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Integration of Resilience into a traditional Production Planning and Control System

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Abstract

Context

Production Planning and Control Systems aim to achieve an optimum of efficiency and flexibility in all processes to cope with the requirements a modern production faces. Events that lead to deviations from actual production to planned are considered to have negative consequences on the achievement of operational objectives. To manage the probability and severity of such turbulences a system can be optimized regard its resilience. Resilience is the capability of a system to avoid and endure a disturbance as long as possible and recover quickly afterwards.

Goal

The goal of this master´s thesis is to develop a framework for the integration of resilience into traditional production planning and control systems. The framework has to guide the reader thru the theoretical context of production planning and control system, risk and resilience management, control systems as well as the creation and integration of resilience in an existing system.

Methodology

The methodology applied to create such a framework is design science research. After the identification of the research problem and the motivation to solve such, the objectives of a solution are defined. The design and development of an artifact that is applicable to solve the research problem is the main contribution to current research knowledge.

Result

By applying the methodology of design science research, a framework for the integration of resilience into a traditional production planning and control system was designed, created and demonstrated. The objectives and requirements for such a framework and the concluding characteristics of a system after applying it are met as defined in the scope and problem statement.

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Executive Summary

The challenges a traditional production planning and control system faces nowadays in terms of efficiency and sustainability, in an environment of uncertainty and volatility, rise the interest of making such systems resilient. Resilience is understood to be the capability of an organization to avoid disruption as long as possible, endure their impact in the presence of such and recover as quick as possible afterwards. The enforcement of such a capability is provided with dedicated resilience management. As traditional production planning and control systems do not consider such a concept to a decent grade, the question arises how to make such systems resilient. How can resilience be integrated into a traditional production planning and control systems? How does a resilient system look like? This master´s thesis aims to answer these questions. The literature to this topic concludes, that although there are various approaches on how to improve and measure resilience, how to configure supply chains and how to manage risks, none does match the requirements of a complete, practitioner-friendly framework for the integration of resilience into a production planning and control system. Therefore, such a framework has to be created.

To create such a framework and structure the thesis in accordance with accepted research methodology, design science research is applied to solve the problem statement and close the research gap. To describe the problem and the motivation to finding a solution, a literature research is conducted to conclude the problem statement. Following this problem statement, the research questions is identified. This represents the determination of solution objectives as specified in the methodology. The main contribution to research is the development and demonstration of the targeted framework that represents the artifact that is created in design science research. How and from which sources this artifact is planned to be build is shown by introducing several theoretical considerations regarding resilience, resilience and risk management, production planning and control, as well as management control systems.

Design suggestions found in research are considered and build on existing approaches for resilience in production systems. A traditional production planning and control system is first modeled with a functional map. This functional map is then complemented with roles and responsibilities of a production system. Then, the production planning and control is also modeled as diagnostic control system with

targets, performance variables and measurements. This diagnostic control model is then combined with the functional map build before to finally picture production planning and control in a transparent way in regards targets, activities, roles and responsibilities.

This transparent model serves to integrate resilience. To apply common approaches from risk and resilience management a 6-step framework is introduced. At first risks that threaten the achievement of before stated targets are identified. Those are then further analyzed in their probability and impact severity. They are afterwards linked to corresponding risk information, which represent the risk in a control system. To cope with those risks, respond strategies that aim to reduce, respond and recover are determined. Combining all these steps, in the last step those risks, risk information and respond strategies are linked to the introduced roles and responsibilities of the production planning and control system. This achieves to connect the management of each risk and fulfillment of operational and strategic targets to dedicated locations in the functional map of the production system. This integrates resilience into an existing, traditional production planning and control system.

The thesis concludes, that by successfully applying design science research methodology and creating a framework as artifact to integrate resilience into a traditional production planning and control system the scope of this thesis is met and the research questions can be answered.

