6), 487–495.

Ugboma, C., Ogwude, I.C., Ugboma, O., Nnadi, K., 2007. Service quality and satisfaction measurements in Nigerian ports: an exploration. Maritime Policy & Management 34 (4), 331–346.

Ugboma, C., Ugboma, O., Ogwude, I.C., 2006. An Analytic Hierarchy Process (AHP) Approach to Port Selection Decisions – Empirical Evidence from Nigerian Ports. Marit Econ Logist 8 (3), 251–266.

van Asperen, E., Dekker, R., 2013. Centrality, flexibility and floating stocks: A quantitative evaluation of port-of-entry choices. Maritime Economics & Logistics 15 (1), 72–100.

Veldman, S., Garcia-Alonso, L., Vallejo-Pinto, J.Á., 2011. Determinants of container port choice in Spain. Maritime policy and management 38 (5), 509–522.

Veldman, S.J., Bückmann, E.H., 2003. A Model on Container Port Competition: An Application for the West European Container Hub-Ports. Marit Econ Logist 5 (1), 3–22.

Wang, X., Kopfer, H., Gendreau, M., 2014. Operational transportation planning of freight forwarding companies in horizontal coalitions. European journal of operational research 237 (3), 1133–1141.

Wen, C., Huang, J., 2007. A discrete choice model of ocean carrier choice. Journal of the Eastern Asia Society for Transportation Studies 7, 795–807.

Wiegmans, B., van der Hoest, A., Notteboom, T., 2008. Port and terminal selection by deep-sea container operators. Maritime policy and management 35 (6), 517–534.

Will, T., 2011. RFID in maritime container logistics: Participant-specific benefits and process optimization. Josef Eul Verlag, Lohmar, Köln.

Willingale, M.C., 1981. The port-routeing behaviour of short-sea ship operators; theory and practice. Maritime Policy & Management 8 (2), 109–120.

Winston, C., 1981. A multi-nomial probit prediction of the demand for domestic ocean container service. Journal of transport economics and policy 15 (3), 243–252.

Wolff, J., 2014. Stakeholder management along maritime container transport chains: Development of a framework and exemplified application in empty container logistics, in: Flämig, H., Gertz, C. (Eds.), Schriftenreihe des Instituts für Verkehrsplanung und Logistik. Harburger Berichte zur Verkehrsplanung und Logistik, vol. 11.

Wong, P.C., Yan, H., Bamford, C., 2008. Evaluation of factors for carrier selection in the China Pearl River delta. Maritime Policy & Management 35 (1), 27–52.

Yeo, G.-t., Ng, A.K., Lee, P.T.-W., Yang, Z., 2014. Modelling port choice in an uncertain environment. Maritime Policy & Management 41 (3), 251–267.

Yeo, G.-t., Roe, M., Dinwoodie, J., 2011. Measuring the competitiveness of container ports: Logisticians' perspectives. European journal of marketing 45 (3), 455–470.

Yuen, C.-l.A., Zhang, A., Cheung, W., 2012. Port competitiveness from the users' perspective: An analysis of major container ports in China and its neighboring countries. Research in Transportation Economics 35 (1), 34–40.

Zhou, J., Dai, S., 2012. Urban and Metropolitan Freight Transportation: A Quick Review of Existing Models. Journal of Transportation Systems Engineering and Information Technology 12 (4), 106–114.

Zuesongdham, P., 2010. Process modeling in project and heavy-lift cargo., Dr. Kovac, Hamburg.

Cost Functions in Freight Transport Models

Katrin Brümmerstedt, Verena Flitsch and Carlos Jahn

Freight transport models are used to estimate the expected impact of policy measures and are a necessary input for the justification of infrastructure investments. Seaport hinterland models can be used to forecast future hinterland traffic and modal split development. For the impact assessment, most freight transport models use a generalized cost approach for the purchasers' costs which amount the operators' costs passed on to the users of transport services and the actual users' costs (e.g. time costs). At present, no comprehensive model exists for the Port of Hamburg. Consequently, it is difficult to estimate the expected impacts of infrastructure measures for the Port of Hamburg's hinterland accessibility. The aim of this paper is to give an overview over the research field of freight transport modelling and to develop an approach for comparing the Port of Hamburg's hinterland connections taking into consideration different types of costs. Finally, the cost functions are applied to the use case "Port of Hamburg" on a macroscopic level.

Keywords: Freight Transport Modelling, Port of Hamburg, Hinterland Traffic, Container

1 Introduction

The international freight transport market grew almost steadily in the last decades, with a sharp decrease during the global financial crisis and stagnation at below crisis levels since then (OECD 2014). Nevertheless, different studies promise a positive outlook for future freight transport development. The current German sea traffic forecast forecasts an overall increase of volumes handled in the German seaports of 63 percent between 2010 and 2030 (MWP et al. 2014). Container handling volumes are expected to increase steeper in German seaports than conventional cargo volumes (MWP et al. 2014).

For foreign trade-oriented countries like Germany an internationally competitive maritime industry is of high economic significance. The maritime industry plays a key role in the competitiveness of the business location Germany and for securing growth and employment. Competitive seaports form the connector between seaside and landside transport modes and are indispensable for functioning international transport chains and foreign trade. However, their competitiveness depends on port efficiency. According to the Organisation for Economic Co-operation and Development (OECD) the doubling of port efficiency of two countries results in a 32 percent increase of their bilateral trade volume (Merk 2013). One factor influencing the efficiency of seaports is their landside accessibility and thus, the quality and number of available hinterland connections (Merk 2013). Consequently, future increase of freight on hinterland transport modes demands sufficient capacities of corresponding transport infrastructures (Ben-Akiva et al. 2013).

Freight transport models are used to estimate the expected impact of policy measures and are a necessary input for the justification of infrastructure investments. Seaport hinterland models can be used to forecast future hinterland traffic and modal split development. At present, no comprehensive model exists for the Port of Hamburg. Current forecasts are based on surveys, e.g. on the Container Traffic Model 'Port of Hamburg', by the Institute of Shipping Economics and Logistics (ISL). For that reason, it is difficult to estimate the expected impacts of infrastructure measures for the Port of Hamburg's hinterland accessibility.

The aim of this paper is to give an overview over the research field of freight transport modelling and to develop an approach for comparing the Port of Hamburg's hinterland connections taking into consideration different types of costs. Currently, a macroscopic freight transport model for the Port of Hamburg is under development. This work forms a first step within the development of a freight transport model for the Port of Hamburg.

In order to narrow the scope of transport modelling this paper focusses on freight transport models only. Cost functions will cover containerized cargo only. Finally, because most hinterland transport flows are long distance transport flows this paper will only take into consideration macroscopic freight transport models.

Section 2 gives a brief introduction to the fundamentals of freight transport modelling. A selection of existing freight transport models is presented in section 3. The differences between these freight transport models are highlighted by using differentiation criteria defined by the researcher. In section 4 the seaport hinterland model currently under development is described. Special focus is given on the underlying logic in order to highlight the role of cost functions as part of the freight transport model. In section 5 cost functions for containerized seaport hinterland traffic are derived and also applied to the use case “Port of Hamburg”. Finally, a discussion and conclusion are provided in Sections 6 and 7. The chapter ends with a conclusion in section 8.

2 Introduction to Freight Transport Modelling

There are a lot issues in freight policy that demand the modelling of freight flows, such as the increase of freight volumes, pricing, logistics performance, changes in vehicle types or external effects of transport. Amongst others the following modelling needs are linked to current key issues in freight policy: forecasting international freight growth, differentiating between goods with different logistic backgrounds, forecasting (cause and impacts of) choice of vehicle type, modelling critical global movements (containers, oil, dangerous goods, food) (Tavasszy 2006).

Transport modelling distinguishes between passenger transport modelling and freight transport modelling. Concerning methodology passenger transport models have achieved a high degree of specialization and are established as tools in strategic transport planning processes. In contrast to this freight transport models have evolved and methodologically developed only since the shorter past (Tavasszy 2006).

First of all, freight transport flows form a relatively small part of total transport flows. In addition, access to necessary data is difficult because of commercial interests of freight transport market actors that want as least transparency (of e.g. costs) as possible (de Jong et al. 2004). On the other hand, due to the high number of different actors involved, such as consignors, shippers, freight forwarders, liner carriers and terminal operators, and their partly conflicting interests, the organization of international freight transport chains is very complex. As passenger transport models only have the passenger as decision maker, they are far less complex than freight transport models (Karafa 2010).

Nevertheless, in the early days of freight transport modelling the developers of these models used the scientific findings of passenger transport models and adopted the concepts, methods and tools to the specific requirements of freight transport. However, by now freight transport modelling has developed its own stream of methods and techniques inspired by disciplines such as economic geography and supply chain management (Tavasszy, de Jong 2014).

A widely spread model structure for passenger transport models is the 'Four-Step Model'. Other models like activity based models and land use models can also be used to fulfil functions similar to those of the Four-Step Model (Transport and Infrastructure Council 2014). The steps of the Four-Step-Model are illustrated in Figure 1.

Within the first step ‘Trip generation’ it is estimated how many person trips are produced within and attracted to each zone (incoming and outgoing passenger trips). The second step ‘Trip distribution’ determines the destinations and origins of the passenger trips. The result is an origin-destination matrix. The ‘Mode choice’ (step three) allocates the origin-destination-trips from step 2 to the available transport modes (mode-specific trip matrices). Finally, the mode-specific trip matrices are assigned to alternative routes or paths (step four, ‘Trip assignment’).

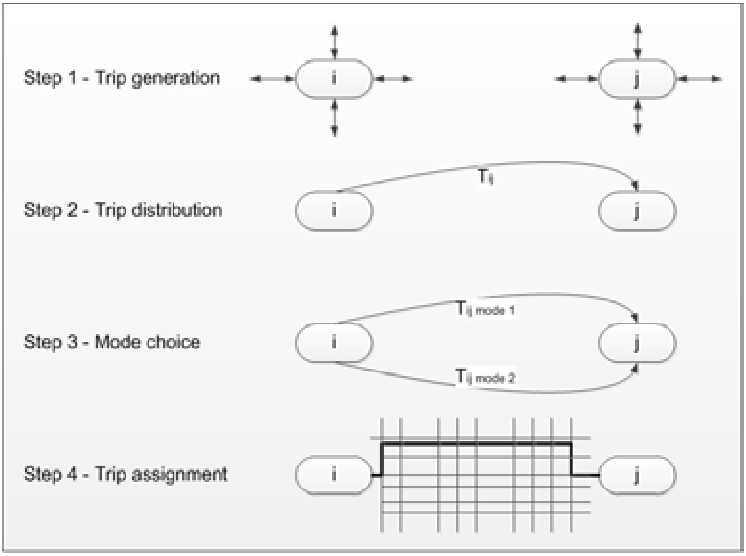


Figure 1 Steps of the Four-Step-Model (author based on Transport and Infrastructure Council 2014)

A significant feature of this model is the iterative feedback of costs arising from trip assignment to trip distribution and mode choice. The iteration between the last three steps enables the replication of impacts of congestion on travel costs (Transport and Infrastructure Council 2014). It is generally accepted that the Four-Step Model of passenger modelling can be applied to freight transport as well. However, due to the complexity of the freight transport system, the individual steps of the Four-Step Model need to be adapted to the requirements of the freight transport system (de Jong et al. 2004).

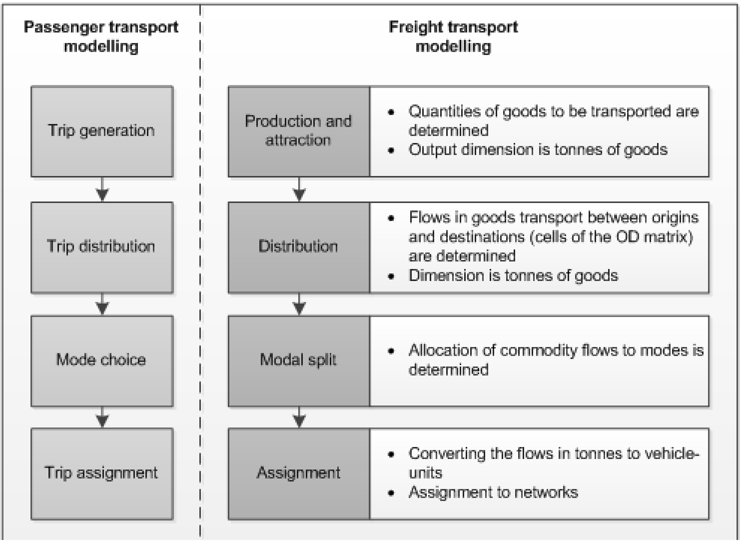


Figure 2 Comparison of Four-Step Models (author based on de Jong et al. 2004)

A number of transformation modules are usually required (de Jong et al. 2004). An example for this is the converting of trade flows in monetary units into physical flows in tons for the first step of the Four-Step Model. As trade forms the basis for freight transport flows this is an inevitable step. For this Tavasszy (2006) enhances the Four-Step Model by a fifth step 'Trade' after the first step that includes the conversion of monetary units into tons. As passenger transport does not relate back to monetary units no such translation has to be carried out in passenger modelling. The following elements of freight transport models are necessary to carry out the illustrated model:

Table 1 Components of freight transport models (author)

Model Component	Description
Demand model	Different regional areas; Origin-destination data for different commodity groups as well as vehicle types
Network model	Different networks for transport modes; Terminals for transfer between transport modes or the integration of logistics processes
Cost model	Fixed and variable costs related to transport modes, vehicle types and commodity groups (or loading units)

The cost model is an essential component of freight transport models. In most models the costs are linked to the network as part of a resistance function. Freight transport models use costs in order to differentiate between different transport modes (and vehicle types) as well as commodity groups (Müller et al. 2012). Costs occur at different stages of the transport chain and can be found as resistors for the mode and route choice during freight transport modelling. As part of common freight transport models the transport mode, transport chain (incl. changes of transport modes) as well as transport route are selected under the principle of minimization of total costs of transport. The cost model is therefore a deterministic model of cost minimization. Consequently, for freight transport models to be as exact and realistic as possible, it is of special importance that the overall costs of possible elements of logistical alternatives are calculated with sufficient accuracy.

3 Macroscopic Freight Transport Models

Existing freight transport models do not only differ in terms of their international, national or regional perspective but also in relation to the data used and their depth of aggregation, corresponding measurement variables used, or their scale of analysis named as aggregated or disaggregated. Examples for macroscopic freight transport models are e.g. the Swedish National Model System for Goods Transport (SAMGODS) and the Swiss National Freight Transport Model (NGVM). Both models cover different transport modes and commodity groups and consider all processes of traditional freight transport chains (transport, handling, storage). SAMGODS and NGVM are selected for further analysis because they can be considered to belong to the best documented freight transport models. Table 2 compares the two models with each other.

Table 2 Comparison of SAMGODS and the NGVM (author based on Vierth et al. 2009 and ARE 2011)

Criteria	SAMGODS	NGVM
Development period	2004-2009	2009-2011
Number of regions	290 in Sweden; 174 outside Sweden	2.945 in Switzerland; 156 outside Switzerland
Level of aggregation	Aggregated and Disaggregated	Aggregated and Disaggregated
Transport modes	Road, rail, sea, air	Road, rail
Logistics processes	Transport, handling, storage	Transport, handling, storage
Number of freight categories	35	118
Software	Own programming	Visum

Both freight transport models are similar concerning the considered criteria. Nevertheless, they differ from each other in their level of detail in terms of the number of freight categories as well as the geographical coverage.

The level of aggregation of the NGVM is named as 'Aggregated' and 'Disaggregated'. Aggregated freight transport models do not take into consideration flows between individual firms and logistics decisions but between regions or zones. Disaggregated means, that logistics decisions (e.g. use of consolidation and distribution centers, shipments sizes or loading units) are included. For this, the NGVM includes so called logistics systems (e.g. full truck load, pallets) (ARE 2011). Due to the fact that the information per shipment is finally aggregated to origin-destination flows for the network assignment the NGVM can be described as an aggregate-disaggregate-aggregate (ADA) freight model system.

SAMGODS can also be understood as an ADA freight model system as illustrated in Figure 3.

Thus, ADA freight model systems model the generation of trade flows and assignment to networks in an aggregate way and simulate logistics decisions at the level of individual firm-to-firm flows (Ben-Akiva, de Jong 2013). According to Ben-Akiva, de Jong (2013) the different logistics decisions could be:

- Frequency/shipment size (incl. inventory decisions)
- Choice of loading unit (e.g., containerized)
- Use of distribution centers, terminals and the related consolidation and distribution of shipments
- Mode/vehicle type used for each leg of the transport chain

These logistics decisions are made with the overall objective of minimizing total logistics costs. ADA freight model systems also have been developed for Norway and Flanders and are currently under development in Denmark and for the European Union (Ben-Akiva, de Jong 2013).
The development of a seaport hinterland model for the Port of Hamburg will follow the underlying logic of the ADA freight model system.

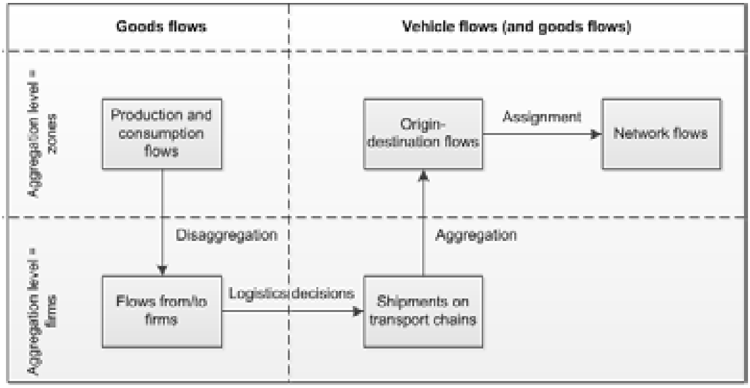


Figure 3 Structure of SAMGODS model (author based on Karlsson et al. 2012)

4 Development of a Seaport Hinterland Model for the Port of Hamburg

The macroscopic freight transport model currently under development is funded by the Ministry of Science and Research of the City of Hamburg. The model follows the logic visualized in Figure 4.
In step 1, the transport networks as well as origin-destination matrices for different commodity groups (according to value and density) are created in

the software environment Visum. This step comprises the first two steps of the Four-Step Model as illustrated in Figure 2. The model includes road, rail and inland waterway networks. These networks connect in total 380 demand zones and 237 terminal zones across the whole of Europe. As part of this first step, origin-destination, distance and time matrices between the demand as well as terminal zones are calculated. These matrices form the input for the second step.

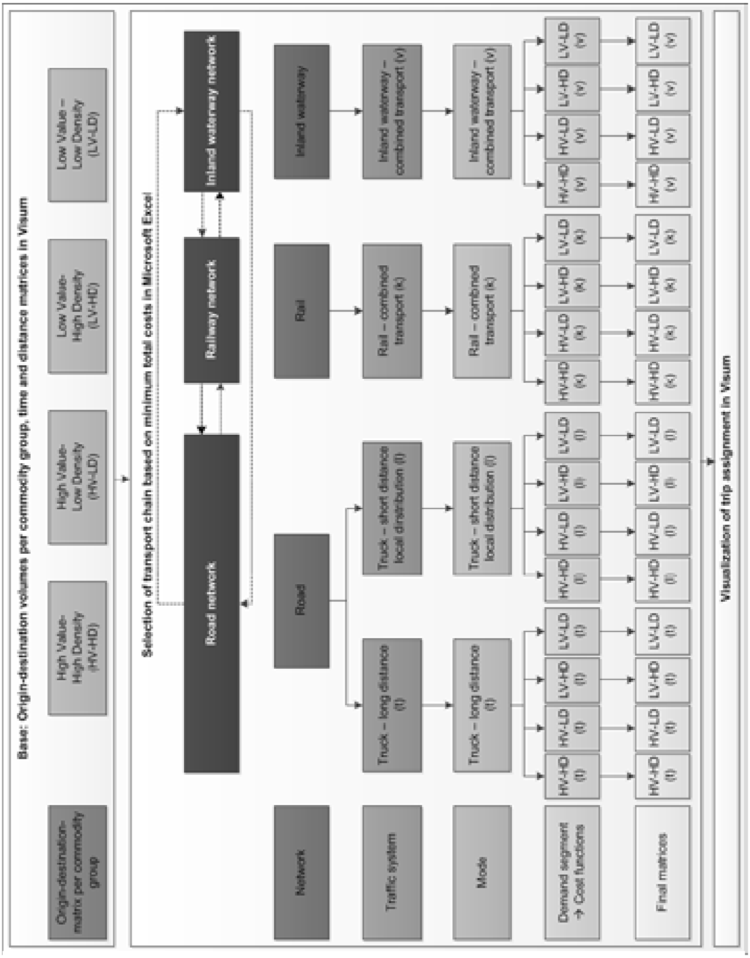


Figure 4 Traffic systems, modes, demand segments and demand matrices of the freight transport model under development (author)

The second step is carried out outside of the Visum environment by using a Visual Basic for Applications (VBA) macro in Microsoft Excel. In this step the least expensive transport chain for each origin-destination relation is chosen by passing the following process:

1. Select the cheapest path between origin and destination without transshipment.
2. Is there a cheaper path between origin and destination with one transshipment move? If yes, select this path - If no, select path between origin and destination without transshipment.
3. Is there a cheaper path between origin and destination with two transshipment moves? If yes, select this path - If no, select path between origin and destination with one transshipment.

The total number of transshipments is limited to two transshipments and distinction is made between different traffic systems (vehicle types). The step complies with the third step of the Four-Step Model (modal split). The result of this step is a certain path with a fixed modal split for each origin-destination relation and commodity group.

The final step consists of the transfer of goods flows in tons into vehicle flows and the assignment to the network. This step is again carried out inside the software Visum and complies with the fourth step of the Four-Step Modal (assignment).

As described, especially the second step of the new model logic bases on cost functions taking into consideration different transport modes, vehicle types as well as commodity groups.

5 Derivation of Cost Functions

In this section cost functions are derived and also applied to the use case of the Port of Hamburg. For this, characteristics of the Port of Hamburg's hinterland connections are presented first. Afterwards, cost functions implemented in the ADA freight model system are analyzed and adapted to the requirements of the model under development. Finally, the cost functions are tested taking into account a transport chain significant for the Port of Hamburg.

Total volumes handled in the Port of Hamburg amount to 145.7 million tons in 2014. This means an overall increase of 4.8 percent compared to 2013. Containers form about 70 percent of total throughput (9.7 million TEU (Twenty-foot Equivalent Unit) in 2014, +5.1 percent compared to 2013 (HHM 2015a). According to the current German sea traffic forecast the relatively high degree of containerization in the Port of Hamburg relates back to the NST-2007 commodity group ‘not identifiable goods’, which amounts to 20 percent of all hinterland volumes. Relevant hinterland regions for this commodity group are especially Bavaria, the Czech Republic, Baden Württemberg, Bremen as well as North Rhine-Westphalia (MWP et al. 2014). However, the relevant hinterland regions for all freight categories handled in the Port of Hamburg are different to that. Around 59.8 percent (5.8 million TEU) of all containers handled in the Port of Hamburg are transported into hinterland regions, most of them via the transport modes road (59.4 percent, 3.4 million TEU) and rail (38.6 percent, 2.2 million TEU) (HHM 2015b). Hinterland transport of containerized cargo via inland waterways forms a negligible low part of all containerized hinterland transports (only 2.0 percent).

Due to the Port of Hamburg's high degree of containerization and the significance of the transport modes road and rail the development of cost functions for transport chains in the hinterland of the Port of Hamburg will focus on containerized cargo into relevant hinterland regions and road only as well as rail-road transport chains.

ADA freight model systems include freight flows between zones or regions as well as individual firms. The basic model for decision-making on the disaggregated level (logistics decisions at the level of individual firm-to-firm flows) is the minimization of total logistics costs. According to Ben-Akiva, de Jong (2013) the disaggregated level consists of shipments of goods in number of shipments, tons, ton-kilometers, vehicle-kilometers and vehicle/vessels per year, by

k, commodity type

l, transport chain type (number of legs, mode and vehicle/vessel type used for each leg, terminals used, loading unit used)

m, sending firm (located in zone r)

n, receiving firm (located in zone s)

q, shipment size

As stated by Ben-Akiva, de Jong (2013) and Vierth et al. (2009) the total annual logistics costs G of commodity k transported between firm m in production zone r and firm n in consumption zone s of shipment size q with transport chain l (including number of legs, modes, vehicle types, loading units, transshipment locations) are:

$$G_{rskmnql} = D_k + I_{kq} + K_{kq} + O_{kq} + T_{rskql} + Y_{rskl} + Z_{rskq} \quad (1)$$

Where

D: Cost of deterioration and damage during transit

G: Total annual logistics costs

I: Inventory costs (storage costs)

K: Capital costs of inventory

O: Order costs

T: Transport, consolidation and distribution costs

Y: Capital costs of goods during transit

Z: Stockout costs

As can be taken from equation 1 the cost functions of ADA freight model systems take into account the costs of all transport, handling and storage processes within a transport chain (logistics costs). The cost function includes operators' as well as so-called senders' costs. According to Vierth et al. (2009) senders' costs include costs that are related to the transported good itself, as well as a certain risk (e.g. risk of delay or damage) cost. These costs are represented by the capital costs of the goods and the cost of deterioration and damage that are included in the equation above.

However, this equation is not focusing on containers as loading unit only. Some characteristics of container transports allow a reduction of the complexity of equation 1: First, goods are not likely to change loading units in long-distance hinterland transport chains. According to the definition of intermodal transport it is even forbidden (Tsamboulas et al. 2007). Most transport chains end in a logistics center. Second, once loaded on trucks it is unlikely that containers switch from road to other transport modes. Finally, transshipment terminals (rail-road) aim at reducing the dwell-time of containers in order not to lose too much time and to increase the competitiveness of intermodal transport compared to road container transport.

A possible cost function representing containerized cargo is developed by Jourquin, Tavasszy (2014). According to Jourquin, Tavasszy (2014) intermodal container transport is an alternative to road container transport when the internal costs of the intermodal trip are competitive in comparison to the internal costs of trucking. Internal costs of moving a container cover the sum of costs incurred by the various parties responsible for the movement of the container (Black et al. 2003).

Following the authors argumentation the attractiveness of the intermodal chain depends on the level of transshipment costs and on the length of the pre- and post-haulages to and from the intermodal terminals. The authors define the cost functions for road (Equation 2) and intermodal container transport (Equation 3) as follows:

$$C_g^{road} = a_{road} * \left(\frac{h_{road}}{f_{road}} + e_{road}\right) \quad (2)$$

$$C_g^{rail-road} = a_{rail}\left(\frac{h_{rail}}{f_{rail}} + e_{rail}\right) + b_{rail-road}\left(\frac{h_{road}}{f_{road}} + g\right) + d_{rail-road} + h_{rail}c_{rail-road} \quad (3)$$

Where

C_g^{road} and $C_g^{rail-road}$:	Generalized costs for road and rail-road transport, per loaded ton
a_{road} and a_{rail}:	Truck-only and rail-only distances
$b_{rail-road}$:	Post-haulage distances for rail-road transport
$c_{rail-road}$:	Transshipment times for rail-road transport
$d_{rail-road}$:	Transshipment costs for rail-road transport
e_{road} and e_{rail}:	Transport costs for road and rail-road transport
f_{road} and f_{rail}:	Transport speeds for road and rail-road transport
g:	Post-haulage cost
h_{road} and h_{rail}:	Value of time

Again, these equations integrate the purchase costs of the goods inside the containers by introducing the variable h (value of time). Due to the fact that this approach fits better to the specific characteristics of containerized seaport hinterland traffic it will be used to calculate the costs of selected hinterland transport chains of the Port of Hamburg. The following transport chains are analyzed:

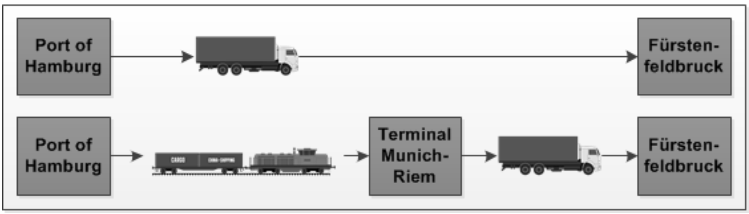


Figure 5 Analyzed transport chains (author)

As illustrated in Figure 5 the above described cost functions are applied to two possibilities to transport containers from the Port of Hamburg into its hinterland zone Fürstenfeldbruck (logistics center): First, as a unimodal transport chain by truck or second, as a multimodal transport chain by rail and truck.

Fürstenfeldbruck was selected as hinterland zone because Bavaria is the Port of Hamburg's most important hinterland region for containerized cargo (HHM 2013). Further, it is located within a radius of about 50km around the intermodal terminal Munich-Riem which is the most important intermodal terminal for containers in the Port of Hamburg's hinterland region Bavaria (HHM 2013). The radius of 50 km relates back to the assumption that the catchment area of intermodal terminals can be described as an ellipse around the terminal with a radius of at maximum 50 km (HHM 2013). In the analyzed intermodal transport chain, the transport mode rail is used for the main haulage. Road transport is only used for post-haulage. Hence, it can also be described as a combined intermodal transport chain (Destatis 2013).

Table 3 Input used in the cost functions for the transport of a 40-foot container (author based on Jourquin, Tavasszy 2014 and HHM 2012)

Variables	Road	Intermodal
a: Main distance (km)	798	$r = a - b$
b: Post-haulage distance (km)	n.a.	50
c: Transshipment time (hours)	n.a.	2
d: Transshipment costs (€/Cont.)	n.a.	22.50
e: Transport tariff (€/Cont.km)	1.17	0.53
f: Transport speed (km/hour)	50	40
g: Post-haulage tariff (€/Cont.km)	0.000	5.33
h: Value of time (€/Cont./hour)	1	1

The results of the research carried out in terms of the quantification of the internal costs are summarized in Table 3. The costs for the transport chains have been determined and quantified empirically by carrying out desk research as well as interviews with freight forwarders in 2015. Different origin-destination relations have been taken into account. Accordingly, the values listed in Table 3 are average figures for the analyzed transport chains. The variable transport tariff includes time-dependent (e.g. capital costs of the vehicle, administrative costs and personnel costs) and distant-dependent costs (e.g. operating and maintenance costs or energy costs) for the chosen transport modes. Using the input data the costs for the different transport chains are

- 949.62 €/40-foot container for road only container transport and
- 707.14 €/40-foot container for intermodal container transport.

The transport costs of a 40-foot container with an average load capacity of 30.40 tons from Hamburg to the logistics center in Fürstenfeldbrück amount to 0.039 €/t.km for the road only transport and 0.029 €/tkm for the intermodal transport. The intermodal option turns out to be significantly cheaper than the road only alternative. This corresponds to observations made by Ricci (2003) or Black et al. (2003).

6 Discussion and Further Research

The chosen transport tariff for road transport is based on the assumption, that the average cost of movement by road amounts to 1.19 €/km for a 40-foot container. This value corresponds to the figures published in Black et al. (2003). As reported by them the value for moving a 40-foot container in Germany is 1.14 €/km. According to HHM (2012) the cost of moving a 40-foot container between Hamburg and Bavaria amounts to 1.17 €/km.

For intermodal transport it is assumed that the average cost for moving a 40-foot container amounts to 0.89 €/km. Again, this figure lies within a range that can be found in different studies. Within the project Hafen Hamburg 62+ systematic comparisons of costs have been carried out for different transport chains between Bavaria and Hamburg. Within the project, rail haul unit costs of roughly 0.79 €/km per 40-foot container were identified for container transports between Hamburg and Munich (HHM 2012).

Following this argumentation, the achieved results are in conformity with the current state of practice. However, several aspects have been neglected so far:

1. Different vehicle types. The calculation does just take into consideration one vehicle type (long-distance truck). But, operational costs can be different for different vehicle types.
2. Different commodity groups with different logistics backgrounds. The variable 'value of time' has not been quantified so far. Consequently, the purchaser's costs of the content of containers are not integrated. Neither are the specific requirements of different commodity groups, e.g. urgency of transport.
3. Different network types. The cost function calculates with average speeds and considers only one possible route.
4. Capacity restrictions. The interdependencies of different transport chains as well as capacity restrictions have been neglected so far. The attractiveness of a transport chain is dependent on the degree of utilization. The more containers are assigned to a transport chain (and route) the less attractive it will be because of an increasing probability of congestion.

Consequently, the described cost function can only be seen as a first approach towards the development of a cost function usable in the model under development.

7 Conclusion

Freight transport models are a useful tool for estimating the expected impacts of policy measures and are a necessary input for the justification of infrastructure measures. Based on cost functions transport demand is assigned to the transport network and different transport modes.

When intermodal transport competes with road transport, trucks are used in two different ways: Either they are used as a substitute for or as a complement for the rail. Nevertheless, for the analyzed Origin-Destination relation (Hamburg-Munich) the intermodal option turns out to be significantly cheaper than the road only alternative (707.14 €/Cont. for intermodal container transport compared to 949.62 €/Cont. for road only container transport).

The described cost function can be seen as a first approach to calculate the total costs of the Port of Hamburg's containerized hinterland transport chains. It needs to be extended by a quality variable that integrates the interdependencies of different transport chains as well as the probability of congestion in order to describe the transport market in a more realistic way. The sensitivity to cost changes or situational responses because of interdependencies as well as the differentiation between goods with different logistics backgrounds are challenges that need to be integrated into cost functions of an appropriate seaport hinterland model for the Port of Hamburg.

References

ARE Bundesamt für Raumentwicklung (2011): Nationales Güter-verkehrsmodell des UVEK. Basismodell 2005: Modellbeschrieb und Validierung. Eidg. Departement für Umwelt, Verkehr, Energie und Kommunikation (UVEK). Zürich.

Ben-Akiva, M.; de Jong, G. (2013): The Aggregate-Disaggregate-Aggregate (ADA) Freight Model System. In M. Ben-Akiva, E. van de Voorde, H. Meersman (Eds.): Freight Transport Modelling. 1st ed. Bingley, United Kingdom: Emerald, pp. 69–90.

Ben-Akiva, M.; Meersman, H.; van de Voorde, E. (2013): Recent Developments in Freight Transport Modelling. In M. Ben-Akiva, E. van de Voorde, H. Meersman (Eds.): Freight Transport Modelling. 1st ed. Bingley, United Kingdom: Emerald, pp. 1–13.

Black, I.; Seaton, R.; Ricci, A.; Enei, R.; Vaghi, C.; Schmid, S.; Bühler, G. (2003): RECORDIT Final Report: Actions to Promote Intermodal transport. Available online at http://www.transport-re-search.info/Upload/Documents/200607/20060727_155159_96220_RECORDIT_Final_Report.pdf&bvm=bv.96339352,d.bGQ&cad=rja, updated on 26/05/2003, checked on 3/03/2015.

de Jong, G.; Gunn, H.F; Walker, W. (2004): National and international freight transport models: overview and ideas for further development. In Transport Reviews. 24 (1), pp. 103–124.

Destatis Statistisches Bundesamt (2013): Kombinierter Verkehr - Fachserie 8 Reihe 1.3. Wiesbaden.

HHM Hafen Hamburg Marketing e.V. (2012): Wege zur Stärkung der Bahn im Container-Hinterlandverkehr zwischen dem Hafen Hamburg und dem Freistaat Bayern. Stärken, Chancen, Entwicklungspotenziale. Ergebnisse eines bayerisch-hamburgischen Kooperationsprojektes.

HHM Hafen Hamburg Marketing e.V. (2013): Kooperationsprojekt Hafen Hamburg 62+. Vertraulicher Abschlussbericht.

HHM Port of Hamburg Marketing e.V. (2015a): Cargo Handling 2014 in million tons. Available online at http://www.hafen-hamburg.de/de/statistiken, checked on 17/06/2015.

HHM Port of Hamburg Marketing e.V. (2015b): Modal-Split in Container Traffic. Available online at http://www.hafen-hamburg.de/en/statistics/modalsplit, checked on 17/06/2015.

Jourquin, B.; Tavasszy, L. and Duan L. (2014): On the generalized cost - demand elasticity of intermodal container transport. In Europe-an Journal of Transport and Infrastructure Research 14 (4), pp. 362–374.

Karafa, J. (2010): State-of-the-Art in Freight Modeling. Undergraduate Paper ITE District No. 5. The University of Memphis.

Karlsson, R.; Vierth, I.; Johansson, M. (2012): An outline for a validation database for SAMGODS. vti. Linköping.

Merk, O. (2013): The Competitiveness of Global Port-Cities: Synthesis Report. Organisation for Economic Co-operation and Development (OECD), checked on 15/06/2015.

Müller, Stephan; Wolfermann, Axel; Huber, Stefan (2012): A Nation-wide Macroscopic Freight Traffic Model. EWGT 2012 - 15th meeting of the EURO Working Group on Transportation. In Procedia - Social and Behavioral Sciences 54, pp. 221–230.

MWP; IHS; UNICONSULT; Fraunhofer CML (2014): Verkehrsver-flechtungsprognose 2030 sowie Netzumlegung auf die Verkehrsträ-ger; Los 2 (Seeverkehrsprognose). Forschungsbericht FE-Nr. 96.980-2011. Im Auftrag des Bundesministeriums für Verkehr und digitale Infrastruktur.

OECD Organisation for Economic Co-operation and Development (2014): Statistics Brief July 2014. Global Trade and Transport. Available online at http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2014/greenhouse-gas-inventory-2014-full.pdf, updated on 17/07/2014, checked on 9/06/2015.

Ricci, A. (2003): Pricing of Intermodal Transport. Lessons Learned from RECORDIT. In European Journal of Transport and Infrastructure Research 3 (4), pp. 351–370.

Tavasszy, L. (2006): Freight Modelling - An overview of international experiences. TRB Conference on Freight Demand Modelling: Tools for Public Sector Decision Making. Washington DC, 25/09/2006.

Tavasszy, Lorant; Jong, Gerard de (Eds.) (2014): Modelling freight transport. First edition. London; Waltham: Elsevier Inc.

Transport and Infrastructure Council (2014): 2014 National Guidelines for TRansport System Management in Australia. Passenger Transport Modelling [T1].

Tsamboulas, Dimitrios; Vrenken, Huub; Lekka, Anna-Maria (2007): Assessment of a transport policy potential for intermodal mode shift on a European scale. In Transportation Research Part A: Policy and Practice 41 (8), pp. 715–733.

Vierth, I.; Lord, N.; Mc Daniel, J. (2009): Representation of the Swedish transport and logistics system. (Logistics Model Version 2.00). vti. Linköping (VTI notat 17A-2009). Available online at http://www.vti.se/en/publications/representation-of-the-swedish-transport-and-logistics-system-logistics-model-version-200/, updated on 9/06/2009, checked on 19/03/2015.

Formal Specification, Testing and Verification on the Truck Simulation

Muhammad Iman Santoso, Bernd Noche, Asep Ridwan, Achmad Bahauddin, Ratna Ekawati and Muhammad Indrahanif

Truck operation for the fertilizer handling in the one of Indonesia's Port turned out to be inefficient and produced long queues (1.3 hours) when operated in the maximum number of trucks, i.e. 30 units - 30 tons load capacity per unit. This paper presents a simulation-based optimization for scheduling quantity and capacity of the fertilizer trucks to achieve handling-target within 24 hours and reduce queue. New procedural technique that combine statistical, modeling, simulation and verification have been developed employing several tools and managed in a structural way using formal specification. Those techniques optimize the truck operation turn into 8 units and also decrease the round trip operation from 220 rounds into 217 rounds. It generates a daily productivity of 6516 tons and minimize truck queue until 0.14 hour. The reduction of resources utilization and queue time will diminish the total fertilizer handling cost.

Keywords: Fertilizer Truck, Formal Specification, Simulation, Verification

1 Introduction

The Port is a critical facility that supports economic activities, particularly for Indonesia, an archipelago country. Delays of the service in the port, notably in the high-volume goods loading/unloading will affect the profit. Therefore, the necessity of quality enhancement in terms of time and optimum resources becomes very urgent.

This paper presents a joint research between the University of Duisburg-Essen (Germany), the University of Sultan Ageng Tirtayasa (Indonesia) and one of the Port Services Company located in Banten - Indonesia. This partner-port is established in the strategic geographic position on the western side of Java that connects the Indian Ocean to South-China Sea and the Pacific Ocean. The most benefit of the area is that location proven as the deepest port in Indonesia. The port customers are multi-enterprises located in Cilegon, Jakarta, and the surrounding area. Their services are docking ships, loading/unloading of goods and warehousing. Particularly, their business core is focusing on the dry bulk products such as fertilizer (FZ), corn, soy, salt, and sugar. The loading and unloading processes have the same pattern, starting from fetching products using the crane toward the hopper (HP), transporting to the tailgate (TG), and then weighing.

Afterward, the product is either unloaded from the truck, then relocated into a temporary warehouse (WH) in the port or directly going to customer warehouse. The loading and unloading activities are addressed as the material handling process. Material handling is an activity of lifting, transporting, and put the material by using means of transportation (Purnomo, 2004).

According to the partner-port experience, fertilizer is one of the products that are sensitive to be handled. It particles are small, lightweight, and easily mixed with water. Fertilizer ship comes to the port jetty in a large capacity, typically taken by more than 10,000 tons. The customers are always asking very quick fertilizer handling time. Due to this demand, the port operates the maximum number of trucks (i.e. 30 units - 30 tons capacity per unit) to perform handling process faster.

In fact, a maximum truck operation becomes counterproductive. It generates a new problem in the truck queue, particularly in the weighing process. This issue is getting worse by back/forth trucks that carry other dry/liquid bulk operated by many forwarders.

The model that built in this paper simulates the existing productivity of fertilizer handling process and then optimizes it. More than calculate the efficient truck capacity, the author also validates the optimum productivity of 24 hours fertilizer unloading.

2 Port Simulation Model for Bulk-Cargo - The State of the Arts

Small paper simulates bulk cargo operation in the port. Utmost studies are usually model bulk cargo services in macro-perspective. Scientists are trying to improve efficiency when the cargo unloaded goods, bulk-port expansion plans and discuss the parameters/values characteristic of port simulation using specific tool or software. Such procedures found in (Agerschou & Sørensen, 1983) (Bugaric. U, 2007) (Cassettari, 2012) (Dahal, 2007) (El Sheikh, J.R. Paul, S.A. Harding, & Balmer, 1987) (Esmer, 2010)

(Kondratowicz, 1990) (Park & Noh, 1987) (Pjevčević D., 2013). Nevertheless, those papers have not verified the data, model and the simulation results in a structural way. (Harrell, 2000) examines data and conducts verification/validation but only dependent on the ProModel. In this paper, (Harrell, 2000) theory and simulation method are extended by implementing multivariate tools and techniques that customizable.

The documentation of all procedures is written as clear as possible before running the simulation. Furthermore, the simulation procedures are managed thoroughly by a strict control mechanism of adequacy as well as verification tests. The tests are performed both manually (hand-calculations) and automated taken by some tools.

