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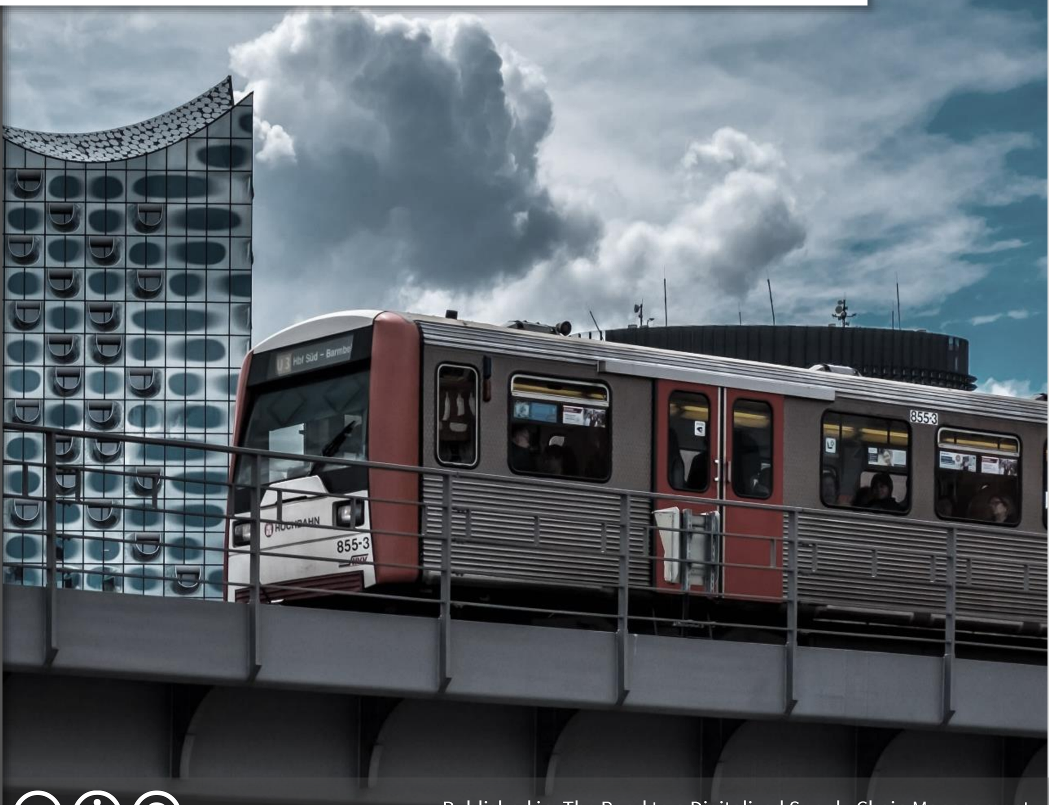

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Multi-Method Decision Support Framework for Supply Network Design

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In a business context characterized by increased competition due to digital transformation and technological breakthroughs, massive penetration of online purchasing, greater customers' expectations and switch of manufacturing paradigms, the role of logistics has become today more critical to firms than ever before. One critical initiative that logistics providers can undertake in order to gain a truly competitive edge is to optimally seize and utilize key resources such as storage and transportation assets. This paper is an effort in that direction and proposes a decision support framework to design a cost effective supply network in the last leg of deliveries. A case study based approach about a postal service provider in Southeast Asia is presented to showcase the applicability of the proposed framework. By leveraging on the integration of data analytics, network optimization and simulation, this work highlights the advantages of adopting a holistic approach to decision making for the used case. Results show that number of storage facilities, and their locations, affect speed and cost-effectiveness of last mile distribution. For the case at hand, 18% of savings in transportation and warehousing cost with no impact on service level can be achieved by reducing the number of facilities in the network from 9 to 4. By reading the present paper, decision makers will gain insights on how to address challenges related with supply network design, transportation costs reduction and optimization of overstretched transportation routes.

