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# RAMP-UP OF COMMERCIAL AIRCRAFT: A RISK ANALYSIS

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**Abstract**
The successful ramp-up of commercial aircraft is still an unconquered challenge and of great importance for the economic survival. The successful ramp-up of commercial aircraft is threatened by a variety of risks. Exploding costs are the result. The provided approach is an overlapping cyclical supply chain risk management framework working in a proactive and reactive way to analyse and mitigate ramp-up risks and disruptions. The aim of this study is to identify and evaluate ramp-up risk in the sector of commercial aircraft.

## 1. MOTIVATION

Aviation news frequently report on delayed or even failed aircraft ramp-ups in these days. Affected are both market leaders Boeing and Airbus. The successful ramp-up of commercial aircraft is threatened by a variety of risks. These risks cause a significant reduction of the targeted production rate (see Figure 1). Exploding costs are the result.

The growing competition and a shorter innovation cycle lead to a rising number of ramp-ups. Besides the complexity of the product aircraft itself future ramp-ups face further challenges. The transition from single to series production and new customization strategies are indispensible in order to reach high production rates. Customisation and a missing test and pilot production are identified key risks. Additionally a global sourcing strategy needs to be implemented to produce cost-efficiently with many competitors coming up. The occurring risks are by no means comparable to automotive ramp-up scenarios. Consequently, a new risk management approach is required.

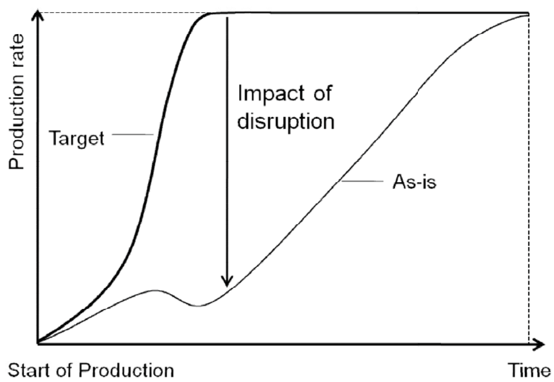


**Figure 1: Reduction of production rate caused by risks (original idea see [1])**

The aim of this study is to identify and evaluate ramp-up risks in the sector of commercial aircraft. Risk can be seen in several ways. For us risk is a negative deviation from normal and is therefore a possibility of danger, loss or any other undesired consequence [2]. A disruption to the supply of services or goods which leads to a downtime causes a failure to satisfy customer requirements [3]. Disruptions usually lead to longer lead times. Long lead times have negative effects on a firm's performance. In our case a disruption leads to a delayed shipment of the finished aircraft.

This study analyses ramp-up risks by using a conceptual framework in order to be able to create mitigation strategies in the future. Mitigation means to lessen the impact and the occurrence of disruptions. [5] provides a simple supply chain risk management approach showing the effect of disruption preparedness and the beneficial effect through quick response. Established recovery plans decrease the response time in case of disruption. Accordingly, a quick recovery can be achieved by reducing the impact of disruptions.

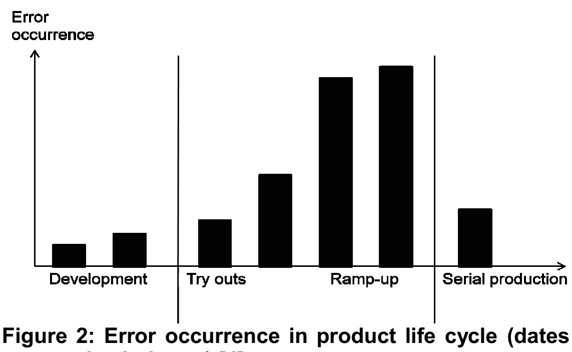


**Figure 2: Error occurrence in product life cycle (dates from automotive industry) [4]**

The paper is organised as follows: The general approach and the overall idea of the proposed framework are described in Section 2. In Section 3 we discuss the application of the approach for ramp-up in the aircraft industry illustrating the practicability and the key features of the framework. Finally, we state results in section 4 and draw a conclusion in section 5.

## 2. RISK MANAGEMENT APPROACH

The above mentioned risks have a significant impact on the entire supply chain. Therefore, we are following a structured approach of supply chain risk management which is bolstered with techniques to analyse the according risks. Supply chain risk management can be applied to analyse risk during ramp-up because during this phase an entire supply chain or at least a part of it is examined including its members and flows (product and information).