1. Introduction

As volumes of single variants decrease but the number of different variants increases (Schuh et al., 2013), many production systems nowadays face the challenges of ensuring a maximum of flexibility whilst complying with standardized processes and guidelines. Nevertheless, the goals regarding efficiency and effective use of resources are high. Production planning systems have to consider all kinds of external and internal events that can negatively as well as positively influence the production system to meet these goals. To ensure high utilization of production machinery and staff production managers have to consider “what could possibly go wrong” in advance to be able to cope with disturbances if they occur. Additional to this preparedness regarding the presence of turbulences, a production system has to eliminate all risks possible by adapting its activities and guidelines to prevent such events as far as possible. Such a concept is referred to as “Resilience”.

This means, that modern production planning and control systems (PPC) constantly strive for controlled production processes (Heinicke, 2014) to avoid the necessity of changes in the production program, which can lead to turbulences inside the internal supply chain and therefore decrease efficiency and output. Also, external circumstances that can be vaguely influenced and controlled by the production planning system effect the production systems objectives and are considered. Initial events that may require changes in the system could for example be unforeseen increased customer demand or sudden shortage of raw material. To cope with the requirements of ever growing efficiency and flexibility in small and medium size companies, managers of production planning and control systems need a way to introduce, standardize and improve resilience in their organizations. This master´s thesis aims to provide a framework for the integration of resilience into production planning and control systems for practitioners.

1.1 Research Scope

The scope of this master´s thesis is to develop and provide a complete framework for the integration of resilience into traditional production planning and control systems. The context and focus is on traditional production planning and controls system where are still a lot of human interaction is required and processes and flow of material and information is not fully automated.

1.2 Literature Review

When researching literature regarding resilience in general and approaches to consider such a concept in a production system context several papers were found, that cover segments of those topics. But none that combine all together to one applicable framework. Resilience mostly deals with avoiding and enduring turbulence or the risk of them and can be put into various contexts such as social, environmental or regarding information systems.

The concept of resilience is not new. Mallak (1998) describes how resilience is put to work in an organizational context and focuses on the employees, more specific the workers that are responsible to fulfill customer requirements. He points out, that an individual that is forced to act resilient needs access to resources. This could for example be in the form of information or decision-making power. By referring to crises like natural disasters, he shows that people cope with such events with different attitudes and strategies. Some stay positive and oriented to solving problems, other tend to neglect or deny the presence and effect of disturbance. He further describes principles for managers to build resilient organizations by training and guiding employees towards a resilient environment and enforcing tolerance for uncertainty. Although the research of Mallak (1998) gives a basic concept of how resilience in organizations can be enforced by management, it misses a specific context regarding production or supply chain domains.

The relevance of realistic thinking in terms of possible risks and disruptive events is highlighted by Coutu (2002). She shows that individuals that face negative events with realism rather than pure optimism perform much better in terms of resilience. This underlines the importance of preparedness and well-structured actions in the presence of turbulences. As this paper focuses more on humans and their mindset, it gives insights of how the culture has to be set in an organization that strives to be resilient, but does not give structure on how to design and implement such in an organizational context.

Brunsdon and Dalziell (2005) describe the challenge of resilience in various case studies. They show, that it is crucial to evaluate hazard events and their consequences critically in advance to maintain and operate infrastructure in presence of unexpected events. In their research Brunsdon and Dalziell (2005) include 10 case studies from various backgrounds, facing different scenarios. They describe the meaning and characteristics of organizational resilience and break it down into two key components of vulnerability and adaptive capacity. As others they see resilience management as combination of risk management and business continuity management. Also, the paper points out some mandatory requirements for evaluating and improving resilience like a standardizes terminology regarding events and activities, or resilience benchmark values. It focuses more on improving, then on designing and implementing specific resilience mechanism into organizations and does not show a specific production systems background.