Keywords: Network Design; Network Optimization; Last Mile Logistics; Transportation Optimization

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1 Introduction

Over the past few years, the attention given by academics and practitioners to supply chain management and logistics issues is increased tremendously (Yazdani et al., 2017). Logistics encompasses several business activities, which mostly relate with planning, organization, and control of the material flow (direct and reverse) from raw material at manufacturers to final points of consumption (Jonsson & Mattsson, 2005). With the surge in online purchasing, the role of logistics has become today more critical than ever before, with the sector registering a spike in the level of competition accompanied by a severe increase in usage of Third Party Logistics Service Providers (LSP). Between 2010 and 2016, the LSP industry has registered a steady yearly growth in revenue, reaching the global amount of 802.2 billion U.S. dollars in 2016 (+64% compared to 2010) (Statista, 2018 a). Worldwide, the market size for LSP in Asia Pacific is the largest. In 2016, the regional market was seized at approximately 305 billion U.S. dollars 2016 (38% of total), followed by North America (25% of total), and Europe (21% of total) (Statista, 2018 b). Constant regional economic growth and rapid surge of middle-class, demographic profile of consumers and businesses, advantageous trading conditions, and recent crystallization of the ASEAN Economic Community (AEC) make in fact Asia Pacific region particularly appealing to global freight forwarders and related firms (Spire Research and Consulting, 2016). Moreover, elements such as low cost for outsourcing, supply chain inefficiencies, and increased demand for LSPs, creates even more favorable conditions for the further increase in the presence of logistics players in near future (Spire Research and Consulting, 2016). Additionally, the gradual liberalization of regional logistics services is slowly increasing competitiveness and foreign participation, thereby introducing more logistics players into the market (Logistics, Insights Asia, 2016). With competition shifting from firm-to-firm to supply chain against supply chain (Christopher & Towil, 2001) there is clear need for LSP to rethink about supply chain and logistics management strategies so as to reduce operational costs and increase competitiveness (Tartavulea & Radu, 2013).

Thus, for a local LSP that wants to operate profitably in such a competitive context, there is a burning need of more streamlined logistical processes so as to gain concurrent cost effectiveness and superior service level. One such important initiative that LSP can undertake in order to gain competitiveness is to optimally allocate and utilize their logistics assets such as storage and transportation. Particularly, practical experience and academic research suggest that number of storage facilities, and their locations, greatly affect both speed and cost-effectiveness of logistics operations (Zhang & Xu, 2014). Therefore, a seamless and effective navigation of storage assets through an optimum design of supply network (SN) would be highly beneficial for an LSP that aims at gaining a truly competitive edge in both offline and online marketplaces, particularly in the final leg of deliveries. Last mile logistics is considered in fact the least efficient, costly, and most polluting sections of the entire logistics chain [(Gevaers, et al., 2014), (Wang, et al., 2016)]. Therefore, by taking these "last mile problems" into consideration, the present work is motivated by the real need to develop location decision models for interested LSPs that aim to streamline their logistics processes through an optimum design of their last mile distribution network and by the potential gain that such models can bring into practice. By focusing on the last mile distribution network of the National postal service provider (PSP), one of the major LSP in Indonesia, we will demonstrate how the proposed models can lead to significant gains in terms of costs, with no impact on service levels, using a real-life case in the Asia-Pacific region. The scope of work is on the PSP' supply network structure which, in the context of one of the most populated urban areas in Indonesia, comprises of 1 large Distribution Centre (DC), 9 intermediate DCs, and several demand points. This paper will assist researchers and practitioners in understanding how the following research questions are to be addressed

RQ1: How to determine the suitable number of intermediate DCs (nodes) to serve a highly populated urban area in one of the fastest developing economy of the Pacific region (Indonesia), and what is the suitable number of DCs for the particular case at hand?

RQ2: How to decide on the locations for the intermediate DCs of an optimized supply network, and what is the optimum network configuration for the particular case at hand?

The remainder of the paper is structured in the following sections. Section 2 presents a review of relevant literature. Section 3 describes the real world application by presenting the logistics landscape of Indonesia, and by setting the background of the case study. Section 4 describes the methodological approach. Section 5 discusses the model implementation for the selected case and results to date. Finally, section 6, highlights managerial implications, limitations, and next steps to reinforce findings to date.

2 Literature Review

Decisions on logistics system design are typically about number of storage facilities, their locations, allocation of products to facilities and to market (Korpela & Tuominen, 1996). Logistics system design studies have been largely applied to commercial sector, and a fair number of research papers are available in the domain of network design. Some research groups looked at strategic and tactical decisions such as flows of commodities across supply networks [(Keskin & Uster, 2007), (Qin & Ji, 2010)], or transportation policies (Tancrez, et al., 2012). Some others focused upon operational issues (Chow, et al., 2012) such as service level improvement (Rodziah, 2017). Substantial contributions have been made in addressing cross-level decisions such as inventory control (Ho & Emrouznejad, 2009), transportation flows (Lee, et al., 2008), location decisions [(Sun, 2002), (Balcik & Beamon, 2008)] or warehouse capacity planning (Francas & Minner, 2009). In literature, network design problems are typically tackled using either mathematical modeling/optimization, Multi-Criteria Decision Making (MCDM), and simulation models. Seldom, two methods of the above are integrated.