The main tasks of supply chain risk management are usually at least split into three stages: risk identification, risk assessment and risk mitigation. In literature there are many different approaches which can be clustered into two different groups. On the one hand, there are approaches without feedback loops and on the other hand, there are approaches including feedback loops. Usually the approaches with feedback loops have just one feedback loop and just a few include two or more feedback loops. We apply the supply chain risk management framework of [6] to analyse the risks of ramp-up of commercial aircraft.

[7] highlights that the framework is beneficial to increase the responsiveness of supply chains being disturbed by disruptive events. Increasing the responsiveness during ramp-up is one major target in our study. The framework of [6] is motivated by the Deming (plan-do-check-act) cycle known from total quality management, quality planning and quality control as well as from material resource planning (MRP II). All three issues structure the execution of the framework. The execution of the framework can be done in a proactive way, to be prepared for risks, as well as a reactive way, to handle unforeseen risks. The double function of proactive and reactive execution raises the attractiveness to apply it. Furthermore, the framework is bolstered with a kit of supply chain risk management analysis methods being techniques of process management, quality management, risk management and strategic management.

Figure 3 shows the applied framework. It consists of four overlapping cycles which are linked with management levels and time horizons, i.e. strategic level/long-term, tactical level/medium term and operational level/short-term. These overlaps provide the user with the ability to go back if something has to be rethought or fitted to new environmental situations. During ramp-up unforeseen disruptions occur frequently. The cyclic framework supports fast reactions to lessen the negative impact of disruptions as the risk management process does not have to start from the beginning. Additionally, cyclic thinking is of particular importance due to growing awareness and altering risks in the course of the ramp-up.

The four cycles are called *Definition & Description*, *Risk Analysis*, *Risk Evaluation* and *Action*. The approach includes two main starting points. One is situated in the topmost cycle (*Definition & Description*) for proactive supply chain risk management and the other one in the bottom cycle (*Action*) for reactive supply chain risk management. The key drivers present the facts which force management to execute proactive supply chain risk management as regulatory compliance or cost reduction.

In the *Definition & Description* cycle the range and objective of the analysis is defined and the system and its corresponding risks are described. The risks are assessed and ranked in the *Risk Analysis* cycle. Mitigation strategies and detailed action to execute mitigation strategies plans for particular risks are developed in the *Risk Evaluation* cycle. In the *Action* cycle the action plans are implemented and arising disruptions are monitored.

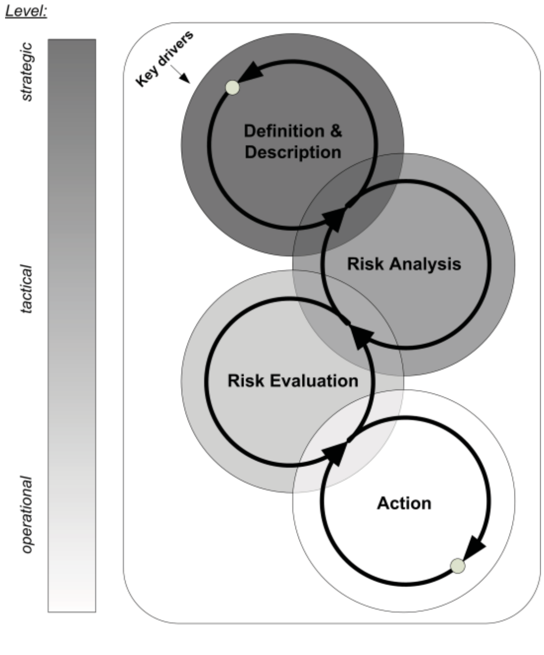


**Figure 3: Overview of the supply chain risk management framework [6]**

## 3. ANALYSIS OF RAMP-UP RISKS

In order to be able to analyse ramp-up risks we just apply the first two cycles of the framework which include the tasks risk identification and assessment, i.e. *Definition & Description* and *Risk Analysis*. The design and execution of counteractions are not in the focus of this study. Therefore, the last two cycles *Risk Evaluation* and *Action* are not executed and described in more detail.

