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Methodical approach for consideration of ramp-up risks in the product development of complex products

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Abstract

A new product development represents a technical, organisational and financial challenge for companies. The use of new technologies and implementation of innovative approaches involves the risk that there may be unforeseen problems in the development and production process. A delay of the production ramp-up leads to loss of profits or substantial damage claims by customers. Due to the strong influence of the ramp-up phase on the success of the product, consideration should be made in the early stages of development. Therefore the aim must be to provide a basis for decisions already during the development under initial uncertainties.
At the beginning of the paper a short overview of the terminology in the field of ramp-up management and risk assessment in the context of product development is given. Based on the literature review several main influencing factors on ramp-up performance are derived. The main influencing factors on the transition will be the basis to identify and visualise company-specific ramp-up risks. Afterwards the methodical approach for assessment of ramp-up risks is presented. And the paper will close with a practical example from the aircraft industry in the field of cabin integration.

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Keywords: Ramp-up management; risk assessment; influencing factors

1. Introduction

The acceleration of new product introduction is driven by increasing customisation, globalisation and shortening of life cycles. The ability to develop, produce and introduce new products faster than the competition is an important success factor for companies [1]. As a result, manufacturers have to cut their development time and perform production ramp-up more frequently [2]. Companies who are first in the market with new products can obtain first mover advantages, extending the selling period and increase their competitiveness [3]. Deviations from the target can lead to significant economic consequences. An international study in the automotive industry ascertained that only 40% of all investigated production ramp-ups were economically and technically successful [4]. The development and market introduction of new products represent high financial effort and expenditure of resources for companies. It is becoming increasingly difficult to realise the payoffs of high development costs during the market cycle whether problems in the industrialisation of a product occur. Therefore it is essential to identify and to manage potential ramp-up risks. Particular attention should be paid especially to new product technologies, as they imply high initial uncertainty. The approach presented in this paper helps to analysis possible causes of deviations during ramp-up in the early stages of development and support decision-making before and during the transition to serial production.

In the following section a short overview of the terminology in the field of ramp-up and risk assessment in the context of product development is given.

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2. State of the art

2.1. Ramp-up phase - Interface between development and production

According to various authors, the ramp-up represents a critical phase in the product life-cycle [4-7]. The ramp-up phase marks the start of the transition between the completed product development and the series production (see Fig. 1). The transfer from development to production normally takes place in stages. The major task within production ramp-up is to achieve the required volume while performance targets, such as product quality, cost and time, are fulfilled. Changes and disturbances in the product and in the process are usually resolved within the pre-series and pilot production with the help of numerous prototypes. The end of this phase represents the achievement of the previously defined output quantity, which then proceeds into series production [8, 9].

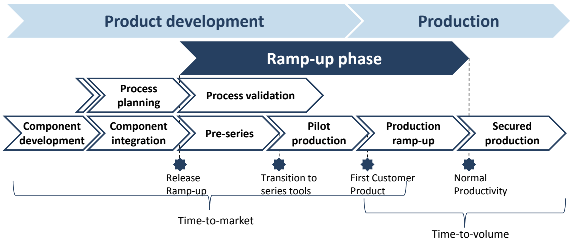

Fig. 1. Alignment of ramp-up phase in the product development process [8]

The ramp-up is a dynamic phase with many changes and mistakes that significantly affect the following processes in the company. The complexity arises from the initial integration of the various design objects (such as technologies, processes, products, supply chain) and disciplines (product development, production, logistics, purchasing) [6]. Terwiesch characterises the situation as follows: On the one hand there is an initial low production capacity caused by poor understanding of the process that is inherently chaotic and on the other hand the high customer demand as a result of the product novelty on the market [2]. Companies have to take several influencing factors into account to overcome the gap between supply and demand with short time-to-volume.

A systematic literature research with the help of co-citation analysis showed up two major research streams [10]. A significant amount of research has been conducted on product success and the linkage to time-to-market. The stream of research consists of analytic models to determine successful market launch strategies and focussing on the fuzzy front end of product development [1, 3, 11].

Additional research addresses the manufacturing aspects to launch a new product and support the production development and immediate ramp-up. The focus is the preparation for production in terms of organisation, planning and controlling, manufacturing equipment, logistics, experienced based learning, simulation and cooperation with suppliers [4, 7, 8, 12, 13].

A risk-oriented consideration of both development and production decisions to support an effective product launch has remain relatively underrepresented [14].