2.1 Supply network optimization

Network optimization refers to a series of methods which, by defining objective functions and constraints, are capable of determining the optimal supply chain network design with the lowest total cost structure [(Beamon, 1998), (Supply Chain Acuity, Management Consulting, 2013)]. A recent work by Kovács, G. et al. (2017) highlighted the need of establishing efficient supply chain operations to withstand the increasing global competition, and suggested to focus on minimum total cost and lead time, and improved customer service level, as objectives of the supply chain optimization. Benyoucef, Xie and Tanonkou (2013) considered a two period SC design model addressing facility location/supplier selection problem. The authors used a Monte Carlo approach in combination with Lagrangian relaxation, so as to minimize fixed DCs location costs, inventory and safety stock costs at the DCs as well as ordering costs and transportation costs across the network. Zokaee, S. et al. (2017) proposed the use of robust optimization to determine the strategic locations and tactical allocation for a four-tier supply chain. Their model was then extended to incorporate uncertainty in key input parameters such as demand, supply capacity and major cost data including transportation and shortage cost parameters. Ghaffari-Nasab, N. et al. (2015) proposed the use of mixed integer nonlinear programming model and linearization using a step-by-step approach to decide on the number, location and operation of hub facilities so as to minimize the total logistics costs for the network for a LSP. Authors compared the performances of two alternative distribution strategies namely hub-and-spoke and direct shipment, with the first showing significant advantages in terms of cost.

2.2 Multi-Criteria Decision Making (MCDM)

MCDM is concerned with structuring and solving decision problems on the basis of multiple decision criteria. A common application of MCDM is to tackle those decision problems for which a unique optimal solution does not exist and it is necessary to use decision maker's qualitative inputs to differentiate between solutions [(Majumder, 2015), (Roh, et al., 2015)] such as facility location problem as per Timperio, et al. (2017). Ho & Emrouznejad (2009), explored the use of a combined approach analytic hierarchy process (AHP) and goal programming (GP) to design a logistics distribution network in consideration of qualitative inputs from domain experts (e.g. on delivery and service level elements), with limited resource availability. Galvez, D. et al. (2015) integrated Mixed Integer Linear Programming (MILP) optimization and Analytical Hierarchical Process (AHP) for the implementation of a logistics network in the domain of sustainable energy production processes.

2.3 Supply chain simulation

Is used for supply network design decisions or design of supply chain policies. The main advantage of simulation is that it allows to assess supply chain behavior in a virtual environment, hence reducing the risk of making costly mistake in implementation (Thierry, et al., 2008). Munasinghe, I. U. et al. (2017) proposed a simulation-based approach to assess the impact of the facility location and product differentiation on supply chain network design. Six different scenarios were tested, with the goal of minimizing total distribution network cost. Salem R. W. & Haouari M. (2017) proposed the use of a simulation-optimization based approach to address a three-echelon stochastic supply chain network design problem. Outcomes of their work included selection of suppliers, determination of warehouses locations and sizing, as well as the material flow, with the objective of minimizing total expected cost.

2.4 Research Gaps and Contribution of the Current Research

Despite the comprehensive literature available in the domain of network design, to our knowledge, most research groups have handled the facility location problem by selecting a single method, and only in few cases two methods were integrated (mostly optimization and simulation). Although previous works provide fair solutions to this category of problems, it is also evident the lack of an adequate holistic support (strategic, tactical, and operational) to decision making. Thus, it appears that none of the research groups have considered an integration of methodologies, and this paper fills this gap. By reading the present paper, decision makers will be able to gain comprehensive answers to the following questions:

How to determine the suitable number of DCs for a cost-effective and time responsive last mile urban delivery?

How to decide on the locations of DCs for a cost-effective and time responsive last mile urban delivery?

As such, the work presented in this manuscript will apply data analytics, network optimization, and dynamic simulation to demonstrate the theoretical and practical relevance of the proposed solution approach. In particular, the study seeks to bring the following contributions:

- Generate deeper insights (static and dynamic) in the domain of network design by uncovering strategic, tactical and operational elements;
- Determine the optimal network configuration for the case study at hand;
- Bridge theoretical knowledge with practice in the nice of network design;

3 Indonesia Logistics Landscape

Located in the South East Asia region, Indonesia is the 14th largest nation by size in the world which covers 1,811,569 square kilometers of land and 5,800,000 square kilometers of water. The country spans three time zones and counts over 260 million people spread over more than seventeen thousand islands.