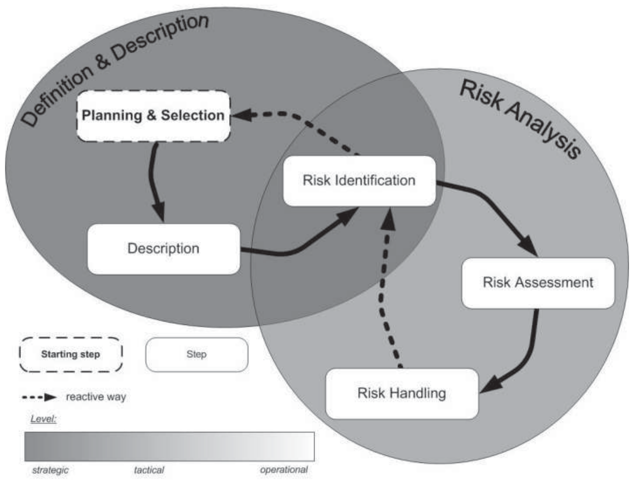


**Figure 4: Applied cycles for risk analysis [6]**

Each cycle comprises three steps as shown in Figure 4. The *Definition & Description* cycle consists of the steps *Planning & Selection*, *Description* and *Risk Identification* and the *Risk Analysis* cycle has the steps *Risk Identification, Risk Assessment* and *Risk Handling*. Where the cycles overlap the step is called a key step as the way of execution can be changed. The way of execution is marked by full lines (proactive) and dotted lines (reactive). The *Risk Analysis* cycle has two key steps as it has two overlaps, i.e. one with the *Definition & Description* cycle and one with the *Risk Evaluation* cycle. These are the steps *Risk Identification* and *Risk Handling*. The starting step for our analysis is *Planning & Selection*. The kit of supply chain risk management analysis methods and techniques provided by [6] supports the steps. If not stated otherwise the ideas which the techniques follows are described in [6].

The methodical analysis of ramp-up risks of commercial aircraft is done the first time. Thus, a proactive analysis is executed and we start from the step *Planning & Selection*. The following sections give an overview of the basic tasks of each step and present the findings.

### 3.1. *Planning & Selection* and *Description* Step

The aim of the first two steps is to define the scope of the analysis by selecting the examined goods and processes as well as to describe them. Furthermore, the key performance indicators used to evaluate the risks as well as which risks are acceptable and intolerable are assigned.

In order to execute these steps expert opinions and flow charts are used. The analysed good is an aircraft within the ramp-up. The scope of the analysis is limited within the boundaries of the organisation. The aim is to identify the top five risks which disrupt the ramp-up of commercial aircraft by applying the idea of risk priority numbers, which will be explained in detail later. The organisation works in an international environment and has multiple suppliers and customers. These facts lead to a complex supply chain structure.

Every aircraft is produced for a particular customer following make-to-order. Even among the very first produced aircraft already is a customer product. Thus, a complete pilot series like in the automotive industry does not exist. In addition, it has to be highlighted that production tests are just partially possible in advance. Hence, possible risks which are identified in the try-out phase (see Figure 2) will occur later on.

### 3.2. *Risk Identification* Step

In this step all possible risks and their drivers which arise during ramp-up are determined. Furthermore, the classification of risks is essential as the grouping of risks may influence further analysis. *Risk Identification* is a key step as the findings may change the scope of the analysis and therefore may redefine findings of *Planning & Selection*. The outcome of this step is a risk catalogue.

The identification of risks is achieved by using expert knowledge (brainstorming and questionnaires), fishbone diagrams as well as on-hand information search, i.e. literature research and past experience. The risks are classified by following the criterion "point of origin" used by [8]. The groups were adapted to our setting and come to three risk categories: internal risks, network risks and environmental risks. Internal risks are risks which arise within the organisation and can be influenced by it. Network risks arise outside the organisation but within the network and may partially be influenced. Environmental risks have their origins outside the organisation and cannot be influenced. Figure 5 gives an overview of these three risk categories and their corresponding subcategories. For further analysis the paper concentrates on internal and external risks as these are risks which can at least be partially influenced by the organisation. In sum 91 risks are identified. The largest category is internal risks: Seven subcategories and around 60% of the risks belong to this category.

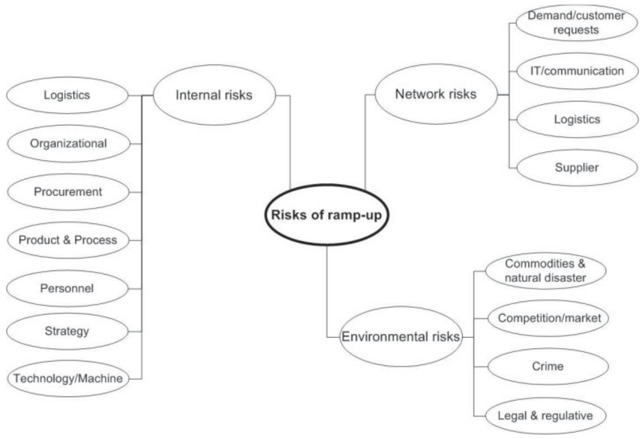


**Figure 5: Risk catalogue**

### 3.3. *Risk Assessment* and *Risk Handling* Step

*Risk Assessment* evaluates the identified risks with respect to several characteristics in a quantitative or qualitative way. Then *Risk Handling* ranks the identified and assessed risks. Moreover, the risks are split in acceptable and intolerable risks. The latter group should be analysed further in the *Risk Evaluation* cycle. *Risk Handling* is a key step. The reasons are twofold. On the one hand, new risks can be identified during *Risk Assessment* and the risk catalogue of the step *Risk Identification* has to be updated. On the other hand, further analysis at the *Risk Evaluation* cycle may identify new risks and leads to an update of the risk catalogue.