3 Research Methodology

This paper enhances several procedures and techniques in the field of material handling process and simulation that are initially invented by (Harrell, 2000). The following methods are carried out to pursue the research objectives: 1) Observation and Interview, 2) Problem identification and Scope, 3) Data Collection and Analysis, 4) Model Design, 5) Model Verification and Validation, 6) Simulation Development and Validation, 7) Running Simulation and Experiment, 8) Output testing and Alternative Comparison (see

Figure 1) The authors present the procedures more flexible using diverse (alternative) tools and introduce the set of “formal-specifications” to conduct the simulation better.

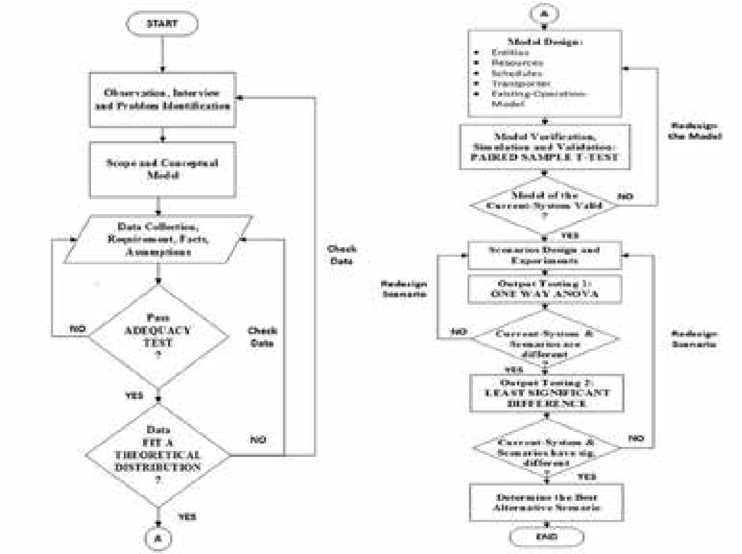


Figure 1 Flowchart of the Research Methodology

Formal Specification (FS) is defined as a systematic and procedural technique that specifies terms/vocabularies of the system and then verifies that design specification through the planning and construction phase. Commonly, FS used to guide the developer (in the field of computer science) during the design, testing and implementation of the systems or software as stated by (Sargent, 2005) (Zengin & Ozturk, 2012) (Zhao & Rozier, 2014) (Navimipour, 2015). Anyone can overview the milestone of FS various techniques in (Edgar & David, 2014).

This paper employs such technique to enhance simulation in the field of operation research instead of computer science.

4 Result and Discussion

This section provides all results obtained from the research. Ultimately, the discussion and analysis are given to deliver a scientific judgment of the result.

4.1 Result

4.1.1 Observation, Interview and Problem Identification

The company has found a problem in the weighbridge (WB). There are many queues of the truck and the peak traffic increase when many ships from other Forwarder unloaded various dry bulk products (e.g. sugar, corn, salt, soy, etc.) at the same time. Such situation will later multiply the number of trucks that exist in the system and causing long queues of vehicles around the WB.

4.1.2 Scope and Conceptual Model

The author set boundary of the research (scope) and the conceptual model in the form of entity diagram (see Figure 2 and 3).

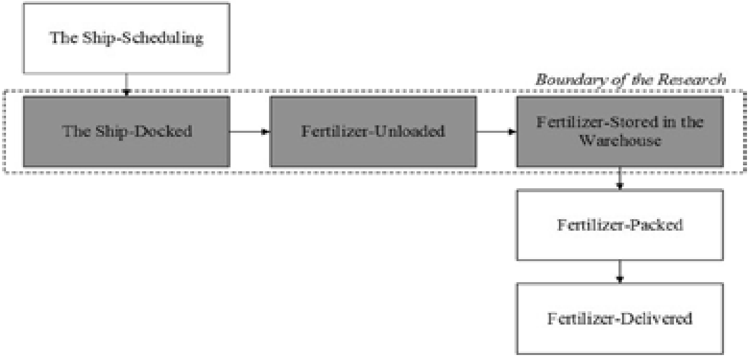


Figure 2 The Boundary of the Research

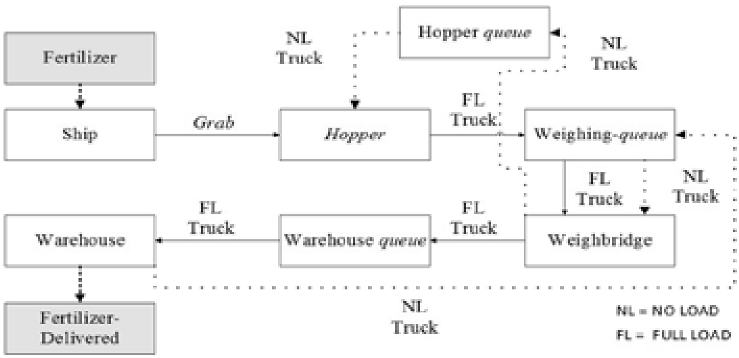


Figure 3 The Entity Diagram of the Process

4.1.3 Data Collection, Facts, Assumptions and Analysis

The research area coverage from the fertilizer discharges out of the ship and transfers it using the truck into the warehouse. The simulation stops when the model mimics the fertilizer handling for 24 hours. Each process employed 50 data samples, which has been collected during the March-2013 to January-2014.

The result of data collection is documented on the following formal specification (see Table 1,2,3).

Table 1 List of Requirements

	Requirements
R1	How to model and simulate existing fertilizer handling system in the partner-port?
R2	How many quantity and optimal truck capacity should be operated to improve quality of the actual process?
R3	How to set optimum productivity of fertilizer-handling in 24 hours that could reduce queue time?

Table 2 List of Facts

	Facts
F1	The simulation entities: Fertilizer (FZ) in a unit of tons and Dummy (used to model empty truck)
F2	Dynamic-Resources: Truck that is currently carrying 30 tons capacity of FZ in amount of 30 units and Grab which is transporting FZ from the ship into the Hopper (HP).
F3	Station: Ship, HP which has 50 ton capacity (2 units), Weighbridge (WB) that can only weighing 1 truck (1 unit) and the warehouse (WH).
F4	Arrival: The fertilizer capacity per ship-arrival, i.e. 12992 tons, and it should unloaded in 2 (two) days. Thus, daily unloaded target is 6496 tons.
F5	Simulation: It is started from 07:00 at March, 5th 2014 and considers four breaking-times in the port, i.e. 12:00 – 13:00, 18:00 – 19:00, 00:00 – 01:00 and 05:00 – 07:00
F6	The processing-time series: 1) Time to fetch FZ from the ship towards the HP using the grab. 2) The travel-time of FZ from the HP into the TG. 3) The travel-time of the FZ truck from the dock into WB. 4) Weighing-time. 5) The travel-time of the FZ truck from the WB into the WH. 6) The unloading time of FZ in the WH. 7) The travel-time of the FZ truck from the WH into the WB. 8) The travel-time of the FZ truck from the WB into the dock.

Table 3 List of Assumptions

	Assumptions
A1	The simulation is started after the fertilizer freighter-ship has come (to jetty) and fertilizer ready to be released
A2	There are three kinds of ships loaded a different number of fertilizers.
A3	The ship has two hatches.
A4	The weather influences are not considered
A5	The break-time during unloading operations is calculated.
A6	Weighing process-time whether full-load or empty-load is assumed equal.
A7	Grab capacity is 12 tons, and the number of grabs is considered to be equal to the number of hatches, i.e. two units
A8	The decision variables are set to be truck quantity (units) and truck capacity (tons).

The facts and assumptions are then verified using ProModel 7.5 feature called "stat-fit". This feature determines the statistical data distribution. Hence, data collection and assumptions were valid, and available to be used directly in the next step of simulation. Furthermore, the input data have to pass adequacy test prior the "stat-fit" calculation.

The adequacy test data is needed to verify the validity of sample data. Adequacy Test Data (Harrell, 2000) formula:

$$N' = \left[\frac{K/_{S}\sqrt{N(\sum Xi\ 2) - (\sum Xi\ 2)^2}}{\sum Xi}\right]^2 ;\ N > N' \qquad (1)$$

where

N' = The number of observations should be done.

K = The level of confidence in the observations. (k = 2, 1-α=95%)

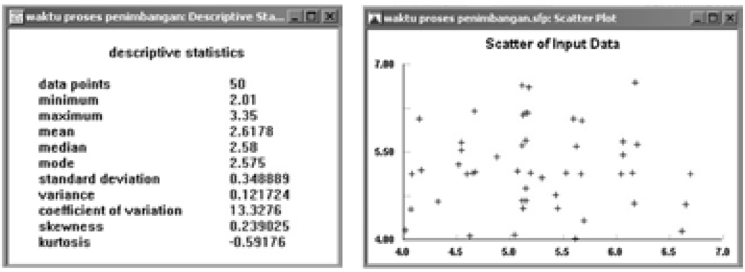
S = The degree of accuracy in the observation (5%)

N = The number of observations that have been made.

Xi = Observation Data

The adequacy of the data achieved if qualifies: $N > N'$

The data have to be "fit a theoretical distribution", such as normal distribution or beta, etc. There are specific tests (see Figure 4,5,6,7,8) that can be performed to determine whether the data is independent and identically distributed (Harrell, 2000).



(a) (b)

Figure 4 Data Independency and Distribution Test: (a) Descriptive Statistics (b) Scatter-Plot

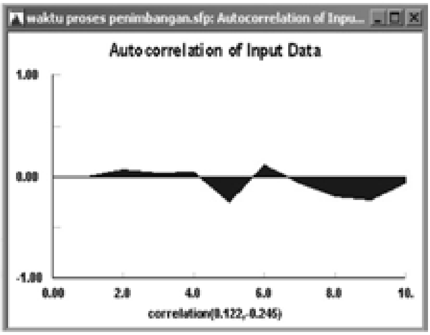


Figure 5 Data Independency and Distribution Test: Correlation of Input Data

waktu proses penimbangan.sfp: Runs Test

runs test on input

runs test (above/below median)

data points	50
points above median	23
points below median	23
total runs	25
mean runs	24.
standard deviation runs	3.35327
runs statistic	0.298216
level of significance	5.e-002
runs statistic(2.5e-002)	1.95996
p-value	0.765538
result	DO NOT REJECT

runs test (turning points)

data points	50
turning points	36
mean turnings	33.
standard deviation turnings	2.92689
turnings statistic	1.02498
level of significance	5.e-002
turnings statistic(2.5e-002)	1.95996
p-value	0.305373
result	DO NOT REJECT

Figure 6 Data Independency and Distribution Test: Input Data Testing

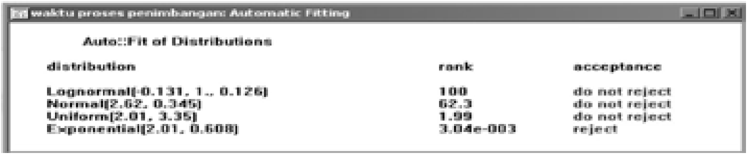


Figure 7 Data Independency and Distribution Test: Fit of Data Distribution

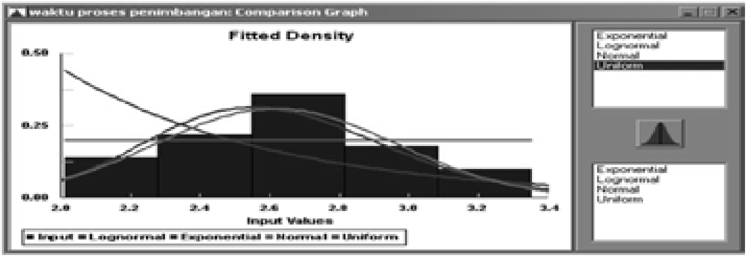


Figure 8 Data Independency and Distribution Test: Fitted Density

The next operation is fitting a theoretical distribution of the data. This step is important to identify which is the most suitable distribution of the sample data. In Promodel 7.5., this basic procedure is divided into three steps checkpoint: (1) One or more distribution selected as a suitable candidate to represent the data samples; (2) Calculate the estimation of the parameters on each distribution (3) Goodness of fit (virtue the data-distribution). The results of input data statistical test are reported in the Table 4.

Table 4 Examination of Data Distribution using Stat Fit

Input Data	Time
The ship towards the hopper	Normal (1.27, 0.141) minutes
The hopper into the truck-tailgate	8.68 seconds/ton
Weighing	Lognormal (2.63, 0.35) minutes
The Warehouse unloading	Uniform (3.32, 3.82) minutes
Transport from the Hopper to the Weigh-bridge	Lognormal (6.42, 1.17) minutes
Transport from the Weighbridge to the Warehouse	Lognormal (4.33, 0.65) minutes
Transport from the Warehouse to the Weighbridge	Uniform (5.02, 7.9) minutes
Transport from the Weighbridge to the Dock	Uniform (7, 10) minutes

4.1.4 Model Design

The modeling phase is conducted using ARENA 14. The model divided into four main modules of data, i.e., entities, resources, schedule and transporters. Besides that, there are also two panels of flowchart modules, namely the Basic and Advanced Process Transfer. Samples of those models are depicted in Figure 9.

Entity - Basic Process

	Entity Type	Initial Picture	Holding Cost / Hour	Initial VA Cost	Initial NVA Cost	Initial Waiting Cost	Initial Tran Cost	Initial Other Cost	Report Statistics
1	Pupuk	Picture.Report	0.0	0.0	0.0	0.0	0.0	0.0	☑
2	Dummy	Picture.Report	0.0	0.0	0.0	0.0	0.0	0.0	☑

(a)

Transporter - Advanced Transfer

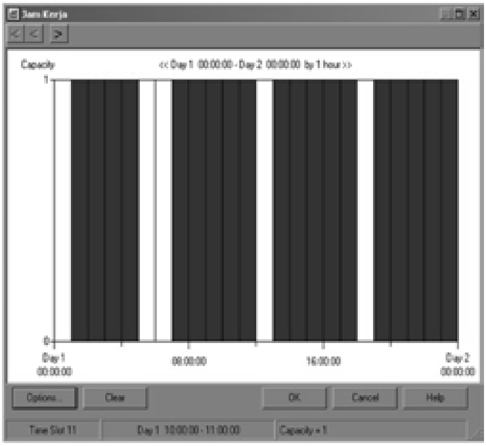
	Name	Number of Units	Type	Distance Set	Velocity	Units	Initial Position Status	Report Statistics
1	Grab	2	Free Path	Grab.Distance	1.0	Per Second	1 rows	☑
2	Truk	30	Free Path	Truk.Distance	1.0	Per Second	0 rows	☑

(b)

Schedule - Basic Process

	Name	Type	Time Units	Scale Factor	Durations
1	Jam Kerja	Capacity	Hours	1.0	8 rows

(c)



(d)

Figure 9 Sample of Arena Modules, (a) Module Data – Entities (b) Module Data – Transporter (c) Module Data – Schedule (d) Module Data Chart-Schedule

4.1.5 Model Verification, Simulation and Validation

This section simulates the actual operation of the partner-port using the designed model. Then, simulation is executed by a replication for 10 times. Replication also named as “several randomized runs” to get accurate estimates because each run varies statistically. Harrell equation (Harrell, 2000) is employed to calculate adequate replication. The result of this calculation is shown in Table 5.

Table 5 Adequate Replication Test

Replication	Unloaded Level (Xi)	$\bar{X}$	Xi-$\bar{X}$	(Xi-$\bar{X}$)2
1	6660	6600	60	3600
2	6570		-30	900
3	6600		0	0
4	6570		-30	900
5	6660		60	3600
6	6660		60	3600
7	6690		90	8100
8	6570		-30	900
9	6450		-150	22500
10	6570		-30	900
Total				45000

$$s = \sqrt{\frac{\sum(\mathrm{Xi} - \bar{X})^2}{n-1}} \tag{2}$$

$$e = \frac{(tn-1,\alpha)S}{\sqrt{n}} \tag{3}$$

$$\text{then,} \quad n' = \left[\frac{Z\left(\frac{\alpha}{2}\right)s}{e}\right]^2 \tag{4}$$

n = replication number

Consider Table 5:

$$\bar{X} = (6660 + 6570 + \ldots + 6570)/10 = 6600 \quad (5)$$

$$X1\text{-}\bar{X} = 6660 - 6600 = 60 \quad (6)$$

$$(X1\text{-}\bar{X})2 = (60)2 = 3600 \quad (7)$$

$$\text{Total} = \sum(\text{Xi} - \bar{X})^2 = 45000 \quad (8)$$

$$s = \sqrt{\frac{\sum(45000)^2}{10-1}} = 70.71 \quad (9)$$

$$e = \frac{2.26 \ x \ 70.71}{\sqrt{10}} = 50.58 \quad (10)$$

$$n' = \left[\frac{Z\left(\frac{\alpha}{2}\right)S}{e}\right]^2 = \left[\frac{1{,}96 \ x \ 70.71}{50.58}\right]^2 = 7.51 \approx 8 \quad (11)$$

The minimum required of replication is equal to 8. Thus, 10 replications tested in Table 5 are more than enough.

After the replication has confirmed, the simulation performance is compared to the field data. The authors conduct this step using SPSS which perform the Paired Sample T – test (see Table 6).

Table 6 Pair Sample T – test Result using SPSS

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std.Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 Real Simulation	-60.7	522.99	165.38	-434.82	313.42	-.367	9	0.722

Consider Table 6:

The 2-tailed significance value (0.722) is larger than the α significance α (0.05), and its confidence interval exceed 0. It can be concluded that H_0 (the initial hypothesis) accepted. Thus, fertilizer-handling model is nearly identical with the field data that manually calculated. Hence, it is stated that the model of existing fertilizer-handling in the partner-port has already approached the target. The summary of the simulation outcome of this model is given in the Table 7.

Table 7 The Simulation of the Existing Fertilizer Handling in Partner-Port

Total Unloaded Fertilizer Per 24 hours (Tons)	The Average Queue Time (Hours)
6600	1.3

4.1.6 Scenarios and Experiments

Experiments are conducted by adjusting decision variables, i.e. the number of trucks and truck capacity. While, the response variable is the target amount of fertilizer unloaded within 24 hours, i.e. 6496 tons. The current number of trucks available is 30 units. Each truck has a minimum allowed capacity in the amount of 28 tons and the maximum allowed capacity in the amount of 30 tons.

Furthermore, scenario is set to minimize the amount of truck in duty without additional costs.

Set Scenario-1: 8 units operation, capacity of each truck is 30 ton.

Set scenario-2: 25 units operation, capacity of each truck is 29 ton.

Those two scenarios simulation-result is reported in Table 8.

Table 8 Scenarios 1 & 2 Execution Summary Compared to Existing Operation

Replication	Existing Operation	Scenario 1	Scenario 2
1	6660	6480	6554
2	6570	6480	6554
3	6600	6570	6554
4	6570	6570	6554
5	6660	6540	6554
6	6660	6510	6554
7	6690	6510	6554
8	6570	6510	6525
9	6450	6510	6554
10	6570	6480	6554
Average	6600	6516	6551.1

4.1.7 Scenarios and Output Testing

The scenarios and output are then compared using one-way_ANOVA. This technique is conducted to check the difference between the outputs of the existing fertilizer models with the proposed scenarios.

Analysis of Variance (ANOVA) separates the total variability in the data sample into two parts. Then, hypothesis is tested to compare two independent estimation of the population variance. The total variability in the data is described as a total sum of squares (Montgomery, 2003). The author employs SPSS to manage such test and the result is reported in the Table 9.

Table 9 One-Way-ANOVA-test using SPSS 16

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	35597.400	2	17798.700	8.551	.001
Within Groups	56196.900	27	2081.367		
Total	91794.300	29			

Consider Table 9, the significance value is less than the value of α (<0.05). Thus, the H0 (the initial hypothesis) is rejected. It means that the result of scenario 1 and 2 have the significant difference value with the value of existing operation. Then, examine those differences by Least Significance Difference (LSD) method (Harrell, 2000), and the result is given by the following calculation:

$$t_{(df(error),\alpha/2)} = t_{(27,0.025)} = 2.05 \quad (5)$$

$$LSD_{(\alpha)} = t_{(df(error,\frac{\alpha}{2})}\sqrt{\frac{2(MSE)}{n}} = 2.05 \times \sqrt{\frac{2 \times 208136}{10}} = 41.86 \quad (6)$$

Furthermore, the authors calculate the absolute value of the difference between two compared models. The significant value is achieved when:

$$|\overline{x_1} - \overline{x}_2| > LSD_{(\alpha)} \quad (7)$$

Table 10 Least Significance Difference Test Result (manual-calculation)

	Scenario 2	Scenario 1
	$\bar{x}3 = 6551.1$	$\bar{x}2 = 6516$
Existing Operation $\bar{x}1 = 6600$	$\lvert \bar{x}1 - \bar{x}3 \rvert = 48.9$ Significant (48.9 > 41.86)	$\lvert \bar{x}1 - \bar{x}2 \rvert = 84$ Significant (84 > 41.86)
Scenario 1 $\bar{x}2 = 6516$	$\lvert \bar{x}2 - \bar{x}3 \rvert = 34.9$ Insignificant (34.9 < 41.86)	

According to the Table 10, it can be concluded that the existing models in compare to the both scenario 1 and 2 have significant different, but between scenario 1 and scenario 2 itself does not have a significant distinction. Afterward, SPSS 16 is employed to confirm the manual-calculation. The SPSS performance is given in the Table 11.

Table 11 SPSS Performance of LSD - Calculation

(I) Model	(J) Model	Mean Difference (I-J) *	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Existing	Scen. 1	84.0*	20.402	.000	42.1370	125.8630
Operation	Scen. 2	48.9*	20.402	.024	7.0370	90.7630
Scen. 1	Existing	-84.0*	20.402	.000	-125.8630	-42.1370
	Scen. 2	-35.1	20.402	.097	-76.9630	6.7630
Scen. 2	Existing	-48.9*	20.402	.024	-90.7630	-7.0370
	Scen. 1	35.1	20.402	.097	-6.7630	76.9630

*. The mean difference is significant at the 0.05 level

SPSS performance of LSD-calculation in Table 11 shows the same results with the prior manual calculation. It is seen that each model has a significant difference in the value $\alpha = 0{:}05$. However, the comparison between the model of scenario 1 and scenario 2 has no significant difference. So, it can be concluded that the result of scenario 1 and 2 have a prospective contribution to produce a better operation and productivity since it has significant difference values to the existing operation. The summary of all simulation results is presented in Table 12. It also considers the average queue time that occurs in the system. This queue time is calculated from a simulation of processing time which is provided in Table 4.

Table 12 The Summary of All Simulation Results

Model	Truck Quantity (Unit)	Truck Capacity (Ton)	Average Fertilizer Unloaded in 24 Hours (Ton)	Average Queue Time (Hour)
Existing Op.	30	30	6600	1.3
Scenario 1	8	30	6516	0.14
Scenario 2	25	29	6551.1	1.02

4.2 Discussion

There are six stages have to be performed in this study. These stages declared beforehand using formal specifications. Set of orders and performance-indicators are stated per stage in a matrix-form in order to conduct the research in a structural way (see Table 13, 14).

Table 13 Matrix of Research Stages I – IV

		Activities	Test & Verification
STAGE I	Order	Observation, Interview & Problem Identification	Conceptual Model Verification
	Performance Indicators	Scope (Research-boundary) Conceptual Model (Entity-Diagram)	Interview
STAGE II	Order	Data Collection	Data Testing
	Performance Indicators	Requirements Facts Assumptions	Data-adequacy Test Data-fit Test (ProModel)
STAGE III	Order	Model Design (ARENA)	Model Verification (ProModel)
	Performance Indicators	Determine the modules Model the Existing Operation	Replication Adequacy Test
STAGE IV	Order	Simulation (ARENA)	Simulation Verification (SPSS)

Table 14 Matrix of Research Stages V – VI

		Activities	Test & Verification
STAGE V	Order	Scenarios Design and Experiments (ARENA)	Output Testing (SPSS)
	Performance Indicators	Set Scenario 1 Set Scenario 2 Set Scenario n	One Way ANOVA Least Significance Difference
STAGE VI	Order	Presentation	Discussion & Final Verification
	Performance Indicators	Determine the Best Scenario	Judgement from Expert / Community

The research stages have to be well documented. All detail occurs during preparation, research and experiments must record. The study is executed in a structural way using formal specification that has been defined earlier. Authors also practice simulations and verify using several tools, i.e. ProModel, ARENA and SPSS. Moreover, several verifications, e.g. data-fit test, replication test, One Way ANOVA and Least Significant Difference are double checked by manual calculation as well.

4.2.1 Simulation of the Actual Case

According to the existing-operation, it is noticed that the average queue time experienced by one truck in 24 hours is 1.3 hours.

Thus, it can be analyzed as follows:
*) The existing operation is handling 6600 tons per day.
*) 6496 tons / 30 tons = 220 rounds, carried by 30 trucks
*) 220 rounds / 30 trucks = 7.33 rounds ≈ 8 rounds

Therefore, in average 1 truck takes 3 hours to complete one round:
24 hours / 8 rounds = 3 hours per truck.
This calculation has proven that the existing operation meet the target (6496 tons) even by practicing waste of resources and time.

4.2.2 Simulation of the Proposed Scenario

The actual operation, Scenario 1 and Scenario 2 have unloaded 6600 tons, 6516 tons and 6551.1 tons respectively (see Table 9). All states meet the fertilizer handling target, because the firm only expects at least 6496 tons released per 24 hours.
The next performance should be considered is the queue time. Refers to the summary (see Table 9), the minimum queue time is produced by Scenario I. It uses 8 trucks in capacity of 30 tons per truck during 24 hours operation. Scenario 1 has able to handle fertilizer in average of 6516 tons during 24 hours and produce average queuing time only 0.14 hours. Eight trucks operation would not consume a lot of waiting time and keep transport round

by round without significant queue time. Such scenario could only be applied at the following assumptions: there is no down time; fair weather; and the truck driver breaks on the certain-schedule. Simple analysis of the scenario can be directed by the following calculation.

*) The scenario 1 is handling 6516 tons per day.
*) The laps made by 8 trucks are 6516 tons / 30 tons = 217.2 rounds. *) Each truck duty within 24 hours: 217.2 rounds / 8 trucks = 27.15 rounds.

Therefore, in average 1 truck takes 0.884 hours to complete one round: 24 hours / 217.15 rounds = 0.884 hours per truck.

There is a decreasing number of a round trip that performed by scenario 1. The actual operation creates 220 rounds and the scenario 1 only 217 rounds. The comparison becomes expressive when it is viewed from the reduction of the truck used, where the existing operation employ 30 units of trucks and the scenario 1 only use 8 trucks. The proposal of 8 trucks operation is significantly reduce 22 trucks utilization per day. These 22 trucks can be more productive to be used for another duty. The other significant improvement is that the Scenario 1 reduces the queue time on the weighbridge until 0.14 hours. Consequently, the reduction of resources utilization and queue time will diminish the total fertilizer handling cost in the Partner-Port Exactly at a certain point, a reduction in the waiting time and the cost of resources will produce the optimal total cost (see Figure 10).

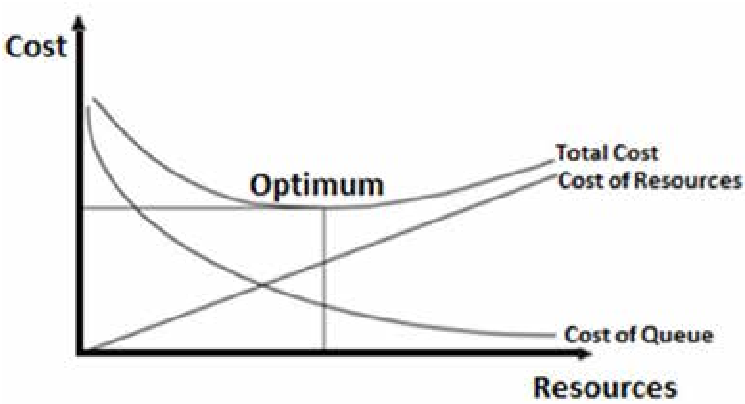


Figure 10 Cost vs Resources Relationship

5 Conclusion

The study of fertilizer handling process in the partner-port has been conducted. A new procedural technique that combines statistical, modeling, simulation and validation have been developed employing several tools and managed in a structural way using formal specification method.

Conceptual entity diagram, data collections - assumptions following by fitting a theoretical distribution of the data are demonstrated to models fertilizer handling. The handling process can be sequenced as handling fertilizer from the ship towards the hopper, from the hopper into the truck tailgate, weighing procedure, the warehouse unloading, transport from the Hopper to the Weighbridge, transport from the Weighbridge to the Warehouse, transport from the Warehouse to the Weighbridge and transport from the Weighbridge to the Dock.

In the last stage, all data that are resulted from the experiments are calculated. The outputs are then compared using ANOVA test group to examine the significant contribution of the alternative scenarios. Furthermore, the Least Significance Difference (LSD) used to review a significance difference value of that contribution.
The actual fertilizer handling has been simulated. It is found that the average productivity of the current system is 6600 tons using 30 units of trucks and generates average queue time of 1.3 hours. It is also reported that in the actual case, every truck takes 3 hours to complete one round.
After several experiments and validations, it can be reported that optimal truck to serve the daily fertilizer handling is eight units in the capacity of 30 tons per unit. The optimum productivity of daily fertilizer handling in the partner-port based on the best simulation result (scenario 1) and validation is 6516 tons. This operation reduces average queue time until 0.14 hours.

References

Agerschou, H. L., & Sørensen, T. (1983). Planning and Design of Ports and Marine Terminals. New York: John Wiley & sons.

Bugaric. U, P. D. (2007). Increasing the capacity of terminal for bulk cargo unloading. Simulation Modelling Practice and Theory Vol. 15, 1366–1381.

Cassettari, L. (2012). Sizing of a 3.000.000t Bulk Cargo Port Through Dis-crete and Stochastic Simulation Integrated With Response Surface Methodology Techniques. International Journal of Systems Applications Engineering & Development-Issue 1, Volume 6, 89-97.

Classen, A., Cordy, M., Heymans, P., & Legay, A. (2012). Formal semantics, modular specification, and symbolic. Science of Computer Programming vol 80, 416–439.

Dahal, K. (2007). Modelling, Simulation and Optimisation of Port System Management. International Journal Agile System and Management. Vol.2, No.1, 92-108.

Edgar, S.-M., & David, M.-V. (2014). State of the Art in the Research of Formal Verification. Ingeniería, Investigación y Tecnología, Volume 15, Issue 4, 615-623.

El Sheikh, A., J.R. Paul, J., S.A. Harding, S., & Balmer, W. (1987). A microcomputer-based simulation study of a port. Journal Operation Research Society Vol 38, 673-681.

Esmer, S. A. (2010). A Simulation for Optimum Terminal Truck Number in a Turkish Port Based on Lean and Green Concept. The Asian Journal of Shipping and Logistics. Vol.26, No.2, 307-327.

Harrell, C. (2000). Simulation Using Promodel. United States of America: McGraw Hill Higher Education.

Kondratowicz, J. (1990). Simulation methodology for intermodail freight transportation terminals. Simulation Vol. 51, 49–57.

Montgomery, D. (2003). Applied Statistics and Probability for Engineers. United States of America: John Wiley & Sons Inc.

Navimipour, N. J. (2015). A formal approach for the specification and verification of a Trustworthy Human Resource Discovery mechanism in the Expert Cloud. Expert Systems with Applications, Volume 42, Issues 15–16, 6112-6131.

Park, S., & Noh, D. (1987). A port simulation model for bulk cargo operations. Simulation Vol. 48, 236–246.

Pjevčević D., V. I. (2013). Analyzing The Efficiency Of Dry Bulk Cargo Handling At The Inland Port Terminal using Simulation and DEA. 1st Logistics In-ternational Conference. Belgrade, Serbia.

Purnomo, H. (2004). Pengantar Teknik Industri. Yogyakarta: Graha Ilmu.

Sargent, R. G. (2005). Verification and Validation of Simulation Models. Winter Simulation Conference. Orlando, FL, U.S.A.

Zengin, A., & Ozturk, M. M. (2012). Formal verification and validation with DEVS-Suite: OSPF Case study. Simulation Modelling Practice and Theory 29, 193–206.

Zhao, Y., & Rozier, K. Y. (2014). Formal specification and verification of a coordination protocol for an automated air traffic control system. Science of Computer Programming, Volume 96, Part 3, 337-353.

II.
Data-driven Approaches for Efficient Process Management

Big Data and Agricultural Supply Chains: Opportunities for Increased Food Security

Dimitrios Tsiolias, Christos Keramydas, Eleftherios Iakovou and Dimitrios Vlachos

Today's interconnected digital world with its multitude of data-collecting devices and means along with augmented data processing capabilities has unlocked new possibilities for increasing the efficiency of contemporary agricultural supply chains, including production, processing and distribution operations. Furthermore, issues such as climate change, global population increase, the rise of alternative energy sources, agricultural technological advances, and shifting consumer dietary preferences have been reshaping the global contemporary food management landscape. These factors, in conjunction with the limited availability of arable land, present challenges regarding the availability, accessibility, utilization, and stability of food worldwide. We present an up-to-date critical synthesis of the most acute challenges of food security and provide a first effort at identifying ways in which big data could help alleviate them. Specifically, satellite imagery and data, groundwater monitoring, the Internet-of-Things (IoT), viewing advantages through the use of drones, updated global atlases, as well as regional and crop yield mapping, precision agriculture, demand prediction accuracy, and the ease-of-use of terminals such as smartphones and tablets are some of the tools of the information age that demonstrate great potential towards increasing the efficiency and competitiveness of food chains worldwide and, ultimately, ensuring food security.

Keywords: Big Data, Food Security, Agricultural Supply Chains, Sustainability

1 Introduction

According to the Declaration of the World Summit on Food Security (Food and Agriculture Organization (FAO) of the United Nations, 2009), food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their needs and food preferences for an active and healthy life (FAO, 2009). Nowadays, in the developing world, lack of food security, i.e. food insecurity, is primarily related to chronic hunger, while the main concerns in the developed world are obesity, and micronutrient deficiencies. Furthermore, four dimensions of food security emerge through the aforementioned definition, i.e. food availability, physical and economic access to food, food utilization, and their stability over time, while food security also embraces energy, protein and nutrient needs for life, activity, pregnancy, growth and long-term capabilities of both individuals, and population as a whole (FAO, 1996). Although food availability is historically a vital key-pillar of food security, mainly through domestic agricultural production, access to food arises as a pivotal concern for achieving food security in modern societies. Of course, food security has also an intrinsic relation to sustainability and sustainable agriculture, i.e. the capacity of agriculture over time to contribute to the overall welfare by providing sufficient food and other goods and services in ways that are economically efficient and profitable, socially responsible, and environmentally sound (United Nations Conference on Sustainable Development, 2012).

Despite the progress being made during the last two decades through the actions developed within the first of the Millennium Development Goals (MDG), i.e. towards the eradication of extreme poverty and hunger that were established through the Millennium Declaration following the Millennium World Food Summit (WFS) of the United Nations in 2000, there is still a long way to go. Indicatively, although the MDG of halving the prevalence (proportion) of hunger up to 2015 will be mostly achieved, falling from 23.4% in 1990 to 12.8% in 2015 (projection), the more ambitious target set by the World food Summit of halving the number of undernourished people, will actually be far from being met (missing the target by almost 300M people, FAO-IFAD-WFP, 2014). Although people chronically undernourished declined by approximately 100M during the last decade, the total number of people suffering from chronic hunger is still high estimated to approximately 805M people. Additionally, there are also about 2,000M people suffering from micronutrient deficiencies (hidden hunger) (von Grebmer et al., 2014), and more than 600M people suffering from obesity (Ng et al., 2014).

Additionally, in the foreseeable future, external forces such as, indicatively, climate change, the global population increase, the rise of alternative energy sources, the agricultural technological advances, the existing high volumes of food waste, and the changes of the dietary preferences underline the global contemporary food management landscape by directly threatening food security. Furthermore, the recent food security crisis of 2007-2008 brought food insecurity to the forefront of the global sustainable development agenda highlighting the need to reconsider the structure and operations of international agrifood supply networks, and to streamline the relevant policy-making. In terms of availability, domestic food agricultural production remains the main source of food, income, and employment in rural areas. However, the access to food is becoming a major concern for the global community, as there are increasing difficulties regarding access to food for net buyers and other vulnerable groups that require policy interventions e.g. strengthening safety nets, social protection, etc., in order to be tackled. Additionally, the stability of the global food system is under threat, as conflicts, natural disasters, price hikes, and even poor governance usually trigger prolonged crises with severe impacts on food security. Moreover, regarding the utilization dimension, inappropriate diet changes over time give rise to obesity and diet-related non-communicable diseases, while in those countries undergoing rapid transformations, undernutrition and overnutrition coexist resulting in the double burden of malnutrition.

On the other hand, the ongoing advances in the field of Information and communications technology (ICT) that is widely known as “big data” appear as a promising contribution in mitigating the aforementioned challenges. Big data refers to the availability of large amounts of different types of data produced with high velocity from a high number of various types of sources, as well as the new tools and methods, such as powerful processors, software and algorithms that are required in order to handle today's highly variable and real-time datasets (EC, 2014). In terms of food security and agriculture, the potential advances in weather prediction (including severe and unseasonal weather), food security tracking, real-time monitoring of dietary habits, precision agriculture, field mapping and soil management, crop yields assessment, pinpoint irrigation and application of nutrients demonstrate great potential towards establishing a sufficient and balanced food supply for earth’s growing populace.

In this context, food security is considered to be one of the most promising sectors, where leveraging the potential of big data advances in near future could prove to be a literally life-changing step towards reinforcing agricultural production, and eliminating undernourishment and poverty within a sustainable development context (EC, 2014). Furthermore, big data has been recognized to have a pivotal role in increasing the efficiency of planning and operating the global food system, as well as in supporting policy development and strategic decision-making on the external factors driving its change at national and global level (Foresight, 2011). Moreover, the MDG's Report in 2014 accepts the critical role of data in global sustainable development and policy-making, as it recognizes that reliable and robust data are critical for devising appropriate policies and interventions for the achievement of the MDGs and for holding governments and the international community accountable (UN, 2014).

This paper aims to investigate the potential of big data tools, methodologies, and practices that could be employed in order to reinforce global food security, or, alternatively, to control and efficiently manage global food insecurity, and the ways that this goal could be achieved. Specifically, the major food challenges that stakeholders, such as citizens, governments, and national and international organizations, will have to cope with in the immediate future within a sustainable food security framework, are identified. Moreover, the contribution of big data in mitigating these challenges is also captured and discussed.

The remainder of the paper is organized as follows: in Section 2, the future challenges regarding food security are identified, while the big data potential in efficiently managing these challenges is discussed in Section 3. Finally, pivotal conclusions and meaningful insights are drawn in Section 4.

2 Food Security Future Challenges

The main characteristic of modern food security crises is that despite the fact that the world community has sufficient food to nourish the entire global population, as well as the means to substantiate it, a significant fraction of the overall global population is still living in poverty, lacking access to vital food products (FAO, 2011). To that effect, the overall problem of food insecurity appears to be a lack of systemic interdisciplinary policy-making schema of the globalized food markets and supply networks, where critical stakeholders such as domestic governments and international organizations have the responsibility to guide the world towards food security in a resource efficient and sustainable manner.

Increasing world population seems to be the main threat to food security in the next 35 years. Although the population growth rate seems to be reducing, FAO projects that global population will increase to 9.15 billion people by 2050, nearly 2 billion more than today (Alexandratos and Bruinsma, 2012). At the same time, arable soil is becoming scarcer every year, mainly due to urbanization and agriculture intensification. These factors will bring a gross mismatch between food demand and supply: there simply will not be enough land to produce the food required for the world population's sustenance, given today's land utilization, crop yields and food production and processing techniques. Therefore, agriculture in general will inevitably have to become more efficient to overcome this conundrum (National Geographic, 2015); an additional increase of 50% in food production is required in order to sustain the soaring demand (Charles et al., 2010).

Increasing food consumption per capita exerts further pressures on global food availability. The global GDP is expected to be 2.5 times of what it is today by 2050, while per capita income will also increase by 80% (Alexandratos and Bruinsma, 2012). This, in turn, will cause the average per capita food consumption to increase in terms of kcal/person/day, driving the demand for agricultural products to increase by 60%, more than twice the population rise, which is expected to be about 25%.

Fluctuation of global food prices (Gandhi and Zhou, 2014; Lawrence, Lyons and Wallington, 2010) is another critical factor that affects food security and was the main cause that brought food insecurity to the forefront in the recent past (2007-2008). In general, higher food prices significantly limit the purchasing power of consumers in developing countries, where 60%-80% of the household spending is directed to food products (10%–20% in developed countries) (UNCTAD, 2009), imposing critical limitations to food accessibility.

Food waste is another open issue that critically affects food security. It is estimated that up to one third of all food produced never reaches the consumers' plates. This in turn, means that a staggering 250 cubic kilometers of water are used and 3.3 billion tons of greenhouse gases are produced per year for no reason, inducing an annual cost of 750$ billion to the world economy (FAO, 2013). These facts greatly highlight the need for interventions targeted towards the improvement of the production, collection, processing and distribution of food worldwide.

Changes in dietary preferences from traditional foodstuff towards higher consumption levels of meat, soya, bread, and processed foods in tandem with the high level of diversification of urban diets have significantly altered the global food production and distribution landscape (Gandhi and Zhou, 2014). "Western-type" diets, which are based more on livestock, rather than raw fruits and vegetables, put a strain on agricultural production, because of the increased need for animal feed and fertile grazing land. Animal husbandry is inherently more resource-heavy than crop raising; about one third of the world's crop calories are fed to livestock, of which the conversion rate to consumable calories varies from 3% to 40% (National Geographic, 2014). On the other hand, population in many developed and even developing countries suffer from overnutrition, e.g. overweight, obesity, and other chronic diseases related to dietary preferences, (Foresight, 2007). Urbanization, including human settlement and urban infrastructure (e.g. roads, housing, etc.), plays also a key role in cropland reduction (Porter et al., 2014). It is estimated that the ratio of built-up area to cropland area will double by 2050 (from 3.5% in 2000 to 7.0% in 2050), creating an additional threat to food availability and accessibility. Moreover, urban markets provide a fertile ground for the establishment of global supermarket chains, with important implications on food supply chains, while urbanization contributes also in altering consumer preferences towards urban diets of high diversification, and strengthens the gaps between urban and rural populations in terms of transportation, prices, and market homogeneity.

The decline in agricultural investments and lack of sufficient infrastructure is another factor that prevents increase in crop yield around the globe (United Nations Environment Programme, 2009; World Bank, 2008). At the same time, lack in relevant investments further inhibits the growth of domestic production, mostly in developing countries, while the existing funding schemes aim only at fostering self- sufficiency of domestic populations (Anderson, 2010).