According to the World Bank's Logistics Performance Index of 2016, Indonesia ranks as 63rd on a global scale in regards to key logistics elements such as customs procedures, infrastructure, international shipments, logistics competence, tracking & tracing, and timeliness (The World Bank, 2016). This translates in logistics costs accounting for the 26% of national GDP (US$ 861 billion), worse than its neighboring countries like Singapore (8%) and Malaysia (14%). Poor logistics performance affect a) Country's economic competitiveness and b) In-country disparities in terms of accessibility and pricing of primary commodities (Indonesia-Investments, 2013). In such a challenging context, having in place an optimized supply network would be highly beneficial for increasing profits and optimizing overstretched routes

3.1 The Case at Hand

This case study focuses on the distribution network of the PSP in Indonesia that operates a countrywide network serving various type of businesses and consumers. However, the focus of this work is on the PSP' supply network dedicated to serve a highly populated urban area in Indonesia comprising of 1 large Distribution Centre (DC), 9 intermediate DCs, and several demand points (Figure 1). After a series of field visits, interactions with operations team, and basic data analytics, it has been identified that the existing network structure is leading to high operational and distribution costs, and therefore in need of a restructuring.

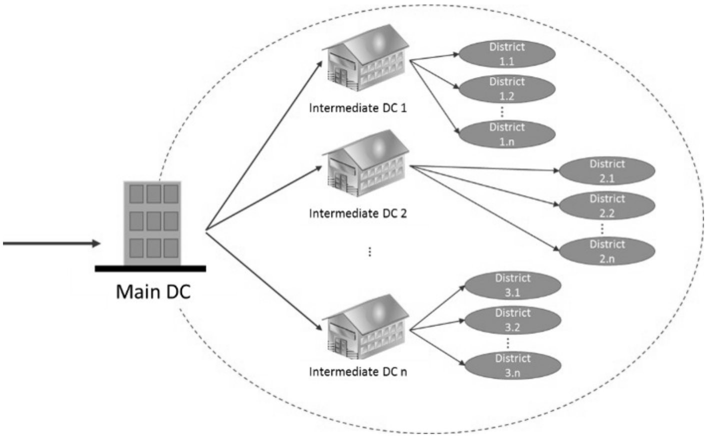

Figure 1: Schematic Representation of PSP's Supply Network (for Illustration Purpose only)

4 Solution Approach

To tackle the research problem of above, a solution approach integrating data analytics, network optimization and simulation has been conceived and tested. The proposed approach encompasses three Phases:

Phase 1. Identification of optimum number of DCs to be included in the supply network;

Phase 2. Structuring and Optimizing the Supply Network;

Phase 3. Stress-testing the supply network and measuring performances based on pre-identified parameters.

Figure 2 shows the proposed integrated decision support framework.

The proposed solution approach is used in this particular case to restructure an existing supply network. However, in those instances whereby a new network is to be established, the same framework can be also applied.

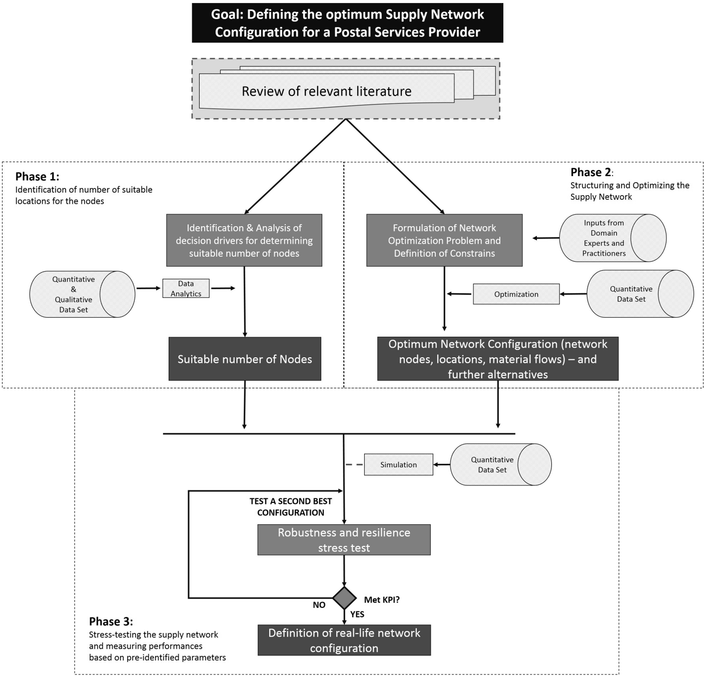

Figure 2: Proposed Integrated Decision Support Framework

In order to restructure an existing supply network the necessary steps include the development of the “AS-IS” Model, followed by the “TO-BE” (Ideal) model, and finally the “TO-BE” (real) in consideration of real-life constraints (Figure 3):