How resilient supply chains support the overall resilience of an enterprise is described by Sheffi & Rice (2005). They focus on a supply chain context of resilience and suggest to combine redundancy with flexibility to avoid and manage disruptions in supply chains. The need for more resilient supply chains in modern business world is highlighted and advised to be part of the enterprises strategy. With 8 stages model the disruption profile as a function of performance over time is shown and described with practical examples from production and supply chain background. This brings a good illustration of activities and key events that are taking place in advance and presence of a disruption. They consider 3 main categories of disruptions: random, accidents, intentional (Sheffi & Rice, 2005, p.43). To assess and categorize possible disruptions they suggest to perform a “vulnerability framework” with which the likelihood and consequences of such events are rated. After rating possible scenarios, the company has to determine if redundancy or flexibility is the right strategy to cope with those threats. They compare the costs and effects of each and show different faces of flexibility, which should be preferred because it also opens opportunities for competitive advantages. The research of Sheffi & Rice (2005) shows an overview of which steps one has to consider when analyzing and improving resilience in a supply chain. It also provides tools for rating and assessing disruptions and drafts strategies how to face them. The characteristics of resilience determined by Sheffi & Rice (2005) are relatable to production planning and control systems, so is the pictured disruption profile. They also highlight the importance of suitable control system to predict and detect disruption preventive, but do not show applicable control systems in detail.

McManus et al. (2007) conceptualized a framework for assessing and improving the resilience of organizations. They analyzed 10 case-study organizations to identify which features contribute positively to an organizations ability to be resilient. Their focus is on how organizations respond and plan for disruptions and how resources are managed during crises. The individual legal and contractual framework, as well as the recovery after disasters were also considered (McManus, et al., 2007, p.v). Building on that, they suggested tools for assessing and improving the resilience of those organizations (McManus, et al., 2007, p.1). McManus et al. defined 5 key elements that are involved in the resilience management process and show assessment and improvement tools for each element (McManus, et al., 2007, p.5). They also define 3 main characteristics of an organizations resilience and combine them with the 5 key resilience elements to determine 15 resilience indicators. These indicators are used to generate resilience profiles of each case-study. The steps to perform according their research are at first awareness building in general for the topic of resilience and second the selection of critical components of an organization. Then the critical components are analyzed regarding vulnerability and further on prioritized.

The last step represents a self-test, where crises are simulated and the assessment and activities performed before are tested regarding their applicability and readiness. By combining resilient communication strategy and emergency planning strategy as resilient management strategies they target to assess and develop all determined resilience indicators. The research of McManus et al. (2007) provides a comprehensive framework for assessing and further improving the resilience of organization. It defines fundamental characteristics of resilience and suggested indicators for assessing resilience via resilience profiles. By analyzing several case-studies McManus et al. (2007) also highlight challenges and advantages of improving an organizations resilience. They also provide a good understanding of what resilience means. But due to the more service and governmental organizations context, they do not consider production or supply chain domains and how to integrate resilient mechanisms into such.

The designing of supply chains under uncertainty is discussed by Klibi et al. (2009). Their research investigates in design criteria for supply chain strategies to cope with disruptive events. They focus on the concept of robustness, responsiveness and resilience and review the importance of such in supply chain design models. The concept of robustness is understood as extent to which a system facing various future scenarios can still perform its activities as planned (Klibi et al. 2009, p.290). They suggest that responsiveness should be enforced by standards, guidelines and safety stock which also support resilience. Klibi et al. (2009) conclude several suitable methods for the design process of robust, value-creating supply chains such as risk analyses, scenario planning and modeling for robustness, but do not focus on resilience itself. Also, the consideration of induvial roles and targets in a production system is missed.