Technological advances in agriculture, including seed technology (hybrids and genetically modified crops), fertilizers, and farm machinery, have a critical contribution in the increase of crop yield and agriculture productivity (Dobermann and Nelson, 2011). On the other hand, these beneficial effects are also debatable regarding the way that they are achieved in practice, as they allow for the concentration of economic and decision-making power to just a few agrochemical companies and grain traders (Branford, 2011).

Environmental concerns raised globally during the last decades, regarding greenhouse effects and climate change in general, triggered significant changes in the energy landscape (Porter et al., 2014). In this context, the perception that biofuels, e.g. biodiesel and ethanol, could potentially play a key role in reducing greenhouse gas emissions, especially in the field of transportation (EU target: 10.0% share of the fuel mix by 2020), led to a rapid increase in their production and demand (FAO, 2006), thus rivaling agricultural production in terms of cropland use, which potentially could have critical implications on food availability.

Global climate change directly affects food production, mainly in terms of crop yield, imposing a great degree of variability (Pangaribowo, Gerber and Torero, 2013). Specifically, storms of high intensity, forest fires, droughts, floods and heat waves occur more frequently, while still difficult to be predicted, thus threatening food stability around the globe, especially in developing countries which are more vulnerable due to their agricultural-based economies. Also, given that agriculture accounts for 70%-85% of the total global water consumption, it is unnecessary to mention that the impeding threat of water scarcity endangers health, mainly of rural populations, and farmer productivity (United Nations Environment Programme, 2009). Melting glaciers in Central Asia and droughts in Africa are just two examples that highlight the importance of water availability on farm production and livestock breeding.

Trade is another critical factor that determines global food security (Pyakuryala, Roy and Thapa, 2010). In the current food trade terrain, developed countries and a few international corporations exert control either over food consumption in developing countries, through their export policies, or food production, through the purchase of cropland (Branford, 2011). As a consequence, developing countries are gradually becoming more vulnerable in terms of domestically produced food quantities, high prices, and land ownership. Furthermore, trade is also a factor that shapes consumer preferences and diets around the globe (United Nations Environment Programme, 2009).

International wars, internal conflicts, and economic embargoes introduce crucial uncertainties to global food supply networks by vitally undermining their stability performance in terms of supply capacity and continuity (United Nations Environment Programme, 2009).

Governance plays also a key role in food security issues, given that policy-making and diplomacy are among the core factors that shape the global food security landscape (Branford, 2011), while they are crucial for the success of both policies and programmes that are formulated and implemented in the complex modern social, political and economic environments (FAO-IFAD-WFP, 2014). Issuing protective trade regulations, maintaining beneficial international affairs, protecting domestic cropland property rights, and ensuring food self-sufficiency are a few of the most challenging decision-making fields where governments have to take targeted action in the near future.

Monitoring of the global food system in general is a prerequisite in order to achieve efficient policy-making. The United Nations have recognized the need for improving food security monitoring and metrics, and thus, the requirement for stronger systems of assessment, monitoring and surveillance, as one of the aims of their Comprehensive Framework for Action (High Level Task Force on the Global Food Security Crisis, 2010). Towards this direction, the role of big data is identified to be more than critical (Foresight, 2011).

3 Big Data Solutions

Accurate weather predictions are of pivotal importance on a strategic and tactical planning level for agricultural production. Besides the obvious importance of temperature and rainfall, environmental conditions affect a number of relevant parameters, such as pests and diseases, carbon dioxide and ozone concentrations, and sea level. Additionally, the shifting climate has been the source of many extreme weather events, such as hurricanes, extreme droughts or floods and heat and cold waves (IPCC, 2014).

The ability to forecast weather conditions and to foresee extremes can be greatly augmented both in terms of range and accuracy through the collection and processing of weather data on a massive scale. The consolidation of weather data collection systems and the building of larger and more complex models backed up both by past observations and real time information can vastly improve meteorological reports. A key observation is that data collection does not necessarily require the installation of specific and expensive equipment. Ever since 2013 with Samsung's introduction of the Galaxy S4 phone model, smartphones have slowly started to include more advanced sensors such as barometers, hygrometers, ambient thermometers and light meters, all of which provide key meteorological data (Johnston, 2013). Additionally, other methods have been put forth, such as correlating a phone's battery temperature with the ambient temperature (Overeem et al., 2013) and collecting Twitter users' own reporting of the weather conditions in their respective areas through monitoring trending weather-related words (commonly known as "hashtags", for example #rain, #sunny, or #humid) (Henschen, 2014).

Precision Agriculture (PA) has been used in practice since the late 1980s, following the commercial availability of the Global Positioning System (GPS). PA consists of observing and analyzing the variability of crops in a field or between fields to aid Site Specific Crop Management (SSCM). In practice, devices ranging from traditional photographic cameras to infrared cameras and sensors that detect the amount of reflected light from plants are mounted on a tractor or similar farming equipment and with the help of satellite-based positioning a map of the field can be designed; this can be used to make decisions about soil treatment, irrigation, and fertilization. However, variables affecting crop yield exhibit both spatial and temporal variations. Therefore, defining specific management zones within a field of a particular crop can prove troublesome (McBratney et al., 2005), while tracking changes over time requires constant or often repeated monitoring, which is often proven to be expensive and time consuming.

The emergence of big data can usher a new era of PA. The commercial availability and ease of use of Unmanned Aerial Systems (UAS), commonly referred to as “Drones”, greatly augments a farm’s data collecting capabilities. Additionally, sensors monitoring variables such as moisture, nutrients and pests are now commonplace in most farms. All this massive amount of data can be collected wirelessly and then fed through cloud technology to processing systems specialized in handling such data, far away from the farm itself, the result being accurate field mapping, both spatially and temporally. The ultimate goal of big data-fueled PA is building and maintaining a real-time decision support system for farm-wide management aimed towards the optimization of returns on inputs while preserving resources. Careful and precise application of all factors that go into agricultural production can maximize crop yields, minimize waste, pesticide, and water usage and, ultimately, provide more and cheaper produce.

One key aspect demanding further scrutiny is minimizing water usage. Today, 18 countries containing almost 4 billion people are overpumping their water reserves to the point of exhaustion in order to produce grains (Brown, 2013). In a world where drought and desertification consume 12 million hectares of arable land each year (United Nations), managing water is one of the key challenges for sustainable agriculture. A big data supported

irrigation system can dynamically evaluate moisture content and dispense water as needed, cutting down on the excess use of this valuable resource.

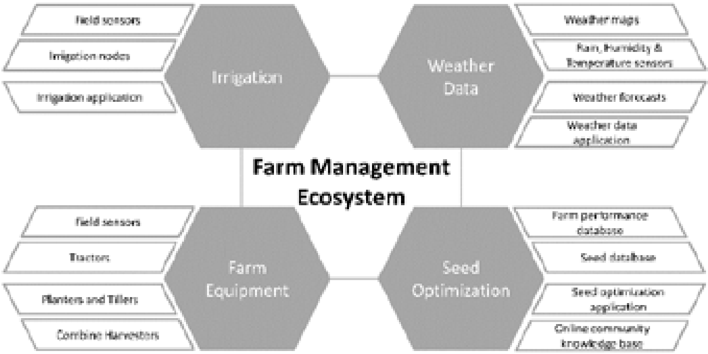


Figure 1 A data-governed farm management system (adapted from Porter and Heppelmann, 2014)

Ultimately, with the emergence of concepts such as the "Internet-of-Things" (IoT - connected devices and components communicate with other devices and the Internet, Morgan, 2014) and the wide adoption of cloud services, all farm functions will become part of a larger ecosystem. Such a digital superstructure will be able to collect and analyze vast amounts of data and adjust the allocation of resources dynamically and efficiently, while simultaneously providing useful insights and communicating information throughout the agrifood value chain (Porter and Heppelmann, 2014).

Another aspect of the big data era that agriculture can benefit from is its interlaced existence with "Web 2.0". Web 2.0 refers to the modern era of the World Wide Web that centers on user-generated content, usability, and interoperability, its byproducts being social networks, forums, message boards, wikis, video sharing sites, etc. Previously, the world's agricultural knowledge was segmented, leaving producers with their own intuition or the expertise loaned from seed companies or third-party consultants. As a consequence, up to 70% of agricultural production costs are focused on decisions of seed selection, fertility, and land access (Darr, 2014). Today, booming communities exist online where they can easily be accessed by individual producers through the widespread adoption of smartphones and tablets and serve as a place to exchange advice and crop management techniques, “dos and don'ts” and information about pricing and commodities values. Additionally, initiatives towards publicly available community-based knowledge databases are emerging trends. The vast amount of information about seed and crop varieties is collected and enriched by individuals, systematically categorized and easily accessed by producers, aiding them in the relevant decision taking. Open Data knowledge bases such as the Global Open Data for Agriculture and Nutrition (www.godan.info), the Plantwise Knowledge Bank (http://www.plantwise.org/KnowledgeBank/home.aspx), and the Food and Agriculture Organization of the United Nations’ own statistical service, FAOStat (http://faostat.fao.org/), have become useful tools in the hands of producers worldwide in their effort towards more efficient production (van Vark, 2013).

The collection and processing of vast amounts of data from various sources, which is at the heart of the big data concept, has made techniques such as genomic selection possible. Genetic modification has made an ever-increasing assortment of plant varieties available, each with its own characteristics and trade-offs (e.g. water requirements, resistance to extreme weather conditions and/or pests etc.) (Kinver, 2014). Genomic selection utilizes statistical modelling to forecast how a specific variety of plant will perform, well before it has to be field tested. An example of this is Cornell University's Nextgen Cassava project (http://www.nextgencassava.org/). The cassava crop serves as the main calorie source for more than 500 million people in the world. The project evaluated and categorized the results of multitudes of breeding projects, with the end result being an open access database containing all the information about cassava breeds and their cultivation (http://www.cassavabase.org/).

Summing up, the contribution of big data in this aspect is twofold: On one hand, paired with improved weather forecasts, the accuracy of yield predictions can be significantly boosted. Ultimately, producers take a huge gamble each and every year concerning their choice of what to grow and how to treat it, and being able to better foresee the outcome of their efforts leads to informed decision-making, optimizing both the production of food worldwide and the state of agriculture as a whole. On the other hand, the public availability of information eliminates margins of market manipulation, prices inflation and other shadowy dealings responsible for the high prices both in agricultural production inputs (seeds, fertilizers, chemicals, etc.) and in the food produced. This will fundamentally lead to fair pricing and, subsequently, improved access to food worldwide.

Food traceability has been a major concern for the past years. As early as 2000, the European Commission adopted a consolidated approach to food safety, covering all stages of the food chain, "from farm to table". (European Commission, 2000) in which "the ability to track any food, feed, food-producing animal or substance that will be used for consumption, through all stages of production, processing and distribution" (European Commission, 2007) serves as a cornerstone. Traditionally though, traceability has been mainly implemented as tags containing basic information such as country of origin, destination, and production date in the form of barcodes or even handwritten labels. Firstly, it is obvious that this information can easily be manipulated, and secondly it is missing vital characteristics of the product pertaining its processing, storage and transport (appropriate temperature, humidity etc.). In the US, 48 million people get sick annually from eating tainted food, of which 128,000 are hospitalized, and 3,000 die (CDC, 2011). In response, the US government signed The Food Safety Modernization Act (FSMA) into law (to be enacted within 2015), which mandates traceability from-farm-to-fork across the entire lifecycle – from source to finished product. A big data-powered solution could take the form of microsensors in food lots measuring all the relevant information that ensures its quality and storing them in advanced tags, which could be either Quick Response (QR) codes, or Near Field Communications (NFC) cards. By reading these tags through easy-to-use terminals (smartphones and tablets) both food handlers and consumers can have an instant view of everything that led a particular product to them. Simultaneously, and with the combination of cloud technology, agrifood supply chains can have real-time visibility of their products and their condition throughout their every stage. This will ultimately lead to improved efficiency of food chains worldwide and significantly less food waste that could be otherwise used to feed starving populations.

4 Conclusions

Food security is undoubtedly one of the most pressing matters of sustainability for the future, with practical, as well as humanitarian implications. Its major challenges include adequately feeding the world's expanding population, while simultaneously closing the gap between the epidemic of obesity in the western world and hunger in developing countries. Considering the world's limited resources, the path to food security lies through the enhancement of agriculture's efficiency throughout all of its stages: planting, growing, collecting, processing and transporting. Agrifood chains will have to ameliorate their capabilities to turn production inputs into food and feed to keep up with growing demand, by cutting down improvidence, extravagance and misuse, or, as the old adage goes, "waste not want not". Luckily, the Information Era and the explosion of big data can provide with a multitude of readily available or in development solutions aimed at enabling growth and productivity in all of agri-production's strata.

The amalgamation of Agriculture and big data has been heralded as the greatest advance in food production technology since the Green Revolution between the 1940s and the late 1960s when one of the biggest waves of research and technology transfer spurred the growth of agricultural production around the world, especially in developing countries (Hazell, 2009). The ability to collect and process vast amounts of observations pertaining to food production and the ease of presentation and manipulation of the results can support the relative decision-making process and facilitate efficacy, competence and growth. In this article, we presented anecdotal references from big data applications in the real-world and further presented opportunities for further unlocking its potential in order to boost the performance of agricultural production. There is strong evidence suggesting that harnessing the capabilities that big data has to offer can be of great service towards securing adequate and nutritious food in the future. It is our hope that this work will spur further research, both qualitative and quantitative, into this promising subject matter.

Acknowledgements

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References

Alexandratos, N. and Bruinsma, J., 2012. World agriculture towards 2030/2050: the 2012 revision. Rome: Food and Agriculture Organization of the United Nations.

Anderson, K., 2010. Globalisation's effects on world agricultural trade, 1960–2050. Philosophical Transactions of the Royal Society B, 365, pp.3007–3021.

Branford, S., 2011. Food sovereignty: Reclaiming the global food system. London: War on Want.

Brown, L.R., 2013. Peak Water: What Happens When the Wells Go Dry? [online] Earth Policy Institute. Available at: http://www.earth-policy.org/plan_b_updates/2013/update115

Centers for Disease Control and Prevention, 2011. CDC Estimates of Foodborne Illness in the United States. [online] CDC. Available at: http://www.cdc.gov/foodborneburden/PDFs/FACTSHEET_A_FINDINGS_updated4-13.pdf

Charles, H., Godfray, H., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J., Pretty, J., Robinson, S., Thomas, S., and Toulmin, C., 2010. Food security: The challenge of feeding 9 billion people. Science, 327, pp.812-818.

Darr, M., 2014. PrecisionAg Big Data Conference: Managing Your Most Elusive Farm Asset is set for August 25, 2014. [online] Integrated Crop Management News and Iowa State University Extension. Available at: http://www.extension.iastate.edu/CropNews/2014/0722Darr.htm

Dobermann, A. and Nelson, R., 2011. Opportunities and solutions for sustainable food production. New York: Sustainable Development Solution Network.

European Commission, 2000. White Paper on Food Safety. Brussels, Belgium: Commission of the European Communities Available at: http://ec.europa.eu/dgs/health_food-safety/library/pub/pub06_en.pdf

European Commission, 2007. Food Traceability Factsheet. Brussels, Belgium: Commission of the European Communities. Available at: http://ec.europa.eu/food/safety/docs/gfl_req_factsheet_traceability_2007_en.pdf

European Commission, 2014. Towards a thriving data-driven economy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM (2014) 442 final of 02 July 2014. Brussels: European Commission.

Food and Agriculture Organization of the United Nations, 1996. World Food Summit: Declaration of the World Food Summit on food security. Rome: Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization of the United Nations, 2006. World agriculture: towards 2030/2050. Rome: Food and Agriculture Organization.

Food and Agriculture Organization of the United Nations, 2009. World Food Summit: Declaration of the World Food Summit on food security. Rome: Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization of the United Nations, 2011. High food prices: the food security crisis of 2007-2008 and recent food price increases – Facts and lessons. [online] Available at: <http://www.fao.org/fileadmin/user_upload/ISFP/High_food_prices.pdf> [Accessed on 28 April 2015].

Food and Agriculture Organization of the United Nations, 2013. Food wastage footprint - Impacts on natural resources. Summary Report. Rome: Food and Agriculture Organization of the United Nations

Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, and World Food Programme, 2014. The state of food insecurity in the world 2014. Strengthening the enabling environment for food security and nutrition. Rome: Food and Agriculture Organization of the United Nations.

Foresight, 2007. Tackling obesities: Future choices. London: The Government Office for Science.

Foresight, 2011. The future of food and farming: challenges and choices for global sustainability (final project report). London: The Government Office for Science.

Gandhi, V.P., and Zhou, Z., 2014. Food demand and the food security challenge with rapid economic growth in the emerging economies of India and China. Food Research International, 63, pp.108-124.

Hazel, P.B.R., 2009. The Asian Green Revolution. IFPRI Discussion Paper 00911. Washington D.C., USA: International Food Policy Research Institute. Available at: http://www.ifpri.org/sites/default/files/publications/ifpridp00911.pdf

Henschen, D., 2014. Bad Winter Weather Meets Big Data Prediction. [online] Informationweek. Available at: http://www.informationweek.com/big-data/software-platforms/bad-winter-weather-meets-big-data-prediction/d/d-id/1114192

High Level Task Force on the Global Food Security Crisis, 2010. Updated comprehensive framework for action. New York: United Nations.

Intergovernmental Panel on Climate Change, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. Geneva, Switzerland: IPCC.

Johnston, S., 2013. WeatherSignal: Big Data Meets Forecasting. [online] Scientific American. Available at: http://blogs.scientificamerican.com/guest-blog/2013/10/11/weathersignal-big-data-meets-forecasting/

Kinver, M., 2014. Mathematics helps find food crops' climate-proof genes. [online] BBC Online. Available at: http://www.bbc.com/news/science-environment-28789716

Lawrence, G., Lyons, K. and Wallington, T., 2009. Food security, nutrition and sustainability. London: Earthscan.

McBratney, A., Whelan, B. and Ancev, T., 2005. Future Directions of Precision Agriculture. Precision Agriculture, 6, 7-23

Morgan, J., 2014. A Simple Explanation of 'The Internet of Things'. [online] Forbes. Available at: http://www.forbes.com/sites/jacobmorgan/2014/05/13/simple-explanation-internet-things-that-anyone-can-understand/

National Geographic, 2014. Feeding Nine Billion. [online] National Geographic Society. Available at: http://www.nationalgeographic.com/foodfeatures/feeding-9-billion/

Ng et al., 2014. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. The Lancet, 384(9945), pp. 766-781.

Overeem, A., Robinson, J.C.R., Leijnse, H., Steeneveld, G.J., Horn, B.K.P. and Uijlenhoet, R., 2013. Crowdsourcing urban air temperatures from smartphone battery temperatures, Geophysical Research Letters, 40, pp.4081-4085

Pangaribowo, E.H., Gerber, N. and Torero, M., 2013. Food and Nutrition Security Indicators: A Review. Foodsecure, Working Paper 04.

Porter, J.R., Dyball, R., Dumaresq, D., Deutsch, L. and Matsuda, H., 2014. Feeding capitals: Urban food security and self-provisioning in Canberra, Copenhagen and Tokyo. Global Food Security, 3(1), pp.1-7.

Porter, M.E. and Heppelmann, J.E., 2014. How Smart, Connected Products Are Transforming Competition. Harvard Business Review, November 2014.

Pyakuryal, B., Roy, D. and Thapa, Y.B., 2010. Trade liberalization and food security in Nepal. Food Policy, 35(1), pp.20-31.

United Nations Conference on Sustainable Development, 2012. Rio 2012 Issues Briefs, No. 9, Food security and sustainable agriculture. New York: UNCSD Secretariat.

United Nations Conference on Trade and Development, 2009. The 2008 food price crisis: Rethinking food security policies. G24 Discussion Paper Series, 56. New York: United Nations.

United Nations Environment Programme, 2009. The environmental food crisis – The environment's role in averting future food crises. A UNEP rapid response assessment. Arendal, GRID-Arendal. Nairobi, Kenya: UNEP.

United Nations, 2014. The Millennium Development Goals Report. New York: United Nations.

United Nations. Desertification Background. [online] United Nations. Available at: http://www.un.org/en/events/desertificationday/background.shtml van Vark, C., 2013. How might open data in agriculture help achieve food security? [online] The Guardian. Available at: http://www.theguardian.com/global-development-professionals-network/2013/nov/25/open-data-food-security-agriculture

von Grebmer, K., Saltzman A., Birol, E., Wiesmann, D., Prasai, N., Yin, S., Yohannes, Y., Menon, P., Thompson, J. and Sonntag, A., 2014. Global Hunger Index: The challenge of hidden hunger. Bonn, Washington, D.C. and Dublin: Welthungerhilfe, International Food Policy Research Institute, and Concern Worldwide.

World Bank, 2008. World Development Report: Agriculture for Development. Washington, D.C.: World Bank.

Intelligent Exchanges and Coordination in Multimodal Supply Chains

René Föhring and Stephan Zelewski

The prototype ORFE of an Online Rail Freight Exchange was developed as part of the CODE24 project. It demonstrates functionalities for a more transparent communication of available transport services and also supports the configuration of multimodal supply chains. The paper describes the efforts and research outcomes of the implementation of ORFE as well as problems that emerged after its finalization. These problems led the authors of this paper to the draft of a new market place concept: Agent-based Freight Exchanges (AFEX). These yet to be implemented, highly automated and interconnected market places are designed to provide autonomous software agents with the infrastructure to perform contractually binding auctions of multimodal freight transport services utilizing a combinatorial exchange model while addressing problems commonly associated with existing market places.

Keywords: Intermodal Transports, Logistics Modelling, Multi-Agent Systems, Combinatorial Auctions

1 Online Freight Exchanges

Organizing freight traffics more efficiently and sustainably has been an important topic for decades, not only for supply chain managers but the logistics community at large. One idea emerging in this context is the more efficient configuration and coordination of supply chains with the help of freight exchanges.

Freight exchanges are marketplaces where offers for and demands for transport services find one another. Contrary to forwarders, which constitute the classic form of freight mediation between shippers and carriers, they themselves are no participants in the processing of transport services. The majority of the companies specializes in the mediation of truck freights. By contrast, multimodal transports are being mediated fewest of all (Merkel and Kromer, 2002).

Since their origination in the 1970s and 1980s the freight exchanges conducted their business primarily via telephone and telefax. With the advent of the internet in the 1990s and 2000s and the rise of e-commerce platforms, new sales channels opened up and provided a more transparent and comprehensive offer for demanders.

2 Establishment of an Online Freight Exchange within the Framework of the CODE24 Project

The joint project CODE24 has been started in the year 2010. For an overview of the project within the INTERREG-IVB-NWE program of the European Union (EU), it is being referred to Brenieck (2014).The primary goal of the project consists in the integration and advancement of the activities on the transport axis no. 24, the main railroad line through the Swiss Alps, which connects the harbors of Rotterdam and Genoa.

The challenges here are manifold: Comprehensive and publicly accessible information on how many freight trains will use the corridor is currently missing. It is also uncertain how much this capacity can be improved through a higher utilization of the existing infrastructure. Finally, a considerable market non-transparency exists for forwarders that take a transport by rail into consideration, especially regarding the connection possibilities to freight transports (Endemann and Kasper, 2012).

As a result, a central component of the project is the conception and implementation of an online freight exchange (Endemann and Kasper, 2011). As a first step towards this goal, the Institute for Production and Industrial Information Management of the University Duisburg-Essen systematically ascertained the requirements for an online rail freight exchange by analyzing the relevant literature as well as interviews and workshops with industry experts (Bruns et al., 2010, Habib and Bruns, 2012, Klippert et al., 2013). Further research results regarding user requirements were contributed by project partners (Dörr and Endemann, 2014, Endemann and Kasper, 2012). One of the most important conclusions was that a freight exchange which only supports rail freight traffic has no realistic market potential. A detailed market analysis consequently showed that no such online freight exchange could establish itself on the European transport market in the long term (Klippert et al., 2013). Especially the transport carrier road has to be involved in order to be able to exhaust the potential of multimodal transport chains.

The software prototype ORFE ("online rail freight exchange") was implemented based on this research. It demonstrates functionalities for the facilitation of contact between potential business partners and the configuration of multimodal supply chains. Since the interviewed experts concluded that future users would hesitate to enter any monetary information, the prototype was built to support the pure mediation between potential business partners. As a consequence, it cannot guarantee contractually binding business transactions as these have to take place outside of the online platform after the contact initiation. For detailed overviews on the concept and development it is being referred to Bruns et al. (2012b) and Föhring and Zelewski (2013).

After the conceptualization and implementation of the ORFE prototype, the project consortium agreed that the final version of the prototype would have to be reimplemented into a commercial software product. Additionally, a viable business model would have to be developed for its operation. For an early review of this work it is being referred to Dörr and Endemann (2014).

It was very important for all questioned project partners and also for other interviewed experts that the future operator of the online freight exchange behaves in an economically impartial way towards all exchange users. This demand can be attributed to the high intensity of competition and mutual distrust in the railway sector (Dörr and Endemann, 2014, Klippert et al., 2013).

Currently there are two potential operators trying to establish themselves on the market (Dörr and Endemann, 2014): "Railcargo-Online" (http://www.direct.rc-o.com/), which since its launch has been integrated into “Cargo Platform” (http://www.cargo-platform.com), and “Freit-One” (http://www.freit-one.de).

Both companies were given access to the ORFE prototype as a working basis and have started operations in late 2013.

3 Real Problems in Operating an Online Freight Exchange

The research around the CODE24 project revealed further obstacles to the successful establishment of an online freight exchange: If the virtual marketplace fails to reach the critical mass and provide a sufficient mediation rate, forwarders and transport carriers will keep settling their transactions the traditional way. Furthermore, freight exchanges are primarily suited for the mediation of transport services that are dealt with through spot markets, but many transports carried out within Europe are still bound to contracts. Therefore a potential exchange has to either control the existing spot market or strengthen the “spot character” of transport services in general (Merkel, 2002).

The requirement analysis for the ORFE prototype showed that the establishment of an online freight exchange in general meets four central real problems:

The first problem is the need for a business model that enables at least the loss-free operating of the marketplace and specifies a fee for every user of the online freight exchange (Bruns et al., 2012a).

The second problem is the disclosure of competition-sensitive data to the future operator. All participants of a centrally organized marketplace are required to submit their data to the central operator in order for him to be able to perform his function as an intermediary. This requires a high confidence in the discretion of the operator.

The third problem is the demanded industry experience of the future operator. The role of the operator of an online freight exchange requires intimate knowledge of the respective transport sector. Yet at the same time the potential marketplace members will question his neutrality. It is therefore difficult to find an operator that has the necessary expertise but is not at the same time a participant of the market in any form (Bruns et al., 2012a).

The fourth problem is the consideration of multimodal transports. The ability to configure transports across different carriers is a requirement which can be found regularly in publications on the requirements for an online freight exchange (Endemann and Kasper, 2012, Habib et al., 2012).

The challenge in solving the first three problems lies in the minimization of the costs of operation and participation and the believable guarantee of the neutrality, discretion and expertise of the operator. It becomes apparent that any future online freight exchange should support multimodal freight traffic by taking several traffic carriers into consideration for any given transport. Furthermore, it becomes clear that the first three problems can be attributed to the centralized nature of the marketplace. A single operator has to bear the costs for the provision of the infrastructure and will dispose of the data of all members. Moreover, he would have to reassure potential users about his expertise for the purpose of customer acquisition.

It should therefore be researched if an automated and decentralized approach would be an economically attractive alternative to the so far pursued centralized approaches. The basic premise of this idea is that a network of agents can form an interconnected marketplace in which they participate as equal trading partners. The agents are provisioning the computational infrastructure through the combination of their individual computing power where all agents share the same set of data amongst themselves. A single, central operator would not be needed, alleviating the first three real problems. The support of multimodal traffics would be easier to realize in an automated freight exchange than in an exchange organized in a central and purely contact mediating way, since the coordination could be left to the agents. Finally, an agent-based system could even strengthen the “spot character” of multimodal transport services.
In the following chapter chosen aspects and requirements for the development and implementation of such an agent-based freight exchange are presented.

4 A Concept for Agent-based Freight Exchanges

4.1 State of Research

There are not many publications on the topic of online freight exchange for transport services in the rail freight and online freight exchanges for the configuration of multimodal supply chains, respectively. The majority of the publications on this topic were published by researchers of the Institute for Production and Industrial Information Management of the University Duisburg-Essen (Föhring and Zelewski, 2013, Klippert et al., 2013, Föhring et al., 2012, Habib et al., 2012, Bruns et al., 2012b, Bruns and Zelewski, 2011, Bruns et al., 2010). Beyond that, only few publications exist and from these many merely assert the need for such an exchange (Endemann and Kasper, 2011, Scheck and Wilske, 2011).

As a consequence, while there are many publications about electronic marketplaces, the literature about electronic freight exchanges and logistics marketplaces is scarce (Wang et al., 2007). Most publications on multimodal transports do not focus on the trading of freight transports, but rather deal with their efficient routing and handling (SteadieSeifi et al., 2014). The usage of double-sided combinatorial auctions is discussed elaborately in specialized literature for different markets (Ackermann et al., 2011, Parkes and Ungar, 2001). The same can be said for the usage of multi-agent systems (Davidsson et al., 2005, Fox et al., 2000, Jennings, 2000) and, despite not being the primary focus, the utilization of agent technology for the auction-based negotiation of transport contracts has also already been discussed in the literature (Van der Putten et al., 2006).

The paper at hand suggests the merging of these findings on the requirements for an online rail freight exchange, on the usage of double-sided combinatorial auctions as well as on the organization of autonomous multi-agent systems in order to enable the conception and prototypical development of an intelligent, agent-based freight exchange (or AFEX for short).

The proposed design is an automated exchange in the form of an electronic marketplace. It is organized as a decentralized system which is able to function without a central marketplace operator. The autonomous trade between equal actors is being enabled by the usage of agents that form a multi-agent system and employ double-sided combinatorial auctions in order to perform auctions of multimodal transport services.

The subsequent prototypical implementation of AFEX will have a graphical user interface through which each human user can control his instance of the agent software. This way, e.g. forwarders can start the software, enter their preferences regarding a freight transport and let the exchange determine the "best deal" in an automated process, which requires no further user interaction.

The following chapters describe chosen aspects and requirements for the development and implementation of such an AFEX system.

4.2 Multi-Agent Systems as Decentralized Electronic Marketplaces

An AFEX-system, contrary to traditional electronic marketplaces, will not require a single operator as central authority. Therefore the system has to be able to organize itself in a decentralized way. This means that, while in case of the central solution all market activity is coordinated by the marketplace operator, the configuration and coordination of the activities in the decentralized version happens by the actors themselves. The marketplace operator is no longer needed as an intermediary; a disintermediation of the trade chain occurs.

In order to develop a multi-agent system that is capable to coordinate itself without a central node, the first requirement is that agents have to be able to locate trade partners. This is a nontrivial problem, as a central authority for mediating the contact between the agents is missing. This "contact problem" can, however, be solved if the agent software enables the manual entry of agent addresses. These describe the necessary information for making contact with another agent through the internet (i.e. an IP address and a port number).

Every time an agent contacts another agent they exchange all contact information known to them. Through this approach each agent gets to discover the whole network known to the other agent. The agent software then has to save the gathered contact information in a way that enables it to contact the known agents again after a restart.

The contact problem can be solved substantially more user-friendly if other software agents can be discovered without requiring user interaction. For this purpose there should be one or more predefined agent instances on the internet whose fixed contact information is embedded in the agent software. These predefined agents have no trading preference but serve as a kind of beacon, i.e. their sole purpose is to answer contact requests. If a list of these "beacon-agents" is going to be embedded in all agents and stands at their disposal after installation, they can be contacted without intervention of the human user.

Figure 1 illustrates this process: Agent A does not yet know other agents beside the beacon-agent B.

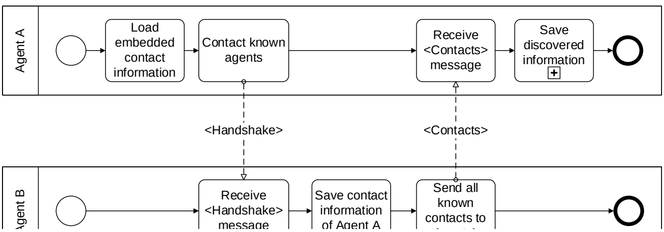

Figure 1 Contact initiation between agents

He contacts agent B and gets further agent addresses from him. Agent A saves the received contacts and can recall them again at the next start and approach them without being dependent on the beacon-agent as a contact mediator.

The advantage of this method is that beacon-agents can be operated, communicated and used independently of each other. They support the decentralized organization of the AFEX marketplace since they solve the contact problem without requiring a user interaction. They are, however, not necessary for operating the decentralized network (as the human users could always build up their own “contact networks” with the manual entry method).

4.3 Capturing Trading Preferences

The agent software has to be usable by a human user. For this purpose an agent’s user can use input masks provided by the user interface to either capture his preferences for an offer or demand for a transport service. This way he specifies similar transport-related preference data (for loading and unloading location, timeframe, etc.) that has also been captured in the ORFE prototype. Figure 2 illustrates this process schematically.

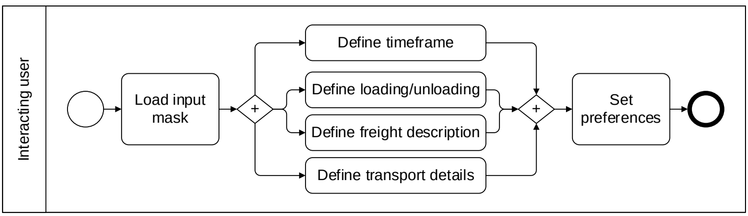

Figure 2 Input process for a demand for a transport service

The difference between the ORFE prototype and AFEX becomes apparent afterwards: The AFEX system does not need further user interaction after the preferences are entered.

4.4 Coordinating Group Formation

Once started with a set of preferences, agents will always advertise the transport services their human user offers and try to buy those transport services which their user demands. For the sake of simplicity, agents that are offering transport services will be called “suppliers” in this paper (and agents that are demanding transport services “demanders”).

All agents know the preferences of all other agents in their network and all preference data is exchanged in a unified format. Therefore it is possible for demanders to determine whether or not the transport services offered by a subset of suppliers can be combined in a way to accommodate at least one of their demands. If this is the case, the demander in question will contact the relevant suppliers and look for a “group” in which the demanded transport services are advertised (which will be called "goods" for the rest of this paper to be consistent with the literature on auctions). If no such group can be found, the demander will ask the suppliers to form one. In this group the agents will be able to submit bids for the demanded goods in an auction. Other agents can find and join the group. A demander might conclude that two groups would have to combine their auctioned goods to be able to accommodate one of his demands. In these cases he can ask both groups to merge in order to form a larger group which addresses more suppliers and demanders. This way, the demanders in a network assist the suppliers in forming the right groups to ensure constant trading.

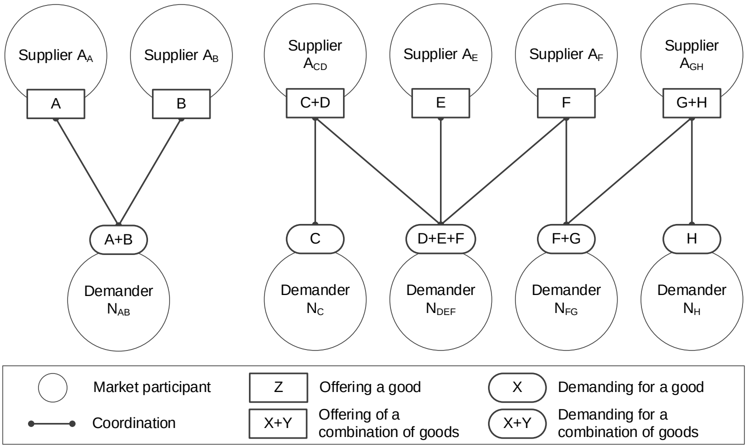

Figure 3 Group formation

Figure 3 shows a schematic representation of a small AFEX system.

In Figure 3, two groups have formed:

In group 1 two suppliers are offering two goods to one demander, in group 2 four suppliers are offering six goods to four demanders. The necessary coordination steps as described above are shown as edges between the agents.

This group concept not only enables agents to frame the coordination of their efforts but also ensures that all participants in a group are interested in the offered goods. These aligned interests are a perquisite for the negotiation of prices.

4.5 Using Double-sided Combinatorial Auctions for Price Negotiation

The pricing between buyer and seller is a challenge any marketplace faces. Three pricing models can be made out (Grieger, 2003):

The bulletin board model that serves primarily for the publication of advertisements and as a pure information and contact platform (this variation was implemented in the ORFE prototype).

The fixed price model in which case the supplier and demander specify the final price for the service being in demand or offered.

Virtual exchanges made possible by the internet that offer its members a dynamic pricing with the help of auctions.

For the design of an AFEX system, the chosen concept should ensure an efficient auction of the traded transport services. From the three mentioned alternatives, this requirement can be only met by the dynamic pricing through auction. The choice of auction form is crucial for the efficiency of the auction execution (Ausubel et al., 1998, Krishna and Perry, 1998). There are two reasons why the employment of the double-sided auction form, in which case the auction participants can appear as buyer and as seller, is reasonable: Firstly, many exchanges and resource markets in the real world are organized as double-sided auctions (Yang, 2003). Secondly, the participants are not assigned dedicated roles ("supplier" or "demander") but can act as both, demanding and offering goods according to their preferences. In order to be able to depict multimodal transport services in an auction, other dimensions next to the price have to be taken into account when computing the optimal allocation of goods. Multidimensional auctions promise a high allocative efficiency despite the possibly complex preferences of the participants concerning the traded dimensions. Combinatorial auctions, sometimes also called combinatorial exchanges, are very well researched multidimensional auctions that make it possible for participants to submit bids for indivisible combinations of goods and only win the bid if they receive exactly the desired combination (Bichler et al., 2005).

Resulting from these considerations it becomes clear that a double-sided combinatorial auction model meets the previously mentioned requirements. But while double-sided combinatorial auctions have major economic advantages, their computational complexity is a well-documented challenge that can be seen as a disadvantage (Sandholm et al., 2002). This complexity largely stems from the fact that each participant in a combinatorial auction has to submit bids for all relevant combinations, which means that the number of bids grows exponentially as the number of participants increases.

An AFEX system mitigates this issue by pre-selecting the participants of each auction through the previously described formation of groups and the concept of "ad hoc auctions".

4.6 Ad hoc Auctions

The auctioneer plays an important role in the trading process as he performs the auction and decides on the final allocation of goods. The fact that an autonomously coordinated exchange without a central operator lacks this central figure constitutes a design challenge: The agents do not only have to find each other and form groups based on their preferences but also have to coordinate the initiation and implementation of auctions by themselves.

After a group has formed and a sufficient number of suppliers and demanders have joined, the group is declared “complete” and the auction starts. For this purpose the agents carry out a spontaneous “ad hoc auction”.

The difference between ad hoc auctions and “normal” auctions in centralized marketplaces is that the auctioneer is dynamically selected from the crowd of suppliers in a group. The role of the auctioneer falls to the supplier that tries to sell the highest number of goods or, if several suppliers make an equal number of offers, that supplier which entered the group first.

The auctioneer carries out a double-sided combinatorial auction according to the auction model and subsequently specifies the final allocation of goods within the group. After all participants agree to this new distribution the group dissolves.

This approach pairs well with the concept of loosely-coupled groups described before: Groups are not only a way to frame the context of an auction by ensuring that all participants are interested in the offered goods but also limit its complexity by limiting the number of participants. Handing the computationally expensive calculations needed to perform the auction to the supplier side is a design decision based on the assumption that suppliers have a natural interest in providing a solid technical foundation in order to enable auctions of the goods they offer.

Figure 4 depicts an AFEX system of 24 agents, six of which formed a group based on the principles described above.

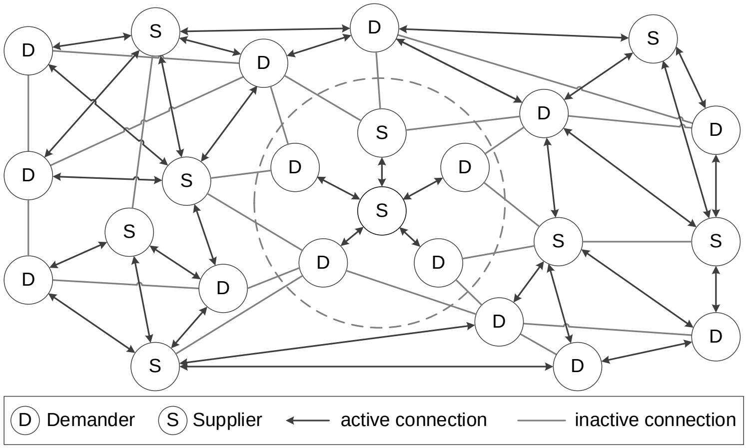

Figure 4 Ad hoc auction inside an AFEX system

The dotted circle in the middle indicates that the group currently performs an ad hoc auction. The figure also illustrates that not all of the agents are maintaining an active connection to each other all the time, e.g. agents currently participating in an active auction are not maintaining any active connections except the one with the auctioneer.

4.7 Critical Reflection

The outlined marketplace concept AFEX should provide three implicit advantages in contrast to conventional approaches:

Equality – all members of the market are subject to the same rules of action. Although agents are started with individual preferences, they cannot deviate one-sidedly regarding their strategy, which is deposited in the software.

Efficiency – the usage of the double-sided combinatorial auctions allows for optimal solutions for pricing through the deployment of mathematical models. The efficiency criteria can be specified in a goal-oriented way during the design phase.

Transparency – from the point of view of the software agents the conditions of the market and the market activity are completely transparent: all agents make contact among themselves and exchange their trading preferences.

In addition, the described approach provides a realistic modeling of the roles played by the members of the marketplace. Agents do not only act explicitly as supplier or demander but also play either the role dependent on the context. However, the described concept also has implications which can be seen as disadvantages:

Transparency – in traditional negotiations, there are often information asymmetries that benefit one or more participants. Therefore, while also an implicit advantage, this aspect can be a disadvantage regarding the acceptance of a completely transparent marketplace.

Social norms – automated negotiations lack the personal element that face-to-face business provides. The world of logistics is just slowly discovering the advantages of automated negotiations and decision support systems.

The kind of automation AFEX aims to provide should therefore not be expected to establish itself in the short-term, but rather seen as a major trend shaping the next decade.

5 Summary and Outlook

This paper described the efforts to establish an online freight exchange for the mediation of multimodal transport services within Europe. The research on online freight exchanges, the development of the prototype ORFE and the challenges that any new freight exchange will face have been described.

The investigation of these problems resulted in the draft of an innovative marketplace concept: AFEX, an online freight exchange that is based on autonomous software agents. Selected requirements for the development of these decentralized and autonomously trading agents have been outlined. It has been described, how these proposed multi-agent systems differ from existing solutions in that they will form intelligent exchanges, which will be decentrally organized, i.e. not require a central authority or operator, and utilize two-sided combinatorial auctions to perform fair, efficient and transparent auctions of transport services within an automated marketplace environment.