(1) “AS-IS” model. This model is required to understand the existing network configuration, operational requirements, and identify bottlenecks and areas for improvement. Performances of “AS-IS” network will be used to set the benchmark for any proposed changes.

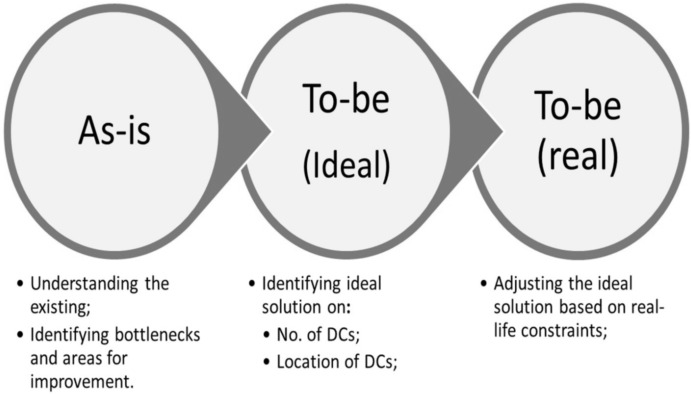

Figure 3: Stages to Supply Network Restructuring

(2) Ideal "TO-BE" model. This intermediate model is needed to identify the "unconstrained solution" (ideal) in terms of number of DCs and their locations;

(3) Real "TO-BE" model. This final model will lead to the identification of real-life solution, that is an adjustment of "TO-BE" ideal based on real-life constraints set by the PSP;

4.1 Phase 1: Identification of number of suitable locations for the nodes

Network design begins with the identification of number of suitable locations for the nodes. These decisions are traditionally based on total cost (warehousing, transportation, lost sales). Two different strategies, centralized and decentralized supply networks, can be adopted based on logistics requirements. Centralized warehousing is a system where a single (or few) DC is used to serve a particular area whereas a decentralized approach encompasses the use of several facilities

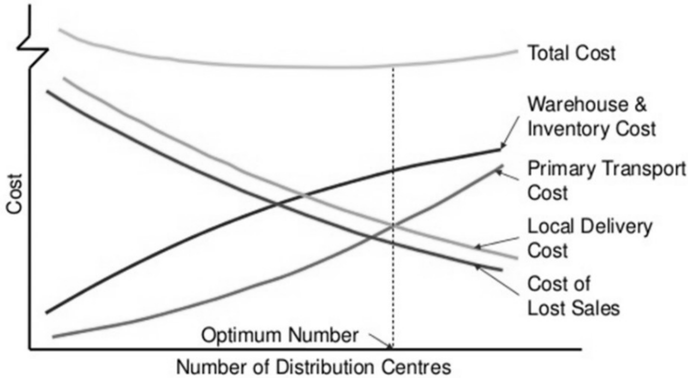

Figure 4: Determining the Optimum Number of DCs in a Conventional Supply Chain

spread out to cover a particular area (Kokemuller, 2014). At changes of number of network nodes (DCs), corresponds a trend of costs as shown in Figure 4.

Source: Barloworld Logistics Africa (PTY) LTD

1. Warehouse & Inventory Cost. Since fewer resources are needed to run one warehouse as opposed to several, lower number of DCs has a positive effect on costs related to warehousing activities. Additionally, variable costs of warehousing such as labor, warehouse management, equipment, and training of personnel can be also kept at minimum in case of centralized system.

2. Primary Transport Cost. The transportation cost of the first tier (e.g. from main DC to intermediate DCs) are lower in case of centralized supply network. Consolidation of shipments can be in fact be implemented, with a positive impact on costing structure.

3. Local Delivery Cost. The transportation cost of the second tier (e.g. from intermediate DCs to final consumers) are higher in case of highly cen-

tralized system. In case of decentralized network in fact, the distance in between intermediate DCs and customers is lower.