For assessing the risks two techniques are used, i.e. bi-criteria analysis [9] and the failure mode effect analysis (FMEA) by asking experts of the organisation. With the support of the bi-criteria analysis the first intuition of the examined characteristics can be captured. FMEA is used to assess the risks in a more systematic way. Furthermore, reasons and consequences are determined. The observed characteristics for the bi-criteria analysis are impact and occurrence ("probability" of occurrence). The FMEA uses besides the same characteristics also the characteristic detection ("probability" of detection). Figure 6 gives an overview of the two characteristics impact and occurrence. Additionally, it shows how risks can be classified into A-, B-, C- and D-risks by applying bi-criteria analysis and FMEA. A-risks are major and important risks and D-risks are minor and more negligible risks. Moreover, Figure 6 gives an overview of the used values which can be assigned to the characteristics impact and occurrence being classified on ordinal scales. The characteristic detection is also an ordinal scale, where 1 denotes easily and 10 difficult to detect.

By using the findings of FMEA the risk priority number can be calculated which is the mathematical product of impact, occurrence and detection. This helps to assign the riskiness to the different subcategories.

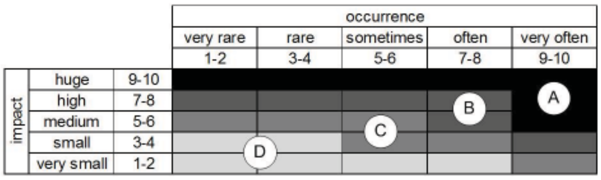


**Figure 6: Risk assessment with ABCD-classification**

Figure 7 shows the ratio of all assessed risk split by the calculated risk priority number. An interesting result is that internal risks are dominant over network risks. The top risk categories looking at both categories (internal and network) are procurement (I4), strategy (I7), product & process (I5) and organisation (I2). This is also valid when we just look on internal risks. Demand/customer request (N1) is the by far highest ranked risk within the category network risks (45%).

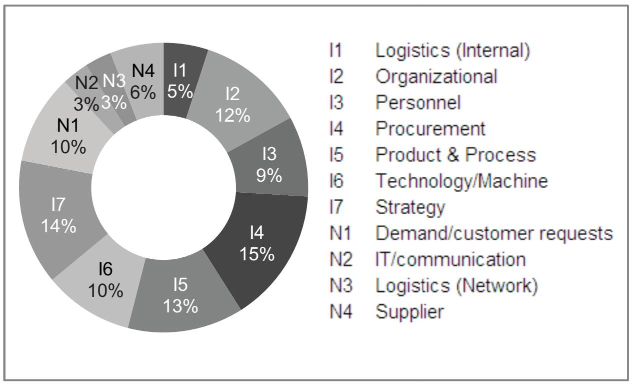


**Figure 7: Ratio of the assessed risk by risk priority number**

By applying both techniques (bi-criteria analysis and FMEA) we are able to categorise the risks into four categories (A, B, C, D) and can check if the findings are consistent with respect to impact and occurrence. Both techniques are subjective ones, as the assessment is carried out by referring to judgements of experts. But by referring once to a first intuition and the other time on a more systematic judgement, errors can be detected. If inconsistencies are found we can question the reasons and check the plausibility. During the analysis this has just been a negligible number. From the identified 91 risks, one risk is an A-risk and 28 are B-risks.

Table 1 presents the top risks assessed by risk priority number and compared with the findings of the bi-criteria analysis looking on the characteristics impact and occurrence. All five top risks belong to the category internal risks and are in line with the findings of Figure 7. The highest risk, insufficient production tests, belongs to the subcategory "product & process". Due to price, size and the comparable small number of production it was yet not considered to carry out complete production tests like in the automotive industry. Thus, the possible errors which occur in the try-out phase (see Figure 2) cannot be integrated in a product and process improvement during production tests. Furthermore, the not detected errors may occur in addition to the ones which occur anyway in the ramp-up (see Figure 2) and may cause even bigger disruptions.

| Ranking | Risk | Category |
|---|---|---|
| 1 | Insufficient production tests | Internal |
| 2 | Extraordinary customisation requests | Internal |
| 3 | Insufficient supplier integration | Internal |
| 4 | Insufficient maturity management | Internal |
| 5 | Insufficient change management | Internal |

**Table 1: Identified top risks ranked by risk priority number**

The second ranked risk is represented by extraordinary customisation requests. These customer´s requests are solutions not prepared by the aircraft manufacturer and cause additional effort for the implementation, which causes delays. This risk belongs to the subcategory strategy. So it is for instance a management decision to mitigate this risk not to allow certain extraordinary customer selections or to prepare such solution in advance by the anticipation of probable customer desires.