The next steps are the development of an adaptive agent behavior that is able to adjust to different situations, a generic traffic route notation for the description of transport routes and a description language for the offer and demand for transport services within auctions.

The last step will be the combination and implementation of all mentioned aspects into a prototypical agent software.

References

Ackermann, H., Ewe, H., Kopfer, H., Küfer, K.H., 2011. Combinatorial Auctions in Freight Logistics. In: Böse, J. (Ed.): Computational Logistics, Second International Conference, ICCL Proceedings 2011, pp. 1-17.

Ausubel, L.M., Cramton, P.C., 1998. The optimality of being efficient. World Bank, Private Sector Development Department, Private Participation in Infrastructure Division, 1998.

Bichler, M., Pikovsky, A., Setzer, T., 2005. Kombinatorische Auktionen in der betrieblichen Beschaffung – Eine Analyse grundlegender Probleme. In: Wirtschaftsinformatik 47(2), pp. 126-134.

Brenienek, J. (unter Mitarbeit von Juchelka, R. et al.), 2014. Logistikcluster entlang des Transportkorridors Rotterdam-Genua: Strukturen, Entwicklungen und Prozesse. Report, Lehrstuhl für Wirtschaftsgeographie, insb. Verkehr und Logistik, Universität Duisburg-Essen.

Bruns, A.S., Günes, N., Zelewski, S., 2010. Online-Frachtenbörse für den transeuropäischen Schienengüterverkehr. Internationales Verkehrswesen 62(11), pp. 25-29.

Bruns, A.S., Zelewski, S., 2011. Übertragung von Projekterkenntnissen auf Kooperationen von Güterverkehrsunternehmen entlang der Alpentransversale „Rotterdam-Genua". In: Zelewski, S., Jene, S. (Hrsg.): Kooperationen zwischen Eisenbahn-verkehrsunternehmen: Grundlagen – Konzepte – Praxisanwendungen. Berlin, pp. 1071-1080.

Bruns, A.S., Zelewski, S., Lehr, T., 2012a. Analyse des Marktpotenzials für Online-Frachtenbörsen im Segment von Schienengüterverkehren und Kombinierten Güterverkehren. CODE24-Projektbericht Nr. 6, Institut für Produktion und Industrielles Informationsmanagement, Universität Duisburg-Essen.

Bruns, A.S., Föhring, R., Zelewski, S., Günes, N., 2012b. Eine Online-Frachtenbörse für Verlader und Güterbahnen. Güterbahnen 11(1), pp. 33-37.

Davidsson, P., Henesey, L., Ramstedt, L., Törnquist, J., Wernstedt, F., 2005. An analysis of agent-based approaches to transport logistics. In: Transportation Research Part C: Emerging Technologies, 13(4), pp. 255-271.

Dörr, H., Endemann, P., 2014. Moving Forward Freight Mobility Innova-tions. Internationales Verkehrswesen 66(2), pp. 60-63.

Endemann, P., Kaspar, T., 2011. Online-Transportbörse soll Schie-nengüterverkehr stärken – Was braucht die Praxis? Güterbahnen 10(4), pp. 31-36.

Endemann, P., Tracksdorf, K., Kaspar, T., 2012. CODE 24 Online Rail Freight Exchange Needs of Potential Users. European Transport Conference 2012, 08.-10.10.2012 in Glasgow, In: URL: http://abstracts.aetransport.org/paper/download/id/3868, accessed Jun 21, 2015, pp. 1-14.

Fox, M. S., Barbuceanu, M., Teigen, R., 2000. Agent-oriented supply-chain management. In: International Journal of Flexible Manufacturing Systems, 12(2-3), pp. 165-188.

Föhring, R., Kuhlmann, A.S., Zelewski, S., 2012. Vorstellung des finalen Softwareprototyps einer Online-Frachtenbörse, CODE24-Projektbericht Nr. 7, Institut für Produktion und Industrielles Informationsmanagement, Universität Duisburg-Essen.

Föhring, R., Zelewski, S., 2013. ORFE: Online Rail Freight Exchange – a software prototype for the configuration of multi-modal supply chains focused on rail freight traffic along the Alps Transversal Rotterdam-Genoa. OrGoLo-Projektbericht Nr. 20, Institut für Produktion und Industrielles Informationsmanagement, Universität Duisburg-Essen.

Grieger, M., 2003. Electronic marketplaces: A literature review and a call for supply chain management research. In: European Journal of Operational Research 144, pp. 280-294.

Habib, S., Bruns, A.S., 2012. Analyse des kompetitiven Umfelds für die Etablierung einer Online-Frachtenbörse zur Vermittlung von Eisenbahngüterverkehren auf der Nord-Süd-Transversale „Rotterdam-Genua“. CODE24-Projektbericht Nr. 5, Institut für Produktion und Industrielles Informationsmanagement, Universität Duisburg-Essen.

Jennings, N. R., 2000. On agent-based software engineering. In: Artificial Intelligence, 117(2), pp. 277-296.

Klippert, S.R., Kowalski, M., Bruns, A.S., 2010. Anforderungsanalyse für eine Online-Frachtenbörse im Eisenbahngüterverkehr – Entwicklung einer Anforderungsspezifikation aus betriebswirtschaftlicher Perspektive. CODE24-Projektbericht Nr. 2, Institut für Produktion und Industrielles Informationsmanagement, Universität Duisburg-Essen.

Klippert, S.R., Zelewski, S., Kuhlmann, A.S., Kowalski, M., 2013. Schienentransporte im KV über eine Online-Frachtenbörse organisieren – Das EU-Verbundprojekt Code24 gibt neue Impulse für den Kombinierten Verkehr (KV) auf der Schiene. EI – Der Eisenbahningenieur 64(5), pp. 91-96.

Krishna, V., Perry, M. (1998): Efficient mechanism design. In: URL: http://econ.la.psu.edu/~vkrishna/papers/vcg20.pdf, accessed Jun 21, 2015.

Merkel, H., Kromer, S., 2002. Virtuelle Frachtbörsen - Top oder Flop? In: Hossner, R. (Ed.): Jahrbuch der Logistik, pp. 82-87.

Parkes, D.C., Ungar, L.H., 2001. An Auction-Based Method for Decentralized Train Scheduling. In: Proceedings of the Fifth International Conference on Autonomous Agents, pp. 43-50.

Sandholm, T., Suri, S., Gilpin, A., Levine, D., 2001. Winner Determination in Combinatorial Auction Generalizations. In: Proceedings of the First International Joint Conference on Autonomous Agents and Multi-Agent Systems: part 1, pp. 69-76.

Scheck, C., Wilske, S., 2011. Infrastrukturentwicklung im europäischen Korridor Rotterdam-Genua: das INTERREG-IV-B-Projekt „Code 24“. In: Hege, H.-P., Knapstein, Y., Meng, R., Ruppenthal, K., Schmitz-Veltin, A., Zakrzewski, P. (Ed.): Schneller, öfter, weiter? Perspektiven der Raumentwicklung in der Mobilitätsgesellschaft. Hannover, pp. 56-71.

SteadieSeifi, M., Dellaert, N. P., Nuijten, W., Van Woensel, T., Raoufi, R., 2014. Multimodal freight transportation planning: A literature review. In: European journal of operational research, 233(1), pp. 1-15.

Wang, Y., Potter, A., Naim, M., 2007. An exploratory study of electronic logistics marketplaces and its impact on customised logistics. In: POMS 18th Annual Conference, URL: http://www.poms.org/conferences/poms2007/CDProgram/Topics/full_length_papers_files/007-0265.pdf, accessed Jun 21, 2015.

Yang, J., 2002. The Efficiency of an Artificial Double Auction Stock Market with Neural Learning Agents. In: Chen, S.-H. (Ed.): Evolutionary Computation in Economics and Finance, pp. 85-105.

Van Der Putten, S., Robu, V., La Poutré, H., Jorritsma, A., Gal, M., 2006. Automating Supply Chain Negotiations using Autonomous Agents: a Case Study in Transportation Logistics. In: Proceedings of the 5th International Joint Conference on Autonomous Agents and Multiagent Systems, pp. 1506-1513.

Optimisation of Intermodal Transport Using Satellite-based Services

Nils Meyer-Larsen, Rainer Müller and Timo Köhler

The European Space Agency (ESA) is currently funding a number of projects in order to develop services for the optimization of transport and logistics processes using satellite assets. One of these projects is I-PORT, especially addressing intermodal container transportation through European ports. In this context, one of the major challenges is the alignment in planning the arrival and departure of different modalities, e.g. vessels and trucks, such that the containers can be transferred without delays. In addition, unproductive waiting times of transport vehicles should be avoided.

To support this, an integrated solution was defined and developed, which utilizes the added value of satellite assets, in particular GPS and Satellite-based AIS (Automatic Identification System). By using these services, the positions of transport vehicles are tracked and the estimated time of arrival (ETA) is calculated and regularly updated. If the I-PORT system detects a deviation from the planned schedule, e.g. a delay in arrival of a vessel, all involved actors are informed pro-actively. Consequently, the related vehicles can be re-scheduled at an early stage and waiting times and unsuccessful attempts to deliver or pick up a container can be reduced. The I-PORT solution was developed based on the elaboration of user needs as well as existing technologies and services.

Keywords: Intermodal Container Transport, Satellite-based Services, Optimisation, ETA Prediction

1 Introduction

Intermodal container transport today still suffers from various bottle-necks (Witte, 2012), which are often caused by the intransparency of logistics processes and the fact that information is not forwarded to all relevant partners in the supply chain. The efficiency of transport processes can primarily be enhanced by a more intelligent disposition of vehicles (ten Hompel, 2014). In addition, it is one of the challenges for container ports to optimize their facilities in order to be prepared for the growing demands concerning the spatial and time aspects of cargo handling related to the increase in vessel size (UNCTAD, 2014). Especially in case of modal changes, e.g. the pick-up of an import container by a truck in a sea port terminal, avoidable delays occur. If the vessel which delivers the container has a deviation in its arrival time from the planned schedule, this information is in general not forwarded to the haulier, who is scheduling the container pickup according to the planned arrival time. If the vessel arrives late, the truck has to wait accordingly or has to leave without the container.

The I-PORT project funded by the European Space Agency (ESA) aims at improving this situation by developing a system for end users which optimises the handling of intermodal freight transport through European ports. The optimisation is realised by providing more visibility to the different actors involved in freight transport. One of the project's key issues is the management of access to ports, which in general have limited information about arrival of trucks, barges and vessels, inhibiting the ability to optimize port throughput. In addition, I-PORT addresses the topic of schedule reliability. Vessels currently use weather-routing systems and sophisticated navigation equipment, but not earth observation equipment or techniques to assist in vessel routing optimization. Furthermore, inland transport movements can be better predicted by using satellite-based services as the organisation of hinterland transports relies on sharing information across many organizations and processes which can be optimized. The latter will also lead to predictable turnaround times as access to ports especially in the UK is managed by a vehicle slot booking process; transport providers can only access those ports if they have booked a respective time slot. This is likely to become a more rigid process, as ports strive to manage internal resources.

Besides I-PORT, a project named Smart SC (e-business standardisation in the maritime supply chain) (Smart SC, 2015) is currently funded by the German Ministry of Economics and Technology as part of the German government initiative on e-business standards. Smart SC looks at the improvement of the data visibility along the container supply chain and includes support systems for truckers for the truck/sea port interface with a regional focus on the German sea ports of Bremerhaven and Wilhelmshaven. Within I-PORT, a link between the Smart SC and I-PORT platforms was developed, enabling the use of synergies between the two projects and establishing added values from interoperability and data exchange between these two platforms.

2 Users and Their Needs

A study addressing the optimization potentials through more intelligent disposition processes of vehicles enabled by an improved visibility (INFORM, 2012) identified the following key benefits: decreased congestion of access roads, reduced unproductive waiting times, improved utilisation of resources, and reduced transport costs. The users targeted in this demonstration project are those which could benefit from optimising intermodal freight transport, including e.g. shipping lines, ports, container terminals, hauliers, railway operators, inland waterways, and storage facilities. In addition, stakeholders include (local) authorities, Customs, Port Community Systems, and other partners who benefit from an optimised visibility of the logistics and transport processes. The users have expressed a number of high level needs for improving freight transport through ports. For instance, hauliers expressed a need to have further information on deviations from the vessels' schedules, which results in early or delayed release of import containers or changes in cut-off times for export containers. Furthermore, there is a need to remove the paper side of vehicle slot bookings in ports to improve efficiency. In addition, ports and terminals expressed a need to improve the visibility of incoming vehicles, e.g. by geofencing.

3 Space Added Value

Space technologies, and above all satellites, have an enormous potential in many areas such as logistics, amongst others. Currently the respective potentials are still underestimated and largely underutilized (Perrin, 2013).

Consequently, I-PORT can be seen as a pioneer project in this area. It integrates space-based information delivered by satellites into an intermodal freight transport system. The use of navigational systems enables improved visibility of the truck fleet by using respective GPS signals. The visibility of vessels is improved by using the vessels' AIS (Automatic Identification System) data which is captured by respective receivers which are both shore-based and satellite-based. Merging these data sources together leads to improved synchronisation between port and supply chain actors, reduces delays and waiting times and thus optimises the throughput and the efficiency of sea port terminals and hinterland transport. Because it is not feasible to equip the complete vessel and truck fleets with additional technology, it is critical for the proposed services to exploit existing technologies to integrate diverse information sources and provide a unified interface to improve visibility and standardise communication. Most importantly, the location data must be used to provide estimated time of arrival (ETA) information of vessels and trucks to the relevant stakeholders. The service must be able to capture the location data from existing tracking systems and/or mobile devices and mobile applications, e.g. using smartphones.

4 Technical Background

The Automatic Identification System (AIS) was developed in the 1990s as a short range identification and tracking system for seagoing and inland vessels (Easyais, 2015). It is a maritime transponder/receiver system defined by the IMO (international maritime organisation) and operates in the VHF frequency band. The purpose of AIS is to assist identifying vessels when not in sight (e.g. at night, in radar blind arcs or shadows or at distance) by transmitting and receiving vessel ID, position, course, speed and other relevant data to and from other nearby ships. During the time of development, it was not foreseen to be detectable from space. Nevertheless, since 2005, experiments were performed detecting AIS signals using satellite-based receivers. Since that time, several commercial companies have started to offer respective services which in combination with the terrestrial AIS receiver network will allow a truly global AIS coverage. The latest development are very little satellites like AISSat-1 which is a nano-satellite measuring only 20 x 20 x 20cm (Norsk Romsenter, 2015) or the 1U cubesat AAUSAT3 weighing only 800 grams (AAUSAT3, 2015). These satellites can carry AIS receivers at very limited costs for construction and launch, which makes the installation of an adequate fleet of AIS satellites feasible.

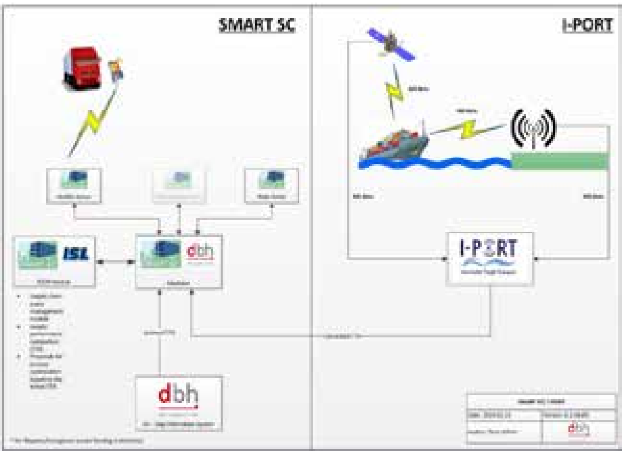

Figure 1 Interaction between the Smart SC and I-PORT systems

5 System Concept

As mentioned above, within I-PORT a link between the Smart SC and I-PORT platforms was developed, establishing added values from interoperability and data exchange between these two platforms. The combination of these two systems as shown in fig. 1 addresses the information requirements of the receivers of containers routed through the ports of Bremerhaven and Wilhelmshaven. These stakeholders need to be informed pro-actively about delays in vessel arrival and receive an updated estimated arrival time of the vessel in order to re-schedule the on-carriage supply chain.
In addition, ports and Shipping Companies require as accurate vessel ETA data as possible; within 2 hours tolerance if practical. However, the current situation is that ETA information (plus destination) contained in a ship's AIS message transmissions is manually entered by a crew member; i.e. it is not derived automatically from the ship's navigation equipment. As well as potential inaccuracies in a crew member typing in the ETA information, it is often also not subsequently updated once the ship is underway. Its entry is also solely at the Captain's discretion, i.e. it is not mandatory. All of this means that any additional information on potential ETA that is derived separately from the AIS message content will be of benefit to ports and Shipping Companies and as such, I-PORT end users.
Shipping companies would ideally like to have any changes reflected in estimated ETA updated in a real time basis. The port companies need to plan in relation to tidal windows (6 hours) and in relation to shift work patterns. The ports would need to know from 24 hours in advance of any changes to the scheduled ETA.

In Smart SC a component named "SCEM (Supply Chain Event Management) tool" was created aiming to compare plan and schedule data with actual status messages (such as vehicle positions) automatically detecting deviations from the plan at an early stage.
The following scenario describes the linking of the Smart SC and I-PORT platforms in detail. The basic precondition is that the I-PORT platform provides the vessels' AIS location data and ETA to the Smart SC system. In the case of importing containers to the ports of Bremerhaven and Wilhelmshaven, the receiver of the goods enters the shipping order into the Smart SC system, which provides the relevant container number(s) and the port of destination (Bremerhaven or Wilhelmshaven). Based on the data available in Smart SC, the information about the vessel transporting the container(s) is derived from the container number(s). The planned date and time of arrival of the vessel at the port of destination, obtained from the SIS system operated by the port community system dbh, serves as to-be data for the SCEM module of the Smart SC system. Based on the AIS vessel tracking data and ETA provided by the I-PORT system, the SCEM module will compare it with the planned time of arrival. In case of deviations from the plan, the SCEM module will pro-actively inform the relevant partners involved in the on-carriage of the container about the delay in order to allow an efficient re-scheduling of the supply chain processes.
Hauliers who deliver export containers to the ports of Bremerhaven and Wilhelmshaven require to automatically receive updates of the closing time for container delivery in order to be in time for the booked vessel. This is especially important in case of deviations from the plan, e.g. delayed arrival

of a vessel. For this case, it was investigated whether the calculated estimation of the vessel arrival time at the port of destination can be used to predict an updated closing time for container delivery, i.e. the time from which on delivered containers are considered as delayed and will not be loaded on the vessel. The updated closing time will be provided back to the I-PORT platform to be made available to I-PORT users.

6 Conclusions

The I-PORT project demonstrates the expected benefits of utilisation of new satellite technologies within freight transport, providing better visibility of a freight's positioning, to all stakeholders. This clarity and precision allows for accurate status of delivery through the duration of the process and greater security, because all freight is traceable at all times. This allows for greater optimising when utilising resources and alleviating congestion at the busiest periods. Considering traffic data and live positioning of freight allows for live updates of ETAs and live scheduling and optimisation of hauliers' processes.

With the specified linkage between the I-PORT system and the Smart SC system, the following benefits are anticipated:

- Better utilisation of port resources, optimisation of efficiency (as an example, between 5%-20% of booking slots are currently wasted due to delays);
- Better planning of truck resources with ETA data available in real time, leading to a reduction of unproductive waiting times and

unsuccessful attempts to deliver or pick up a container and consequently to a reduced impact on the local community and the environment (reduced emissions and reduced traffic on access roads);

- Automatic rebooking of slots and advise to the driver in the event of late or early arrival, saving wasted journeys and/or waiting time;
- Reduced administration time managing slots and missed slots;
- React to the growing demands concerning spatial and time aspects of cargo handling related to the increase in vessel size;
- More capacity for growth.

The systems were developed and are currently in the phase of implementation and integration in the port community system. The expected benefits mentioned above will be validated during the subsequent demonstration phase in a real-life environment.

References

AAUSAT3, 2015, Available at <https://en.wikipedia.org/wiki/AAUSAT3> [Accessed 25 June 2015]

Easyais, 2015, What is AIS?, Available at <http://www.easyais.com/en/ais-information/what-is-ais/> [Accessed 25 June 2015]

ten Hompel, M. et al., 2014, Logistik und IT als Innovationstreiber für den Wirtschaftsstandort Deutschland, Positionspapier, Bundesvereinigung Logistik, 2014

INFORM, 2012, Optimierungspotenziale in der Lkw-Zulaufsteuerung bei Industrieunternehmen, Institut für Operations Research und Management, Aachen, 2012

Norsk Romsenter, 2015, Norway's Satellites, Available at <http://www.romsenter.no/eng/Norway-in-Space/Norway-s-Satellites> [Accessed 25 June 2015]

Perrin, Sarah, 2013, Tapping into the vast potential of satellites, Available at <http://phys.org/news/2013-04-vast-potential-satellites.html> [Accessed 26 June 2015]

Smart SC, 2015, Available at <http://www.smartsc.isl.org/> [Accessed 20 June 2015]

UNCTAD, 2014, Review of Maritime Transport 2014, United Nations, New York and Geneva, 2014

Witte, Patrick A. et al., 2012, Chokepoints in corridors: Perspectives on bottlenecks in the European transport network in: Research in Transportation Business & Management Volume 5, December 2012, p. 57–66

Address Matching Using Truck Tours Feedback

Dalicia Bouallouche, Jean-Baptiste Vioix, Stéphane Millot and Eric Busvelle

When researchers or logistics software developers deal with vehicle routing optimization, they mainly focus on minimizing the total traveled distance or time of the tours, and maximizing the number of visited customers. However, in real transporter situations, the actual data received is often of bad quality, particularly the irrelevance of addresses and address geocoding errors. Therefore, trying to optimize tours with impertinent customers' GPS-coordinates, which are the most important input data for solving a vehicle routing problem, will lead to an incoherent solution, especially if the locations of the customers used for the optimization are very different from their real positions.

Our work is supported by a logistics software editor Tedies (2013) and a transport company Upsilon (2009). We work with the company's real truck routes data to carry our experiments. The aim of this work is to use the experience of the driver and the feedback of the real truck tours to validate and correct GPS-coordinates to the next tours. Our method significantly improves the quality of the geocoding.

This study shows the importance of taking into account the feedback of the trucks to gradually correct address geocoding errors. Indeed, the accuracy of customer's address and its GPS-coordinates plays a major role in tours optimization. This feedback is naturally and usually taken into account by transporters (by asking drivers, calling customers, …), to learn about their tours and bring corrections to the upcoming tours. Hence, we develop a method to do most of that automatically.

Keywords: Driver Experience Feedback, Geocoding Correction, Real Truck Tours, Address Matching

1 Introduction

Our study is in the context of a project of route optimization of collection/delivery vehicles. We work with a software development company that proposes transport and logistics software keys for transporters. During the development of this project, we noticed an important problem which does not fall in the scope of the vehicle routing optimization. However, it is an issue that has much impact on the quality of the optimization in real world situations. The problem is the inaccuracy of the customers' positions (GPS coordinates). The optimization of the vehicle tours, and other studies, strongly depends on the location of customers on the map. Indeed, transporters and transport and logistics software developers complain about the fact that geocoders do not always give pertinent address geocoding. Geocoding is a crucial step ahead many GIS (Geographic Information System) projects. Hence, transporters have to hire employees to check or correct all GPS coordinates of their customers' addresses. This takes a big part of their time. Transporters and transport & logistics software editors assert that geocoding errors coming from automatic geocoders and human errors could lead tours optimization or any other GIS project to failure.

A related problem is the address writing errors issue. Hence, a badly written, incomplete, or inaccurate (human errors) address, necessarily implies geocoding errors.

As well, an obvious geocoding issue is that the mapping used by the geocoders is not uploaded regularly. Also, in the case of larger companies or shops, their geocoding positions are usually different from the place where the vehicle should make its deliveries. For instance, in airports, a geocoder returns GPS coordinates which do not necessarily indicates the freight area.

Clearly, the correctness of upstream customers' addresses and a rigorous address geocoding are crucial conditions to carry out the vehicle routing optimization and other GIS projects. Benefits resulting from optimization may be transformed in extra costs, painful for the driver, and may lead to give up the optimization software assistance. Foote and Huebner (2000, sec.1), claim that spatial data errors, inaccuracy, and imprecision can "make or break" a GIS project.

The aim of this work is to use the experience of the driver and the feedback of the real truck tours in order to first validate the GPS coordinates of an address which were pretty well geocoded, and, second, bring a geocoding correction to the rest of badly geocoded addresses. To achieve this, we rely on the real truck tours of the transporter. We retrieve tours data from truck GPSs to use the feedback of the trucks for validating/correcting our spatial data. Obviously, any GPS with data logging capabilities, including smartphones, may be used for this application.

In the next session, we will discuss on related works treating our problematic. In section 3, we will state the required tools to carry out our experiments. We will, thereafter, explain our algorithm in section 4. In section 5, we will present some results of our method. Finally, we will give in section 6 a conclusion and a preview of the further work of this paper.

2 Background and Discussion

Address geocoding is considered in many fields. There is an increasing number of applications that rely on GIS. For instance, transport and logistics field, the field of health (Lewis-Michl et al., 1996; English et al., 1999; Rushton and Lolonis, 1996; Anselin, 1995; Geschwind et al., 1992; Kulldorff and Nagarwalla, 1995), etc.

Cayo and Talbot (2003, para.10) assert that very limited published information exists on address geocoding errors in automated street level geocoding. In the context of our work, no published papers were found about the problem that we had noticed in transporters real case situation. Especially, the problem of geocoding errors in the context of vehicle routing problem optimization, traveling salesman problem or other studies related to the transport and logistics field were not raised. Researchers of this field, mostly, consider that all the upstream data (in our case, customers positions on the map, or spatial data in general), are free from errors and all their optimization methods might work and give the same results as in theoretical case simulations.

Furthermore, we found some related research in other fields (different from transport and logistics). Most of them are related to the environment and health areas. Cayo and Talbot (2003) studied positional error in automated geocoding in the field of Environmental and Occupational Epidemiology. Authors match between geocoded points and true known locations. Authors acquired residential addresses from the NYSORPS (for New York State Office of Real Property Services) and evaluate GPS coordinates errors caused during automated address geocoding. Authors use the distance between each geocoded point and its true location, and then measure the variation of these errors depending on population densities (urban, suburban and rural). Their conclusion is that errors increase as population density increases. Our method, also, deals with matching geocoded points with customers' addresses. However, in contrast to the study of Cayo and Talbot (2003), we do not rely on the true locations of these addresses because we don't know them. Instead, we construct them according to the real path of the truck tour. In the same paper, the authors use a method of geocoding using property parcel data (NYSORPS) instead of the traditional linear interpolation method. In this last, the interpolation error increases as the street segments are longer. In fact, Levine and Kim (1998, p.563) conclude that geocoding errors of interpolation algorithms vary with the street segment length and urban areas typically contain shorter segments compared to rural areas. Also, the geocoding software that uses interpolation algorithms supposes uniform intervals between street numbers along a street segment (Telogis, 2015; Google Maps, 2015; Cayo and Talbot, 2003, para.30), which is not the case in reality. Indeed, when addresses are not evenly spaced along a street, the probability to get an interpolation error increases.

An alternative solution is possible when the traditional geocoding methods do not give expected results. The use of property parcel points provides greater positional accuracy and reduces geocoding errors. In fact, individual house locations and separations are more accurate in property parcel data than in TIGER (Topologically Integrated Geographic Encoding and Referencing System) based files, where parcel centroids are rarely at the exact locations of the houses (Cayo and Talbot, 2003). In addition, parcel data is updated annually for tax purposes, so match rates are improved, unlike with commonly used street centerline files which are less regularly updated (Cayo and Talbot, 2003, para.34).

Various researches are based on match rate statistics (Gregorio, Cromley, Mrozinski and Walsh, 1999; Howe, 1986; Levine and Kim, 1998; Yu, 1996). Authors found a positive dependency between computerized geocoding rates and population size and urbanity (Howe, 1986, p.1460). This could be justified by the fact that address information, in more densely populated areas, is often more complete in street reference and commercially enhanced files (Gregorio et al., 1999, p.177). Hence, geographic differences can alter study results.

Zinszer et al. (2010) examine the impact of address geocoding errors through the estimation of the spatial distribution of the disease. The authors evaluate address geocoding errors for a selected reportable disease in a large urban center in Canada (Zinszer et al., 2010, p.163). Researchers use an address verification algorithm on extracted data for all notifications of campylobacteriosis from the Montreal public health department to determine the accuracy of the residential address for each case and to suggest corrections for invalid addresses. Authors estimate address errors types as well as the resulting geocoding errors. For this, researchers calculate the distance gap between the original address and the correct address, like in Cayo and Talbot research (2003, para.2 and 11), as well as changes in disease density (Zinszer et al., 2010, p.164).

Communicable disease surveillance in public health practice has an equivalent problem with transporters on the received IDE (Information Data Exchange). Many errors are introduced on the informed addresses. Indeed, the way information (addresses and medical information) is carried from diverse sources (hospital registries, laboratories reports, physical offices…) to the central databases of the public health department varies. It goes from a fully automated transmission to a fax to which manual data entry are added (Zinszer et al., 2010, p.164). The objective of the study is to examine address errors for a selected reportable disease in a large urban center in Canada and to assess the impact of identified errors on the estimation of the spatial distribution of the disease. To do that, Zinszer et al. (2010, p.164) compare the collected addresses of the public health dataset to the PCAD (the Postal Code Address Data) file of Canada Post. The authors determine if the street name, street number and postal code of an address from the public health data correspond to a correct street segment in the PCAD file. The resulting matchings between the public health dataset addresses and the PCAD are classified as exact matches, recoverable addresses or unprocessable addresses (Zinszer et al., 2010, p.165 and 166). The researchers based their study on an official file of good quality addresses.

The difficulty in our study is that we only work with data (addresses) received from the IDE. Thus, customers requesting the delivery/collection services write the received addresses. Then, we build our customers' addresses real positions based on the real trucks data tours to compare with the received customers addresses from IDE.

A recently opened project, named BANO (for Base Adresses Nationale Ouverte) (2014), shows the importance of handling the problem of poor quality addresses and inaccurate geocoding. It is an open source project of OpenStreetMap® (2015) France. The objective of this project is to collect data (addresses) from hundreds of contributors, opendata sources, land registry, etc., to construct from these gathered addresses the most complete and correct version of each address, then, match each address on the corresponding street in the map.

3 Experimentation Tools

3.1 The Context of our Study

The transporter includes all transport (collections and deliveries) of goods that require at least one stop on a platform to a sorting operation, collecting, or unbundling. It receives the packages to deliver from other transporters early in the morning, between 2:00 and 4:00AM. Meanwhile, received packages have to be sorted and dispatched after their recipients' addresses are geocoded and validated/corrected. Transport operators must do it very quickly so the drivers can make their deliveries, generally between 5:00 and 6:00AM. In average, the vehicles delivers 305 packages per day for 110 addresses, among them 30% of new addresses, with a fleet of 10 vehicles. The customers have to be delivered as soon as possible, by taking into account their collection/delivery constraints (time windows, collection/delivery equipment, etc.). Practically, the covered region by the transporter is within a radius of 100 km around the freight center. Each truck delivers some cities along its route. The addresses may vary from day to day and drivers may spend a lot of time with unknown addresses (especially new or inexperienced drivers).

The transport company performs other kind of transportations, like batch transport. However, a batch of packages is carried out permanently from a single source to a single customer, so we are not interested in this simpler case.

Our tool helps the transport operators in the address geocoding phase (after receiving the addresses of delivery and before dispatching the corresponding packages). The validation and correction of address geocoding is done automatically in upstream. Thereby, it saves time for transport operators, and they can focus on the remaining tasks of the transport operations.

3.2 GPS Data Retrieving

The vehicles fleet of the transporter is equipped with TomTom® GPS units (2015) that continuously send trucks data to a remote database. It sends around one data message every 10 seconds. This message includes data related to the message (id, recording time and type, …), data related to the truck (vehicle registration number, driver id, driver name, latitude, longitude, speed, odometer, …), data related to the tachograph, FMS (Fuel Management System), vehicle order messages, etc. We recover these data from the database through TomTom Web Service. We select data which would be useful for our research and process it before being stored in a local database for use.

3.3 The Road Network

To carry out our work, we lean on OpenStreetMap® (2015) road network of the region of Burgundy (France). We only select this region because the transporter performs its collections/deliveries within this area. The road network is mainly composed of ways and nodes. We must know the topology of the road network graph to, particularly, get the road intersections that will be used to identify the stops at intersections and differentiate them from the stops for deliveries/collections. For more details, refer to section 4.

3.4 Details on Address Geocoding

The company uses Google geocoding API and Bing Map Geocode Service API to geocode customers' addresses of its transporters. The geocoding precision is returned with each address geocoding request (Google Maps, 2015; Bing Maps, 2015). These geocoding precisions are saved in the software database and indexed in order to be used for our work. Values are given to addresses according to the precision of their geocoding. Geocoding precision 1 is the “ROOFTOP” geocoded addresses. It indicates that the GPS coordinates returned by the geocoding API are precise. Here, we have an accuracy down to the street address level precision. It is the best geocoding precision. Address geocoding of precision 2 is the “RANGE_INTERPOLATED” address geocoding precision. Here, the geocoder does not know the precise location of the address but knows the location of the street address and two precise points of addresses on the same street address. Hence, the geocoding of our address is done by interpolating between these two precise points. It is a geocoding of medium quality. Precision of geocoding 3 is the “GEOMETRIC_CENTER” precision. It returns GPS coordinates of the center of a region (the city of the address) or the middle of the street of the address (if the street is known). This geocoding precision is bad. Finally, address geocoding of precision 4 is the “APPROXIMATE” precision. It returns an approximate geocoding result. It is often of very bad quality.

We introduced another address geocoding precision, we denote it geocoding precision 0. It is not returned by any geocoder. It indicates that the geocoding is corrected or done manually by the user (transport operator). In fact, an address could be not geocoded at all if it is not understandable by the geocoder (incorrect, incomplete or badly written address). It is equivalent to geocoding of precision 1 because the user must be very accurate in searching for and assigning GPS coordinates to a customer's address.

We use these precisions to give priorities for validating and correcting address positions on a map (matching between addresses and real delivery points). Indeed, an address with a geocoding precision of 1 (accurate geocoding) and an address with a geocoding precision of 3 or 4 could not be matched with delivery points in the same manner. More details are given in the next section.

4 Algorithm

Before starting to explain the algorithm, some definitions of basic aspects we use in this work are required. The matching is done between GPS coordinates of customers' addresses (geocoded using geocoders) and their real positions on the map. We recover the vehicle's path during its tour. The required data for our work are the speed of the vehicle and its GPS coordinates along its way. We use these data to determine the vehicle's delivery points. In fact, to deliver a customer, the vehicle needs to stop. Hence, we detect all the vehicle breakpoints (zero speed). They could be stops on road intersections, biological breaks or delivery/collection services. We suppose that, to deliver a customer, a vehicle takes at least a minimum period of time. Therefore, to determine delivery points on a tour, we select all the breakpoints where the vehicle is stopped at a location for a specified period of time. This downtime is the minimum delivery time (time threshold). It is a non deterministic parameter, hence, we can't entirely rely on this value. A way to select the good breakpoints that we search for, namely, the delivery points, is to get rid of other vehicle breakpoints of a different kind, especially the road intersection stops. Indeed, we identify all the intersections of the road network and eliminate all the breakpoints where the vehicle is close to the intersections. The breakpoints for biological breaks will not disturb us because they are relatively very few.

The matching is done route by route. For each route, we require addresses of the customers we had planned to deliver, the vehicle's breakpoints and the road intersections of the area where the vehicle made its trip. Vehicle breakpoints are unique to every real route, unlike customers' addresses where two planned routes (with different vehicles or with the same vehicle on different dates) might have customers' addresses in common. For instance, a customer can be delivered everyday by the same vehicle or with different vehicles, hence on the same area and, then, the same road intersections.

The general scheme of the Algorithm is shown on figure 1. For each vehicle route of the transporter, we select all the vehicle delivery points and their closest road intersections.

For each delivery/collection point and its closest road intersection, we search for all the closest customers' addresses within a specified radius (also stated as distance threshold). We store them in a list and in an increasing order of their distance to the delivery point. Initially, a delivery point is unmatched. While the delivery point has not been matched and we have not covered all the list of its closest customers (selected before), we search for the best customer's address to match with the delivery point. We first choose the first customer of the list (the closest one). If it does not comply the conditions to be matched with the delivery point, we move to the next customer of the list, and so on.

Figure 1 General algorithm scheme

The selected customer's address is likely to be matched with the delivery point if the delivery point is closer to the customer than to its closest road intersection. There are cases where the selected delivery point and the customer's address could, pretty well, be matched, even if the precedent condition fails. This often happens in situations where the customer position is very close to the road intersection of the breakpoint. To relax our condition, we shorten the distance threshold. Thus, if the distance between the delivery point and the customer's position does not exceed a smaller distance threshold (by multiplying the last specified distance threshold by α, with $\alpha \in]0,1[$), which means that the delivery point is very close to the customer, therefore, the matching is possible.

Before matching, we have to ensure that the delivery point and the address have not been matched yet. Also, if the customer address is already matched with another delivery point, we check if the customer is closer to this new delivery point than to its precedent delivery point. In this case, we update the matching of the customer's address with the new delivery point. Consequently, this will give delivery points that will be free again (not matched). These latter should be matched at the forthcoming matching rounds, with other close and not yet matched customer addresses.

The matching round between delivery points and customers addresses of a route is done until there is no change in the situation of the selected delivery/collection and customers' addresses points, like new or updated matching between a delivery point and a customer's address position.

Our matching algorithm is first applied on customers' addresses that have been geocoded with precision 1 and 0. We prioritize them compared to other address geocoding precisions because their geocoding is more accurate. After that, we move to match customers' addresses of geocoding precision 2. For matching these addresses, we give a slightly greater value for the distance threshold parameter. In fact, the positions of addresses could be somewhat far from their true location. Then, with a greater value, we can achieve matching these addresses with their corresponding delivery points. Finally, we try to match the rest of potential delivery points with customers' addresses geocoded with precision 3 and 4. Since these latter have bad geocoding precisions, they will be, mainly, far from the truck trajectory. So, matching rate will be very low.

The delivery points that have been matched with addresses with a geocoding precision of 1 or 0 will not be candidates for matching with customers' addresses of other geocoding precisions. Those that have been matched with addresses geocoding precision 2 will not be available for matching with customers addresses with a lower geocoding precisions, etc.

Our method is used to automatically validate a big part of the customers' GPS coordinates. This was done manually by the transporter, before implementing our algorithm. In fact, after each back from tour, transport operators check the real delivery points of their customers and ask the drivers to validate or indicate the locations of the customers' addresses with which they had trouble. Generally, drivers have experience and could easily spot the real locations of the customers. At worst, they could ask the way to the customer if they have trouble with finding a customer's address location (they are on the field!).

To release transport operators from this heavy task, we develop our algorithm to do that automatically by detecting the potential delivery/collection points (breakpoints) of the vehicles. However, not all customers' addresses are matched with delivery/collection points. Indeed, for the remaining unmatched customers' addresses, this could be justified either by the fact that a service cancellation order has occurred during the path of the vehicle (the customer's position would be far from all delivery points or the whole ride of the vehicle), but this is still uncommon, or the customer's address point is simply unmatched because of a distance bigger than the fixed threshold. For precautionary measure, these unmatched points have to be matched manually by the transport operators. The rates of the remaining unmatched customers' addresses and delivery points are rather weak. The manual matching is, thus, not really constraining.

5 Results and Discussions

In our experimentations, there are some parameters to initialize. Namely, the maximum distance for choosing the closest customer's address to a delivery point (distance threshold) and the minimum delivery time. The distance threshold is set to 300 meters. In fact, it depends on the area of the deliveries. In urban areas, addresses are near each other, therefore, the delivery/collections points could be also near each other. Then, the distance threshold should be small enough to avoid matching confusion. In contrast to rural areas where addresses are spaced each other. Then, the distance threshold could be big enough not to miss matchings.

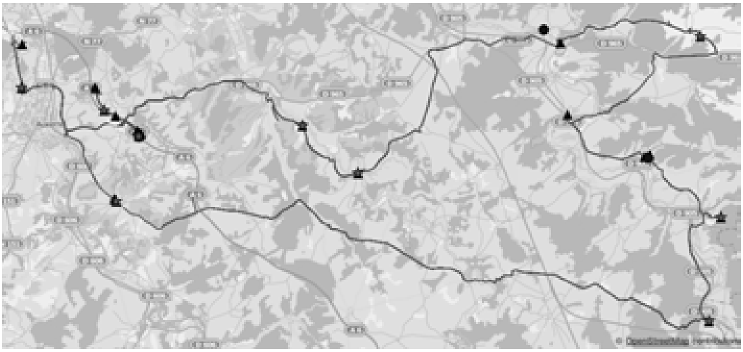

Figure 2 Example of a truck route with addresses, breakpoints and matchings

Considering the driver experience, we suppose that the minimum delivery time takes at least 70 seconds. This value might seem to be low but deliveries/collections could be very fast for small packages.

To display our vehicle tours, address points and vehicle breakpoints in an map, we use QGIS® (2015) (a free and open source geographic information system), in which we integrate OpenStreetMap® (2015) electronic map.

Figure 2 shows a vehicle real tour on the map. The solid line is the route crossed by this vehicle. This route line is composed of sequential line segments called Ways in the road network. We construct the path of the vehicle by selecting the Ways where the GPS of the vehicle has sent a data message (including its GPS coordinates) during its tour. We can observe missing segments (ways) on the truck path route. It is explained by the fact that the GPS had missed sending messages when it had passed on these Ways (short way, loss of GPS signal,…). The triangles are the potential truck delivery points (or breakpoints in a general way). As explained in section 4, they are points belonging to the truck route where the vehicle downtime exceeds a minimum delivery/collection service time. The circles are the customers' addresses positions as they are geocoded and used in the software. For clarity reasons, we select only addresses with geocoding precision 1 and 0. For other precisions, the procedure is the same. The only difference is the parameter settings as stated in section 4. Small circles are the matched addresses and big circles are those that are unmatched. The stars indicate that matching is done between a customer address and a delivery/collection point.

We run our program for matching customers' addresses of precision 1 and 0, with delivery/collection points of a route in figure 2. For this last, we achieve 75% of matched addresses with geocoding precision 1 or 0. We have 9 matched customers' addresses over 12 addresses of geocoding precisions 1 or 0.