4. Cost of Lost Sales. A decentralized system helps in achieving shorter lead times and higher percentages of on-time delivery, resulting in higher service level, and thus lower cost of lost sales.

In the case study undertaken in this research, data analytics and green field analysis were used to determine the cost items. Green field analysis is a GIS/center of gravity based approach (Russel and Taylor, 2010), which seeks to determine the geographic coordinates for a potential new facility. Computations are based on minimum transportation cost (calculated as "distance" * "Product Amount") (AnyLogistix, 2018) in consideration of aggregated demand for each customer and product, customer locations (direct distance between customers and DCs/Warehouses), and service distance (or number of facilities to locate) (AnyLogistix, 2018). To perform green field analysis, 2 years of operational information on historical demand (by location, amount, and time distribution), product flows, and costs were required. A template in MS Excel was shared with the company to facilitate data provision. The company provided the historical data referring to the biennium 2016 and 2017.

4.2 Phase 2: Structuring and Optimizing the Supply Network

Once Phase 1 is completed and the number of suitable locations for the network nodes is determined, Phase 2 will be used to identify the optimum network configuration in terms of both nodes (location of DCs) and arcs (connections in between DCs) using Network Optimization (NO). NO is an optimization technique which seeks to find the best configuration of a supply chain network structure as well as the flows based upon an objective function, which typically maximizes profits (Sample in Table 1),

Table 1: NO Cost Components

Component	Amount [$]
Revenue	XXX, XXX, XXX, XXX
Supply Cost	(XXX, XXX, XXX)
Production Cost	(XXX, XXX, XXX)
Transportation Cost	(XXX, XXX, XXX)
Inbound Processing Cost	(XXX, XXX, XXX)
Storage Cost	(XX, XXX, XXX)
Outbound Processing Cost	(XXX, XXX, XXX)
Fixed Cost	(XX, XXX, XXX)
Opening Cost	(XX, XXX, XXX)
Closing Cost	(XX, XXX, XXX)
Profit	XXX,XXX,XXX

The mathematical model can be formulated as such:

Let:

x_{ijk} = quantity of product k shipped from DC i to demand point j

y_i = indicator (binary, 1 = Yes and 0 = No) variable for the selection of DC i

δ_{ij} = indicator (binary, 1 = Yes and 0 = No) variable for the selection of shipping from DC i to demand point j

f_i = operating cost for each DC i

c_{ij} = unit cost of moving a unit weight, w_k of product k from DC i to demand point j

p_{ik} = unit cost of processing a unit weight of product k in DC i

m = total number of DC to consider

n = total number of demand points

d_j = demand from demand point j

M = maximum number of DC in the network

α = maximum number of DC to fulfil a demand point j

The formulation is as follows:

$$min\left[\begin{pmatrix} facility \\ operating\ cost \end{pmatrix} + \begin{pmatrix} transportation \\ cost \end{pmatrix} + \begin{pmatrix} facility \\ processing\ cost \end{pmatrix}\right]$$
$$min \sum_{i}^{m} f_i y_i + \sum_{i}^{m}\sum_{j}^{n}\sum_{k}^{K} c_{ij} x_{ijk} w_k + \sum_{i}^{m}\sum_{j}^{n}\sum_{k}^{K} p_{ik} x_{ijk} w_k \tag{1}$$

Subject to Maximum number of DC. As an additional planning consideration, the maximum number of DCs to include in the network can be limited due to constraints such as budget.

$$\sum_{i}^{m} y_i \leq M \tag{2}$$

Demand-supply balance. In the case of deliveries of items, the network must (hard constraint) be able to fully fulfil the demand.

$$\sum_{i}^{m}\sum_{j}^{n}\sum_{k}^{K} x_{ijk} = \sum_{i}^{m}\sum_{j}^{n}\sum_{k}^{K} d_{jk}\delta_{ij} \tag{3}$$

Flow constraint. The connection of a demand point to a DC can only exist if and only if the DC is open.

$$\delta_{ij} \leq y_i \forall i, j \tag{4}$$

Fulfilment constraint. Demand fulfilment can be either from multiple sources (multiple DCs) or constrained to a single source (single DC).

$$\sum_{i}^{m} \delta_{ij} y_i \leq \alpha \forall j \tag{5}$$

In this case, the NO model was developed using AnyLogistix (ALX) software.