2.2. Influencing factors of the ramp-up performance

A significant amount of research has been conducted on how firms can bring their products to market more quickly. In the following section a short selection of empirical findings on factors influencing successful ramp-up is given.

Especially for complex series products, the transition phase represents special requirements for the design of the interface between development and production. Extensive knowledge is required due to the large number of systems, components and different technologies. Decreasing depth of development requires additional coordination with external organisational units and generating organisational complexity [8]. Furthermore, a successful transfer into series production is affected by the novelty or innovativeness of the product and its quality [7].

Empirical studies confirm the previously described factors. According to the results of Coughlan, the probability of a delay during the ramp-up phase increase by the degree of innovation of the product and process technologies. In particular, the use of new materials is causing problems [15]. Tyre confirms in his study a highly significant correlation between the duration of the ramp-up and the complexity of new technologies, the extent of system change and also the project scope [16].

Almgren notes in his study that the number and frequency of disturbances within the ramp-up phase cause that the organisation is heavily congested, which leads to a loss of production capacity. As an essential cause, among others, Almgren identifies the number of design changes of the product during the development and ramp-up phase. Late engineering changes lead to lower maturity of the product, high change effort in manufacturing and problems in the material supply. Most of the suppliers are unable to adapt quickly enough [5, 17].

Qualitative studies warn that the achievement of the target parameters (time, cost and quality) requires an efficient network across the entire value chain including the integration of suppliers into development process and flexibility of manufacturing processes [1, 6, 8, 18].

From an organisational point of view Terwiesch et al. identifies three main ways to reduce ramp-up time. First, a gradual transfer of pilot series to series production significantly increases the performance. A step-by-step approach helps to reduce uncertainty and realise sufficient learning curve effects for novel technologies. Secondly, clear responsibility and a cross-functional organisation promote a better transition between development and production. Thirdly, the introduction of product platforms leads to more effective use of previously collected experience of new products [1,2].

Based on different empirical studies, a simple impact model can be constructed (Fig. 2.) to illustrate the relationship between main influencing factors and ramp-up targets from product development point of view.

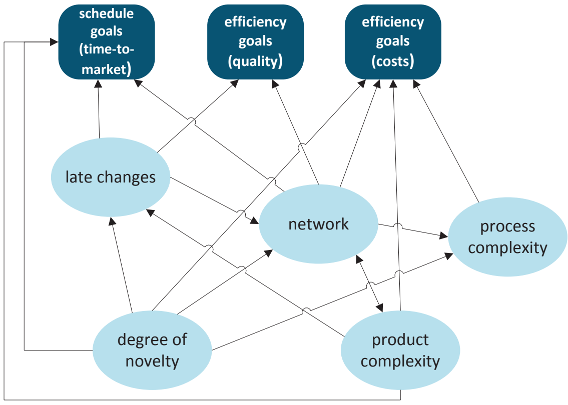

Fig. 2. Relationship between main influencing factors and ramp-up targets

The model supports qualitative statements about the correlation between main influencing factors, such as late engineering changes, degree of novelty or product complexity on the targets of the ramp-up. It forms the basis for the assessment.

2.3. Risk assessment methods in the field of product development

The following section gives a brief overview of the most common methods for the identification, evaluation and classification of risks. For this paper the definition of risk from Lührig is used. Lührig defines the term risk as follows: “Risk is the result of a negative deviation from the expected value size. It is not known, whether and in what amount the deviation occurs. But it can be specified a subjective or objective probability of the occurrence (probability) of this event and/ or the amount of deviation (impact)” [19]. There are different perspectives on the general definition of risk, which are depending on the circumstances and goals of the risk analysis. This paper follows the asymmetric effect-related risk assessment, also known in the literature as risk in the narrow sense. The literature contains various methods; hence only two of the most established methods (FMEA, FTA) will be presented [20].

The Failure Modes and Effects Analysis (FMEA) is a method that systematically analyses the components and their failure mode characteristics to assess risk and reliability of the product [20]. The starting point is the decomposition of the product into subsystems. The essential feature of the method is the identification and evaluation of all possible causes that may be responsible for an error to determine the effect they have at the component level. It is a widely used method but requires a detailed level of system or component design [19]. Additionally, it does not capture component interactions explicitly but relies on expert knowledge.