The importance of understanding the interdependencies and effects of such in a production control system has been highlighted by Schuh, Potente and Thomas (Schuh et al., 2013). As Heinicke (2014), they considered socio-technical aspects regarding configuration of production planning and control systems. Referring to control systems and principles Schuh et al. (2013) state, that due to a lack of transparency and therefore understanding, the decision and execution process performed by different employees in a production system often does not match with the organizations´ objectives. They also show, that some objectives are contra productive. Whilst logistics wants to ensure fast delivery and low stock costs, production strives for high utilization of production equipment and maximum output, often neglecting working capital and stock. The balance between stability and adaptability is considered as a tradeoff to cope with a dynamic environment. This can be understood as a kind of resilience to endure or manage thru turbulences. Also, an example for turbulence cause such as high frequency of urgent orders and changes in priorities which leads to confusion on the shop floor and increases throughput times is shown. Schuh et al. (2013) do explain the task and configuration of production planning and control systems, mention the importance of control principles and also refer to examples and finding from real cases, but further do not show how to find and use specific control systems accordingly.

Heinicke (2014) introduces a framework for resilient production systems. He defines resilience as a concept of combining robustness and agility. Robustness serves to endure disruptions, whilst agility helps to change the production configuration to cope with a disrupted environment. More specific, robustness is the first mechanism in case of disruptions and agility is used as second if robustness is no longer sufficient.

He points out, that a standardized flow of information and material is mandatory as basis for building resilience. By making production systems transparent thru picturing them as a functional map and adding the hierarchies of such a system, he introduces an approach to consider socio-technical aspects to determine interdependencies of individuals objectives and possible dissipations. This transparency aims to support interventions at the operational level in case of turbulences. To force adequate decisions, he suggests to use route-cause-diagrams and apply the three steps of identification, classification and prioritization of disturbances to eliminate their effects. Further, Heinicke implies, that the downtime caused by a disruption is used as a key figure regarding relevance of that specific disruptive event (Heinicke, 2014, p.206). As the paper describes, it only introduces a framework for resilient production systems and therefore does miss to demonstrate the full concept of resilience in production planning and control systems and the practical implementation of such. Also, he states further research is needed for more intricate production systems.

In his research Heinicke (2014) also refers to the identification of supply chain dynamics under uncertainty as researched by Ivanov & Sokolov (2013). They researched in the field of perturbed supply chains and point out, that although it is understood that uncertainties have a possible negative impact on supply chain performance, quantitative analysis and a systematic terminology in regards supply chain disturbances are limited (Ivanov & Sokolov, 2013, p.313). They consider the performance of a supply chain to be defined by its effectiveness in terms of service level and efficiency in terms of its costs. These performance indicators are affected by uncertainty in the planning stage and disruptions in the execution phase of the supply chain. To avoid or at least reduce the impact of those, Ivanov & Sokolov (2013) suggest the analyses of a supply chain in regards of its stability, robustness, resilience, security, flexibility, disruption-tolerance and complexity. They identify these as problem classes and developed a control framework for supply chains performance under uncertainty.

The used terminology of problem classes and modeled control framework provide a good basis for the understanding of resilience and disruptions in supply chain context. They refer to resilience as the ability to maintain, execute and recover performance during crises and further give applicable definitions for stability, flexibility and disruption-tolerance. The separation of the planning state which faces uncertainty and the execution state that deals with disruption-risk is also relatable to traditional production planning and control system. Still, the research of Ivanov & Sokolov (2013) does not provide a framework for the development and integration of resilience as targeted. The importance of robustness and agility in the context of supply chain risk is also researched by Wieland & Wallenburg (2012).

Wieland & Wallenburg (2012) investigate the linkage of risk management practices and strategies to supply chain performance under risks. They consider supply chain risk management to be a balance of proactive activities to support robustness and reactive approaches to ensure agility. They show, that both these concepts have to be managed to cope with vulnerabilities (Wieland & Wallenburg, 2012, p.890). They analyzed survey data from numerous cases to provide proof for their concept to deal with supply chain risks. As their research shows, agility understood as reactive and robustness understood as proactive risk coping strategy is strongly supported by practical evidence. Wieland & Wallenburg (2012, p.898) show that whilst agility mostly deals with customer side risk and has positive effects on customer value of the supply chain, robustness improves the handling of supplier side risk and contributes to customer value and business performance. They also state, that the key for managing supply chain risks are the identification, assessment and control of risks as applied in risk management standards. These findings can be considered for the development of a resilient production planning and control framework, but do only draft such considerations.