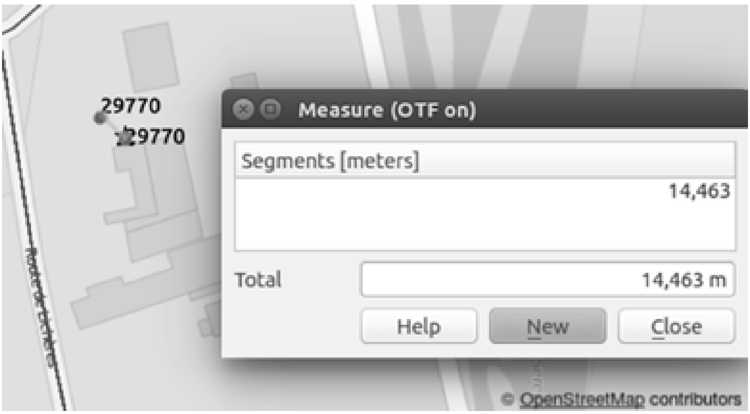

Figure 3 An example of a perfect address matching

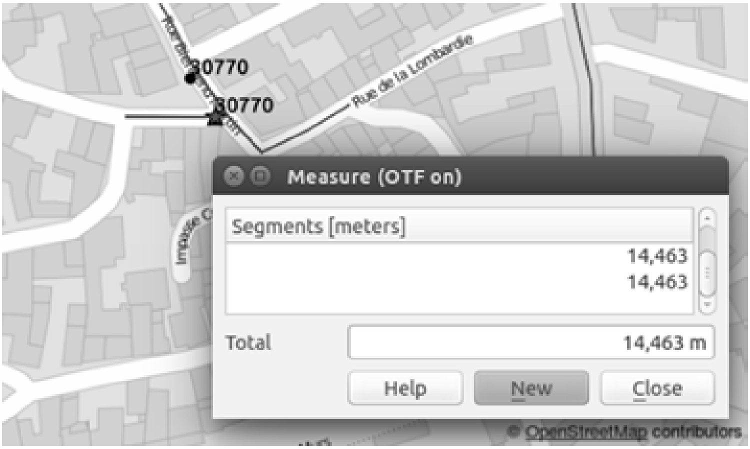

Figure 4 An example of an address matching near a road intersection

In figure 3, we show an example of a perfect matching on the route in figure 2. The vehicle has joined the customer at his exact delivery location.

In figure 4, we see that the matching is done between the customer's address and the delivery point, even if the delivery point is very close to a road intersection. It is stated in section 4 that we relax our matching condition when a breakpoint is very close to the customer's address (refer to section 4 for more details).

Figure 5 shows the matching of a customer address of geocoding precision 1 and 0. We see that the position of the customer's address on the map is not precisely positioned because it is a bit far from the breakpoint of the truck (delivery/collection point). This is justified by the fact that the delivery is for this customer, but the freight area is in another special building. In this case, the delivery point and the customer's address are close enough to be matched.

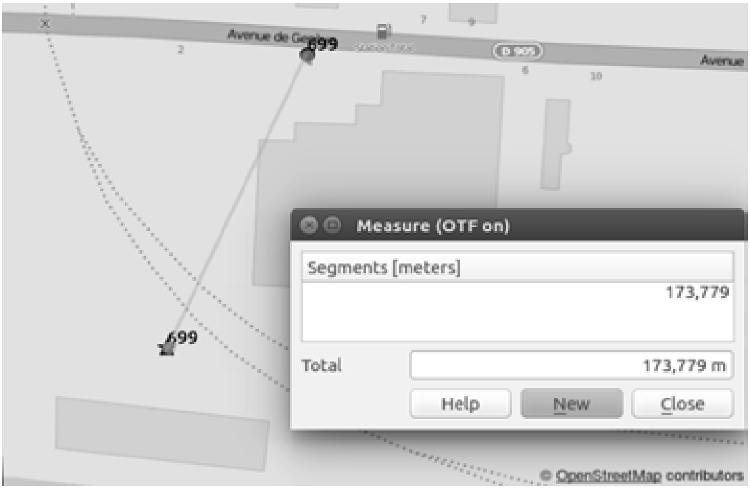

Figure 5 Another example of address matching

Figures 6 and 8 show two unmatched addresses. In figure 6 we have an unmatched address and a breakpoint at 238 meters from this customer's address. However, the matching is prevented because the nearest breakpoint is closest to a road intersection (87.5 meters far from it) (see figure 7). Hence, it is not considered as a delivery point but as an intersection stop. In figure 8, we see that the customer's address is far from the whole vehicle trajectory and at more than 2 km far from the closest breakpoint. The reason why the addresses of figures 6 and 8 are unmatched could, also, be explained by the fact that the addresses of the customers are not accurately geocoded. Indeed, geocoders are not exempt from errors (even with a geocoding precision 1) and human error can't be completely avoided (geocoding precision 0).

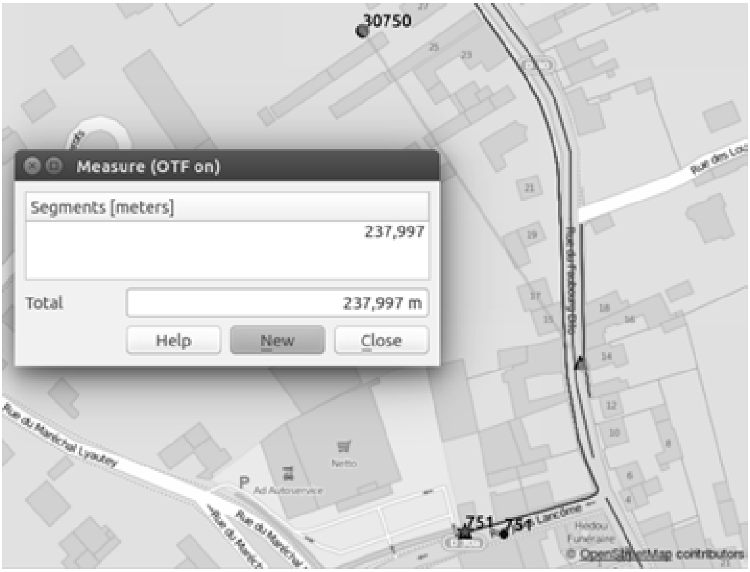

Figure 6 Example of avoided address matching because of the closeness of an intersection to a potential delivery point (breakpoint)

We have selected tours of a vehicle over a month, on which we had run our matching program. We achieve an average of 75% address matching per tour, including all addresses geocoding precisions. We have a total of 122 different delivered addresses by these tours and 60% of them were validated after running our program. Each pair of the vehicle tours could have common customers to deliver. Otherwise, we have 40% unmatched addresses per tour. This remains a rather high rate. It is mainly because of the address geocoding precisions 3 and 4. In fact, geocoding of these precisions are often far outside the vehicle path. Hence, matching could be unsuccessful at this stage. Each matched customer address will be positioned on its

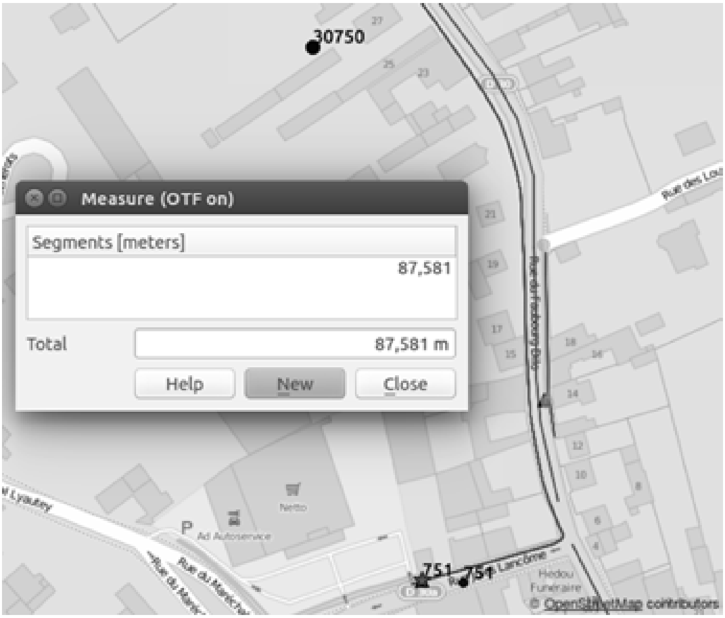

Figure 7 Example of a breakpoint near road intersection

corresponding delivery/collection point. It is considered as the real position (freight area) for serving the customer. The more we have matched good quality addresses (precisions 0, 1 and 2), the easier it would be to match the remaining few bad quality addresses (precisions 3 and 4).

The transporter delivers an average of 110 addresses per day, the transport operators have to check the validity of all the real position (GPS coordinates) of these addresses before sending the drivers to deliver them. To geocode, validate or correct an address, an experimented user spends 3 minutes in average (from 1 minute for a clear and quite simple address,

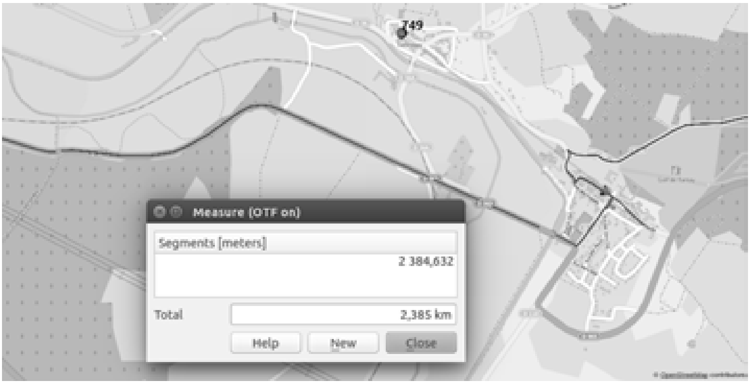

Figure 8 Customer's address out of vehicle path.

to 5 minutes for an unclear (badly written) and difficult to geocode address. It could be more if the transport operator have to ask an experimented driver to help him to find the real location of an address). As we correct an average of 75% of addresses for each tour in upstream, we save for the transporter 75% of the total time of address geocoding correction, in average. Precisely, if the users spend 3 minutes for geocoding each of the 110 addresses, instead of taking 5.5 hours for address geocoding correction, they will take only 1 hour and 22 minutes.

6 Conclusion and Future Work

We have emphasized an important issue that could break a vehicle routing optimization or any other GIS project. In fact, geocoders are not exempt from errors and they can give impertinent GPS coordinates. Also, even with a good geocoding, a poorly written, wrong or inaccurate address (human errors) can lead to a bad or completely incorrect geocoding. We work with a company of editing transport and logistics software and a transport company. Both assert that they encounter big problems because of this address geocoding issue. We propose a method that takes into account the reality of the ground to correct address geocoding, and this, by means of the real truck routes feedback. Indeed, the best way to have the correct information is to go on the field. This is done manually and unconsciously by the transport operators before implementing our algorithm. In fact, the reflex to seek information from drivers after the return of the vehicles has always existed among transporters employees. Manually considering the feedback of the truck routes for address geocoding correction could become a heavy task. This is why having a tool for doing that automatically is of great use. Our collaborators confirm that.

Our algorithm achieves to match 75% of addresses per tour, in average. Transport operators will do the remaining unmatched addresses manually. Since we have identified the delivery/collection points on the vehicle path, the manual matching remains a fairly simple task.

With our geocoding validation and correction method, when a vehicle makes its tour, for each visited customer, it might have trouble with finding this customer's address (or the good warehouse entry of the customer) at most once. In other words, the vehicle would be wrong at most once for each customer's address (the first time the truck delivers it). As the vehicle stops near the customer for a delivery time, we will have the good GPS coordinates for this address at the next matching round.

We are currently working on enhancing the matching rates, especially for addresses with low geocoding precisions (3 and 4), with which we still have matching difficulties. Also, setting the distance matching threshold and the minimum delivery time parameters to fixed values is not appropriate. In fact, if the distance between the customer and the breakpoint is one centimeter greater than the distance threshold, matching will not be done. We, then, develop a method to adapt these parameters depending on the geocoding precision, the position of each customer's address compared to the breakpoints, the intersection, etc., in order to make matching decision.

References

Anselin, L., 1995. Local indicators of spatial association-LISA. Geographical analysis, 27(2), pp.93–115.

BANO, 2014. BANO(Base Adresse Nationale Ouverte), OpenStreetMap. [online] Le projet BANO. Available at: <http://openstreetmap.fr/bano>.

Bing Maps, 2015. Bing Maps Geocode. [online] ProgrammableWeb. Available at: <http://www.programmableweb.com/api/bing-maps-geocode> [Accessed 25 Jun. 2015].

Cayo, M.R., and Talbot, T.O., 2003. Positional error in automated geocoding of residential addresses. International Journal of Health Geographics, 2(1), p.10.

English, P., Neutra, R., Scalf, R., Sullivan, M., Waller, L., and Zhu, L., 1999. Examining associations between childhood asthma and traffic flow using a geographic information system. Environmental Health Perspectives, 107(9), pp.761–767.

Foote, K.E., and Huebner, D.J., 2000. Error, Accuracy, and Precision. [online] Error, Accuracy, and Precision. Available at: <http://www.colorado.edu/geography/gcraft/notes/error/error_f.html>.

Geschwind, S.A., Stolwijk, J.A., Bracken, M., Fitzgerald, E., Stark, A., Olsen, C., and Melius, J., 1992. Risk of congenital malformations associated with proximity to hazardous waste sites. American Journal of Epidemiology, 135(11), pp.1197–1207.

Google Maps, 2015. The Google Geocoding API. [online] Google Developers. Available at: <https://developers.google.com/maps/documentation/geocoding/> [Accessed 25 Jun. 2015].

Gregorio, D.I., Cromley, E., Mrozinski, R., and Walsh, S.J., 1999. Subject loss in spatial analysis of breast cancer. Health & Place, 5(2), pp.173–177.

Howe, H.L., 1986. Geocoding NY State Cancer Registry. American Journal of Public Health, 76(12), pp.1459–1460.

Kulldorff, M., and Nagarwalla, N., 1995. Spatial disease clusters: detection and inference. Statistics in medicine, 14(8), pp.799–810.

Levine, N., and Kim, K.E., 1998. The location of motor vehicle crashes in Honolulu: a methodology for geocoding intersections. Computers, environment and urban systems, 22(6), pp.557–576.

Lewis-Michl, E.L., Melius, J.M., Kallenbach, L.R., Ju, C.L., Talbot, T.O., Orr, M.F., and Lauridsen, P.E., 1996. Breast cancer risk and residence near industry or traffic in Nassau and Suffolk Counties, Long Island, New York. Archives of Environmental Health, 51(4), pp.255–265.

OpenStreetMap, 2015. OpenStreetMap. [online] Available at: <http://www.openstreetmap.org/>.

QGIS, 2015. QGIS. [online] QGIS A Free and Open Source Geographic Information System. Available at: <http://www.qgis.org/en/site/>.

Rushton, G., and Lolonis, P., 1996. Exploratory Spatial Analysis of Birth Defect Rates in an Urban Population. Statistics in Medicine, 15(7-9), pp.717–726.

Tedies, 2013. Tedies. [online] Edies. Available at: <http://www.tedies.eu/>.

Telogis, 2015. Address Interpolation and Point Address Data. [online] Address Interpolation and Point Address Data. Available at: <http://docs.geobase.info/html/7fd14468-fa46-4b9d-9908-09fdabbc621b.htm>.

Tomtom, 2015. Tomtom. [online] Fleet Management & Vehicle Tracking - Tomtom Telematics GB. Available at: <https://business.tomtom.com/en_gb/>.

Upsilon, 2009. Upsilon. [online] Upsilon, le spécialiste du transport et de la logistique dans l'Yonne. Available at: <http://upsilon89.com/>.

Yu, L., 1996. Development and Evaluation of a Framework for Assessing the Efficiency and Accuracy of Street Address Geocoding Strategies. State University of New York at Albany.

Zinszer, K., Jauvin, C., Verma, A., Bedard, L., Allard, R., Schwartzman, K., de Montigny, L., Charland, K., and Buckeridge, D.L., 2010. Residential address errors in public health surveillance data: a description and analysis of the impact on geocoding. Spatial and Spatio-Temporal Epidemiology, 1(2-3), pp.163–168.

Decision Support Platform for Urban Freight Transport

Pedro David Gutierrez Quijano

Urban transport in cities is composed of many micro-transport systems. Each one of these has negative effect on the urban mobility. The study and analysis of one of these micro-transport systems is an effective way to understand the problem and consequently to propose new solutions, as well as a source of information to improve the urban transport system. In this paper we focus on the urban goods transport system that emerges from a particular supply chain, we support on a GIS (Geographic information system) computer simulation model to understand and analyze a case study. The simulation model developed is an example on how the abstraction approach of agent-based modeling (ABM) integrated with GIS can be used to represent the complexity inherent in the urban transport system. The novelty of our approach lies mainly in the fact of being able to analyze the combined effect between supply chain management and transportation system. The use of ABM allow us to model behaviors, negotiations and other social properties of the system's entities represented as agents, it can also help with understanding the emerging system's behaviors from an independent level. As a result of our study, the conceptual multi-agent model is presented and implemented in JAVA programing language, which is used for simulation experiments on the analysis of routing and departure time choice, with the goal to propose a plan to improve the micro-transport system under study.

Keywords: Supply Chain, Transport, Agent-based, GIS

1 Introduction

Today, 54 per cent of the world's population lives in urban areas, it is estimated that by 2050 two thirds of the world's population will live in cities. Projections show that urbanization combined with the overall growth of the world's population could add another 2.5 billion people to urban populations by 2050, United Nations Development Programme (2014). In a world of rapidly increasing urbanization, with an unprecedented transition from rural to urban areas, urban transport is at risk of collapsing in the next years, with a panorama that it can affect the quality of life of hundreds of thousands of citizen, it is not surprising that the urban transport must be high on the plans for politician, city planners and other specialists, as well as researchers.

Owing to their large and densely urban populations and widespread commercial activities, urban areas require the distribution and collection of large quantities of goods and the provision of a wide range of services for commercial and domestic use, resulting in considerable freight activity. However, in spite of its importance, lately politician and researchers have paid relatively very little attention to urban freight in contrast to passenger transport. Again like in the industrial revolution, urban freight transport pose us new logistical challenges, there is a need to contemplate how best to tackle urban freight transport logistics because it is vital to achieve the ultimate objective for urban areas: mobility and accessibility for both freight and passenger, efficiently supporting commercial transport with high quality of life for his citizens.

One approach regarding to the issue of urban freight that it has great potential despite still, it is in development process. It is related with the simulation models, decision makers trust on models, abstractions of the real world to test a number of scenarios before implementing a chosen scenario in practice. It make sense because, it is excessively costly and risky to perform scenarios in reality, it may then sound evident that, if the models are used to test decisions that will have an impact on the real world, they should be good representations and precise reflections of that same real world for which the decisions are intended. Unfortunately, transport models are more often than not poor representations. Consequently, they result in bad.

There have been numerous attempts to improve the performance of urban freight while simultaneously reducing its negative environmental impacts. The results, however, have been disappointing, and most pilot projects have not survived. This may be due to the fact that the solutions have been designed and evaluated without taking into account the particular characteristics of different city areas. A supply chain management approach may be applied to urban freight transport where the complete process is taken into consideration, emphasizing the role of customers as well as transport suppliers.

In contrast, we propose a model for urban freight transport, in which the behavior of freight agents and their relationship in supply chains are integrated, the model covering all links in the supply chain from supply through production up to the distribution and his transport until the final consumer. The approach aims assess the isolated impact of one supply chain on the urban transport.

This document summarizes the work done by the authors during three year, it aims to propose a decision support platform for urban freight transport and to show his application to analyze the urban freight movement in the Palmira city area. In the next pages, a brief introduction to simulation and agent-based modeling (ABMS), the main concepts and application areas are illustrated, a review of some previous work on the subject is done, and a review is made of existing methodologies to model agent-based systems. The proposed platform is discussed and the details on model formulations are provided. A practical application around the modeling and simulation based on agents (ABMS) in the supply chain related to the baker sector of the city of Palmira, Valle Colombia. The final section provides conclusions and recommendations on the proposed model.

2 Agent-based modeling (ABM)

Agent-based simulation has proven to be a very useful technique for modeling complex systems, especially social systems, Gilbert (2004). Using agent-based simulation, the modeler explicitly recognized the actors that make up complex systems, and in particular the social relationships between these, which are the product of individual behaviors and their interactions. The main difference between the agents and other modeling techniques-based simulation is the way to build the abstraction of the real system and consequently, the formal model is built.

On formal models built using agent-based simulation, the basic components of the real system are explicitly and individually represented in the model, Edmonds (2001). In this sense the organizational boundaries that define the fundamental components of the real system correspond to the boundaries of the model agents and interactions that take place among the fundamental components of the real system correspond to the interactions that take place between the agents of the model. In this sense the organizational boundaries that define the fundamental components of the real system correspond to the boundaries of the model agents and interactions that take place among the fundamental components of the real system correspond to the interactions that take place between the agents of the model. This direct correspondence is precisely the main attraction of the agents modeling since it is capable of increasing the realism and the scientific rigor of formal models thus constructed.

Agent-based systems are characterized by understanding various agents that are in greater or lesser degree heterogeneous, autonomous and independent, showing everyone their own goals and objectives, and are generally able to interact among themselves and with their environment, Torsun (2010). Often, but not always, they are systems characterized by the existence of large numbers of relatively simple agents, which can evolve over time to adapt to new conditions or new goals. In particular, agent-based simulation is particularly important in complex systems with the following characteristics:

— Systems in which the geographical space can have a significant influence. In many systems, the fact that two individuals are separated in space means a probability of lower interaction. Agent-based modeling facilitates the representation of physical space in which they move and interact agents.

- Systems where there is social interaction networks. Interactions between system components can be influenced by several factors in addition to the physical space. Agent-based modeling facilitates social interaction networks that are not necessarily structured spatially explicit representation.
- Systems in which the individual components of the system are able to learn, and it is convenient to represent explicitly and individually each component of the system.

Agents-based methodology has been widely used to model systems in a wide range of scientific disciplines: for example, economy, Tesfastion (2002), finances Lebaron (2000), management of natural resources Bousquet (2004), political sciences Axelrod (1997), anthropology Kohler (2000), sociology Conte (1997), biology Paton (2004), supply chain and medicine Mansury (2002), where on the basis of rules which determine the individual behavior of the agents intends to infer the global properties of the entire system. Agents-based methods facilitate the study and modeling of complex systems from the units that compose them, allowing us to build experimental models of reality from a different from the traditional point of view: from the most simple to the complex, from the particular to the more general.

Since the emphasis on agent-based simulation is to find appropriate abstractions that describe the basic components of the system and their interactions, rather than seeking abstractions that handled directly on the global dynamics of the system, this modeling technique is particularly useful to model macroscopic processes that arise from interactions between actors in a system.

There are various research contributions that seek to assess the true value of the application of this approach in decentralized supply chains around the theme of ABMS, Borshchev and Filippov (2004) explains that the ABMS is by nature decentralized, since the overall behavior of the system is never defined, on the other hand the model defines individual behaviors allowing the behavior of the global system to emerge from individuals, also known as simulation, Arango Serna, Serna Uran, and Alvarez Uribe (2012), in decentralized chains however the overall behavior of the system is difficult to measure, because of the dispersion in terms of topological, functional, administrative, etc., of different organizations.

2.1 Methodologies

In the context of the ABMS have been proposed different methodologies, however very few focus on the supply chain (SC), Hernández, Alemany, Lario, and Poler (2009), some of these appear in the review made by Labarthe, Espinasse, Ferrarini, and Montreuil (2007) where needs to incorporate elements of complexity to modelling and go into detail on specific methodological elements are explicit. For the development of this work, three contributions were taken into account in particular:

Initially, Labarthe, Espinasse, Ferrarini, and Montreuil (2007) it proposes a methodology based on agents applied to the case of a SC of the industry of golf clubs, includes an experimental analysis by means of simulation, the authors propose a methodology comprised of three levels (i) a conceptual level, in which the real SC is modelled by means of domains and then reformulated to agents approach resulting in a conceptual model, (ii) an

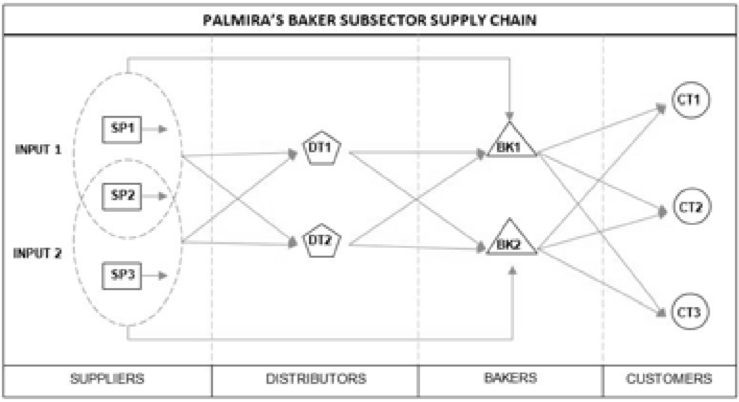

Figure 1 Palmira's baker supply chain

operational level which is developed a computational model known as operational model, (iii) a level of exploitation, in which the simulation is carried out based on scenarios.

Hernández, Alemany, Lario, and Poler (2009) presents the implementation in a case study on one car CS, proposes a nine phased methodology that considers the modeling AB and linear to support programming operational planning in SC nine phrases are developed through three blocks of action that are similar to those proposed by Labarthe, Espinasse, Ferrarini, and Montreuil (2007): (i) conceptualization that corresponds to the identification of the problem, conceptualization, and obtain parameters, (ii) modeling AB: beginning with the identification of main and intermediate agents representation of behaviors and the conceptual model AB, (iii) the application considers the development of the application and the final validation.

Finally, Ivanov, Sokolov, and Kaeschel (2010) combined application of the control theory, operations research and modeling AB on a methodology for Adaptive SC. The authors consider different types of structures for decision-making is the SC: products, functions, organization, technology, topology, information and finances, the importance of this approach is the identify relationships in operations resulting from the different types of structures. The authors also present a methodology based on three phases: conceptual modeling, mathematical modelling and validation in simulation environment.

3 Case Study

The case study that analyzed in this work is composed of 80 companies in the planning sector of the city of Palmira, Valle. The characterization of this supply chain was carried out by members of the Group SEPRO (Society Economy and Productivity) in previous stages of the research. Below I present a summary of the current situation of these previous research-based supply chain.

3.1 Description

Following is the supply chain based from three points of view, as it proposes, (Cardenas, 2013) in its methodology.

3.1.1 Normative View

Organizational structure: From the raw material production to the final consumption, the Palmira's baker subsector supply chain is composed of four levels: Supply, Distribution, Manufacture and Consumption; each level conformed by only one actor (Figure 1), these actors interact with each other with the goal to transform the resources into goods, and finally, distribute them to consumers.

Functional Structure: Based to the SCOR model the functional structure of Palmira's baker subsector supply chain is illustrated in the (Figure2), the production process is simple, initially the suppliers supplied the input materials to produce the bread, this materials are dealer to the distribution centers, later the bakeries buy these materials to the distribution centers or directly to the suppliers, and then the bakers make bread and await that the customers will buy bread.

Decisional Structure: In accordance with the classification of Chu and Leon (2008), the Palmira's baker subsector supply chain is a "private information

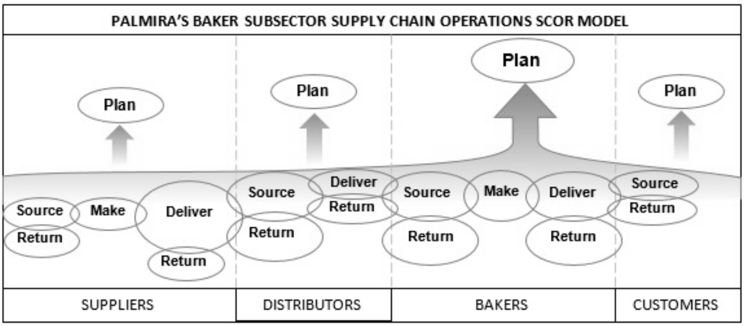

Figure 2 SCOR Model

system” in other words a system where the decision-making authority is “decentralized” since no actor has authority to make decision for other actors in the system, and the access to information is “partial” because the decision-makers has access to only limited information of the system (private information). In this case there are no any decision structure, the decisions are taken individually by each actor of the supply chain, and the particular benefit governs the system. This is related to the fact that neither exists any informational structure.

General Polities: Although the decisions are taken individually by each actor of the supply chain, the suppliers have more influence than all other actors in the chain, because of them depends the supply of raw materials to the other actors.

Applicable laws: The main control institution is the Secretary of Health, who is responsible to inspect, evaluate and enforce the GMP (Good Manufacturing Practice) based on the decree 3075 of 1997.

3.1.2 Infrastructure View

The study area is located in Palmira, it is a city and municipality in southwestern Colombia in the Valle del Cauca Department, located about 30 km east from Cali, the department's capital. The city covers an area of 1.160 square meters, and have about of 296.200 habitants, Chamber of Commerce (2011) distributed on 16 comunas of which 7 comunas are located in the urban area. According to the official data supply by the Palmira’s Chamber of Commerce, the city have 204 bakeries of which 80 bakeries participated in the study. We have the geographic position of each of the bakeries.

The suppliers and the distributors have wineries where they stored his products; these wineries generally are leased by other people. The main transportation means used in the supply chain are bike and motorcycle however the suppliers and the big distributors use tucks.
Studied bakeries are located within the urban area of the city of Palmira, where 96% are in the lower middle strata (2 and 3) and plants which develop their activities are rented by 82%. However this sector providers, have different locations designated as local, regional and national. Transport of inputs and distribution of the finished products are made only by land; for the transport of inputs used bicycle, motorcycle and bike trailer for small distributors, while producers or larger distributors used vans for transportation of inputs. Used labor is essentially technical.
Information infrastructure is basic, is limited to the use of means of telephone communication between bread and distributors or producers, without registration or support of such communication, use of additional media such as the use of email, software or fax is not recorded.
Financial structure, within the supply chain transactions, there are basically two methods of payment. Cash payment and payment on credit, the latter with greater presence in the bakeries of small size. There is no evidence of electronic payments, or any other transaction.

3.1.3 Logistic View

Physical flow: The logistic flow from the raw materials to his transformation in final product, happens from suppliers to the customers (see Figure 1), the flow of raw materials begins with the producers, inputs flow water down through dealers, to converge in bakeries, and finally reaching the final consumer in the form of cakes and pastries from this level. There is no surge while raw materials flow down the chain.

Information flow: The information flow about to the logistic operation between actors of the chain supply is completely null, the only information that flows through the chain is related to the commercial exchange between the actors in the chain.

Financial flow: Opposite of logistic flow the financial flow happens from the customers to the suppliers, the flow of money begins with the commercial exchange between consumers and the bakery: consumers buy bread at the bakers products, then money flows between the bakery and the distributors and sometimes between bakeries and producers: bakeries use part of their profits in the purchase of the necessary inputs for manufacturing their products to distributors or directly to producers Finally the money flows between distributors and producers since distributors buy inputs to producers.

3.2 Results

The simulation platform is still a prototype. All the modules are programmed but still is phase of validation and verification. The next step is to compare the simulated trip patterns with actual data from field research. The results look very reasonable and promising. The model is capable of describing trip patterns, predicting route choice and calculating effects on accessibility and environment.

4 Computational Platform

In the last few years, the agent-based modeling (ABM) community has developed several practical agent based modeling platforms that enable individuals to understand each individual system separately supply chain or transport system. However, real life does not works in this way, our approach is develop a platform that enable to logistic analyst to understand the complete system.

4.1 Modeling

The platform proposed uses the multi-agent paradigm to model a supply chain and her emerging transport system, in order to apply multi-agent system tools to simulate supply chain management. A supply chain may be defined as an integrated process wherein a number of various business entities (suppliers, manufacturers, distributors, and retailers) work together in an effort to: (1) acquire raw materials, (2) convert these raw materials into specified final products, and (3) deliver these final products to retailers. Following, we describes each one of the agents proposed to model under study system.

4.1.1 Agent 1: Supplier

The objective of this agent is supply the demand of raw material of the producer's agents, it only have direct relation with agents type 2. With the idea of simplify the model, this agent is modelling like supplier with endless supplies.

4.1.2 Agent 2: Producer

The objective of this agent is supply the demand of final product efficiently, always with the idea of maximize its own profit, it is customer of agent 1 at the same time it is supplier of the agent 3.

4.1.3 Agent 3: Retailer

The objective of this agent is supply the demand efficiently, at the right time, in the required quantity and required quality. It is customer of agent 2 at the same time it is supplier of the agent 4.

4.1.4 Agent 3: Distributor

The objective of this agent is the keep finished product available for sale, while it has already set a frequency with which the batches of production will be carried out, must calculate how many products must be built and put on sale, why it should consider the expected demand, available inputs and the current inventory of finished product.
The assumptions that are handled for this agent are mainly three: (i) the agent has a daily frequency of fixed and known production, (ii) the production of finished products (breads) time is deterministic and known, (iii) the agent boasts a daily demand according to the day and month.

4.2 Implementation

The computational framework for implementing the proposed strategy consists of the following components: the computation control module, the

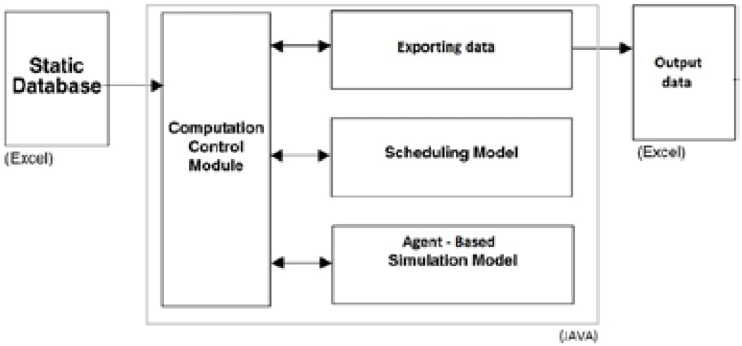

Figure 3 Computational components

three models for exporting, scheduling and simulation, and the static database feeds the system, as shown in (Figure 3). The computational control module provides centralized computation management and control of interactions with the other computational components. Its various functional roles include:

1. Generation of deterministic demand forecasts and demand scenarios.
2. Generating/updating and releasing commands for executing the planning, scheduling and simulation models.
3. Issuing commands for retrieving/recording in the databases.
4. Re-processing the outputs of planning and scheduling models as inputs to scheduling and simulation models respectively.
5. Reporting the computation results.

The static database contains the information defining the case problem. The data is saved in a Microsoft Excel Workbook file. One spreadsheets for agent and inside of each spreadsheets, the data is categorized based on their relevance and saved in its corresponding spreadsheets. The categories of the static data are as follows:

1. Quantities related: number of agents of each type, number of product types, number of grades, number of packages, and number of processing units in each production facility, production capacities.
2. Time related: length of simulation horizon, length of the horizon and of each period in the planning and scheduling models.
3. Demand related: demand proportion of each product type, package ratio, proportion of regional demands, parameters for demand patterns of each product.
4. Analysis related: number of iterations for the outer optimization loop, convergence tolerance.
5. Extras: inventory cost, backlogging cost, safety stock shortage cost, transportation cost, transportation time, initial safety stock levels.

The output data records the computational results and provides the updated output data. The following summarizes the information kept in this the output database:

1. Current time related indices: current iteration number of the outer loop, current iteration number of the Monte Carlo loop, current simulation clock (date and time of the current point at a simulation).
2. State variables: on-hand inventory levels, WIP at each processing units at each agent, demands backlogged and products in transit,

which are updated at each scheduling time period as the simulation proceeds.

3. Demand data: the deterministic demand forecast and the demand scenarios.

The GIS and agent based simulation model is fully written in JAVA language and support by different open source frameworks.

5 Conclusion

Transport and urban development projects are often a source of major controversy, as they can generate significant benefits as well as difficulties for various local actors. Methodologies are needed that can incorporate different points of view in order to find sustainable solutions for transport, mobility and logistics. Computational models can be used in the context of complex transport-policy decisions, allowing all of the different stakeholder perspectives to be taken into account and structuring the discussion by assessing the relative weights of all the factors involved.

In urban contexts, freight transport is an important part of the local economy and employment and, at the same time, one link in a larger supply chain. It is therefore important to look for solutions that fit in with urban policy objectives and the commercial model of the supply chains. Therefore, solutions require a combination of local policy, new technology and varied logistics solutions.

There have been numerous attempts to improve the performance of urban freight while simultaneously reducing its negative environmental impacts. The results, however, have been disappointing, and most pilot projects have not survived. This may be due to the fact that the solutions have been designed and evaluated without taking into account the particular characteristics of different city areas. A supply chain management approach may be applied to urban freight transport where the complete process is taken into consideration, emphasizing the role of customers as well as transport suppliers.

The proposed model is a comprehensive approach to model freight transportation in a way that systematically reflects the individual behavior of freight agents. The model incorporates individual behaviors by considering the largest influence of each freight agent at each stage. The model takes into account the fundamentals of goods transport, which is consequence of goods flowing through supply chains. Each agent is assumed to behave rationally in freight transport activities (such as goods purchasing, carrier and vehicle size selection, and vehicle routing) by trying to minimize his own total costs in each activity. The proposed model was applied to analyze the freight transport in the Palmira city area. The results of model application suggest the need follow working for models reflect reality more accurately, this concept is very promising.

The proposed model for vehicle routing is still rather simple and considers only the distribution purpose while pick-up purpose is not yet incorporated. Vehicle routing with time window constraint is also suggested for an improvement of the model. The variations in the pattern vehicle routing are needed to be considered in the future.

Multi Agent-based models in traffic and transport planning are still relatively new, but have proven to provide more accurate and richer result sets, although currently somewhat slower. That is, they are better reflections of reality. Also, they are much more intuitive to understand and to validate, an aspect often over looked in evaluating the quality of a model’s output.

References

Arango Serna, M. D., Serna Uran, C. A., and Alvarez Uribe, K. C. (2012). Collaborative Autonomous Systems in Models of Urban Logistics. Dyna, 79(172), 171-179.

Axelrod, R. (1997). Advancing the Art of Simulation in the Social Sciences. 2-7.

Borshchev, A., and Filippov, A. (2004). From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools. The 22nd International Conference of the System Dynamics Society, (pp. 1-15). Oxford, England.

Bousquet, F. (2004). Multi-agent simulations and ecosystem management: A review. Ecological Modelling, 313-332.

Chu, C.-L., and Leon, V. (2008). Single-vendor multi-buyer inventory coordination under private information. European Journal of Operational Research, 485-503.

Conte, R. (1997). Simulating Social Phenomena. Berlin: Springer-Verlag, 21-98.

Edmonds, B. (2001). The use of models - making MABS more informative. 3-15.

Gilbert, N. (2004). Agent-based social simulation: Dealing with complexity. 1-11.

Hernández, J. E., Alemany, M., Lario, F. C., and Poler, R. (2009). SCAMM-CPA: A supply chain agent-based modelling methodology that supports a collaborative planning process. Innovar, 19(34), 99-120.

Ivanov, D., Sokolov, B., and Kaeschel, J. A. (2010). Multi-structural framework for adaptive supply chain planning and operations control with structure dynamics considerations. European Journal of Operational Research, 200, 409-420.

Kohler, T. (2000). Dynamics in human and primate societies: Agent-based modeling of social and spatial processes. Vienna, Austria: Springer, 53-135.

Labarthe, O., Espinasse, B., Ferrarini, A., and Montreuil, B. (2007). Toward a methodological framework for agent-based modelling and simulation of supply chains in a mass customization context. Simulation Modelling Practice and Theory(15), 113-116.

Lebaron, B. (2000). Agent based computational finance: suggested readings and early research. 1-20.

Mansury, Y. (2002). Emerging Patterns in Tumor Systems: Simulating the Dynamics of Multicellular Clusters with an Agent-based Spatial Agglomeration Model. Journal of Theoretical Biology, 343-370.

Paton, R. (2004). Evolvable social agents for bacterial systems modeling. NanoBioscience, IEEE Transactions on. 208 - 216.

Tesfastion, L. (2002). Agent-based computational economics: growing economies from the bottom up. 3-24.

Torsun, I. S. (2010). Foundations of Intelligent Knowledge-based Systems. New York: Jones and Bartlett Publishers, 157 - 184.

United Nations Development Programme, U. (2014). Annual Human Develop Report 2014. New York: United Nations Development Programme, (UNDP), 33-45. Retrieved from http://hdr.undp.org/sites/default/files/hdr14-report-en-1.pdf

III.
Supply Chain Security Insights

A Decade of GAO's Supply Chain Security Oversight

Toni Männistö and Juha Hintsa

This study characterizes and synthetizes reports that the US Government Accountability Office (GAO), an independent government watchdog organization, has published on supply chain security (SCS) since 2005. The study follows a systematic and transparent protocol for examining the 25 identified GAO documents. The document review reveals benefits and drawbacks of US SCS policies, initiatives and regulations. The findings allow contrasting of the US government's approach to SCS to the one of the European Commission. This comparison reveals differences and similarities in supply chain security policies both sides of the Atlantic and allows the policy makers to benchmark their approaches to supply chain security. The comparative analysis also paves the road for further EU-US harmonization and mutual recognition of the SCS programs. The study is part of European FP7-Project CORE.

Keywords: Supply Chain Security, Government Accountability Office, Customs and Border Protection, FP7-CORE

1 Introduction

1.1 Background

The terrorist attacks of September 11 in 2001 started a new era in the security management and control of international trade and logistics networks. The tragic events raised concerns, particularly among the policy and law enforcement circles, about the possibility that terrorist organizations could exploit global supply chains to move tools, materials and operatives across borders. In the most alarming scenario, the terrorists would hide a weapon of mass destruction in a shipping container and detonate it at its destination. Soon after the September 11 tragedy, the focus on supply chain security shifted from theft prevention towards counter-terrorism (Lee and Whang, 2005, pp. 289), and this change in the general mindset eventually lead to introduction of a large number of new supply chain security (SCS) programs, laws and regulations (Hintsa et al., 2009, pp. 346). However, the problem with the new SCS initiatives was that they tended to disrupt free trade and international flow of goods. In other words, due to the new security regimes, it took now more time for shipments to travel through the global supply chain. What is more, the delivery times did not only get longer but also less reliable. And perhaps most importantly, the extra security increased shipping costs.

Governments and the trading community soon recognized that securing the supply chain without disrupting the cross-border flow of goods is to a large extent a matter of regulatory harmonization and mutual recognition. Back in early 2000’s and still today, incompatible security regimes force traders and logistics actors to comply with a broad disarray of security requirements (Grainger, 2011, pp. 39-40). In some cases, security controls are redundant: even if security checks are done in one country, the same controls must be redone in one or more countries along the international supply chain. The regulatory harmonization and recognition of one another's security controls would help to rationalize security processes throughout the international supply chains.