4.3 Phase 3: Stress-testing the supply network and measuring performances based on preidentified parameters

Once the ideal network configuration is defined (Phase 2), Phase 3 will stress-test the supply network based on performance measures (e.g. service level, profits). This final phase will assess network robustness and resilience, as well as measure operational performances. This Phase can be undertaken by using various computer simulation techniques such as discrete-event simulation in AnyLogistix (ALX) software.

5 Implementing the Solution Approach

The implementation of the integrated solution approach described above for the PSP case was initiated by collecting structural (existing network structure, transportation assets, product flows) and operational data (demand patterns, costs). An initial analysis of data led to the identification of bottlenecks, criticalities, as well as areas for improvements. A sample of district-level demand patterns is in Figure 5.

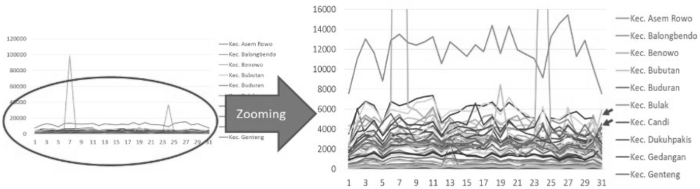

Figure 5: District-level Demand Patterns

5.1 Phase 1: Identification of number of suitable locations for the nodes

Given the unique nature of the business whereby the PSP in consideration operates in, the only cost item driving the decision about optimum number of facilities are transportation cost. In fact:

Warehouse and inventory cost are not relevant due to 1) PSP does not carry any inventory, and 2) Manpower is fixed, regardless the number of DCs; Cost of lost sales does not apply since there is no other competitor offering the same service; Transportation cost, which includes primary transport cost and local delivery cost, have been calculated using green field analysis in AnyLogistix (ALX) (sample in Figure 6). Transportation cost and marginal cost reduction with changed number of DCs is in Figure 7.

Results show that by increasing the number of intermediate DCs, the overall transportation costs to serve final customers would reduce.

5.2 Phase 2: Structuring and Optimizing the Supply Network

Once Phase 1 is completed, next step consists of optimizing the baseline network configuration. This phase will select the optimal network nodes out of the subset of suitable candidates from Phase 1, based on costs. The optimization problem of calibrating the baseline network configuration consists of finding the optimum number and location of the distribution centers as to effectively distribute goods, while satisfying multiple constraints.

In this work, Transportation Cost, Inbound Processing Cost, Outbound Processing Cost and Fixed Cost were considered for formulating the NO model. Other cost items listed in Table 1 were not considered due to a) Data unavailability (opening and closing costs) and b) Limited relevance based on the nature of the PSP business (Supply, production, storage).

Results show that the ideal “TO-BE” (ideal) network configuration should be inclusive of 4 intermediate DCs (Figure 8 and Figure 9), which will minimize overall supply chain cost, with no changes on service level as compared to ”AS-IS”.

In order to define the “TO-BE” (REAL) network configuration, the constraint on maximum distance travelled per delivery man (100 km) in a day was included. Results highlighted that ”TO-BE” Ideal and ”TO-BE” real overlap.

A comparative analysis of ”TO-BE” network versus ”AS-IS” network shows that while terms of service level the two network perform similarly, in terms of cost effectiveness the ”TO-BE” network surpasses the ”AS-IS” by nearly the 1% of total costs. Although a lower number of DC determines higher transportation cost (+7.74%), the saving coming from a lower fixed costs of facilities (-8.76%) is more substantial. On these two cost items in fact, an overall improvement of over 4% in costs can be appreciated. Although not yet assessed, further savings could be achieved via economies of scale e.g. through consolidation of manpower and/or transportation assets.