In further research Wieland & Wallenburg (2013) also analyzed how relational competencies influence the resilience of a supply chain. Again, they addressed the two resilience dimensions of robustness and agility and investigated how communication, cooperation and integration affect supply chain performance. They consider communication as the transmission process of information and cooperation as the active participation in such information transmission (Wieland & Wallenburg, 2013, p.302). As others they find, that the active involvement of individuals and their communication and cooperation relationships have strong influence on the success of resilient systems. These results give suggestions for the integration of resilience, but need to be expanded to create a complete framework.

1.3 Problem Statement

To meet requirements for the desired “complete” framework as defined in the scope for the integration of resilience into a traditional production planning and control system, such a paper has to guide the reader thru the process of understanding, assessing, improving and implementing resilience. Therefore, the theory regarding production planning and control system and further the connection to resilience and management system has to be explained first. Then the assessment of risk and uncertainties for an existing production system has to be shown and adequate respond strategies designed. Finally, the systematically integration of these resilient mechanisms into the existing production system must be illustrated. All this has to be bundled in one framework, applicable for practitioners like production or process managers. These determined requirements can be summarized as follows. The targeted framework needs to cumulative fulfill these requirements:

- ✓ Give a brief introduction into production planning and control and resilience in context of such.
- ✓ Show how resilience mechanism can work.
- ✓ Guide the reader thru the process of defining, designing, implementing and testing a resilient system
- ✓ Use practical examples
- ✓ Show the advantage of resilience in production planning and control systems

As shown, the literature review concludes, that no practitioner-oriented framework for the integration of resilience into production planning system is provided. Many researches show approaches for assessing and improving resilience (Brunsdon & Dalziell, 2005; McManus et al., 2007), others suggest design considerations for resilient organizations (Mallak, 1998; Coutu, 2002). The motivation and initial advantage of risk and resilience management in production context is for example described by Heinicke (2014), Schuh et al. (2013), Ivanov & Sokolov (2013), Wieland & Wallenburg (2013), Klibi et al. (2010) as well as Sheffi & Rice (2005). This shows, that the research gap is the designing and integration of a complete framework for resilience in production planning and control systems.

1.4 Methodology

The methodology used for this thesis is design science research (DSRM). As shown by Miah et al. (2014), this methodology suits well for developing an information systems framework. It is based on the 7 guidelines for conducting a design science research introduced by Hevner et al. (2004) and structured according to the nominal sequence of 6 activities determined by Peffers et al. (2008). Beside the identification of the problem and the objectives of the solution it is crucial to design and create an artifact that solves this problem and meets the before defined objectives. An artifact is described as something that naturally did not exist until it was created or modified by human workmanship and is designed for a specific purpose (Artifact, 2017). The artifact created in this thesis is a framework for the integration of resilience into a traditional production planning and controlling system. The applied methodology also concludes the structure of this thesis (see table 1).

Table 1: Activities of DSRM (Geerts, 2011, p.144)

DSRM activities	Activity description	Knowledge base
Problem identification and motivation	*What is the problem?* Define the research problem and justify the value of a solution.	Understand the problem's relevance and its current solutions and their weaknesses.
Define the objectives of a solution	*How should the problem be solved?* In addition to general objectives such as feasibility and performance, what are the specific criteria that a solution for the problen defined in step one should meet?	Kowledge of what is possible and what is feasible. Knowledge of methods, technologies, and theories that can help with defining the objectives.
Design and development	*Create an artifact that solves the problem.* Create constructs, models, methods, or instantiations in which a research contribution is embedded.	Application of methods, technologies, and theories to create an artifact that solves the problem.
Demonstration	*Demonstrate the use of the artifact.* Prove that the artifact works by solving one or more instances of the problem.	Knowledge of how to use the artifact to solve the problem.
Evaluation	*How well does the artifact work?* Observe and measure how well the artifact supports a solution to the problem by comparing the objectives with observed results.	Knowledge of relevant metrics and evaluation techniques.
Communication	Communicate the problem, its solution, and the utility, novelty,and effectiveness of the solution to researchers and other relevant audiences.	Knowledge of the disciplinary culture.