1.2 Post-2001 Supply Chain Security in the US

Ever since 2001, the US government has taken strong efforts to strengthen the security of the US-bound supply chain. The US Customs and Border Protection (CBP) launched a voluntary Customs-Trade Partnership Against Terrorism (C-TPAT) to engage the business community in the fight against terrorism. Not long after this precursor program, a stream of other SCS initiatives followed, most notably the Container Security Initiative (CSI) and the Known Shipper Program. At the same time, the US government modernized its regulatory framework in areas of air cargo security, maritime security and customs security.

The US government has naturally been very interested in monitoring effectiveness and efficiency of its SCS initiatives, and the impact of the security initiatives on the cross-border flow of goods. The US Government Accountability Office (GAO) has taken a major role in overseeing the US SCS initiatives. On its website, the US Government Accountability Office (GAO) characterizes itself as "an independent, nonpartisan agency that works for Congress." Colloquially speaking, GAO is a government watchdog organization with a mission of ensuring efficient use of US taxpayers' dollars. In fiscal year 2014, GAO had a budget of $543,6 million, and it employed around 3000 people. The organization proclaims that at every dollar invested in GAO saves 100 dollars of the US taxpayers' money. Indeed, over the past ten years, GAO has produced a rather impressive library of independent, objective and open reports and testimonies on various US SCS initiatives. The quality of the GAO documents appears high: each report draws on the best possible information set available, whether it is a set of interviews, statistics or survey data.

The GAO reports comprise a unique body of SCS knowledge and experience that helps us to understand many benefits, drawbacks and development opportunities of most of the SCS initiatives that the US government has introduced. This information also allows foreign governments to better understand innovations and mistakes of the US programs and apply the lessons' learned when they launch or update their own SCS programs. The GAO information is especially useful for the European Union (EU) that runs many similar SCS programs than the US government. Besides, the GAO reports' detailed descriptions of the US SCS initiatives help policy-makers in other countries to see what it takes to align and harmonize requirements of their own and the US initiatives. Understanding the similarities and differences between the programs set the basis for mutual recognition of SCS initiatives.

Given the uniqueness and relevance of the GAO information for the policy-making in the EU, this study reviews reports that the US Government Accountability Office has published on supply chain security since 2005. This review seeks to identify drawbacks and benefits of the US SCS programs, and contrast them against their counterparts in the EU. Formally stated, this study addresses following research question.

RQ: What can the EU supply chain security learn from the GAO's publications?

2 Research Methods

To carry out this review study, our research team respected the two main principles of the so-called systematic literature review (SLR) methodology: transparency and accountability (Tranfield et al. 2003). Our analysis, however, differed from the purist approach to the systematic literature review by focusing only on one body of literature, the GAO reports and testimonies, instead of exploring the full range of academic, governmental and business studies on the topic. Before engaging in the document reviews, our team devised an eight-step analysis procedure to extract relevant information from to-be-reviewed GAO documents. The team also agreed on system for documenting and archiving the review findings.

Next, after defining the common rules for doing the review, the team searched for suitable GAO documents to be reviewed by executing online inquiries with major academic and non-academic search engines and by visiting the GAO's official website. The team applied two inclusion criteria for the candidate GAO publications, which number totaled around 300 testimonies and reports. The documents had to discuss supply chain security or closely associated themes such as trade facilitation, and they had to been published in 2005 or later. The reason why we did not consider documents, that were older than ten years, was our intention to avoid reviewing obsoleted documents and outdated information. After the team had identified the initial pool of documents, individual members of the team had an opportunity to suggest some additional GAO documents for the review that had escaped the initial search. The final sample of GAO documents ended up being 24 reports and testimonies.

The research team also agreed on an eight-step protocol for describing and analyzing the review documents (table 1 below). Besides basic citation information, the protocol instructed document reviewers to summary the document, examine the document using the common SWOT – strengths, weaknesses, opportunities, threats – framework, and to link review findings with the FP7-Project CORE work packages and demonstrations. In essence, the protocol guided the document reviewers to pay attention to the same issues, and facilitated the team to produce consistent and comparable document reviews that later enabled writing of quality cross-analyses and summaries.

Table 1 The 8-steps of the review protocol

Step	Importance
1. Basic citation of the document; and document availability	Mandatory
2. Summary of the document, including overall relevance for CORE	Mandatory

Step	Importance
3. Classification / keywords / navigation / tags for the document	Mandatory
4. Brief analysis, e.g. in "SWOT-style" (strengths, weaknesses, opportunities, threats) – if available either in literature or in your own work	If available
5. More detailed analysis of relevance for CORE, on WP / Task / Deliverable level	Nice to have
6. Cross-referencing between two or more documents	Nice to have
7. Anticipation whether CORE could have an impact on the future versions of this document	Nice to have
8. Full citation of the document, following Emerald guidelines	Nice to have

The document reviews produced 24 written document summaries, each of which follows the structure of the 8-step review protocol. As most of the reviews are too long to be included in this paper, the table 2 below presents a three-step excerpt of one GAO document review. The headline of the table shows the full citation details of the reviewed document. The main body of text summarizes the document (step 2) and elaborates its relevance to the CORE project (step 3). In particular, the analysis highlights that CORE's work on risk management and awareness building benefit from the insights the reviewed GAO document describes. The full, eight-step analyses are five pages long on average, so due to the space constraints, we illustrate only the protocol's three most consequential steps in the table below.

Table 2 Example of two first steps of a GAO document review

SUPPLY CHAIN SECURITY - DHS Could Improve Cargo Security by Periodically Assessing Risks from Foreign Ports, GAO
This GAO report reviews maritime supply chain security programs that the Department of Homeland Security and its component agencies – mainly the Customs and Border Protection (CBP) and the Coast Guard – have implemented since 2001. The report examines (1) the extent to which DHS has assessed risk levels of foreign ports and allocated security resources accordingly and (2) activities DHS has taken to monitor and improve efficiency and effectiveness of its security initiatives. Drawing on numerous interviews of key stakeholders and examination of key documents, the report recommends CBP to consider expansion of its Container Security Initiative (CSI) into new ports based on a periodic risk assessment of foreign ports. The report also highlights opportunities for further harmonization of the US maritime security initiatives with their foreign counterparts through mutual recognition agreements. Since this report contains fundamental information about the US maritime security programs, many CORE work packages are likely to benefit from the insights this report provides. Especially, the demonstrations, which involve ocean shipping, as well as the risk cluster, can use this information to support and guide their work.
Detailed analysis of relevance for CORE: The report provides a comprehensive outlook on the US maritime supply chain security initiatives that

the DHS and its component agencies – mainly CBP and Coast Guard – have implemented since 2001. The report features some interesting figures that map the security initiatives on the global supply chain and that illustrate current solutions the US government employs to screen and examine US-bound shipping containers. The CORE's demonstrations that involve maritime shipping are likely to benefit from the information this report provides. Also the risk cluster can use the information, and especially the mapping of the US maritime security initiatives over the global supply chain, to design risk-based, layered approaches to maritime supply chain security. The education cluster can also reuse the contents of this report to produce relevant and informative training material for various supply chain stakeholders that are involved in the seaborne trade and logistics.

3 Analysis

3.1 Descriptive overview of GAO reports

The final review sample comprises 24 GAO documents. Of these documents, nine are testimonies (37,5%), and the remaining fifteen are reports (62,5%). The testimonies are formal statements addressed to one or more Congressional policy-making bodies, and which contents and recommendations are based primarily on earlier, more technical GAO reports.

Each of the GAO documents has a headline theme that is announced in the document's name with capital letters. The headline themes, as illustrated in the Figure 1 below, give a general summary of the topics that the GAO documents address, and they also indirectly hint about priorities of the US government's SCS priorities. The most significant themes are supply chain security (38%), maritime security (33%) and aviation security (13%). More narrow topics – transportation security administration, transportation security, and transportation security information sharing and port security grant program – were the headline themes in one reviewed GAO document only. It is surprising, however, that none of the GAO documents discuss security in the context of road or rail transport. It would be reasonable if future GAO research or studies by other organizations addressed also these currently neglected modes of transport. Also, the existing GAO reports largely overlook important supply chain security themes such as cyber security and supply chain resilience. This statistics is visualized in figure 1 below.

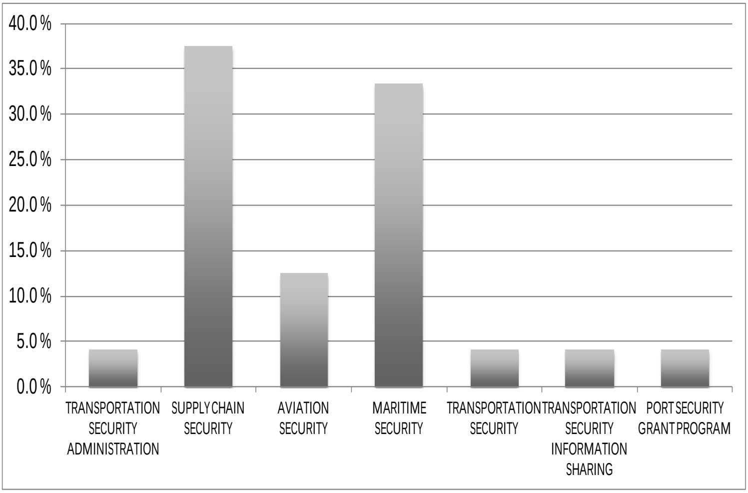

Figure 1 Statistics on the GAO document headline themes

The GAO documents are often addressed to a particular policy-making audience. Most of the reviewed GAO reports were addressed for "Congressional Requesters" in general. Testimonies, in turn, were often addressed for specific working groups and committees of the U.S Senate and the House of Representatives, for example the Committee on Homeland Security, the Subcommittee on Transportation and Infrastructure and the Committee on Commerce, Science and Transportation.

Table 3 Recommendation type

Theme	Number	Percentage
Information management	7	20,6%
Risk assessment	7	20,6%
Performance monitoring	5	14,7%
Cost-benefit analysis	3	8,8%
Resource planning	3	8,8%
Feasibility assessment	2	5,9%
Compliance monitoring	2	5,9%
Updating of plans	2	5,9%
Improved scanning	2	5,9%

The GAO reports and testimonies give many recommendations for various US government agencies. These recommendations are the key instruments for GAO to promote its mission that is to "the audit, evaluation, and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people." The table 3 lists main types of recommendations that the GAO provide. Most often, the reports urge the US agencies to improve their processes for collecting, recording, analyzing and making use of information. The recommendations on information management also urge the agencies to collaborate more actively with one another and with their foreign fellow organizations. The second most common theme of the GAO recommendations is the risk assessment that includes identification of risk, evaluation of their likelihoods and impacts and assessment of overall vulnerabilities in the supply chain. Many of the reviewed reports also highlight the need to establish and improve indicators, measurements and procedures for monitoring performance of security initiatives. Related to the overall performance monitoring, many of the reports urge the US agencies to carry out cost-benefit and feasibility analyzes of governmental security investments. Resource planning and periodic revision of plans was also considered important area of improvement by the GAO documents. Important yet less commonly proposed recommendations consider calls for improved scanning technologies and more stringent and common compliance monitoring.

When the research team selected the GAO reports for this review, they decided to include all supply chain security reports that the organization has published in 2005 or later. Despite this scoping decision, in the final sample of 24 articles, all reports and testimonies have been published after 2006. The oldest article dates back to 2007, and the newest one has been published in January 2015. Otherwise, the rest of the articles have been published relatively evenly over the years. The figure 2 below illustrates the distribution of the 24 reviewed articles over the past ten years. We see that many of the GAO documents are relatively old. Therefore, the SCS community would benefit from a more recent, up-to-date analyses of the initiatives. Therefore, EU funded supply chain security projects, such as the FP7 CORE, might choose to update the obsoleted documentation and this way increase the project's impact on SCS policy making and practice.

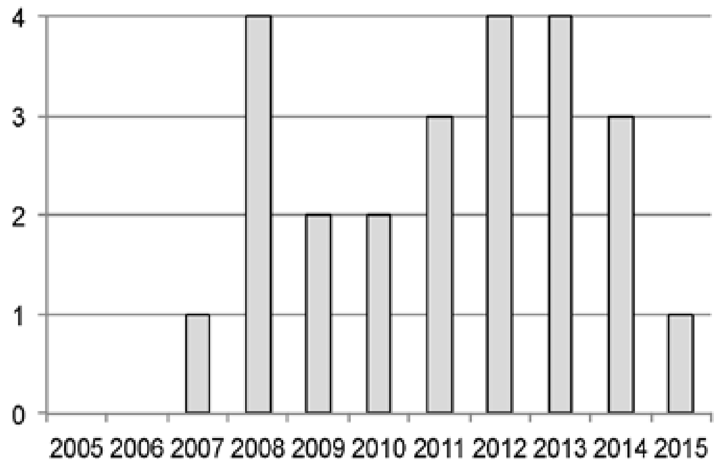

Figure 2 Publishing years of the 24 reviewed articles

3.2 Analytical Findings

The 24 reviewed GAO documents discuss a broad variety of US SCS initiatives. Many of these initiatives share similarities with the equivalent EU initiatives, and thus the EU policy-makers and authorities should at least consider whether the GAO recommendations could be applied in the EU context as well. This section shows connections between equivalent SCS programs in the US and in the EU and summarizes main recommendations that might be reasonable to put into effect on the both sides of the Atlantic. Readers who are interested in learning more about technicalities of the discussed SCS programs are advised to visit online sites of the US homeland security and European Commision. These online sources provide a large array of documentation on past and ongoing SCS initiatives.

Ocean-going vessels carry around 80% of the world's cargo by volume and 70% by value (UNCTAD, 2014), so it is not a surprise that the importance of the sea transport for the global cargo flows has attracted wide interest in maritime supply chain security both in the US and in the EU. Today, the US maritime security scheme comprises a set of security layers that are designed to mitigate the risk of maritime-related terrorist attacks. One key component in the US maritime security is the Advanced Targeting System (ATS), a risk assessment tool that calculates risk scores for US-bound maritime shipping containers and selects those containers that should be inspected for contraband at foreign ports or at the US destination upon arrival. The ATS uses an advance cargo information data (ACI), that carriers and importers submit to the CBP according to the 24-hour rule and 10 + 2 Importer Security Filing requirement, to calculate the risk levels. The equivalent risk assessment scheme is in place in the EU as well, though the targeting is carried out by member states and the ACI dataset is submitted as part of the entry (or exit) summary declarations, before the goods enter (or leave) the EU customs security area (EU-28, Switzerland and Norway). The GAO reports suggest that the US CBP should update the weight set that the organization uses to calculate the risk scores, periodically, based on results of the most recent risk assessment. The reports also proposes that the CBP would create performance metrics to check effectiveness of the risk targeting efforts and to clarify rules that lead to waiving of container inspections at foreign ports. The table 4 below illustrates the US and EU programs on advance cargo information and targeting and related GAO recommendations.

Table 4 Advance cargo information and targeting

US program	Equivalent EU program	Main GAO recommendations
Advance Targeting System (ATS) based on 24-hour rule and 10 + 2 Importer Security Filing	National risk assessment systems based on Entry summary declaration	Ensure that future updates to the weight set are based on assessments of its performance Establish targets for performance measures and use those measures to regularly assess effectiveness of the weight set Clarify, harmonize and enforce the rules and the procedures for waiving the high-risk containers from examination

The advanced cargo information and the targeting highlights those shipping containers that require scanning with non-intrusive imagining technologies (colloquially referred as “X-rays”), radiation detection measures, or both. This scanning targets primarily radioactive and radiological weapons or material that could be used for terrorism on the US soil. The US has been rather active in setting up new counter-terrorism maritime security programs that involve scanning of shipping containers. The CBP did launch its first counter-terrorism container screening program, the Container Security Initiative, in January 2002. The vision of this program was to screen high-risk US-bound shipping containers for terrorist threats already at foreign ports. The US Department of Homeland Security also rolled out the Secure Freight Initiative (SFI) to screen a higher percentage of US-bound containers with the non-intrusive imagining technologies and the radiation detectors at foreign ports. SFI has been operational in six foreign ports since early 2007. At the ultimate program, as part of the “Implementing recommendations of the 9/11 Commission act of 2007,” the US Congress required scanning every US-bound maritime container at the last foreign port. This 100% scanning legislation has been considered unfeasible by the trading community and by many foreign governments, and the Congress has already postponed its implementation two times. It is important to note that while the US has been active in promoting their maritime security scheme internationally, the EU has not established any major programs for screening EU-bound containers in foreign ports. To sum up, the table 5 below summarizes the US container screening programs and recommendations that the GAO reports propose to improve them.

Table 5 Maritime container screening

US program	Equivalent EU program	Main GAO recommendations
Secure Freight Initiative	N/A	Conduct periodic risk assessment in foreign ports
Container Security Initiative (CSI)	N/A	Revise staffing model Improve collection of process information (e.g., performance of scanning teams) Develop performance criteria Conduct periodic risk assessment of foreign ports
100% scanning legislation	N/A	Conduct feasibility study

Another important theme in the GAO documentation is air cargo security. The reviewed documents highlight the importance of establishing voluntary secure supply chain programs, which would allow air cargo operators to move security screening away from congested airports towards the upstream of the air cargo supply chain. The US Known Shipper and Certified Cargo Screening Programs (CCSP) are fundamentally similar to the European Known Consignor (KC), Account Consignor (AC) and Regulated Agent (RA) air cargo security programs. The both concepts aim to ensure that air cargo originates from a trusted source and it travels to the airport through trusted logistics middlemen and that the cargo gets screened by certified screening operators. The GAO documents recommend (GAO, 2007; GAO, 2008b) US air cargo operators to improve security screening through better technology and procedures and to step up compliance monitoring of certified air cargo operators.

Another topical theme in the air cargo sector is the security of inbound cargo that comes from foreign countries. The problem in ensuring adequate security for the inbound cargo is that authorities cannot easily verify and enforce that security procedures are being carried out up to a satisfactory standard in foreign jurisdictions. To remedy this problem, both the US and EU legislators have been introducing new legal frameworks that force airlines, that operate from abroad into their jurisdictions, to comply with their security rules. Regulating the airlines avoids the problem of imposing rules directly on sovereign governments and meddling with their national legislations. In the EU, the law for ensuring adequate security of inbound air cargo is called ACC3 (Air Cargo or Mail Carrier operating into the Union from a Third Country Airport), and this piece of legislation was introduced as part of the amendment Regulation 1082/2012 of the EU Regulation 185/2010. The legal basis of the equivalent US legislation for screening inbound air cargo is the "Implementing Recommendations of the 9/11 Commission Act." The GAO reports recommend the US authorities to establish a risk-based air cargo screening strategy that would facilitate screening operators to identify high-risk shipments and assign them to more thorough screening. The reports also propose that the US authorities would increase both frequency and stringency of compliance monitoring activities that seek to ensure that the air cargo industry complies with the legal requirements. The table 6 below lists the main air cargo security programs and presents recommendations that the GAO documents propose to improve them.

Supply chain security is fundamentally about collaboration between government agencies and the trading community. Put it simple, companies generally ship and move cargo, and the governmental actors enforce that the companies comply with necessary security and other regulations.

Table 6 Secure supply chain programs

US program	Equivalent EU program	Main GAO recommendations
Known Shipper / Certified Cargo Screening Program (CCSP)	Known Consignor (KC) / Account Consignor (AC) / Regulated agents (RAs)	Improve screening Step up compliance monitoring
100% screening of inbound air cargo	ACC3	Establish a risk-based air cargo security strategy Improve interagency communication nationally Step up compliance monitoring of foreign air cargo industry's stakeholders

Especially the US government has been very active in encouraging the business sector to strengthen voluntarily the security of their supply chains. The US Customs and Border Protection (CBP) has been running its security-centric AEO program, Customs-Trade Partnership Against Terrorism (C-TPAT), since November 2001. As part of the program, the CBP promises faster and simpler customs formalities for companies that agree to implement a set of voluntary security controls. Being the first operational AEO program, the C-TPAT has been an example for many subsequent AEO programs: for example, the EU AEO, the Canadian Partners In Protection (PIP), Secure Exports Scheme in New Zealand, and the Jordanian Golden List Programme. The GAO reports essentially recommend that the US CBP would improve its processes for validating and revalidating C-TPAT applicants and current members of the program. The reports also highlight the importance of setting up formal performance measures for assessing the degree of compliance with the C-TPAT requirements. The Table 7 below shows recommendations that GAO documents (GAO, 2008a; GAO, 2008d) propose for improving the C-TPAT government-business supply chain security program.

Table 7 Authorized Economic Operator programs

US program	Equivalent EU program	Main GAO recommendations
C-TPAT	EU AEO	Improve the process of validating security practices of C-TPAT members Develop performance measures

4 Discussion

The GAO reports raise many concerns regarding performance monitoring and auditing of the US SCS initiatives, and this emphasis could be seen as an incentive for the EU officials to check their approaches in these critical areas. Moreover, the information of the GAO documents set a solid basis for transatlantic harmonization of SCS regulations and programs. There are many SCS initiatives both sides of the Atlantic that seek to achieve the same security objectives. For example, both the European Commission and the US government run their own security-centric authorized economic programs, EU AEO-S and C-TPAT respectively. There are also quite similar security programs on air cargo security, and the US and EU authorities could look for ways to align these programs in terms of security requirements, renewal periods and training to align their Known Shipper, Known Consignor and Certified Cargo Screening programs.

The GAO reports highlight the importance of avoiding certain mistakes that the US SCS initiatives have made in the past. Most important lesson to learn is that it is often critical to involve relevant industries when designing new regulations and to get their buy-in, at least at some level, before forcing companies to comply with new security requirements. The US 100 percent scanning requirement is an archetypal example of a security regulation to which the US government has been spending a great deal of money and effort only to achieve mediocre impact: the legislation is still pending, and most likely, it will never become operational due to the fierce criticism from the trading industry, port operators and foreign governments.

The thoroughness of the GAO analyzes imply that the recommendations that the reports suggest are reliable and justified. These recommendations highlight issues that the US SCS programs have encountered, and thus the recommendations might prove useful also for EU authorities that run similar SCS programs than their US colleagues.

Having said all this, the EU policy-makers should still remain skeptical about the applicability of the GAO recommendations in the EU context. Sometimes differences between seemingly equivalent security programs exist, and these differences justify if not require different approaches to managing the programs. For example, the EU member states do not always share the US views on security risks and threats. From the European perspective, some of the US counter-terrorism initiatives, most notably the 100 percent scanning legislation, seem excessive and disproportionate to the risks they seek to address. Besides the perceptual differences, also the review methodology sets some limits to the validity and the generalizability of the findings. First of all, many of the GAO documents are relatively old, and they thus may contain obsolete information about the US SCS initiatives.

Bottom line, the review team found that the GAO documents are not only highly relevant for SCS management and governance but also of high quality. In the EU, there are no similar independent watchdog organizations that would review SCS practices across the member states and suggest improvements for more efficient and effective use of government spending on SCS. Given the high relevance of the GAO reports, we therefore recommend the EU to consider establishing a quality assurance body equivalent to the GAO and to mandate this body to undertake periodic reviews on the EU's SCS programs. If this new auditing body had qualified experts onboard, it could also take care of evaluation of scientific quality of the many SCS research projects that the European Commission is funding. The table 8 summarizes the key findings and arguments of this discussion section.

Table 8 Summary of discussion

What GAO reports and testimonies offer	How EU policy making can benefit from the GAO reports and testimonies	Possible benefits
Detailed analysis of US SCS initiatives and programs	Understand similarities and differences of SCS programs both sides of the Atlantic	Alignment of C-TPAT and EU AEO-S programs Further harmonization of air cargo security regimes
Recommendations for improving SCS	Consider relevancy of the recommendations in the EU context	Learn from US mistakes and successes
Evidence of high quality government oversight	Consider establishing equivalent quality assurance body in the EU	Periodic, independent assessments EU's security programs Better oversight of EU's research projects

5 Conclusions and recommendations

The review of the GAO documents leads to some interesting findings. We found that the reviewed documents focus primarily on maritime and air cargo security, and that they largely overlook rail and road modes of transport. The air and maritime domains no doubt merit a great deal of attention, but we nevertheless recommend future GAO studies to investigate security challenges in road and road transportation, as well. The reviewed sample of GAO documents also neglects cyber security and supply chain resiliency, two increasingly relevant themes in the practice and theory of the modern-day SCS. We therefore recommend that GAO researchers and political entities, that assign studies to GAO, would address these themes in more detail in near future. Many GAO documents have also been published years ago, so there is an apparent need to update the contents of many GAO reports, especially in the area of air cargo security, a domain that has been subject to a relatively recent regulatory reforms (e.g., the regulation 185/2010 of the European Commission).

Moreover, given the high quality and relevancy of the GAO documentation to the SCS practice and theory, the EU might consider establishing a similar watchdog organization to assess effectiveness and efficiency of the SCS programs and SCS projects in the EU. The GAO documents provide, at least for the most part, first class analysis and propose warranted recommendations for improving US SCS programs. Because many of the US programs have their counterparts in the EU (e.g., the EU AOE is the equivalent of the US C-TPAT), and because similar programs most likely encounter similar problems at the both sides of the Atlantic, it would be useful for EU officials to study recommendations that the GAO reports propose and consider whether it makes sense to put some of the recommendations in practice in the EU. The recommendations urge authorities, for example, to improve their information management practices, compliance monitoring, performance monitoring and risk-based decision-making. For instance, stepping up the compliance monitoring of the EU Authorized Economic Operator (AEO) program would allow border control agencies to put more trust on certified AEO companies and facilitate their cross-border trade. The risk-based decision-making holds a great promise for improving air cargo security screening without slowing down the speed of this time-critical mode of transport: if we were able to identify high-risk cargo, based for example analysis of rudimentary shipping information (e.g., sender, receiver and declared contents), we could subject high-risk shipments to stringent security controls and facilitate screening of low-risk cargo. Most importantly, understanding the GAO description of the US programs and the associated recommendations is crucial for a variety of EU regulators and policy-makers so that they can pursue further US-EU regulatory harmonization and mutual recognition of SCS programs. In particular, further harmonization could be achieved in air cargo security domain between the US certified screening program and the EU's security supply chain concept (covering Known Consignors, Account Consignors and Regulated Agents), at least in the areas of compliance monitoring and training. Also further harmonization of trusted trader programs, the US C-TPAT and the EU AEO, would lower security-related red tape and barriers for trade and logistics.

The review findings have some implications to the FP7-CORE. By addressing the overlooked themes and updating the obsolete GAO documentation, the CORE consortium could increase the project's impact on the SCS policy making and practice. Those reviewed documents that deal with cybercrime and cyber security, clearly indicate that supply chain actors should pay more and more attention on the security of their ICT-based systems and communications. For this apparent reason, the CORE demonstrations might choose to include more elements of cyber security.

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References

Government Accountability Office, 2007. Federal Efforts to Secure U.S.-Bound Air Cargo Are in the Early Stages and Could Be Strengthened, Aviation Security. Washington: GAO.

Government Accountability Office, 2008a. CBP Works with International Entities to Promote Global Customs Security Standards and Initiatives, but Challenges Remain, Supply Chain Security. Washington: GAO.

Government Accountability Office, 2008b. Transportation Security Administration Has Strengthened Planning to Guide Investments in Key Aviation Security Programs, but More Work Remains, Aviation Security. Washington: GAO.

Government Accountability Office, 2008c. Examinations of High- Risk Cargo at Foreign Seaports Have Increased, but Improved Data Collection and Performance Measures Are Needed, Supply Chain Security. Washington: GAO.

Government Accountability Office, 2008d. U.S. Customs and Border Protection Has Enhanced Its Partnership with Import Trade Sectors, but Challenges Remain in Verifying Security Practices, Supply Chain Security. Washington: GAO.

Government Accountability Office, 2009a. Vessel Tracking Systems Provide Key Information, but the Need for Duplicate Data Should Be Reviewed, Maritime Security. Washington: GAO.

Government Accountability Office, 2009b. Feasibility and Cost-Benefit Analysis Would Assist DHS and Congress in Assessing and Implementing the Requirement to Scan 100 Percent of U.S.-Bound Containers, Supply Chain Security. Washington: GAO.

Government Accountability Office, 2010a. DHS Progress and Challenges in Key Areas of Port Security, Maritime Security. Washington: GAO.

Government Accountability Office, 2010b. DHS Should Test and Evaluate Container Security Technologies Consistent with All Identified

Government Accountability Office, 2011a. Risk Model, Grant Management, and Effectiveness Measures Could Be Strengthened, Port Security Grant Program. Washington: GAO.

Government Accountability Office, 2011b. Progress Made, but Further Actions Needed to Secure the Maritime Energy Supply, Maritime Security. Washington: GAO.

Government Accountability Office, 2011c. Progress Made, but Challenges Persist in Meeting the Screening Mandate for Air Cargo, Aviation Security. Washington: GAO.

Government Accountability Office, 2012a. Progress and Challenges Faced in Strengthening Three Key Security Programs Transportation Security Administration. Washington: GAO.

Government Accountability Office, 2012b. Container Security Programs Have Matured, but Uncertainty Persists over the Future of 100 Percent Scanning", Supply Chain Security. Washington: GAO

Government Accountability Office, 2012c. DHS Could Improve Cargo Security by Periodically Assessing Risks from Foreign Ports, Supply Chain Security. Washington: GAO.

Government Accountability Office, 2012d. Progress and Challenges 10 Years after the Maritime Transportation Security Act, Maritime Security. Washington: GAO.

Government Accountability Office, 2012e. CBP Needs to Conduct Regular Assessments of Its Cargo Targeting System, Supply Chain Security. Washington: GAO.

Government Accountability Office, 2013a. Action Needed to Strengthen TSA's Security Threat Assessment Process, Transportation Security. Washington: GAO.

Government Accountability Office, 2013b. DHS Could Benefit from Tracking Progress in Implementing the Small Vessel Security Strategy Maritime Security. Washington: GAO.

Government Accountability Office, 2013c. Progress and Challenges in Key DHS Programs to Secure the Maritime Borders, Maritime Security. Washington: GAO.

Government Accountability Office, 2014d. Ongoing U.S. Counterpiracy Efforts Would Benefit From Agency Assessments, Maritime Security. Washington: GAO.

Government Accountability Office, 2014e. Progress and Challenges with Selected Port Security Programs, Maritime Security. Washington: GAO.

Government Accountability Office, 2014f. Stakeholder Satisfaction Varies; TSA Could Take Additional Actions to Strengthen Efforts, Transportation Security Information Sharing. Washington: GAO.

Government Accountability Office, 2014g. CBP Needs to Enhance Its Guidance and Oversight of High-Risk Maritime Cargo Shipments, Supply Chain Security. Washington: GAO.

Government Accountability Office, 2015. Operational Scenarios to Ensure the Technologies Will Function as Intended, Supply Chain Security. Washington: GAO.

Grainger, A. 2011. Trade facilitation: a conceptual review. Journal of World Trade, 45(1), 39-62.

Hintsa, J., Gutierrez, X., Wieser, P., & Hameri, A. P. 2009. Supply chain security management: an overview. International Journal of Logistics Systems and Management, 5(3), 344-355.

Lee, H. L., & Whang, S. 2005. Higher supply chain security with lower cost: Lessons from total quality management. International Journal of production economics, 96(3), 289-300.

United Nations Conference on Trade and Development, 2014. Review of Maritime Transport. Geneva: UNCTAD.

Supply Chain Security: Survey on Law Enforcement Agencies' Training Needs

Juha Hintsa, Juha Ahokas, Rosie Gallagher and Toni Männistö

This paper studies of the types of training material which needs to be developed to order to help law enforcement fight crime more effectively in the context of international supply chains. The research is based on a survey of law enforcement officials and policy makers, concerned education and training matters. The results of this study highlight areas of supply chain security where the global law enforcement community may need new training material and information most urgently. Despite the fact that the relatively small and diverse sample size limits the validity and generalizability, the findings of this study help to design priorities, methods and target audiences for future law enforcement training programs. Over time, addressing these identified training needs makes the law enforcement community more able to prevent, detect and investigate supply chain crimes such as cargo theft, trafficking, and terrorism. The study also complements the limited body of empirical research on supply chain security and contributes to the theory of supply chain security by showing how law enforcement agencies perceive supply chain crime and the types of security solutions which they consider most useful for fighting it.

Keywords: Supply Chain Security, Law Enforcement Agencies, Training Needs, FP7-CORE

1 Introduction

This paper describes the design and piloting of a training needs survey for law enforcement on the topic of supply chain security. It took place in relation to the CORE Project, the world's largest supply chain security research project, funded through the European Unions' Seventh Frame-work Program. One aspect of the CORE Project seeks to disseminate its findings to key stakeholders by way of the development of education and training materials.

Knowing that law enforcement authorities are potentially important stakeholders in supply chain security matters, the project proposes to develop tailored training materials for this audience. The overall aim of this exercise is to enhance law enforcement capacity to prevent and investigate crimes linked to global supply chains.

First, we review the available literature on the subject of adult learning generally, and then on adult learning in law enforcement contexts in particular. We then provide a brief overview of the literature available on the subject of supply chain security. We explain the ways in which these bodies of work influenced the design of the survey.

The paper then discusses in detail the survey design, explaining in turn each question which was included in the survey. Subsequently, we dis-cuss the results of the survey based on the responses derived from con-ducting the survey at the LE TrainNet Meeting (Networking Meeting of the Law Enforcement training institutions) which took place in Baku, Azerbaijan, 28-29 April 2015.

2 Literature Review

2.1 Adult Learning

The study of adult learning as an academic discipline has gained increased interest in recent decades.

Knowles (1973), a key proponent of adult learning theory, is credited with revitalizing the use of the term 'andraogy,' as the equivalent of pedagogy for adults, revived from a term employed in Germany as early as 1833. Working within a humanistic framework, Knowles' work around andragogy revolves around the notion of adults as being autonomous, self-directed learners whose acquisition of knowledge is facilitated by teachers or trainers. Knowles put forward a number of principles of adult learning, stating that: adults are self-motivated and self-directed, adults bring their life experiences and knowledge to their experiences of learning, adults have a readiness to learn, and are relevancy-oriented and practical in terms of their learning.

Fidishun (2000) further put forward the premise that adult learners have a great deal of agency in their learning, and that they are resistant to learning when they feel that the information is being imposed on them. The Baku survey takes heed of this principle, by asking the audience to identify their own precise training needs.

Brookfield (1995) explored four key areas of research in adult learning which together compose a central body of work for adult learning theory. Firstly, the notion of self-directed learning is critical to adult learning theory, whereby adult learners seek out their own learning goals and resources and play an active part in evaluating their progress. Secondly, he raises the point of critical reflection, knowing that adults approach learning with critical thinking, paying careful attention to context. Thirdly, Brookfield notes a convergence towards establishing experiential learning as a central tenet of adult learning, given that making reference to real-life adult experiences give meaning to the processes of learning. Finally, he consolidates the literature around the process of 'learning to learn' in adults. This focusses on the notion that adult learners take ownership and interest in the process by which they acquire knowledge, such as taking the time to understand their own learning styles and patterns, with a view to optimizing their own cognitive acquisition of knowledge.

Houle (1961) developed a typology for different kinds of adult learners, arriving at three broad categories: goal-oriented (those seeking to achieve specific objectives), activity-oriented (those who partake in learning in order to derive meaning from the social circumstances) and learning-oriented (those who seek learning for the sake of learning). The main impact of this for the Baku survey was that there is clearly no 'one-size-fits-all' solution for adult learning, just as there is no single profile for an adult learner. Thus, in Q4 of the survey (which addresses learning methods) it was important to suggest a range of options and not privilege one type of learner over another.

2.2 Adult Learning, for Law Enforcement Authorities (LEAs)

There exists a great deal of literature on the topic of effective strategies for adult education, and a smaller but consolidated body of literature on effective training for law enforcement authorities.

In applying Knowles principles of andragogy to police training concepts, Vodde (2012) establishes six constructs for structuring effective police training, as follows:

1. Institutional and instructional philosophy - should reflect the mission statement of the police institution.
2. Affective orientation: climate, tone and environment - creating a learning environment which challenges yet nurtures police trainees.
3. Self-concept and self-directedness - recognizing the role of individual autonomy in police training activities.
4. Integration and facilitation of curriculum - training curricula should respect the interlinked and inter-related nature of the subjects it covers.
5. Application and integration of experiential learning - police training should provide opportunities for exercising new skills in practical environments.
6. Stress and discipline - principles of accountability and hierarchy should be worked in to training activities, whilst still fostering an environment of mutual trust and respect.

Thus when devising the Baku survey, it was important to select learning methods which work within these themes and are accepted to be effective for law enforcement training generally. The main themes which were picked up on were: constructivism and problem-based learning, lifelong learning and flexibility, and construction of knowledge as a social process. Each of these will be detailed below, with an explanation of the way in which they were incorporated into the Baku survey.

2.2.1 Constructivism and Problem-based Learning

Firstly, it is widely established that training for law enforcement is most effective when it is hands-on, practical and with direct applications to the daily work of officers. Working within this framework, the value of using constructivism to view police training and education can be underscored. Constructivism, whereby meaning is generated from interactions with others, can be a useful lens through which to view police training, as it implies the effective identification of problems whilst planning for the resolution of these problems in real-life environments. According to Goldstein (1990, quoted in Glasgow and Lepatski, 2012): effective policing consists of proper recognition and research of "problems" and planning to try and solve those problems. Problem-based learning is thus a highly-effective strategy for use in police training.

Constructivism and problem-based learning centralises the learner as the makers of meaning and knowledge, and brings together problem solving and free discovery in order to assist in the development of a learners' ability to solve real-life problems. For this reason, the Baku survey invoked the possibility of using problem-based learning, practical exercises and demonstrations.

2.2.2 Lifelong Learning and Flexibility

The importance of lifelong learning, closely correlated with the knowledge and skills needs of the workplace has been underscored by a number of theorists. Lieb (1999) noted that training programmes for adults should take into account the fact that, unlike child learners, train-ing constitutes a commitment of time and/or resources, knowing that adults are often heavily committed elsewhere in terms of their profes-sional and family lives. As a consequence, a number of theorists have cautioned that programmes for adult learning must be flexible, adaptable and sensitive to the particular needs and constraints of the adult learner. Davis et al (2004) outlined an infrastructure for online learning: "once developed, any infrastructure must be able to evolve in order to accommodate changing student needs, technologies and curricula."

In the case of law enforcement, there is a strong potential for the application of lifelong learning as there is a clear need for training to be frequent, repeated and constantly updated in order to match the ever-evolving needs of the profession. Working within this framework, the Baku survey recognised that e-learning, distance, blended learning, or mobile phone application solutions may be of value in transmitting knowledge on sup-ply chain security to a global law enforcement audience, in addition to proposing the traditional Socratic methods. According to Lieb (1999) and others, adult educators notice that learning happens in each individual as a continual process throughout life.

Training solutions thus need to be flexible and adaptable, and envisage modalities other than the traditional classroom-based ones so that they can be taken up, in theory, by any officer at any time. For this reason, some of the suggested outcomes (Baku survey Q4) include e-Learning, mobile applications, blended learning and case studies.

2.2.3 Construction of Knowledge as a Social Process

A number of theorists underline the construction of knowledge as a social process, particularly in the constructivist tradition. Jonassen (1999) postures that constructivism creates a highly-fruitful learning environment in which students become actively involved in the creation of their own knowledge. Socialisation is key to this process, as the constructivist environment encourages learners to 'bounce' ideas off one another. Indeed, in this school of thought learning occurs best within a social group (Karagiorgi and Symeou, 2005), where there are some elements of the real-world environment, which replicate the workplace.
Collaborative groups can be used in police training to "test [their] own understanding and examine the understanding of others as a mechanism for enriching, interweaving, and explaining [their] understanding of particular issues or phenomena." (Savery and Duffy, 2001, quoted in Glasgow and Lepatski, 2012).
Therefore in designing the survey, we placed an emphasis on learning modalities which were interactive and with a strong social dimension including: collaborative problem-based learning, debates, practical exercises, role playing and serious games.

2.3 Supply Chain Security

Supply chain security management aims at mitigating the likelihood and consequences of intentional acts meant to cause harm in the supply chains (e.g., Pfhol, Köhler and Thomas, 2010; Nagurney, Manuj and Mentzer, 2008; Closs and McGarrel, 2004).

According Männistö (2015) the main goals of supply chain security solutions are discouragement and opportunity reduction, protection of cargo integrity, detection and interception, and investigation. Discouragement and opportunity reduction includes increasing efforts needed to commit crimes (e.g. strengthening targets with security locks and controlling access to accounting systems), increasing risk to be arrested and convicted (e.g. strengthening formal surveillance such as police and guard patrolling), and reducing rewards (e.g. using product authentication technologies, licensed customer care). Protection of cargo integrity means measures which prevent motivated offenders to bring valuable assets in their possession. These measures encompass structures that give resistant against manual, electronic or electromagnetic efforts to break-in (burglar resistance doors and windows, tamper proof containers) and security technologies and services that detect intruders and alert people who are capable to intercept intrusion. Männistö includes here also security screening and vetting aimed at detecting dishonest employees and business partners. Detection and interception means security solutions which prevent the escalation of security incidents while offenders have already succeeded to initiate criminal acts, such as the concealing of contraband in transportation units. These security solutions include scanning of containers and risk assessment techniques that help to detect dangerous or contaminated containers and consignments. Investigative measures come into a play when the adverse consequences materialize. They aim at limiting the extent and duration of supply chain breach and assessing financial losses or personal injuries and casualties. Investigations can also shed light on current supply chain vulnerabilities that can be mitigated and prevented in the future.

The main goal of the FP7-CORE project is to develop and test technologies which facilitate legitimate trade and minimize disruptions due to inefficient customs processes and other law enforcement controls. Consequently, the survey focuses on technologies, methods, tools and databases which improve detection and interception, and public-public and public-private data sharing and collaboration. Data sharing encompasses both multi-agency collaboration on national level and international level, and includes improved data sharing between customs and police. The questionnaire includes tools and databases that enable to assess, screen and inspect the cargo traffic focusing on specific crime types, trade lanes, transport systems or commodity types. Overall threat and vulnerability assessments are also included. In addition, tools to assess compliance with compulsory and voluntary supply chain security programs and initiatives were assessed in the questionnaire. The last group contains different cargo screening and scanning technologies, electronic seals and transport vehicle track & trace technologies.

The findings of the literature review provided us with a basis from which to develop a survey which was both sensitive to the realities of education and training in a law enforcement context, and to contemporary issues in global supply chain security.

3 Baku Survey Design

This survey gathers information with the aim of determining the types of training materials which need to be developed in order to help police and customs law enforcement agencies to better combat crime in the context of international trade lanes. The survey features five survey questions with five Likert scale response options, as below: 1. Not at all useful / important / effective, 2. Not very useful / important / effective, 3. Somewhat useful / important / effective, 4. Very useful / important / effective or 5. Cannot say. The five questions are listed below and explained in turn.

Question 1. How useful would it be for your organization to access new and enhanced training materials with regard to the following crime areas?