The third ranked risk, insufficient supplier integration, considers that supplier may not meet the requirements during ramp-up. That might be caused by a late integration or wrongly selected supplier. During the ramp-up certain supplier need to be able to modify their item due to changes in requirements. This requires a development capacity and willingness to respond to changes which is a special requirement in the supplier selection process.

The fourth ranked risk refers to the missing maturity of products and processes. As in the aircraft industry between the predecessor and the successor model could possibly be more than 20 years for the successors are completely new technologies adapted. For these new technologies often is only limited experience available. Thus, maturity often is a problem. Since these new technologies frequently also require new manufacturing processes, which are characterized by normal learning curve behaviour, the maturity of processes for the first units is a problem.

Insufficient change management is the last among the five top-ranked risks. This is very important since changes in this phase of the product life cycle are common. Beside missing maturity and insufficient production tests lead late modifications or weight optimization campaigns to many changes concerning design of the aircraft, interfaces and finally manufacturing processes. The result are increasing lead times and costs. These change processes need to be steered by an appropriate change management approach in order to find solutions for occurring problems and changes in an economical manner.

| Risk | Category |
|---|---|
| Customer does not accept customisation rules | Network |
| Insufficient influence on supplier | Network |
| Wrong production planning | Internal |

**Table 2: Additional identified risks for the risk catalogue**

In order to study three of the top ranked risks in more detail we decided to use tree analysis (event tree analysis and fault tree analysis) to understand the connection and drivers between the risks. Furthermore, we are able to identify risks which are missing in the risk catalogue and which could be important to be assessed in more detail. Table 2 highlights additional risks which are identified by the tree analysis. With the new findings we can restart the *Risk Analysis* cycle by updating the risk catalogue of the *Risk Identification* step. If we are satisfied with the results of the *Risk Analysis* cycle so far we can go on with the next cycle, *Risk Evaluation*, and develop mitigation strategies for particular risks.

## 4. CONCLUSION

The aim of this paper is to analyse the ramp-up risks of commercial aircraft and identify a method to manage ramp-up risks. We are one of the first researchers who examine these risks by applying a structured approach. With this work we build a basis for further risk analysis and mitigation. This paper contributes to a successful supply chain risk management for future ramp-ups. We see that a combination of several techniques within the process of identifying and assessing risk is beneficial because otherwise risks could be missed.

The highest-ranked risk is the insufficient production test. Detailed production tests have a significant impact on lead time and also on the final adaption of the supply chain and the product. In addition, it was shown that the majority of risks origin within the organisation which is in contradiction to the common experience that risks origin external to the organisation. Therefore, the risk mitigation needs to be adapted for the here identified risks and sensitized for special ramp-up requirements.

The partial overlap of the cycles is proven to be successful in adapting the risk management in a quickly changing environmental like the ramp-up. This is of particular importance in the ramp-up of highly complex products like aircraft. As already stated, ramp-ups are not a common thing in the aircraft industry yet. So far products and processes achieve maturity late. Technology risks are considered to be among the most important risks because new technology does not always meet the exact expectations and therefore possibly need to be reconsidered. This again has got impact on product and process design. Therefore the occurrence of risk needs to be reconsidered regularly which is supported by this approach.

The proposed conceptual supply chain risk management framework offers the possibility to improve the responsiveness after a disruption. For further research the latter two cycles of the applied supply chain risk management framework, i.e. *Risk Evaluation* cycle and *Action* cycle, can be implemented. By executing these two cycles mitigation strategies can be analysed and particular action plans can be executed in case of a disruption.

Furthermore, we consider the integration of a dynamic risk simulation as a great enabler in order to evaluate the impact of disruptions on the performance of the aircraft production network. The disruption parameters are variable in impact and occurrence of probability according to the progress of the ramp-up. Moreover, the simulation model serves as an environment to evaluate mitigation strategies. The object of the simulation is to identify adequate measurement of response for prioritised risks. Thereby we differentiate between cause or impact orientated measurements. First successful trials have already been made.

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