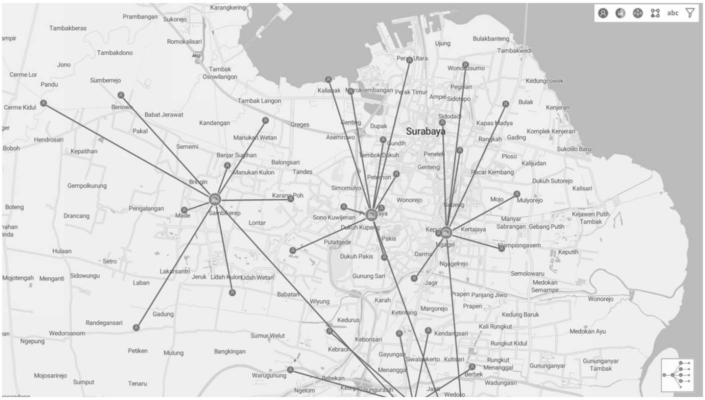

Figure 6: Illustration of Green Field Analysis

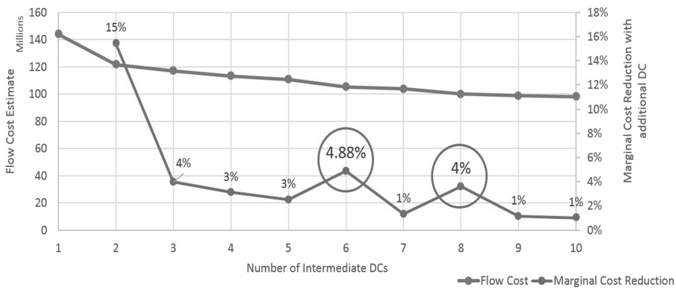

Figure 7: Transportation Cost and Marginal Cost Reduction with Changed Number of DCs

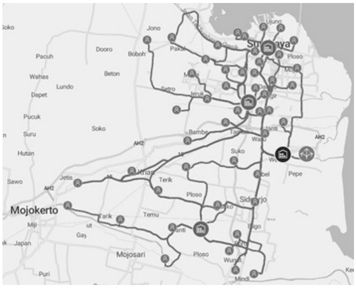

Figure 8: ”TO-BE” (Ideal) Solution

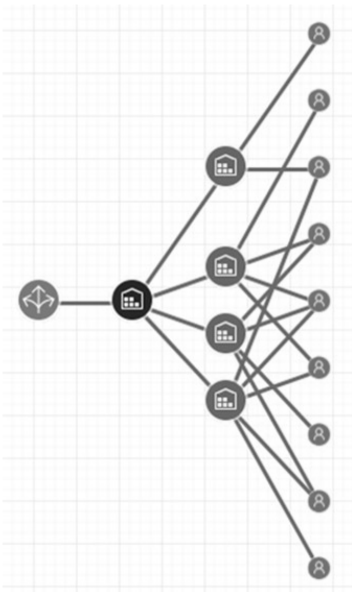

Figure 9: ”TO-BE” Ideal, Material Flow

6 Conclusions & Managerial Implications

This paper has proposed a decision support framework for network design and has demonstrated the applicability to real life case on a PSP operating in Indonesia. Starting from an initial identification of suitable locations for the network nodes, the proposed framework depicts procedures and tools to leverage on across the various phases of the problem's solution seeking. The full implementation of the proposed approach would lead to the definition of the optimum network configuration, assessment of its robustness and measurement of operational performances. However we applied the framework partially, as to define a preliminary solution to the problem at hand.

As anticipated in the introduction, this paper can assist researchers and practitioners in understanding how the following research questions are to be addressed, and key findings include:

RQ1: How to determine the suitable number of intermediate DCs (nodes) to serve a highly populated urban area in one of the fastest developing economy of the Pacific region (Indonesia), and what is the suitable number of DCs for the particular case at hand?

The suitable number of intermediate DCs (nodes) to serve a highly populated urban area in one of the fastest developing economy of the Pacific region (Indonesia) can be determined by combining data analytics with green field analysis, and network optimization. For the geography of reference (greater Surabaya), and with the provided datasets, the number of suitable intermediate DCs should be equal to 4.

RQ2: How to decide on the locations for the intermediate DCs of an optimized supply network, and what is the optimum network configuration for the particular case at hand?

Locations for the intermediate DCs of an optimized supply network can be selected using a network optimization approach. The optimum network configuration for PI in Greater Surabaya should include the four nodes as per Figure 8. The identified set of facilities guarantees enhanced cost effectiveness (-18% of transportation and warehousing cost) at comparable service level;

Managerial Implications. This study is able to support decision makers in a wide range decisions in the context of network design. GFA can help decision makers with the determination of transportation cost at increased number of DCs, as well as identification of potentially suitable locations. The NO can help logistics managers to make strategic decisions about DCs' locations.

Limitations. This work has few limitations. First, the dataset on demand is limited to the biennium 2016-2017. An extension of the dataset with inclusion of more data points would provide a more accurate solution to the problem at hand. Secondly, inclusion of cost items such as cost for opening or closing a DC and manpower allocation would help to fine tune the proposed solution.

Next steps. In order to reinforce the findings to date, a dynamic simulation model can be developed (Phase 3). This would allow to:

- Determine transportation (fleet size) and storage requirements;
- Perform what-if analysis with comparison of alternative network configurations;

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