The Fault Tree Analysis (FTA) is a method to capture event paths from failure root causes to top-level consequences. This approach is applied in the product development to ensure the safety and improve the reliability of products/systems [20]. FTA shall enable the user to identify all critical paths that could lead to a negative event such as system failure. However, FTA also relies notably on expert input. The interactions and system dynamics are not adequately captured for supporting design decisions in early development phases [19].

2.4. Need for research

Deviations from the target must always be expected in the development process. Hedging practices will help to minimise impacts and potential risks. The majority of risk analysis methods focus on securing product design and its requirements. Due to the strong influence of the ramp-up phase on the success of the product the transfer to production should be considered in the early stages of development. At the beginning of development, the scope of action is larger and the costs of changes lower. Statements about the ramp-up capability of the product and processes will help to facilitate the development within a targeted risk communication and serve as the basis for efficient decision-making processes and selection of hedging measures. In the following section, a methodical approach is presented that provides an assessment of influencing factors from development to ramp-up phase.

3. Methodical approach for consideration of ramp-up risks in the product development of complex products

The framework for the general procedure was first developed in [21] and will be extended here (Fig. 3.). The procedure is divided into two main parts.

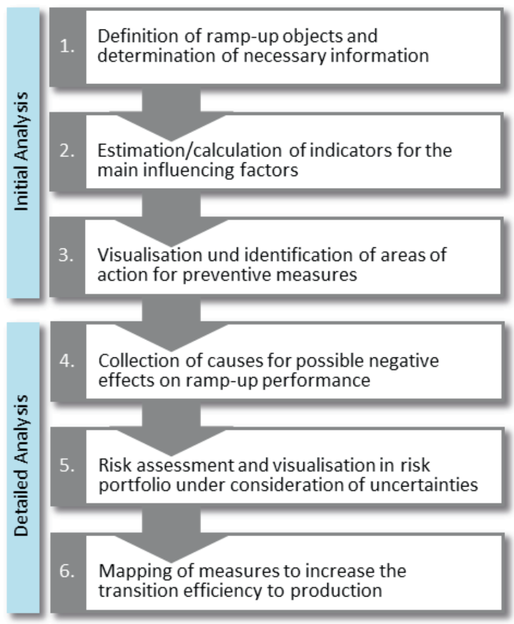

Fig. 3. Procedure of methodical approach for consideration of ramp-up risks

At the beginning, an initial analysis is conducted to estimate the general type of project scope and to identify areas of action. In the second part of the procedure the detailed analysis is focusing on the critical areas and the assignment of possible measures.

3.1. Initial analysis of influencing factors

At the beginning, an initial analysis is conducted to estimate the general type of project scope (e.g. new platform, new product or variation of an existing product) and to identify different areas of action, which could cause a possible delay or a negative influence on the transfer.

The described impact model serve as a starting point and can be adapted to company specific requirements. To estimate the five main influencing factors of the model (Fig. 2.) different indicators for each section were found (Table 1). For meaningful assessment in the context of the early development phase, it is important to put the key figures in relation to the previous product.

Table 1. Indicators for the main influencing factors.

degree of novelty	network complexity	process complexity
new technologies	vertical range of development	number of processes
new components	vertical range of manufacture	variety of processes
new processes	number of suppliers	coupling of processes
new materials	supplier relationship	degree of automation
new interfaces		
product complexity	**late changes**	
number of components	late changes in processes	
variety of components	late changes in components	
degree of coupling	late changes in network	

The key figures are derived from the various indicators. The criteria for evaluation can be divided into two groups, the qualitative and quantitative evaluation. Especially for the qualitative assessment the uncertainty of information has to be taken into account. Therefore, expert interviews with different stakeholders (e.g. engineering, logistics, manufacturing engineering) will be conducted. This leads to a reduction of uncertainty within an early qualitative evaluation.

The entity of the new product attributes determines the behaviour during the ramp-up. Even simple estimation in concept stage such as number of components or coupling may allow conclusions about the behaviour during ramp-up. The input for the initial estimation can be received from different established tools and visualisations methods of the product and process structure, expert interviews (different stakeholders) and the previous product. For instance the modular interface graph (MIG) can be used for the investigation of product structure and interfaces to make a point about the product complexity [22, 23]. For process complexity analysis the assembly priority chart adapted from [24] helps to create an understanding of possible assembly steps, equipment, degree of automation and parallelisation of processes. In order to make a statement about possible engineering changes, a design structure matrix (DSM) represents a way to estimate the propagation of changes due to the interfaces and the product structure [25, 26]. The visualisation of the different indicators is conducted in a radar chart. The reference line represents the previous product. Indicators above this line should receive special attention and will be analysed in the second part of the approach. Factors which may lie below the line display positive effects on the ramp-up targets. A strengthening of these areas promotes as an enabler of the transition and can be taken into account within the alignment of measures in the second analysis. Furthermore, represents this kind of visualisation the possibility to take uncertainty of the assessment into account.