This first question identifies the key crime areas relevant to police and customs law enforcement work, where there is a need for new and enhanced training materials. Some of the crime areas proposed are: cigarette and tobacco trafficking, corruption, cybercrime, financial crime & tax evasion, maritime piracy, pharmaceutical crime and terrorism.

Question 2. How useful is it for your organization to learn about advancements in the following areas of supply chain security methods, tools, programs and datasets?

Here we have collected a list of technologies, tools, practices and programmes such as tracking and tracing technologies, anti-tampering technologies, risk management tools for overall threat and shipment, databases with intelligence on criminal acts and trends, collaboration practices among governmental agencies on national and international level. These options are derived from technologies, tools, practices and programmes which will be demonstrated over the CORE Project, currently being funded by the European Union.

Question 3. How important do you consider it to be that the new training materials on supply chain security include the following types of content?

The contents of this list are derived from the discussions of a workshop in the framework of the CORE Project, which aimed at identifying approaches, aspects and perspectives which could be of use in developing new training materials. We listed items such as case study approaches, collaborative approaches, assessment of negative consequences and impacts, cost-benefit analyses, human factors and proactive approaches instead of reactive ones.

Question 4. Please rate each of the following learning methods, based on how effective you think they are for your law enforcement training activities.

Similar to Question 3, we created a list of training and learning methods and asked the audience to assess them according to their potential effectiveness. Learning methods proposed here included blended learning, classroom lectures, debates, e-learning, practical exercises, and role playing.

Question 5. How would you assess your expectations with regard to the benefits of new supply chain security training materials for your organization?

We were also interested to learn what kind of outcomes police law enforcement agencies could envisage for new education and training material on supply chain security from the perspective of their organisations. We compiled options such as better use of organizational resources, improved efficiency and increase of successful prosecutions, seized goods and arrests.

4 Baku Survey Results

The research is based on a the responses of 16 law enforcement officials and policy makers, who took part in the LE TrainNet Meeting (Meeting of Networking of the Law Enforcement training institutions) which took place in Baku, Azerbaijan, 28-29 April 2015.

4.1 Target Population

The UNODC's LE TrainNet meeting seeks to promote closer cooperation between various organizations and institutions engaged in law enforcement training. Specifically, its key aims are to establish an inter-regional network of training entities encompassing all manner of law enforcement authorities, whilst establishing focal points within this network to facilitate the exchange of information of best practices in law enforcement training. A further aim is to explore the establishment of a common database of law enforcement training materials, using secure access procedures to restrict access to a law enforcement audience. Central to the LE TrainNet approach is the inclusion of law enforcement entities with varying mandates. It acknowledges that there are a number of topics and challenges relating to training for law enforcement globally, which are common to police, customs, specialised law enforcement units and border agencies. Those in attendance therefore represented agencies from a variety of law enforcement backgrounds, with a common interest in topics of capacity building and training.

The interagency and inter-regional nature of this audience created a useful environment for the piloting of this survey, knowing that the aim of the exercise was to identify training needs for law enforcement in the framework of global supply chain security, to enable them to better combat criminal intrusions in the supply chain.

4.2 Profile of Respondents

The survey was shared with the attendees of the LE TRAIN-NET Meeting in Baku, Azerbaijan. A total of 16 responses were received, which reflects a response rate of 23.2%, given there were 69 delegates registered from the conference. However, based on an assessment that approximately 15 delegates were listening to an interpretation track when English was spoken, we can estimate that the response rate amongst English speakers was closer to 42.3%.

Of the respondents, the largest group came from governmental organisations (56%), with the remainder coming from inter-governmental organisations (25%) and academic institutions, (6% of respondents indicated 'other' or did not give a response.)

Of those who came from government, 44% identified as coming from police authorities, 12% identified as coming from customs authorities, and 6% from border guard authorities. The remaining 38% of respondents did not identify with one of these groups in particular, suggesting that more than a

third of respondents came from organisations with a broader law enforcement profile.
Geographically, respondents came largely from Europe and Asia, including the Middle East. Some countries of the Americas, namely Jamaica and the USA, were also represented in the respondents.

4.3 Limitations of the Survey

It is important to note that the relatively small sample size may limit the implications of the survey. However, an advantage of this sample is that those in attendance were representatives from various law enforcement training institutions, or of the training departments of major law enforcement organizations, often with a broad oversight of law enforcement training needs. Thus, where possible, the members of the audience were able to assess from an organization-wide perspective a number of the questions posed, and were often able to correlate their responses with their acute understanding of law enforcement training.

4.4 Results of the Survey

When the participants of the conference were asked to identify the crime areas which could be addressed through new and enhanced training material following areas were valuated the highest: corruption, narcotics and drug precursor trafficking, financial crimes and tax evasion, trafficking in human beings, trafficking in counterfeit goods, terrorism and cybercrime (Table 1). The participants had lowest interest in maritime piracy and export violations of dual use and strategic goods. The lesser interest in these areas may be explained by the fact that these areas are clearly more closely correlated with customs authorities.

Table 1 Question 1. How useful would it be for your organization to access new and enhanced training materials with regard to the following crime areas?

Crime Area	Average
Narcotics and drug precursor trafficking	3,8
Corruption	3,7
Cybercrime	3,5
Financial crime & tax evasion - including fraud in customs duties, sales tax, excise tax etc.	3,5
Terrorism – focus in trafficking of chemical, biological, radioactive, nuclear or explosive weapons	3,5
Trafficking in human beings	3,5
Trafficking in counterfeit goods	3,4
Pharmaceutical crime	3,3
Cultural heritage & works of art trafficking	3,2

Crime Area	Average
Firearms & light weapons trafficking	3,2
Cigarette and tobacco trafficking	3,1
Natural resource trafficking - timber, fish etc.	3,1
Waste trafficking - hazardous & electronic waste etc.	3,1
Stolen vehicles	2,9
Wildlife trafficking - CITES violations	2,9
Dual use / strategic goods export violations	2,6
Maritime piracy	2,2

The survey then asked respondents to rate the extent to which a number of advancements in supply chain security methods, tools, programs and datasets would be of use for the work of their organisation (Table 2). The advancements in multi-agency collaboration including improved data sharing between customs and police were seen the most useful (if they focused on national agencies). Governmental agency collaboration on global level was assessed much lower. In the context of international supply chain crimes the difference is quite surprising. The present study doesn't give an answer for this difference, but previous studies imply that lack of trust is possible factor which prevents sharing information among agencies (Urciuoli, 2013). When this situation is expanded to a global level, distrust often increases, leading to a reluctance to share information among agencies on an international level.

Table 2 Question 2. How useful is it for your organization to learn about advancements in the following areas of supply chain security methods, tools, programs and datasets?

Supply chain security methods, tools, programs and datasets	Average
Multi-agency collaboration on national level, including improved data sharing between customs and police	3,7
Databases with intelligence on criminal acts and trends across the global supply chain	3,5
Tools for risk management, focusing on overall threat and vulnerability assessment	3,4
Tools for risk management, focusing on a specific shipment / movement risk profiling and targeting	3,4

Supply chain security methods, tools, programs and datasets	Average
Technologies for screening & scanning cargo containers and other transport units	3,3
Tools to improve x-ray image interpretation among the front-line government officers	3,3
Governmental agency collaboration on international level, including improved data sharing between customs in two or more countries	3,3
Databases in international trade, supply chains and transport systems – with information on countries, export products, trade lanes, supply chain actors etc.	3,2
Databases to exchange x-ray images between agencies	3,2
Electronic seals and other anti-tampering technologies for cargo & transport vehicles	3,1
Tools for systems based security controls and audits, focusing on company processes and IT systems	3,1

Supply chain security methods, tools, programs and datasets	Average
Databases with intelligence on cyber threats and cyber criminals – specific to global supply chains	3,1
Due-diligence tools for companies	3,0
Databases on commodities – with information on restrictions and prohibitions, tax rates, dangerous goods, standard quality controls etc.	3,0
Automated license plate recognition tools	2,9
Cargo and transport vehicle track & trace technologies	2,9
Synergies between supply chain security and global trade performance	2,9
Trusted trader certification programs (AEO, C-TPAT etc.; including benefits for the companies)	2,6

Tactical, operational and strategic intelligence are key methods in the toolbox of police law enforcement officers. Tactical intelligence provides analytical support for crime investigation and prosecution processes. Operational intelligence stands to benefit from a closer link to real-time information which describes present location and current or following movements of suspect consignments. The latest advancements in tools focusing on a specific shipment movement, using risk profiling and targeting were also assessed as useful. Also, x –ray interpretation tools, screening and scanning technologies were assessed valuable for their potential to provide learning materials. They make it possible to accurately time operations and the seizure of the goods.

Strategic intelligence focuses on criminal trends and new patterns, such as shifts in criminal markets and changes in organized criminal structures. It is therefore not surprising that databases with intelligence on criminal acts and trends in the global supply chain were assessed as valuable in the survey.

Methods, tools, programmes that are most commonly affiliated with customs matters were rated lowest; for instance, trusted trader certification programs are based on customs laws. The programs are fully managed by different customs authorities. Similarly, global trade performance parameters were not assessed as pertinent to police law enforcement work.

Table 3 Question 3. How important do you consider it to be that the new training materials on supply chain security include the following types of content?

Training content	Average
Human factors in crime and security covered	3,7
Collaborative approaches and best practices, both public-public and public-private	3,5
Consequences / negative impacts of illegal activities explored and explained	3,5
Case studies on security in global supply chains	3,4
End-to-end supply chain thinking - from sourcing, manufacturing & transport; to distribution, retail & reverse logistics	3,4
Proactive approaches and global best practices – in terms of crime prevention, risk mitigation etc.	3,4
Benchmarking with world-class organizations	3,3
Cost-benefit analysis included	3,3

Training content	Average
Multi-disciplinary approaches - e.g. operational, economic and legal aspects covered in parallel	3,3
Training materials grounded on solid theories in crime prevention, security, supply chain management etc.	3,3
Quantitative / numeric data included	2,9

We used the survey to explore which aspects the respondents wished to emphasize in training and education (Table 3). The audience aimed to highlight collaboration with other public and private stakeholders. They also wanted to see the role of human factors in often very technology-oriented security training.

The survey results highlight the importance of practical approaches in training and education methods. Case studies, practical exercises and role-playing were assessed the most useful methods (Table 4). Interactive approaches to the creation of learning materials, such as blended learning (combining classroom-based learning and e-learning) fits best with the requirements of the survey participants. This is perhaps unsurprising, given the established links between problem-based learning and effective learning outcomes for law enforcement.

Table 4 Question 4. Please rate each of the following learning methods, based on how effective you think they are for your law enforcement training activities.

Learning methods	Average
Blended learning (combines classroom and e-learning)	4,0
Case studies	3,8
Practical exercises	3,8
Role playing	3,7
Collaborative problem –based learning	3,5
Debates	3,4
e-Learning	3,4
Serious games	3,3
Shadowing / monitoring / learning by observing others	3,3
Simulations	3,3

Learning methods	Average
Demonstrations	3,2
Classroom lectures	3,1
Mobile phone / mobile device learning applications	2,9
Textbook reading	2,8
Modular learning	2,7

The final question of the survey addresses the potential organizational benefits of developing supply chain security training materials (Table 5). From the results of this question, it becomes clear that police organizations are goal-oriented. In this question, improved use of resources was evaluated higher than direct performance indicators such as increases in the number of seizures, arrests or successful prosecutions.

Table 5 Question 5. How would you assess your expectations with regard to the benefits of new supply chain security training materials for your organization?

Benefits	Average
Increase in number of successful prosecutions	3,4
Better use of organizational resources in intelligence	3,3
Better use of organizational resources in crime detection	3,3
Increase in number of seizures of illicit goods	3,2
Increase in number of arrests	3,2
Better use of organizational resources in crime investigations	3,1
Improved efficiency in processes & cost reductions	3,1
Increase in number of detection of serious offences	3,1

5 Summary and Conclusions

Whilst the small sample size limits the significance of results, some important trends emerge which concur with major themes in literature around adult education and law enforcement education. Practical approaches to learning, as well as an emphasis on human factors and intelligence-led policing stand out as important considerations when developing training materials for law enforcement on the topic of supply chain security. We have preliminary plans to replicate this exercise with a broader law enforcement audience, to be disseminated via electronic channels (such as email and Survey Monkey), with the option of translating it into other languages to expand its reach.

Of crucial importance during the Baku pilot was the fact that respondents acknowledged the possible added-value of supply chain security training for law enforcement, meaning that enhanced capacity in this area could lead to optimal direction of resources in intelligence-gathering exercises. This could clearly lead to greater organizational efficiency. Acknowledgement of this point is a promising sign of recognition from the law enforcement agencies themselves that supply chain security training is a worthwhile investment for their organizations.

This exercise equally underscores the importance of conducting thorough training needs assessment activities before developing training materials. A comprehensive training needs assessment phase is a vital aspect in this exercise, as it ensures that the resulting material can be and will be used by the people for whom it was designed.

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References

Brookfield, S. 1995. Adult Learning: An Overview. In A. Tuinjman (ed.) International Encyclopaedia of Education. Oxford: Pergamon Press, pp. 1-16.

Closs, D. J., & McGarrell, E. F. 2004. Enhancing security throughout the supply chain. IBM Center for the Business of Government, pp. 1–52.

Davis, A., Little, P. and Stewart, B. 2004, 'Developing an infrastructure for online learning', in T. Anderson and F. Elloumi (eds), Theory and practice of online learning. Athabasca: Athabasca University, pp. 97-114.

Fidishun, D. 2000. Teaching adult students to use computerized resources: Utilizing Lawler's keys to adult learning to make instruction more effective. Information Technology and Libraries, 19(3), pp. 157-158.

Glasgow, C. and Lepatski, C. 2012. 'The evolution of police training: The investigative skill programme,' in M. R. Haberfield, C. Clarke and D. Sheehan (eds), Police Organization and Training: Innovations in Research and Practice. New York, NY: Springer, pp. 95 - 111.

Goldstein, H. 1990. Problem-oriented policing. New York, NY: McGraw-Hill.

Houle, C. 1961. The Inquiring Mind. Madison, WI: University of Wisconsin Press.

Huang, H. 2002. Towards constructivism for adult learners in online learning environments. British Journal of Educational Technology, 33(1), pp. 27-37.

Jonassen, D. 1999. Designing constructivist learning environments. Instructional design theories and models: A new paradigm of instructional theory, 2, pp. 215-239.

Karagiorgi, Y. and Symeou, L. 2005. Translating Constructivism into Instructional Design: Potential and Limitations. Educational Technology & Society, 8 (1), pp. 17-27.

Knowles, M. 1973. The Adult Leaner: A Neglected Species. Houston, TX: Gulf Publishing Company.

Lepatski, C. 2010. Investigative Skills Education Program: Innovation in Police Education. International Police Training Journal, 1, pp. 17-22.

Lieb, S. 1999. Principles of Adult Learning. [online]. Available from http://www.lindenwood.edu/education/andragogy/andragogy/2011/Lieb_1991.pdf. Accessed 9 June 2015

Männistö, T. A. 2015. Mitigating Crime Risks in the International Logistics Network: the Case of Swiss Post. École Polytechnique Fédérale de Lausanne.

Nagurney, A., Manuj, I., & Mentzer, J. T. 2008. Global supply chain risk management strategies. International Journal of Physical Distribution & Logistics Management, 38(3), pp. 192–223.

Pfohl, H. C., Köhler, H., & Thomas, D. 2010. State of the art in supply chain risk management research: Empirical and conceptual findings and a roadmap for the implementation in practice. Logistics Research, 2(1), pp. 33–44.

Rothwell, W. 2008. Adult Learning Basics. Alexandria, VA: American Society for Training and Development Press.

Urciuoli, L., Hintsa, J., and Ahokas, J. (2013). Drivers and barriers affecting usage of e-Customs - A global survey with customs administrations using multivariate analysis techniques. Government Information Quarterly, 30, 473–485.

Vodde, R. 2012. Changing paradigms in police training: Transitioning from a traditional to an andragogical model,' in M. R. Haberfield, C. Clarke and D. Sheehan (eds), Police Organization and Training: Innovations in Research and Practice. New York, NY: Springer, pp. 27-44.

Supply Chain Security Related Services

Magdalena Jażdżewska-Gutta

Since the terrorist attacks in 2001 the security issue has become an important topic for the companies involved in international trade. It has been confirmed in numerous studies that the companies became more interested in conducting risk assessment or introducing supply chain security management. Although not all the companies are interested in enhancing security of their business, and often supply chain security is not their main concern, the security industry based on B2B services is growing. There are numerous new companies offering security related services such as monitoring of shipments, video monitoring, physical security, cyber security, consulting, and advisory. Also existing companies, especially in the area of logistics, consulting and physical security have started to offer supply chain security services.
The purpose of this paper is to analyze the supply chain security industry, categorize the services offered by the companies and to determine the advantages and disadvantages of outsourcing security related processes to other parties. The methodology involves analysis of business offers of companies representing the industry from several countries. The paper analyses also potential for future growth of the industry and its place in international supply chains.

Keywords: Supply Chain Security, Security Industry, Private Security, Supply Chain Security Management

1 Introduction

Since 2001 security sector has been one of the fastest growing industries. The growth on a year to year basis reached 10% between 2001 and 2011. It is characterized by great advances in technology and growing number of security product manufacturers and security service providers.

Supply chain security (SCS) and the decisions whether to introduce any security measures, and whether to outsource them or not, became very important for many companies. Some managers still believe that supply chain security should be provided by governments (Jażdżewska-Gutta, 2014), however more and more companies decide to introduce private security measures and outsource security services.

The aim of this study is to analyze the supply chain security industry, categorize the services offered by security companies and to discuss the potential for future growth and the role of the sector for the companies involved in the supply chains. The first section contains a brief description of SCS sector and explains the motivation for the research. This is followed by literature review presenting theoretical and practical background for further analysis. This chapter defines SCS and its role for the companies, as well as provides an analysis of the nature of supply chains and SCS measures. The next section presents the findings from desk research which involves analysis of business offers of companies representing the industry from several countries. It contains the analysis of the sector both from demand and supply perspective. The aim of the last section is to discuss the trends in the security market.

2 Theoretical Background and Literature Review

The aim of this section is to present review of the academic and industry literature on SCS and security sector. By integrating different areas and perspectives of research it sets background for further analysis of supply chain security industry.

2.1 The Nature of a Supply Chain

For the purpose of discussing supply chain security the most simple definitions of a supply chain can be applied. According to Lambert et al., supply chain is an alignment of firms that brings product or services to the market (Lambert et al., 1998). The Glossary of Council of Supply Chain Management Professionals states, that supply chain consists of "material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user, where all vendors, service providers and customers are links in the chain" (CSCMP, 2013). Supply chains, especially those of international range, are often characterized by long and complicated processes, and involvement of many actors. These actors are not limited to suppliers, manufacturers, distributors and retailers, but also involve public authorities, service providers in the area of logistics, transportation, finance, security etc.

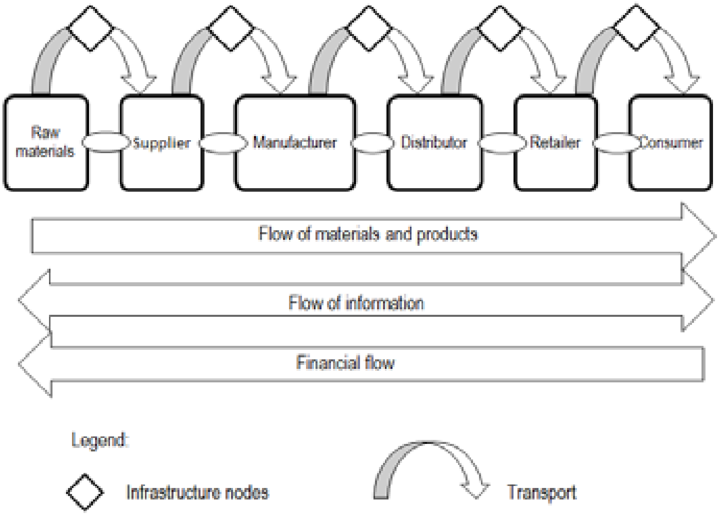

Figure 1 Elements of a supply chain

There are three types of flows in a supply chain (see figure 1) - flow of goods (materials and products), flow of information and financial flow, however the latter is often omitted in the analysis (Christopher, 2005; Harrison and van Hoek, 2008). From the perspective of supply chain security, the financial flow are also important, but in most cases, excluding cash transit, this is an area of interest for financial institutions and financial management. For this reason, the analysis of security of financial flows has been excluded from this study. All the above mentioned flows can be analyzed both in inter-organizational and intra-organizational dimension.

SCS covers not only aforementioned flows but also elements of transport, logistics or IT infrastructure, transport nodes, companies' fixed and movable assets (including inventories, vehicles, terminals, production sites) and people. It includes elements of corporate security, facility protection or critical infrastructure protection. The security of the entire supply chain will depend on security of the least secured element. For that reason, all links in the supply chain should be involved in the process.

Usually the suppliers, manufacturers or retailers are the actors who are the most interested in enhancing security. Some companies protect their assets, people and information with their own resources but the protection of all aforementioned elements can be as well outsourced to specialized security companies.

2.2 Supply Chain Security

The term 'security' has a lot of meanings. The origin of this word is in Latin 'securus' (from se- meaning 'without' and cura meaning 'care'), which means 'feeling no apprehension' (Oxford). Based on that, Oxford dictionary defines 'security' as 'a state of being free from danger or threat'. In supply chain and business context, this definition can be developed into the safety of a company, organization or supply chain against criminal activity such as terrorism, theft, or espionage. Security thus implies a safe and predictable environment in which an organization can achieve its goals without disruption or fear of disturbance (Fischer et al., 2013) thanks to its ability to defend against threats. In a similar way supply chain security is defined as “general system property characterizing uninterrupted performance of a supply chain functioning to achieve its goals under protection against external purposeful threats” (Ivanov and Sokolov, 2010).

Security can also be interpreted trough dynamic approach as it changes over time according to two factors: threat and vulnerability, and can be presented as a function (Hofreiter, 2012):

$$S(t) = f\{ T(t) \, x \, V(t) \} \tag{1}$$

where:

S - security, T - threat, V - vulnerability, t - time

Threat is an incident caused by human forces that makes sense of security decrease or disappear, and that may cause losses to the company if occurred. Vulnerability reflects the sensitivity of a company or supply chain to disturbance resulting from external or internal risks (Christopher and Peck, 2003; Waters, 2007). It may be interpreted as a combination of disruption probablility and the scope of its possible consequences (Sheffi, 2007; Tandler and Essig, 2013). Wagner and Bode suggest that vulnerability depends on specific supply chain characteristics (Wagner and Bode, 2006). Svensson argues that preventive actions may reduce the likelihood of disturbances (Svensson, 2002). These actions should be aimed at reducing the probability of intentional disruption which will lead to increased security (Sheffi, 2007). These findings indicate that applying security measures by governments or companies may lead to higher level of security.

SCS measures can be proactive or reactive. Proactive measures include activities that are targeted at minimizing the risk of disruption. Reactive measures are, in turn, a reaction to a disruption. Proactive measures are thus more favorable for security and uninterrupted supply chain performance (Briano et al., 2009; Knemeyer et al., 2009; Craighead et al., 2007; Gould et al., 2010). The private security measures are believed to be more proactive than reactive. For that reason they are regarded by companies as more efficient.

2.3 How, for Whom and at What Cost?

In order to determine the role of security industry for the corporations, their supply chains and for public security, some important issues have to be considered. Salter raises three major questions regarding security (Salter, 2008):

1. How is supply chain security assured?
2. For whom?
3. At what cost?

The first question refers to the choice between public and private security (SCS measures applied by public and private entities). Moreover, corporations have to decide whether to outsource or insource security activities. Insourcing (also called "proprietary services') would mean hiring in-house security personnel, such as CSO (Chief Security Officer) and security forces, while outsourcing (using contract services) would involve using services of outside companies representing security industry. Both activities fall under the definition of private security which is described in detail in the next section (Purpura, 2011; de Waard, 1999).

The application of SCS measures and the decision whether to outsource or insource security is in the area of interest of supply chain security management (SCSM), which can be defined as the application of policies, procedures, and technology to protect supply chain assets from man-made threats (Closs and McGarrel, 2004). There are three layers of SCS activities within SCSM: strategic, tactical and operational (see figure 2). Activities at operational level are most common for outsourcing. More and more companies are offering also SCS related services at tactical level, i.e. consultancy or developing security plans. The most advanced SCS service providers can also manage all of their customers' operational, tactical and strategic SCS activities, as the 4PL providers do in the area of supply chain management.

Figure 2 Layers of SCS outsourcing,
adapted from Tsiakis and Tsiakis (2013)

Companies may thus choose to design their security strategy on their own or to outsource the entire SCSM. After 9/11 many companies created the positions of CSOs at the level of senior managers (Ritchey, 2011), that were responsible for development and implementation of security strategies and security programs within the organization. Even if the risk assessment and development of security plans is the responsibility of the CSO, the company may still outsource such activities as technology design and implementation as well as training of the personnel.

The second question draws the attention to actual beneficiaries of security, and the problem of external benefits and public good. The last question concerns financial motivation for introducing supply chain security measures.

Although over many years the security issue has been in the area of interest of governments and public authorities, one can observe a clear trend toward privatization of security and growth of private companies representing security sector. Nowadays the security measures can be undertaken and financed either by public institutions or by private entities.

When it comes to public security it is usually the government who takes responsibility for introducing security measures. If, due to security measures, a disruption does not occur, the society will benefit from higher security level. In this context, security can be considered as an external benefit because it affects also third parties, not only those directly involved in the supply chain (Button, 2012). Supply chain security has also some features of public good (Dulbecco and Laporte, 2005; Button, 2012) which is characterized by non-excludability, (no one can be excluded from consuming this

good once it is produced) and non-rivalry, (it can be consumed by several individuals without diminishing its value) (Holocombe, 2007).
The public good approach to supply chain security is mostly relevant in case of low-probability, high-impact events, such as terrorism or WMD smuggling as they mostly affect the society. In case of these threats, the governments impose obligatory regulations for protecting the state, society, transportation networks from intentional criminal activity, that will affect companies and result in additional costs for supply chains. Other threats, such as thefts in transit or taking over the cargo by false carriers, affect companies and their supply chains rather than their environment. When security is financed by private sector (due to other than obligatory reasons), the effect for the society and surrounding are not so obvious.

2.4 Security Industry

The security industry represents private as opposed to public security. It is known also as corporate, organizational and commercial security, loss prevention or security management (Smith and Brooks, 2013; Fischer et al., 2013). Private security can be defined as a "profit-oriented industry that provides personnel, equipment and procedures to prevent losses caused by human error, emergencies, disasters or human actions" (Hess, 2009). Report of the Task Force on Private Security defines it as "self-employed individuals and privately funded business entities and organizations who provide security-related services to a restricted clientele group for a fee, for the individual or entity that retains or employs them, or for themselves in order to protect their persons, private property, or interests from varied hazards"

(NCJRS, 1976). According to these definitions, private security must be performed for a fee.

There are some more significant differences between private and public security. The tasks of public security are mainly to provide security to state and society, which is in line with the public good approach, whereas private security concentrates its efforts on protection of assets, people and information of its customer, who can be an individual or an organization (Smith and Brooks, 2013; Fischer et al., 2013, Cook and MacDonald, 2011).

Some researchers argue that private security (both outsourced and insourced), as opposed to public security, can only redistribute crime, instead of enhancing security through preventing crime. There are two basic effects of private security: diversion and deterrence, depending mainly on whether the implemented security measures are observable or not (Cook and MacDonald, 2011; Shavell, 1991; Zimmerman, 2014). Researchers suggest that observable security precautions might possibly displace crime to unprotected targets. In the scope of supply chain security such situation might take place when criminals move from protected truck parking spaces to unprotected sites, or from a fenced, guarded and monitored production site or warehouse to less secured locations. Such tendencies may be seen as negative externalities of private security. The situation is slightly different when it comes to unobservable precautions. If they are implemented, criminals are not sure which facility or element is protected so they might resign, causing the crime rates fall. This might be interpreted as a positive externality of private security. The use of private guards on board of commercial vessels (complemented by military efforts) led to minimizing the number of pirate attacks in the Gulf of Aden. The pirates might resign as they are not sure which vessel is protected or not.

Cook and MacDonald also point out that remunerative opportunities need better protection (Cook and MacDonald, 2011). More valuable assets (from the point of view of possible thefts) and critical industries or infrastructure (from the point of view of terrorist activity) should be better protected than other venues as they are attractive targets for criminals and terrorists. This means that several industries such as energy sector, oil extraction and refining or pharmaceutical industry are more likely to become customers of security industry.

Security industry is not well and clearly defined. The main obstacle is the fact, that goods and services delivered by this sector are not easily separable from statistics based on the NACE classification, where they are combined with data on such industries as defense and private security activities, IT services and different areas of manufacturing (Directorate-General…, 2009). Security sector can be defined as the industry delivering goods and services required to protect people and property from insecurity (Martí Sempere, 2010). Due to the specific nature of supply chain, SCS industry provides not only a range of goods and typical security services, but would also management services i.e. risk and security assessment, planning, implementing and controlling security measures, required to protect supply chain flows, assets and people from crime and terrorism. Although this paper is concentrated on services, it includes also the analysis of material goods market, as usually the goods delivered by the sector are complemented by several services, such as design, assembly, maintenance, training and advisory.

European Commission in Action Plan published in 2012, distinguishes eight sectors of EU security industry (European Commission, 2012): aviation security; maritime security; border security; critical infrastructure protection; counter-terror intelligence; crisis management/civil protection; physical security protection; and protective clothing. Not all these sectors relate to supply chain security. Moreover, this list does not include security management which is also a part of SCS industry. The more appropriate classification distinguishes 18 core elements of security (ASIS Foundation, 2009): 1/ physical security, 2/ personnel security, 3/ information systems security, 4/ investigations, 5/ loss prevention, 6/ risk management, 7/ legal aspects, 8/ emergency/contingency planning, 9/ fire protection, 10/ crisis management, 11/ disaster management, 12/ counterterrorism, 13/ competitive intelligence, 14/ executive protection, 14/ violence in the workplace, 16/ crime prevention (general), 17/ crime prevention through environmental design and 18/ security architecture and engineering.

Both classifications are however for the entire security sector and not all the activities will be valid for supply chain security. For SCS analysis, at least the following sectors should be excluded - event security, custody of detainees and prisoners, supervision of apartment blocks, and all security services provided to individuals. In turn, other services such as security certification and supply chain security management should be added.

3 Costs and Benefits of Outsourcing Security

Many companies decide not to outsource security services because of fear, trust and loyalty issues or prestige associated with own security resources

(Hess, 2009; Fischer et al., 2013). There are some areas in the business activity that are not prone to outsourcing, such as management and formulating strategy and policy of the company. All other activities, including risk and security analysis and management, security planning, monitoring etc. can be outsourced.

3.1 Benefits

3.1.1 Reduced Cost

Most experts agree that the use of outside resources leads to greater efficiency and minimizing the cost of a certain activity. The same situation would apply to security services.

The external security providers, due to economies of scale, are able to spread the total cost over several customers lowering the unit cost per customer. The outsourced service becomes therefore more competitive than executing security through company's own resources. What is more, inhouse corporate security officers tend to expect higher wages from the companies that hire them, which makes insourcing even more expensive (Fischer et al., 2013). By outsourcing security companies can also lower additional costs of insurance, equipment, training and holidays.

Moreover, outsourcing security allows to cover a broad range of supply chain activities which would be extremely costly if done with own resources only.

3.1.2 Expert Knowledge

Security industry experts usually possess in-depth knowledge on all aspects of security as well as on recent trends and newest technology. Training in-house staff to the same level of expertise would be very time and money consuming. Also hiring and keeping trained personnel is often very costly. What is more, security experts working for several customers usually have a broader view and fresh perspective on supply chain security issues than officers working in-house. Having access to expert knowledge is also useful in the certification processes.

3.1.3 Concentrating on Core Business

The companies that decide to outsource supply chain security can focus their attention and expenditures on other activities within the organization. They are able to reduce their administration efforts thanks to resignation from recruiting, training and supervising security personnel, especially when it comes to guards. Some expenditures for equipment can be also reduced through outsourcing.

3.1.4 Flexibility

Outsourcing allows the company for greater flexibility in staffing or replacement of technology. In case of technological changes, outsourcing of integrated security solutions might give the access to recent technical solutions without the need to replace all systems and equipment in-house.
Problems with staffing can be solved due to no need to deal with trade unions' expectations, or with excessive or insufficient number of employees

during irregular seasons such as production shutdowns, rush seasons or holidays (Fischer et al., 2013).

3.2 Costs

3.2.1 Loss of Internal Control for the Organization

Outsourcing security activities such as monitoring or guards may lead to loss of control over several processes within the company. This is particularly evident when it comes to hiring new personnel as the process is usually more detailed and careful when performed for in-house employees.

3.2.2 Trust and Partnership

When leaving some functions to be performed by outside company, there is a need to establish trust between cooperating partners. The companies tend to hire trusted and approved security providers. This might explain the popularity of outsourcing security to market leaders and the existence of several security industry associations. However, even well-established partnership might fall apart when some communication problems occur and the vision of the service provider proves to be inconsistent with the plans of its customer.

3.2.3 Unexpected Costs

Whitworth names some hidden costs that can arise from outsourcing and which should be taken into consideration in decision-making process (Whitworth, 2005). This is basically the cost of switching to a new provider when the contract period ends or when the security provider goes out of business. The cost might be also higher than expected due to poor service or increase of costs compared to the initially planned amount.

4 Supply Chain Security Sector – Results of Research

4.1 Characteristics of the Sample

The offers of supply chain security service providers were subject of desk research. The number of analyzed offers reached 70 companies from different countries. Almost 76% of the companies declared exporting their goods and services, of which 46% were present in the global market. The countries were thus aligned on the basis of origin of the company.

The choice of the companies was random, based on their presence in industry trade shows and on the Internet. The original intention was to investigate offers from the major security markets – i.e. United States, which is global leader of security industry, United Kingdom, which is a European leader and some Polish companies. Due to required country adjustments, the sample of the countries is different than expected. The sample contains 30 companies from United Kingdom, 18 from the US, 6 from Poland, 4 from Germany, 2 from Switzerland and one firm from the following countries: Sweden, Spain, Taiwan, Romania, the Netherlands, Malaysia, Italy, Canada, Australia and UAE.

Most of the companies were established before 2001. The foundation of only 27% of the companies took place in 2001 or later and the major part of them (42%) is represented by consultancy firms. This sector of supply chain security was characterized by great growth potential after 2001 as more and more businesses were interested in implementing supply chain security management practices into their operation and strategy. However, also other segments developed after 2001, by expanding their range of products and/or services with new SCS solutions. One company grew out of aviation industry magazine into a big security consultancy group. Also some transport and guarding companies as well as manufacturers of monitoring and scanning equipment started to offer new services.

The sample contained companies of different size, from SMEs to big global companies hiring more than 10 thousand employees (see table 1). The small companies represented mainly consultancy and new technologies segment. The companies with more than 10 thousand employees are global players in labor-intensive guarding sector, or parts of bigger capital groups (i.e. in telecommunications sector), where only one branch of the company is involved in the security industry.

Table 1 Size of the companies

Number of employees	Number of companies
1-10	5
11-50	19
51-200	6
201-500	4
501-1000	6

Number of employees	Number of companies
1001-5000	7
5001-10000	2
More than 10000	11

4.2 Main Segments of the Market – Supply Side

Some segments of the market can be distinguished on a basis of services offered by the analyzed companies. Due to a small sample the results cannot be generalized to the entire population. The most represented sectors were consultancy, video monitoring, scanning, screening and detection, guards, IT communication systems, seals, customized security and integrated supply chain security solutions, fences and other security technologies. Other segments were represented by counter-espionage, engineering, inspection, maritime security (Private Maritime Security Company), packaging, security training and radar technology. The most strongly represented sectors are presented in table 2.

Table 2 Segments of security sector

Segment of the market	Number of companies	Average number of offered products and/or services	Characteristics of the size of companies
Consultancy	17	8	65% companies having less than 50 employees
Video monitoring	8	1,5	50% companies having more than 50 employees
Scanning, screening and detection	6	1,6	Varied size
Guards	5	4	100% companies having more than 10000 employees
Fences	4	1,5	Varied size
Seals	4	1,75	Varied size
IT and communication systems	3	3,5	Varied size

Consultancy companies usually offer wide range of security services and integrated security solutions. Apart from advisory, management and certification, they offer security architecture and engineering and some technological solutions. For example, many consulting firms are dealing also with CCTV and IP video monitoring, which used to be typical for manufacturers and distributors of equipment. Similar trend, but on a lower scale is observable in guarding sector.

The sample revealed that typical technology manufacturing firms usually offer only some complementary advisory services, so their portfolio is not as rich as in the case of consulting sector.

Most companies from the sample offered the following goods and services: training - 20 companies, risk assessment - 19, risk and security management - 18, consultancy - 17, developing security plans, programs and procedures - 16, video monitoring - 15, physical access control - 10, scanning and detection - 9, security software - 9, crisis management - 9, secure communication - 8, guards - 7, ISO 28000 certification - 7. The analysis of the sample reveals that SCS sector's focus is on implementing technology and supply chain security management practices.

4.3 Types of Customers – Demand Side

Almost 89% of the companies supply their goods and services to business sector. The rest is targeted towards government sector and public institutions or critical infrastructure (ports and airports). Only a few companies offered their services to the transport sector only.

Around 16% of those companies that were focused on business customers dedicated their services particularly to exporters and importers. Such companies usually offered certification and advisory for ISO 28000, TAPA, C-TPAT and AEO. The focus on AEO was typical for Polish companies, although it has a little in common with real supply chain security, as most of the companies are interested in the Customs and not in Security certificate. It is also important to mention that the business customers in general represent specific industries, which are more prone to terrorist or criminal activities. The analyzed companies' offers were usually customized according to different industries. Most of them concerned transport companies, energy sector, oil extraction, pharmaceuticals or industry in general. These are the most remunerative industries mentioned in the previous section, that are more likely to become a target of criminals. In order to protect supply chains, the companies decide to introduce private security measures.

5 Trends in Supply Chain Security Market

Several trends can be identified in supply chain security market:

1. The growth of the sector will be very dynamic. In some regions, mainly due to terrorist and other security threats, the growth will be relatively higher.
2. Human work in many sectors will be replaced by technology.
3. There will be greater demand for well-educated security specialists.
4. Integration of services and companies will be progressing.

In 2011 the security industry was ten times bigger than in 2001. Then the value of the market reached approximately EUR 10 bn, while in 2011 security goods and services accounted for around EUR 100 billion. The growth of security sector has shown such dynamics that it many countries it outpaces the economic growth. ADS Industry Outlook states that the sector in United Kingdom grew in 2013 five times faster than the country's economy (ADS, 2014).

According to several industrial analyses, the security market will be dynamically growing over the following years. The industry is expected to reach around EUR 300 billion in annual revenues at the end of the period (Risk UK, 2015).

Industry forecasts predict that the share of European security industry in the global security market will drop by 5 percentage points to 20% between 2010 and 2020. This is mainly caused by rapid growth of the industry in other locations such as Middle East, India, Kenya and Horn of Africa. G4S, a global security company, predicts high (at 10% on an annual basis) growth of security market in Egypt and Gulf States (FM World, 2015). The rise is driven predominantly by the need to protect from risks involved in extraction of natural resources.

As for human involvement in security sector, guarding services are still one of the most important segments of security industry. However in many location they are replaced by recent technological advancements such as automated monitoring or CBRNE (Chemical, Biological, Radiological, Nuclear, and Explosive) Detection systems. Even with such equipment, there is still need for a human that would supervise all the processes. The trend might be towards better trained security personnel, as well well-educated CSO, who will be experts in security assessment, planning, architecture and engineering.

Another trend is towards the integration of security services. As a result of growing market potential, many security providers started to add new security services to their portfolio. For example, companies that started in the guarding sector, are offering broad range of consulting services and specialized security management. The companies that started with selling security equipment expand the scope of their services with security architecture and engineering. The other way of expansion is through mergers and acquisitions. As a result, the industry may see a new type of External Security Providers (ESP) - major security integrator. Such a service provider might be called Lead Security Integrator (LSI) or Lead Security Provider (LSP). Similarly to Lead Logistics Providers, such company can offer complete management of Security or Supply Chain Security, including planning, implementing, controlling and coordination of all security aspects within the company or supply chain. Security might be fully outsourced to LSI, however the control should always stay within the commissioning company.

6 Conclusions

The above analysis shows that SCS services sector is very diverse in terms of size, offered services or year of establishing. The common feature is that it started to grow after year 2001 and one can predict that in the increasingly turbulent environment, it will continue to grow. Due to lack of harmonization of public authorities' efforts, companies will continue to turn to private security in order to minimize the vulnerability to disruption.

SCS sector is a vital component of SCSM. An important decision in this area that has to be made by the management is whether to outsource supply chain security or not. The benefits of using outside resources, a wide range of available security services and trends towards more integrated security services may encourage companies to outsource even more security activities.

References

ADS, 2014. UK Security sector outpacing overall economy by five times. [online] ADS Group https://www.adsgroup.org.uk /articles/45362 [Accessed 1 June 2015].

ASIS Foundation, 2009. Compendium of the ASIS Academic/Practicioner Symposium 1997-2008. [online] ASIS Foundation <https://foundation.asisonline.org/FoundationResearch/ Publi-cations/Documents/1997-2008_CompendiumofProceed-ings.pdf> [Accessed 1 June 2015].

Briano, E., C. Caballini, R. Revetria, 2009, Literature review about supply chain vulnerability and resiliency, Proceedings of the WSEAS In-ternational Conference on System Science and Simulation in En-gineering.

Button, K., 2012. Putting Economics into the Security of the Transporta-tion Supply Chain: Some Reflections. Logistics & Sustainable Transport, Vol. 3, No. 2, pp. 1–11.

Christopher, M., 2005. Logistics and Supply Chain Management. Creating Value-Adding Networks. FT Prentice Hall, Harlow.

Christopher, M., Peck, H., 2004. Building the Resilient Supply Chain, Inter-national Journal of Logistics Management, Vol. 15, No. 2, pp. 1-13.

Closs D.J., McGarrel E.F., 2004. Enhancing Security Throughout the Supply Chain, The IBM Center for the Business of Government.

Cook, P.J., MacDonald, J., 2011. Public Safety Through Private Action: An Economic Assessment of BIDs. The Economic Journal 121, pp. 445-462.

Craighead, C.W., Blackhurst, J., Rungtusanatham, M.J., Handfield, R.B., 2007. The Severity of Supply Chain Disruptions: Design Character-istics and Mitigation Capabilities. Decision Sciences, Vol. 38, No. 1.

CSCMP, 2013. Supply Chain Management. Terms and Glossary. [online] Council of Supply Chain Management Professionals <https://cscmp.org/sites/default/files/user_uploads/…/glossary-2013.pdf > [Accessed 22 February 2015].

de Waard, J., 1999. The Private Security Industry in International Perspec-tive. European Journal of Criminal Policy and Research 7, pp. 143-174.