In the introduction, the broad context of this thesis and the meaning of resilience in production planning and control are described. The research scope and therefore the motivation of this thesis are explained. Following, in the literature review, the problem statement is conducted. It shows, that current research does not cover the desired requirements of a suitable framework, although the importance of resilience in production systems is highlighted. This covers the first DSRM activity according to Geerts (2011, p.144). Further on, the thesis guides thru the main theoretical topics that will be considered to design the artifact later on. State of the art knowledge and methods on resilience, production planning and control and management control systems are shown. This draws the profile of how such a framework can be designed and therefore shows how the problem should be solved, which is according DSRM activity 2. After the problem and motivation are explained and the single theoretical segments are introduced, the artifact is created. By considering current knowledge and combining provided approaches, a new framework with the purpose to show the integration of resilience into production planning and control system is developed. This meets activity 3 of the design science research methodology. After the framework is created the integration is explained. The 4th activity of DSRM shows that the developed framework can solve the before stated problem. By comparing the artifact and its demonstration to the thesis´ objectives the compliance to the set goal is evaluated as described in DSRM activity 5. Finally, the process of objective setting, artifact development, demonstration and evaluation are summarized and conclusions are drawn. This communicates the problem and its solution and finishes the DSRM methodology. By following the guidelines to perform a design science research methodology the structure of this thesis is conducted and it is ensured that the problem statement is solved in a systematical way.

1.5 Research Question

Considering the problem statement as explained above, there are a few questions that evolve from this research gap. According to design science research methodology the artifact that will be created is the framework for building and integrating resilience into traditional production planning and control systems. The primary research question deriving from this is defined as:

"How can an existing, traditional production planning and control system be made resilient?"

Further on, there are other questions that this thesis strives to answer:

"How does a resilient production planning and control system look like?"

"How can resilience be integrated into an existing system?"

Concluding, this paper wants to show how a resilient production system is designed and integrated into an existing system.

1.6 Expected Result

The expected result of this thesis is the closing of the found research gap and answering of the research questions as explained above by applying design research methodology and therefore creating an artifact that serves as framework for the integration of resilience into traditional production planning and control system. The artifact is expected to be created by combining segments from knowledge of various research references. The context of production and supply chain in regards resilience will be analyzed to consider design guidelines for this framework. Approaches from risk and resilience management will be used to develop a procedure to identify, asses, categorize and manage risks. As suggested by research on supply chain configuration, the processes and objectives of such will be made transparent in a functional map and prepared for the modeling as diagnostic control systems. The integration of this framework is expected to be shown by linking goals, responsibilities, risks, risk information and risk coping strategies to individual roles and tasks in the production planning and control system.