3.2. Detailed analysis to select suitable measures

Within the second step a root cause analysis for the identified factors is performed. Therefore, a detailed analysis of possible drivers for a negative impact on the identified factors is analysed. Based on known risk assessment procedures, impact and probability as well as the correlation to ramp-up targets (cost, time and quality) are estimated. For example a high degree of novelty could be caused the use of a new material or technologies. Therefore, the relevant effects on component properties, process steps or supplier quality have to be investigated.

To consider different aspects of stakeholders and uncertainty of information in early development phases a workshop is performed. The results are displayed in a risk matrix. Due to the different ratings of the workshop participants, different scenarios can be formed with the help of simple statistical evaluation (min, max, most likely value) [21]. Therefore, based on [27] a triangular function is used. For prioritisation of potential risk, the associated uncertainty and the effect on the factors of the impact model are criteria for selection.

The impact model will be used to select suitable measures to reduce the negative impact and increase the ramp-up performance in advance. The categories of measures are connected to the influencing factors of the model and can be categorised into preventive and reactive strategies. The effectiveness of strategies to mitigate the identified risks depends on the influencing factors and their crosslinking to other factors. The selection of measures is based on established methods and empirical findings from literature and can be extended by company specific lessons learned from previous ramp-ups. In case of using e.g. a new material suitable measures could be used to increase the knowledge by numerous tests. If the material is new to the company, the manufacturing of corresponding components could be transferred to experienced suppliers. Furthermore, the application of new material could be limited to several modules and enlarged with future variants of the product family. In general, identified problems regarding the degree of novelty or the degree of complexity in the concept phase can be addressed with the help of product structuring measures, such as modularisation or platform development. In particular, platform development delivers long term benefits to ramp-up. This supports the increasing share of parts carried over and the standardisation of interfaces to reduce potential risk drivers.

4. Case Study application

The developed procedure is applied in terms of a case study. A cabin interior lining from aircraft industry is used as product example. The objective of introducing a new concept is to develop a product architecture which supports a postponement strategy and thus at the same time a better control of variance in the production. To obtain suitable information for the assessment the system boundaries of consideration are determined and the product structure is visualised with the help of a module interface graph (MIG) [22].

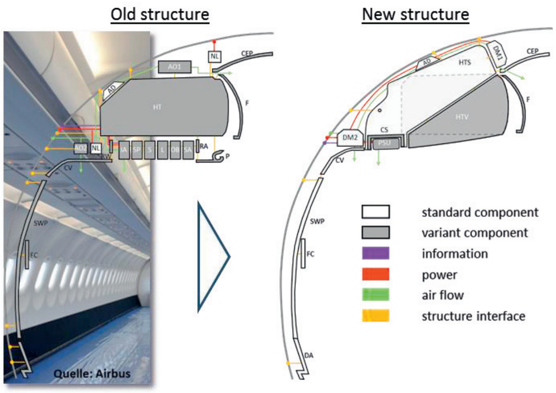

Fig. 4. Visualisation of product structure with the MIG

The main distinguishing characteristic for the customer is the opening mechanism of the overhead stowage compartment. The customising effort in the production results from different bracket positions and components for each variant. The difference between the previous product and the new concept is the coupling of variant components to modules and the introduction of a new interface to increase the degree of standardisation. For the assessment of the various indicators of the influencing factors additional visualisation tools are necessary. For the estimation of the different indicators the assembly priority chart, MIG and DSM were used. The following figure (Fig. 5.) represents the results of the initial estimation of the different indicators.

Points that lie more on the edge of the circle can be interpreted as more critical for the ramp-up. Below the dashed line, an improvement is expected for the new product concept. Compared to the previous product the concept is less complex due to the new module product structure. This leads to potential benefits during the ramp-up and integration processes. A new bracket concept for the central hatrack support module (HTS) reduces the assembly effort. But some points in the chart are highlighted for the detailed analysis, the possibility of late changes (1) and the degree of novelty (2).

For the detailed analysis a workshop with four experts was performed to identify potential risks regarding the indicators. Due to the strong interconnection between other influencing factors, it could be possible that identified positive effects are neutralised.