Directorate-General Enterprise&Industry, 2009. Study on the Competi-tiveness of the EU Security Industry. ECORYS, Brussels.

Dulbecco P., Laporte B., 2005. How can Security in International Trade be Financed in Developing Countries? A Global Public Good Ap-proach. World Development, Vol. 33, No. 8, pp. 1201-1214.

European Commission, 2012. Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee. Security Industrial Policy. Action Plan for an innovative and competitive Security Industry, COM(2012) 417 final.

Fischer, R.J., Halibozek, E.P., Walters, D.C., 2013. Introduction to Security. Ninth Edition. Butterworth-Heinemann, Oxford.

FM World, 2015. G4S predicts growth of Middle East security sector. [online] FM World Online <http://www.fm-world.co.uk/news/fm-industry-news/g4s-predicts-growth-of-middle-east-security-sector/#sthash.Lc0BnWc8.dpuf> [Accessed 1 June 2015].

Gould J. E., Macharis C., Haasis H.-D., 2010, “Emergence of security in sup-ply chain management literature”, Journal of Transportation Se-curity (2010) 3.

Harrison, A., van Hoek, R., 2008. Logistics Management and Strategy. Competing through the supply chain. FT Prentice Hall, Harlow

Hess, K.M., 2009. Introduction to Private Security. Fifth Edition. Wadswoth Cengage Learning, Belmont.

Hofreiter, L., 2012. Wstęp do studiów bezpieczeństwa. Krakowska Akademia im. Andrzeja Frycza Modrzewskiego, Kraków.

Ivanov, D., Sokolov B., 2010, Adaptive Supply Chain Management, Spring-er Verlag, London, pp. 81.

Jażdżewska-Gutta, M., 2014, Supply Chain Security Measures - The Busi-ness Perspective, in: Innovative Methods in Logistics and Supply Chain Management. Current Issues and Emerging Practices, ed. T. Blecker, W. Kersten, C.M. Ringle, Hamburg University of Technolo-gy, epubli GmbH, Berlin.

Knemeyer A.M., Zinn W., Eroglu C., 2009. Proactive planning for cata-strophic events in supply chains. Journal of Operations Manage-ment 27, pp. 141-153.

Lambert, D., Stock, J., Ellram, L., 1998. Fundamentals of Logistics Man-agement, Irwin/MacGraw-Hill, Boston.

Martí Sempere, C., 2010. The European Security Industry: A Research Agenda. Economics of Security Working Paper 29, Berlin: Econom-ics of Security.

NCJRS, 1976. Report of the Task Force on Private Security. National Crimi-nal Justice Reference Service, Washington D.C.

Oxford Advanced Learner's Dictionary. [online] Oxford Dictionaries. Available at: <http://www.oxforddictionaries.com/definition/ english/security> [Accessed 10 June 2015].

Purpura, P.P., 2011. Security. An Introduction. CRC Press, Taylor and Fran-cis Group.

Risk UK, 2015. G4S communicates strong Annual Report for 2014 with revenues totaling £6.8 bn. Risk UK. Security and Fire Management, May 2015.

Ritchey, D., Proud to be security: How Roles Changed After 9/11, Security Magazine, September 2011.

Salter, M.B., 2009. Political science perspectives on transportation securi-ty. Journal of Transportation Security, (2008)1, pp. 29-35.

Shavell, S., 1991. Individual Precautions to Prevent Theft: Private versus Socially Optimal Behavior. International Review of Law and Eco-nomics, (1991)11, pp. 123-132.

Sheffi Y., 2007, The Resilient Enterprise. Overcoming Vulnerability for Competitive Advantage, The MIT Press, Massachussets.

Smith, C., Brooks, D.J., 2013. Security Science. The Theory and Practice of Security. Butterworth-Heinemann.

Svensson, G., 2002. A conceptual framework of vulnerability in firms' inbound and outbound logistics flows. International Journal of Physical Distribution & Logistics Management, Vol. 32, Issue 2, pp. 110 – 134.

Tandler, S., Essig, M., 2013. Conceptual Framework of Supply Chain Safety, in: Supply Chain Safety Management. Security and Robustness in Logistics, ed. M. Essig et al., Springer-Verlag, Berlin Heidelberg.

Tsiakis, T., Tsiakis, P., 2013. Managing the Risks of Outsourcing IT Security in Supply Chain. In: ed. Folinas, D., 2013. Outsourcing Manage-ment for Supply Chain Operations, Business Science Reference.

Wagner, S.M., Bode, C., 2006. An empirical investigation into supply chain vulnerability. Journal of Purchasing and Supply Chain Manage-ment 12, pp. 301-312.

Waters, D., 2007. Supply Chain Risk Management. Vulnerability and Resili-ence in Logistics. Kogan Page, London and Philadelpia.

Whitworth, M., 2005. Outsourced security - the benefits and risks. Network Security, October 2005.

Williams Z., Lueg J.E., Taylor R.D., Cook R.L., 2009, Why all the changes? An institutional theory approach to exploring the drivers of supply chain security (SCS), "International Journal of Physical Distribu-tion & Logistics Management", vol. 39, No. 7, pp. 595-618.

Zimmerman, P.R., 2014. The deterrence of crime through private security efforts: Theory and evidence. International Review of Law and Economics, 37(2014), pp. 66-75.

Weaknesses in European e-Waste Management

Sangeeta Mohanty, Elise Vermeersch, Juha Hintsa,
Vittoria Luda Di Cortemi-glia and Mary Liddane

Illegal exports of waste electrical and electronic equipment – WEEE – from industrial to developing countries is a growing criminal phenomena posing serious threats to the human health and the environment. Several loopholes in the current jurisdictional systems along the supply chain in the European Union; deficiencies in law enforcement capacity, knowledge and training; and other supply chain related weaknesses prevent an effective response to such criminal activity. This paper identifies the vulnerabilities along the supply chain, the shortcomings in the legislative framework around WEEE, and its limited implementation and enforcement that facilitate leakages from the legal WEEE streams. An understanding of the weaknesses will enable the governmental bodies to develop appropriate counter-measures to improve the prevention, detection, investigation and prosecution of WEEE violations. This paper presents a comprehensive gap analysis across the EU member states, Norway and Switzerland. It focuses on the key issues surrounding the international and national legislative frameworks and the implementation thereof, law enforcement capacity, knowledge and training, information management, and penalties and prosecution. The study helps to identify the underlying problems and the key concerns faced by national authorities - and, this information will lead to a set of recommendations for the European Commission and the EU member states to address the problem of illegal e-waste exports.

Keywords: WEEE Supply Chain, Illicit Trade, Supply Chain Security, FP7-CWIT

1 Introduction

The exponential growth of the global electrical and electronics equipment (EEE) market and shorter lifespan of consumer electronics have resulted in one of the fastest growing waste streams worldwide, including in and out-from Europe (Eurostat, n.d.). Some 9 million tonnes of e-waste were generated in 2005 in the EU, which is expected to grow to 12 million tonnes by 2020 (EC, 2015). The rising volume of waste electrical and electronic equipment (WEEE) in Europe contributes to the increasing number of illegal exports to less developed nations, particularly in Asia and Africa. Evading high disposal and recycling costs is the main incentive for businesses to dump WEEE overseas. The increase in domestic demand for used electronics, used parts and materials in the developing world facilitates the illegal trade activities. A robust regulatory and enforcement regime along with a tightly controlled supply chain are necessary to thwart such unlawful acts. However, a number of structural, administrative and procedural weaknesses mark the existing legislative framework and supply chain system. This paper carries out a gap analysis to identify commonalities and discrepancies across Europe with specific focus on jurisdictional loopholes, penalties and prosecution; law enforcement capacity, knowledge and training; and supply chain weaknesses.

Following a brief literature review and a methodology chapter, the three sub-topics - jurisdictional loopholes, law enforcement capacity and supply chain weaknesses - are presented, providing information on various EU countries. The current situation in legislation and enforcement are examined in details and then wrapped up with a brief discussion on the main challenges faced by European countries with some high-level improvement suggestions.

2 Literature Review on WEEE Legislative, Law Enforcement and Challenges in Supply Chain

Just like in the rest of the world, there are two main basic streams of e-waste in the European Union: Business to Business (B2B) and Business to Consumer (B2C) chains. B2B waste arises, for instance, when companies discard old IT equipment, typically handing it over to recyclers. Unscrupulous recycling companies, as observed for example in the UK, sell it off to smugglers, instead of performing recycling activities themselves. The other source of e-waste are the consumers, who take the obsolete equipment to designated collection facilities. Local recycling sites are often found to be the source of illegal e-waste. Investigations have shown that the material passes through many brokers and middlemen between collection and destination. Some companies are directly exporting and some are selling off to exporters. The European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL) has estimated that approximately 1.5 million waste-loaded containers are shipped illegally every year (IMPEL, 2012, p. 6).

A lack of oversight by compliance schemes frequently allows leakages of e-waste from the civic amenity sites. Some compliance schemes sub-contract the collection and recycling of select categories of e-waste. The large number of Producer Compliance Schemes further complicate the control mechanism for example in the UK. According to industry experts, this competitive system drives down the price paid for recycling to such levels that responsible recyclers are displaced from the market (EIA, 2011, pp. 2-11). In the Netherlands, retail collection points are identified as vulnerable points for illegal exports. Fridges, televisions and smaller equipment are dispatched to developing countries from these facilities (Wang, 2009, p. 70).

Prosecution related to violations is a problem in many countries: prosecutions are infrequent or too late, and the fines imposed too low. Many environmental inspectorates are not empowered to impose administrative fines, or are given have the powers of the criminal police - necessitating good collaboration with the police, which is often missing, as exemplified by Italy. The judicial police usually have insufficient human capacity to deal with these issues (EC, 2011, p.54). As an illustrative example, in the Netherlands, around 30% of Waste Shipment Regulation (WSR) cases are not prosecuted (Geeraerts, Illes and Schweizer, 2015, p. 26).

Recent research has identified several weaknesses in the Netherlands. In terms of human capacity, severe limitations were noted. Apparently, only 4 inspectors were employed in Rotterdam harbour, where 6 million containers were shipped each year, 15 percent being waste. Only 14 inspectors were in charge of inspection activities all over the Netherlands. Only a limited number of customs and police officers were involved in daily activities, without having received adequate training on the enforcement of the WSR (Wang, 2009, pp.68-69). Lack of coordination between competent authorities and the destination countries is another missing element in that is important in tacking e-waste crimes.

There is also limited assessment on the impact of enforcement activities and the effectiveness of the WSR enforcement due to weaknesses in the registration systems in the environmental inspectorate and customs, and due to the lack of systematic reporting by the police and customs (Geeraerts, Illes and Schweizer, 2015, pp.25-26). Moreover, gaps exist in electronic data interchange within the enforcement network, in general information management, and in the customs ICT systems where customs data does not accurately reflect the compliance rate and customs control strategy (Algemene Rekenkamer, 2012, pp.7, 10, 35 and 38).

Two recent studies report a number of deficiencies existing in many of the EU member states. Limited personnel and financial capacity appear to be a general problem preventing better export controls. There are huge discrepancies in the number and the nature of inspections; enforcement organisations involved; available resources; and penalty and prosecution systems across the EU countries. The notable gaps identified include the following:

- lack of inspection planning and risk assessments;
- insufficient provisions on the burden-of-proof;
- lack of "up-stream" inspections (of waste producers, collection points, interim storage, recovery and disposal operators);
- lack of targeted training for waste authorities;
- incompleteness of existing guidelines;
- shortage of technical equipment;
- incompleteness of existing guidelines;
- practical difficulties arising from the broad definition of waste in the WSR, and the existence of two different code systems (the

WSR/Basel codes and the international tariff codes used by customs authorities);
- inadequate system of receipt and processing notifications; and
- insufficient coordination and cooperation across competent authorities-- (Geeraerts, Illes and Schweizer, 2015, pp.26-27 and Recast Directive, pp.15-19).

3 Study Methodology

Building on the literature review findings, three sets of questionnaires focusing on different target groups were produced by partners within the CWIT (Countering WEEE Illegal Trade, FP7-project) – consortium and sent to experts in the 28 EU countries, Norway and Switzerland – covering law enforcement and environmental authorities as well as industries. The following subset of questions is related to the information analyzed and presented in this conference paper:

1. Has your country transposed the WEEE Directive re-cast into the national legislation?
2. Does your country have any actual or future program to exchange information on inspections carried out?
3. Under your national legislation, what are the measures implemented/planned to monitor shipments of used EEE?
4. Is there a template available in your country for the declaration made by the holder who arranges the transport of the EEE that none of the material or equipment within the consignment is waste?

5. In your country, is there a protocol or guidelines available for a used EEE functionality test?
6. Under your national legislation, are exporters of used EEE obliged to provide a certificate of functionality of the appliances transported?
7. Is there a guide or set of criteria available in your country to define appropriate protection of the goods against damage during transportation?
8. Under your national legislation, are there reporting requirements for e-waste? If yes, what?
9. 9. What criteria are used to distinguish used electrical and electronic equipment (second-hand equipment) from WEEE?
10. Is there any specialised training for the detection, investigation and prosecution of illegal trade in waste and related offences in your country?
11. Under your national legislation, what are the specific WEEE related penalties for collection and trading offenses?
12. Who should be prosecuted with regard to the illegal trade of e-waste?
13. Is liability with regard to the illegal trade of e-waste considered to be criminal, civil or administrative?
14. In your view, is your national legislation adequate to prosecute offenses related to trade of e-waste?
15. In your view, what kind of additional provisions should be included into your national legislation for enhanced prosecution of such cases?

16. In your view, what kind of additional provisions should be included into the international legislation for enhanced prosecution of such cases?
17. Please provide any additional information you may deem important in relation to the illegal trade of WEEE.

We received written responses from 17 countries out of the 30. The main outcomes are shared in the next three chapters of this paper.

4 Jurisdictional Loopholes Along the Supply Chain

Despites some improvements made by European regulations, violators of WEEE regulations take advantage of the legislative loopholes for their personal gain. The recast WEEE Directive (Directive 2010/19/EU of the European Parliament and the Council of 4 July 2012) builds upon the original WEEE Directive by providing a better regulatory environment and further limiting the negative externalities of improper WEEE disposal.

4.1 Legal Challenges and Loopholes

A couple of European countries have not yet completed the transposition of the recast WEEE Directive in their national legislation within the agreed deadline. As of the time of writing of this paper, the recast WEEE Directive was not yet transposed in Germany, Poland, and Slovenia - as well as in the non-EU country of Norway (see Figure 1).

Figure 1 Overview of recast WEEE Directive across Europe

Discrepancies in the definition and classification of WEEE have a considerable impact on the illegal trade. In particular, Belgium showed concerns about the national differences in the classification of WEEE. For instance, the same material is considered green listed in one member state and amber in another. Consequently, offenders may try to export waste from those countries with the most flexible classification. Offenders also capitalize on the differences in classification to avoid prosecution in the case of detection.

Ireland refers to the ambiguity in international legislations, specifically the differences in the wording between the WEEE Directive and the Basel Technical Guidelines regarding the inclusion of components, such as a motherboard or a printed circuit board.

Another frequently mentioned issue is the lack of strategy and guidance for the law enforcement agencies (LEAs) and transporters on how to distinguish between WEEE and UEEE (used electrical and electronic equipment). In fact, one of the most common modus operandi to illegally trade WEEE is to declare the goods as UEEE instead of WEEE.

Some countries including Austria, Denmark, Norway, Switzerland and the UK have prepared guidelines for LEAs and transporters. However, such guidelines, including an inspection strategy, were missing in a number of countries like Germany, Greece, Italy, Romania and Spain.

The implementation of a ban on cash transactions in the scrap metal trade in France resulted in an increase in the quantities collected at the national level indirectly pointing to a reduction in thefts or other illicit activities for valuable components of e-waste (ADEME and OCAD3E, 2013, p.28). But, it was observed that in due course it led to a higher incidence of theft from collection points in border areas. The analysis also revealed a shift in illegal activities to neighboring countries where such a ban does not exist, underlining the necessity for further harmonization of regulations at the European level.

4.2 Penalties and Prosecution

There are considerable differences in the penalty systems for illicit WEEE activities across the EU. Collection and trading offences can be prosecuted through the administrative or the criminal procedure, and liability may be considered as administrative, civil or criminal, depending on the country. While this offers wider options for addressing violations, resorting to civil or administrative fines may give the impression that the offence is not serious. For instance, in the UK, the penalties for waste offences (up to 2 years imprisonment) are significantly lower than for other illegal trade offences, like illicit narcotics (up to 10 years imprisonment.)

While some fines apply in all EU member states, imprisonment is not applicable everywhere. Other sanctions, such as confiscation of assets; temporary or permanent, total or partial closing of facilities; suspension/revocation of license; temporary disqualification from the executive offices of legal entities and enterprises and from public offices; publication of the criminal judgment of conviction; and fees on return shipments, may also apply.

As opposed to other countries such as Romania, Estonia and Portugal, where maximum legal fines are lower than 50.000 Euros, financial penalties are quite high in Spain, where an illegal shipment of hazardous waste can result in a fine of up to 1.75 million Euros. Such discrepancies have the potential to shift illegal activity from one country to another, where the consequences are less severe.

Specialized prosecution offices are found only in couple of countries including Belgium, Greece, the Netherlands, Spain and Sweden.

Some countries reported shortcomings in their legislation, where an illegal waste shipment is completed only when it has crossed the border. For example Norway has been working to address this issue, by making an attempt to export´ an offence (Kristensen, 2012). The lack of corporate liability in criminal law in Germany has been viewed as a weakness in the legislative framework around WEEE. In Romania, the national framework does not provide clear provision regarding who is held liable for prosecution in case of an illegal export. There are no clear provisions on penalties for the

illegal collection and exports of WEEE, for regular checks of the enforcement bodies (environmental guard, customs), and for compliance.
Countries including Denmark, Finland, Norway, Scotland, Sweden and the UK have expressed concerns about proving guilt in WEEE cases. More specifically, they experience difficulty in proving the hazardous nature of the shipment, such as finding appropriate documentation of the WEEE contamination levels as defined in relevant national and international legislations. Adding to the difficulty is the fact that often the waste is not returned to the country of origin, preventing the authorities from determining if the composition is above or below established limits to be considered hazardous. In Denmark the burden of proof is prohibitively high for authorities when it comes to prosecuting other actors in the value chain of UEEE and WEEE before the shipment takes place. Belgium faces a challenge to collect evidence on who is responsible for the violation.
The recast WEEE directive has introduced a provision facilitating the prosecutors' activities by placing the responsibility of proving the functionality of the equipment to the exporter. However, without proper guidelines for the testing, recording of test results and packaging of EEE, exporters can circumvent actual functionality testing and falsely declare equipment as UEEE while it is actually non-functional –and prosecutors lack evidence against WEEE exporters. The Netherlands has referred to a lack of experience of the enforcement in implementing the new legislation. Romania also considered that the awareness of the provisions of the recast WEEE Directive should be improved.

As a consequence of the lack of means and human resources, prosecutions happen only in the most serious cases. For example, while the Scottish legislation requires prosecution of the transshipments of hazardous waste after only one administrative warning, in practice this applies only for “significant cases” - e.g. for more than 50 items in a container, falsified documents, or an attempt to conceal, and if there is evidence that the suspects have generated a large profit, or are known to be systematic offenders.

4.3 Summary on Jurisdictional Loopholes

Several shortcomings in the national and international regulatory framework can be noted from the above discussion. Despite the transposition deadline of February 2014, some European countries have not transposed all aspects of the Directive recast. Even among the countries that have transposed the recast WEEE Directive, there are remaining concerns on the clarity of the concepts. These ambiguities include the number of waste classification systems in use, particularly European Waste codes versus Basel codes, differences among countries in classifying certain types of waste (green vs amber), and in the accepted thresholds of contamination.

In addition, the lack of harmonization of the penalty systems and of the classification of WEEE appear to be two major bottlenecks coming in the way of enforcement activities. At the international level, particular need was expressed to harmonize the minimum standard on offences and provisions, such as the cash ban in metal scrap trade. This would simplify enforcement in transboundary cases, and reduce the number of criminals from shifting their activities to lower-risk countries within the EU. Further,

a number of authorities reported difficulties in collecting evidence, such as proving the liability of offenders or the hazardous nature of a waste.
A common challenge faced by some member states is the level of penalty applied that is related to the classification of the crime. When a shipment is intercepted before it has left national borders, authorities are only able to classify the act as an “attempt to ship". In some countries, this means that the penalty is much lower than for the actual act of illegally exporting WEEE, and in others, it may not be considered an offense at all.
The above legislative challenges indicate the necessity of reviewing and re-inforcing both national and international legislations, to provide a solid foundation for an effective enforcement system.

5 Gaps in Law Enforcement Capacity, Knowledge and Training

Effective enforcement relies on a number of factors, including financial and human resources of the authorities involved in WEEE related activities; the level of expertise of the personnel; and coordination between the key administrations.

5.1 Knowledge and Training

A common practice to illegally ship WEEE is to load containers with WEEE and other goods – for example second-hand cars, electronics, clothing, and bikes- which makes detection of illicit WEEE more difficult. It is well known that LEAs do not have the capacity to physically inspect all the containers dispatched from Europe; just a minor sub-set. As an indication, one respondent from a major European port estimated that about twenty containers of WEEE are packed each week (approximately 1000 containers per year) in this port, and the authority inspect just about ten containers a year. In fact, one of the main modus operandi used by offenders to circumvent controls consists in the false declaration of WEEE containers as UEEE or metal scrap.

Some countries in the EU specifically highlight the current gaps in their capacity building activities. In Belgium the prosecutors require additional training on environmental law issues, whereas inspectors and police would benefit from specific training on WEEE issues. A different issue reported in Austria is the reliance of police and customs on external experts to determine if the loads are in fact waste. Because this consultation process is time-consuming, it is often bypassed. In Greece, priority seems not to be given to the WSR and the agencies involved are not equipped with the necessary legal powers. Further, environmental inspectors lack equipment to assess the hazardous nature of a WEEE shipment. In addition, the customs facilities lack adequate storage capacity for seized waste shipments (EUROSAI, 2013, pp.36-37). In Lithuania, the need is recognized to increase number of inspectors involved in waste shipments control and to introduce systematic trainings and workshops for inspectors. In Slovakia there is a need for continuous awareness rising and training due to personnel changes at relevant institutions - including the need for human, financial and technical resources, as well as IT-systems for monitoring illegal traffic. A number of countries including Finland, Lithuania, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and the UK, provide training programs on inspections, detections, investigations, and prosecutions to various authorities - such trainings typically covering all types of waste.

Guidance to LEAs and businesses is also provided in a number of countries - including Austria, France, Germany, Ireland, the Netherlands, Poland, Slovakia, Sweden, Switzerland and the UK - covering especially the issues of distinction between UEEE and WEEE; detection of illegal trade in waste and related offences; and waste classification or outlining the requirements of the WEEE Regulation.

5.2 Interagency Collaboration

Once detected, a tendency for criminals is to move their activity from one country or one specific sea port to another where control might be weaker - a practice known as "port-hopping." This demonstrates a lack of national and international coordination and harmonization among authorities.

In Denmark a need for collaborative ties with the environmental authority is recognized, due to the complexity of the legislation. In general terms, no single agency has sufficient capacity or authority to control waste shipments single-handedly.

The Dutch authorities have pointed out a lack of cooperation with other organizations - mostly at international level - and the lack of harmonization, specifically related to national differences in the classification of certain waste streams. Further, controls are not carried out by customs, but only by the environmental inspectorate that has limited capacity and legal powers. An IMPEL report underlines a wide range of practicability and enforceability issues arising in the application of the WSR in the Netherlands, including differences in the frequency of the controls among the EU member states; ambiguity in the legislation; a lack of cooperation in enforcement activities; and difficulties on how to set-up cross-border agreements. These enforcement difficulties are largely linked to the extensive scope and complexity of the WSR; the strong challenges for authorities addressing waste shipments; and the rapid development of new waste streams and mechanisms of shipments (IMPEL, 2011).

France has recognized the necessity to improve collaboration between customs and police forces of various European countries, in coordination with international organizations involved in the fight against organized crime, e.g, via the exchange of information, cross-checking of databases and executing joint operations.

According to a 2013 report, Greece shows deficiencies in the information and communication systems, and issues with the existence of two different code systems (EWSR/Basel codes and customs codes) (EUROSAI, 2013, pp. 55-56).

The German police has noted difficulties in coordination among the competent authorities, specifically because they do not have access to the customs databases. This is a strong barrier when it comes to targeted inspections. The police may put customs on alert for a particular container, but often do not receive any updates on the inspection outcome.

In Northern Europe the level of cooperation is not uniform across all agencies involved and there is room for improvement in coordinating actions between some authorities. In fact, information exchange between police, customs and the environmental agency is limited due to the existing legislation and the differences in the mandates of the organizations. Moreover, cooperation with the authorities in the e-waste recipient countries in Africa and Asia poses even bigger challenges.

Because WEEE has not yet been a focus for authorities in the Czech Republic, they had little experience and demonstrate no cooperation in the area. But some collaboration existed with the competent authorities in a neighboring country.

Poland has noted the need to "improve direct, working contacts with competent authorities from non-Annex VII countries in case of illegal transboundary shipment of waste".

Lithuania has acknowledged a need to improve the cooperation between national and international competent authorities and a more effective system of exchanging information on experiences and best practices between parties.

In terms of coordination with destination countries, varying responses are provided by the UK. A lack of communication among law enforcement authorities across jurisdictions was considered a major obstacle and a most necessary area of improvement. One additional problem is that in the event of detection in the destination port, the shipments are generally not repatriated to the point of origin for further action.

Lastly, an improvement suggestion is made by the Dutch environmental inspectorate: introduce a real-time system allowing involved authorities to engage in the timely exchange of intelligence, or one system accessible for all.

5.3 Summary on Law Enforcement Gaps

In terms of governmental capacity, limitations in human and monetary resources are repeatedly reported by authorities in the entire enforcement chain. These include the number of staff involved, in particular their skills and knowledge on such a specialized issue, which is a major obstacle to detect infringements. The lack of training on distinguishing between WEEE and UEEE appears to be a common problem. Even though training programs and guidance documents on illegal shipments of waste or WEEE for LEAs exist in many countries, the shortage of human capacity is a stumbling block in proper inspection activities.

The gap analysis shows the involvement of a large range of authorities in the countering of illegal WEEE trade but collaboration and exchange of information across these agencies appear to be missing, creating barriers for effective controls, including targeted inspections.

Furthermore, due to the low penalties associated with WEEE violations, authorities may only be granted limited investigative powers. LEAs' action can also be hindered by the burden of proof requested by the law. Proving the hazardous nature of a shipment may require external assistance, a process that is often long and costly. Without such proof, no action can be taken against the individual(s) responsible for the shipment. Countries also face difficulty in proving who exactly can be held responsible for the reported violation.

With respect to prosecution, again limited resources and knowledge seem to be major gaps. Only five countries reported having specialized environmental prosecutors involved. Due to insufficient resources, only the most serious WEEE cases - involving high profits, multiple shipments and/or repeat offenders - are pursued for prosecution. And, when a WEEE case is brought to the court, sentences applied are too lenient, the prison terms issued are too few, and the fines imposed are usually too low to create a disincentive for offenders.

As can be seen from the discussion, many of the problems encountered by law enforcement bodies are associated with insufficient financial means and human resources. The resulting loopholes create enough leeway for criminal operators to circumvent control, and in case of detection, to get away with minimum penalties.

6 Supply Chain Weaknesses

Examining the weaknesses of the WEEE supply chain is necessary to better understand the exit points from reported WEEE streams. WEEE has the potential to enter illegal streams at any point, starting from the initial discard by the consumer, to collection, consolidation, treatment and its final destination. Different type of actors and violations have been reported.

WEEE can exit legal treatment streams even before being collected from households in countries where a street pick-up service is provided. Unauthorized street collection by informal actors facilitates illegal exports, in numerous places across Europe. The offenders are aware of the scheduled visits, picking the select e-waste before the council trucks can retrieve it.

Industry representatives mainly refer to the theft of WEEE and its components, and informal buyers operating at collection points. The Spain respondents specifically highlight the "cannibalization/ cherry picking" of

WEEE components, such as compressors, refrigerant tube circuits, and deflection coils from CRT televisions and monitors. Such thefts imply a lack of security and oversight and a lack of police control over the waste collection sites.

WEEE may also exit reported streams through dealers, brokers, distributors or transport companies collecting waste and second-hand material, for export purposes to Eastern Europe, Asia and/or Africa. Enhanced regulation of the activities of scrap dealers and greater transparency of all material flows by all actors - not only the collection systems - have been suggested as improvement measures.

The UK has spotted a weakness in the reporting method. When the compliance schemes give the WEEE to recyclers for treatment, the recycler must provide an “evidence note” stating the amount that has been treated; receiving remuneration based on this amount. Obviously, these documents can falsely claim that a certain amount has been treated when it is in fact being exported illegally. However, a different system has been recently introduced, which adds greater visibility and has eliminated the involvement of brokers in selling evidence notes.

Besides purely illegal actors, a number of legitimate businesses, such as WEEE management organizations, WEEE treatment facilities, and street pick-up services, directly circumvent WEEE regulations by exporting it to non-OECD countries.

A good practice to improve WEEE supply chain security has been indicated in a French study showing that tracking the WEEE flows restricts leakages and increases the formal collection of WEEE. Among the retailers examined in this study, only one initiated an IT system for tracking the flow of WEEE collected in stores and during deliveries. The volume of WEEE collected in the region trebled during the months that followed the setting up of the tracking system (ADEME and OCAD3E, 2013, p. 28).

The above discussion indicates that WEEE has the potential to enter illegal streams at multiple points in the supply chain. It could begin at the initial discard by the consumer, at collection facilities, or through any of the legitimate or illegitimate actors involved in WEEE flows. In addition, some loopholes in WEEE management, as identified in the UK, facilitates its diversion from licit to illicit streams. Thus enhanced monitoring at exit points, coupled with the exchange of good practices, such as the French example, would be appropriate preventive measures to secure the WEEE supply chain.

7 Discussions and Conclusions

As with many other environmental offenses, the WEEE sector remains attractive to criminals due to the current low risk of enforcement action, the low level of applied sentences and the relatively high profits to be made. This gap analysis has aimed at giving an overview of the common specific weaknesses in the WEEE legal framework, enforcement, and supply chain among European countries.

Three main shortcomings have been observed in the national and international legislative frameworks. The full transposition of the EU Directive has not taken place in all member states. There are considerable differences in waste classification systems and there is a lack of harmonization of provisions and penalties across the EU.

Effective enforcement relies on a number of successive steps to thwart unlawful activities. These include detection of the crime, arresting or taking enforcement action against the offender, or prosecution to convict the offender.

At the initial level of detection, countries face a number of challenges. A shortage of human capacity is a strong barrier to carrying out inspection activities. There is no unified information system among national and international agencies that would enable targeted inspections, Adding to this is the difficulty in distinguishing between UEEE and WEEE, when shipments are being inspected.

When detection does take place, authorities face other challenges to take action against the violator. Collecting evidence against the perpetrator is not easy. Authorities are sometimes not granted sufficient investigative powers as the crime is not considered severe in many EU member states. Finally, the fines imposed are too low to act as a deterrent to non-compliance.

Regarding prosecution, only the most severe cases are taken to this stage due to limited means. For those handful of cases brought to court, the high burden of proof is restrictively high to prove guilt.

As is evident, there are considerable obstacles encountered by authorities in every step of the enforcement chain.

The strength and the consistency of the legislative framework have a huge importance over the WEEE sector compliance as they are determining factors of the LEAs' activity and capacity. The gaps identified on this level give

rise to ambiguities and create loopholes for criminals to circumvent controls or escape punishment. Strengthening national and international framework is, thus, the first and foremost step to facilitating enforcement.
It was observed that a lack of human and financial capacity creates many barriers in key activities of the enforcement chain like detection and prosecution. A general lack of awareness among governmental authorities of this crime type appears to be an inhibiting factor in the allocation of resources. Penalty levels are generally low, except in some countries. Stronger penalties and punishments in some member states do not prove to be very effective as illegal operators shift their activities to regions with less severe consequences for violation.
It appears that a large number of national agencies are involved in countering in WEEE related infringements, due to the nature of this crime. This situation results in a diffusion of relevant information with each administration holding partial information. Such a division of intelligence creates barriers for effective controls, including targeted inspections.
Finally, the general lack of oversight in WEEE collection points leads to many thefts of WEEE and its components strongly affecting the collection rates and facilitating its diversion to illegal streams.
Criminals are aware of the existing vulnerabilities in each step of the WEEE chain as well as the weakness in the enforcement system and continue being active. To deter such acts, better allocation of resources, stronger penalties, greater harmonization of national systems, enhanced security measures, and stronger cooperation among administrations are most necessary improvement measures.

In terms of future research, the authors make the following recommendations: (i) gather further information on the key issues identified in the gap analysis through questionnaires and interviews; (ii) identify best practices in the most problematic areas identified; and (iii) do further research on the key area of inspection planning and strategy, and derive from it further examples of best practices to disrupt the illegal WEEE supply chains.

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References

ADEME and OCAD3E, 2013. Projet de quantification des déchetsd'équipementélectriquesetélectroniques (DEEE) en France – Gisement et destinations des DEEE ménagers et assimilés. Available at: <http://www.ademe.fr/projet-quantification-dechets-dequipements-electriques-electroniques-deee-france> [Accessed 25 May 2015].

Algemene Rekenkamer, 2012. Enforcement of European Waste Shipment Regulation.

Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on Waste Electrical and Electronic Equipment (WEEE).

EC, 2011. Implementing EU waste legislation for green growth.

EC, 2015. Available at: <http://ec.europa.eu/environment/waste/weee/index_en.htm> [Accessed 22 May 2015].

EIA, 2011. System Failure: The UK's harmful trade in electronic waste. Available at: http://ewasteguide.info/files/EIA_2011_UK.pdf [Accessed 1 June 2015].

EUROSAI, 2013. Coordinated audit on the enforcement of the European Waste Shipment Regulation.

Eurostat, n.d. Waste Electrical and Electronic Equipment. Available at: http://ec.europa.eu/eurostat/web/waste/key-waste-streams/weee [Accessed 2 June 2015].

Geeraerts, K., Illes, A. and Schweizer, J.P., 2015. Illegal shipment of e-waste from the EU: A case study on illegal e-waste export from the EU to China.

IMPEL, 2011. Practicability and enforceability of the Waste Shipment Regulation. Final Report. Institute European Environmental Policy.

IMPEL, 2012. Waste sites Manual, Identification and control of "upstream" storage and treatment facilities used for problematic waste exports. Available at <http://impel.eu/projects/waste-sites-phase-2/> [Accessed 10 May 2015].

Kristensen, M., 2012. Proposed Increase in Criminal Penalties for Illegal Export of Waste. International Law Office Newsletter, Environment & Climate Change – Norway. Available at <http://www.internationallawoffice.com/newsletters/Detail.aspx?g=266f0d5b-9e5f-4c6f-88f1-01dbcf5e2cdb&redir=1> [Accessed 10 May 2015].

Wang, J., 2009. Transboundary Shipments of E-Waste: A global problem. Available at <http://repository.tudelft.nl/assets/uuid:bd356625-3d70-41a7-93c4-db261f201f4e/Wang%20J.pdf> [Accessed May 25 2015].

List of Authors

A

Ahokas, Juha

j.ahokas@interpol.int
Interpol
Capacity Building and Training Directorate
France

Alfathi, Najlae

najlae.alfathi@gmail.com
laboratory of innovative technology
Morocco

B

Bahauddin, Achmad

baha@ft-untirta.ac.id
University of Sultan Ageng Tirtayasa
Center for Transport-System and Logistic
Indonesia

Blecker, Thorsten

blecker@tuhh.de
Hamburg University of Technology (TUHH)
Institute of Business Logistics and General Management
Germany

Bouallouche, Dalicia

dalicia.bouallouche@u-bourgogne.fr
University of Bourgogne Franche-Comté / LE2I UMR6306
Laboratory of electronics, image and computer science (CNRS)
France

Brümmerstedt, Katrin

katrin.bruemmerstedt@cml.fraunhofer.de
Fraunhofer Center for Maritime Logistics and Services CML
Germany

Brunner, Uwe

uwe.brunner@fh-joanneum.at
Fh Joanneum University of Applied Sciences
Industrial Management
Austria

Busvelle, Eric

busvelle@univ-tln.fr
University of Toulon
Laboratory of information sciences and systems (LSIS)
France

E

Ekawati, Ratna

ratna_ti@ft-untirta.ac.id
University of Sultan Ageng Tirtayasa
Center for Transport-System and Logistic
Indonesia

F

Flitsch, Verena

verena.flitsch@cml.fraunhofer.de
Fraunhofer Center for Maritime Logistics and Services CML
Germany

Föhring, René

rene.foehring@pim.uni-due.de
University of Duisburg-Essen
Germany

G

Gallagher, Rosie

r.gallagher@interpol.int
INTERPOL
Capacity Building and Training Directorate
France

Gutierrez Quijano, Pedro David

pdgutierrezq@unal.edu.co
National University of Colombia
Industrial Engineering
Colombia

Günthner, Willibald A.

guenthner@fml.mw.tum.de
Technical University Munich
Germany

H

Hintsa, Juha

juha.hintsa@cross-border.org
Cross-border Research Association
Switzerland

Hoppenheit, Steffi

hoppenheit@fml.mw.tum.de
Technical University Munich
Institute of Materials Handling, Material Flow, Logistics
Germany

I

Iakovou, Eleftherios

eiakovou@auth.gr
Aristotle University of Thessaloniki
Laboratory of Quantitative Analysis, Logistics and Supply Chain Management, Department of Mechanical Engineering
Greece

Indrahanif, Muhammad

muhammadindrahanif@gmail.com
University of Sultan Ageng Tirtayasa
Center for Transport-System and Logistic
Indonesia

J

Jahn, Carlos

carlos.jahn@cml.fraunhofer.de
Fraunhofer Center for Maritime Logistics and Services CML
Germany

Jażdżewska-Gutta, Magdalena

m.jazdzewska@gmail.com
University of Gdansk
Institute of International Business
Poland

K

Keramydas, Christos

chkeramy@auth.gr
Aristotle University of Thessaloniki
Laboratory of Quantitative Analysis, Logistics and Supply Chain Management, Department of Mechanical Engineering
Greece

Köhler, Timo

Timo.Koehler@dbh.de
dbh Logistics IT AG
Germany

Kühn, Mathias

mathias.kuehn@tu-dresden.de
Technische Universität Dresden
Germany

Kersten, Wolfgang

w.kersten@tuhh.de
Hamburg University of Technology (TUHH)
Institute of Business Logistics and General Management
Germany

L

Lasch, Rainer

rainer.lasch@tu-dresden.de
Technische Universität Dresden
Department of Business Management and Economics
Germany

Lyhyaoui, Abdelouahid

lyhyaoui@gmail.com
laboratory of innovative technology
Morocco

M

Männistö, Toni

toni.mannisto@cross-border.org
Cross-border Research Association
Switzerland

Männistö, Toni

toni@cross-border.org
Cross-border Research Association
Switzerland

Martínez Flores, José Luis

joseluis.martinez01@upaep.mx
Universidad Popular Autónoma del Estado de Puebla
Director of Graduate Management Logistics and Supply Chain,
Mexico

Meyer-Larsen, Nils

meyer-larsen@isl.org
ISL Institute of Shipping Economics and Logistics
Information Logistics
Germany

Millot, Stéphane

stephane.millot@tedies.fr
Tedies Company
France

Müller, Rainer

mueller@isl.org
ISL Institute of Shipping Economics and Logistics
Information Logistics
Germany

N

Noche, Bernd

bernd.noche@uni-due.de
Universität Duisburg-Essen
Transport-system and Logistic
Germany

O

Olivares Benítez, Elías

elias.olivares@upaep.mx
Universidad Popular Autónoma del Estado de Puebla
Interdisciplinary Center for Graduate Studies and Research
Mexico

P

Pumpe, Andreas

andreas.pumpe@fh-muenster.de
Muenster University of Applied Sciences
Institute of Process Management and Logistics
Germany

R

Ramos Torres, Isidro

isidro.ramos@industrial.uson.mx
Universidad de Sonora
Industrial Engineering
Mexico

Romero Dessens, Luis Felipe

lromero@industrial.uson.mx
Universidad de Sonora
Industrial Engineering
Mexico

Ridwan, Asep

asep.ridwan@stud.uni-due.de
Universität Duisburg-Essen
Transport-system and Logistic
Germany

Ringle, Christian M.

c.ringle@tuhh.de
Hamburg University of Technology (TUHH)
Institute for Human Resource Management and Organizations

S

Santoso, Muhammad Iman

muhammad.santoso@stud.uni-due.de
Universität Duisburg-Essen
Transport-system and Logistic
Germany

Sedqui, Abdelfettah

abdelfettah.sedqui@gmail.com
laboratory of innovative technology
Morocco

T

Tsiolias, Dimitrios

dtsiolia@auth.gr
Aristotle University of Thessaloniki
Laboratory of Quantitative Analysis, Logistics and Supply Chain Management, Department of Mechanical Engineering
Greece

Schmidt, Thorsten

thorsten.schmidt@tu-dresden.de
Technische Universität Dresden
Germany

V

Vallée, Franz

vallee@fh-muenster.de
Muenster University of Applied Sciences
Institute of Process Management and Logistics
Germany

Vioix, Jean-Baptiste

jean-baptiste.vioix@u-bourgogne.fr
University of Bourgogne Franche-Comté / LE2I UMR6306
Laboratory of electronics, image and computer science (CNRS)
France

Vlachos, Dimitrios

vlachos1@auth.gr
Aristotle University of Thessaloniki
Laboratory of Quantitative Analysis, Logistics and Supply Chain Management, Department of Mechanical Engineering
Greece

Vogel, Wolfgang

Wolfgang.Vogel@mailbox.tu-dresden.de
Technische Universität Dresden
Department of Business Management and Economics
Germany

Völker, Michael

michael.voelker@tu-dresden.de
Technische Universität Dresden
Germany

W

Wagner, Regina

r.wagner@tuhh.de
Hamburg University of Technology (TUHH)
Institute of Business Logistics and General Management
Germany

Wallner, Martin

martin.wallner@fh-joanneum.at
FH JOANNEUM University of Applied Sciences
Industrial Management
Austria

Z

Zahid, Taiba

taiba.zahid@tu-dresden.de
Technische Universität Dresden
Germany

Zelewski, Stephan

stephan.zelewski@pim.uni-due.de
University of Duisburg-Essen
Germany

Zsifkovits, Helmut

helmut.zsifkovits@unileoben.ac.at
University of Leoben / Montanuniversität
Lehrstuhl für Industrielogistik
Austria

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