1.7 Summary Chapter 1

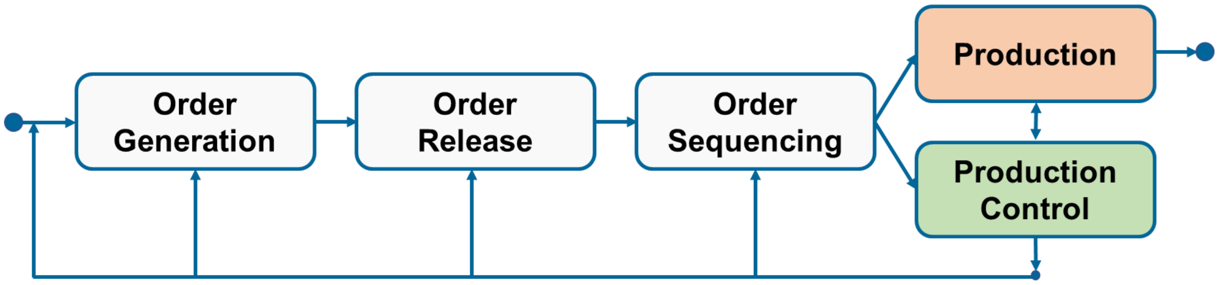
Chapter 1 of this thesis represents the introduction into the context and scope of this master's thesis. The research scope of this paper was determined to lay on providing a complete framework for the integration of resilience into traditional production planning and control systems for practitioners like process or production managers. The literature review on the topic of resilience in general, resilience in supply chain context and production control systems itself conclude, that currently no such framework is introduced. Such a framework was defined to firstly guide the reader thru basic theory of production planning and control systems and introduce resilience in production context. Also, the main characteristics of resilience management and management controls should be explained. After providing such introduction, the development and application of a framework to establish and integrate resilience have to be shown. Since this is not yet existing, the problem statement was conducted. It states, that the research gap is the designing and integration of a complete framework for resilience in production planning and control systems. The suitable research methodology for this thesis was found to be design science research. The application of the activities given by this methodology enables to define a problem, draft the possible solution and then develop and artifact that solves this problem. To demonstrate the viability of this artifact, its applicability is shown and evaluated in regards fulfillment of set objectives. The problem definition and conducted research question were found to be: *"How can an existing, traditional production planning and control system be made resilient*?" Further: *"How does a resilient production planning and control system look like?"* and also: *"How can resilience be integrated into an existing system?"*. The thesis strives to answer this questions by applying design science research methodology. The expected result is determined to be the creation and application of a framework that is built from various research inputs and put into the perspective of production planning and control systems to integrate resilience. By combining knowledge on production planning and control, resilience and risk management that suggest how to identify, analyze and manage risks as well as control systems to manage and control an organizations achievement of objectives the desired complete framework as defined as research gap shall be developed.

2. Resilience in Production Planning and Control Systems: Theoretical Considerations

2.1 Production Planning and Control: Traditional Systems

The production planning and control (PPC) department is responsible for the planning, generating and releasing of orders and the control if all processes are operated as planned (Halevi, 2014). The tasks of production planning and control are most times bundled in one department, performed by one or many individuals, depending on type and size of production itself. Although, actually, the planning and the control component of production planning and control refer to different task, they are closely linked due to practical reasons. The production planning can be seen as the bridgebuilder between the customer and sales domain of a company and the production department. Sales dictate which product is demanded in which quantity and production transfers raw materials to finished products, salable to customers. Without production planning, the production would probably not meet the amount of various products, demanded on various dates in volatile quantity. On the other hand, if the demand regarding quantity and delivery date of products as wished by the customers would be directed straight to production machines, the company would not comply with nowadays competitiveness concerning production efficiency and performance. To balance the interests of sales and production and achieve goals set by management, the production planning strives to achieve ideal operating points for all products, delivery schedules and machinery. This balancing is applied when generating, releasing and sequencing orders. The production control then strives to ensure compliance to this program in regards of quantity, quality and time. The configuration of the main activities is described in numerous research with slight variations. For this thesis, they are defined as a variation of the one suggested by Schuh et al. (2013, p.146) and also Heinicke (2014, p.202).

Figure 1.: PPC- Order Generation, Order Release, Order Sequencing and Production Control



Order Generation

An order in production terms is the summary of information and guidelines that needs to be fulfilled in production to produce a product that is saleable. The information imbedded in a production order can be quantity and quality of a product, the bill of materials, official technical drawings that specify the product, packaging guidelines, labeling templates, etc. It can be understood, that if a production worker gets such an order, he or she knows what and how to do to fulfill it, because all necessary information is included or at least referred. This production order is the translation of an order initiated from customer demand or future, forecasted demand. The order generation represents the starting point of production planning and control. Here lot sizes and type of product are determined. Also, the availability of resources that is needed to produce this order is checked.