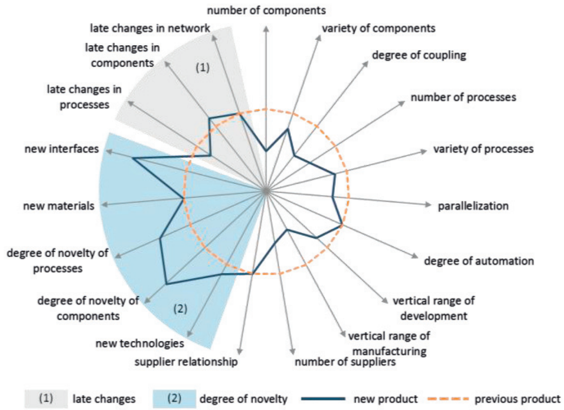

Fig. 5. Identification chart for detailed analysis

Thus, even small risks due to the mutual influence could have a large impact on the ramp-up targets. The first step in the workshop was to identify the potential risks regarding late changes and degree of novelty. Afterwards, the assessment of impact and probability was conducted. As in established methods the risk factor was obtained by multiplying the impact and probability. Due to the different participants the uncertainty was considered with the help of minimum, maximum and most likely value. The results are shown in Fig. 6. The prioritisation of the risks is performed based on the most likely value and the uncertainty in the assessment (range between min. and max. value).

For the new cabin lining concept the new interface between central hatrack support module (HTS) and variant hatrack module (HTV) represents a central area of actions. It is assumed that the connection technology could lead to late changes if problems during the joining process occur, tolerances are not met or the design is too heavy. Furthermore, the new structure and the assembly steps require a bracket concept with click and snap principle. However, this requires a calibration process as well as the possibility of adjustment afterwards. The central module of HTS provides some advantages but due to its central position and linkage to other modules and components it could be a driver for changes.

	ID	possible risk items	0 10 20 30 40 50 60 70 80 90 100
degree of novelty	R1	lack of experience in handling new components	
	R2	additional weight due to new interfaces	
	R3	lack of tolerance flexibility due to new brackets	
	R4	complex calibration process of new brackets	
	R5	additional pre-assembly steps necessary	
	R6	complex joining process due to interface HTS/HTV	
	R7	difficult supply of power/information to PSU	
	R8	high assembly effort due to production tolerance	
late changes	R9	interconnection of HTS causes changes	
	R10	pivotal loads are not adhered to new interface	
	R11	low adaption speed of suppliers	
	R12	manufacturing problems lead to changes	
	R13	low maturity of new interface between HTS/HTV	
	R14	changes of DM1 due to complex air ducting	
	R15	change of interface connection technology	

Fig. 6. Assessment of different risk factors regarding degree of novelty and late changes

The selection of measures depends on the focus of risk assessment and will be supported by the derived impact model. A collection of different measures can be allocated to the influencing factors and additionally to general enablers like organisation and resources. The measures can be categorised into preventive and reactive. Preventive measures to lower the degree of novelty are additional validation tests, increasing degree of carry over parts from previous product and early integration of supplier knowledge. Due to the small number of prototypes and the first time right strategy in aircraft industry a flexible cabin demonstrator to simulate the integration with production staff at an early development stage is a promising approach. As in other industries, the learning curve can be improved and problem solving processes accelerate by repeating the assembly steps.

To reduce late changes the focus lies on reactive measures. Due to the late occurrence the main objective is the implementation of changes as quickly as possible. Therefore, from manufacturing point of view the realisation of flexible capacity, increasing the parallelisation, balancing workloads and reducing the batch size represents promising strategies. The implementation and effectiveness of these strategies will be supported by a modular product structure.

5. Concluding remarks

This paper highlights the need for early consideration of the ramp-up phase in the development of complex products. Empirical studies in literature show a variety of influencing factors that have to be taken into account to launch new products into the market. The aim of the methodical approach presented in this paper is the early identification and minimisation of possible ramp-up risks. The approach describes two related main steps, the initial and detailed analysis. The first step is based on the generic impact model and is used to evaluate the influence factors by indicators. So the focus can be placed on the relevant risk drivers. The risk assessment in the detailed analysis enables a targeted selection of measures to increase the scope of action and to provide effective response strategies during the transition to production. The applicability in early design stages will be increased by the help of expert workshops. Concrete recommendations for action must be substantiated with heuristics and industry-related lessons learned.

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