Order Release

If all resources are available or future availability is confirmed, the order is good to go to the operations level – the production.

Order Sequencing

As the generation and releasing of orders is done several times in a row over a planning period, the orders need to be sequences to determine in which order the have to be produced. This can for example be done by first-in-first-out, customer priority or for efficiency reasons.

Production Control

Here the control component of PPC is located. The production control, compares planned performance to current performance and considers all specifications and targets imbedded in the production order. If deviations are detected, control inputs are send to the corresponding components of the PPC process. Thereby, the production control directly influences productivity, achievement of targets, costs and overall performance of the production system.

2.2 Resilience: The Immune System of an Organization

As already mentioned in the introduction of this thesis, resilience deals with avoiding, enduring and recovering if disruptions hit a system. In a simple way resilience can be compared to the immune system of the human body, if a disruption is like sickness. The body is defended against the sickness by the immune system and if it still gets infected the immune system then strives to recover as quick as possible and get the body healthy again. In literature definitions and understandings of resilience are manifold. They depend on the scope of research and context of the systems that are investigated. Referring to Walker et al, (2006) McManus states that resilience is described as:

"…the capacity of system to absorb change (generally conceptualized in the form of sudden shocks) and still retain its essential functionality."

(Walker et al, 2006)"

Other approaches that where found when researching for this thesis to define resilience as are:

"…*the ability of a material or system to absorb change gracefully whilst retaining core properties or functions*."

"…the ability to rebound to original shape/form after deformation that does not exceed its elastic limit."

"…the ability of a system to recover easily and quickly from adversity."

(Brunsdon & Dalziell, 2005, p.28)

"…the ability to bounce back from a disruption."

(Sheffi & Rice, 2005, p.41)

"…to avoid disruptions as much as possible, as well as the means to bounce back quickly when hit."

(Klibi et al., 2010, p.291)

"…the ability to maintain, execute and recover (adapt) the planned execution along with achievement of the planned (or adapted, but yet still acceptable) performance…"
(Ivanov & Sokolov, 2012, p.319)

"Resilience is the capacity of a system to survive, adapt, and grow in the face of unforeseen changes, even catastrophic incidents."
(Center of Resilience, 2017)

It shows, that in their definition some focus more on the enduring of crises, whilst others also consider the avoidance of being hit by such. The motivation for organizations to be resilient is to minimize risks, especially in operational context and continue business even in turbulence times to not lose market share to competitors. Therefore, resilience is also considered as a competitive advantage (Sheffi & Rice, 2005, p.44). The research of McManus et al. 2007 gives a good explanation why companies should strive to be resilient. A resilient organization is aware of its environment and key stakeholders. It also knows its major vulnerabilities as well as the risk and chances those conduct. This knowledge helps the organization to adapt to changing conditions in business environment. Resilient organizations are more resistant to turbulences and cope with them if a crisis hits. Also, they detect and take advantage of opportunities that can evolve from such events and continue to move forward in challenging times. This ensures to operate in and following crises and significantly improves the impact on the organization´s recovery and long-term stability. McManus et al. (2007, p.1-3) refer to resilience as a function of an organization's:

- *"Situations awareness,*
- *Management of keystone vulnerabilities and*
- *Adaptive capacity*

in a complex, dynamic and interconnected environment."

For this thesis, the characteristics of a resilient system are determined as follows:

1. **The organization knowns its main targets and vulnerabilities.**
2. **The organization has determined and implemented corresponding strategies to cope with those risks.**
3. **Those strategies focus on preventing, reducing, enduring and recovering from disruptions.**
4. **The organization understands its resilience management as continuous process that is developed iterative.**
5. **The resilience management involves individuals and does consider their capabilities as well as their responsibilities.**

If a system meets these characteristics it is considered as resilient. Therefore, when designing this framework for the integration of resilience into a traditional production planning and control system the target is to systematically develop such systems towards these characteristics.

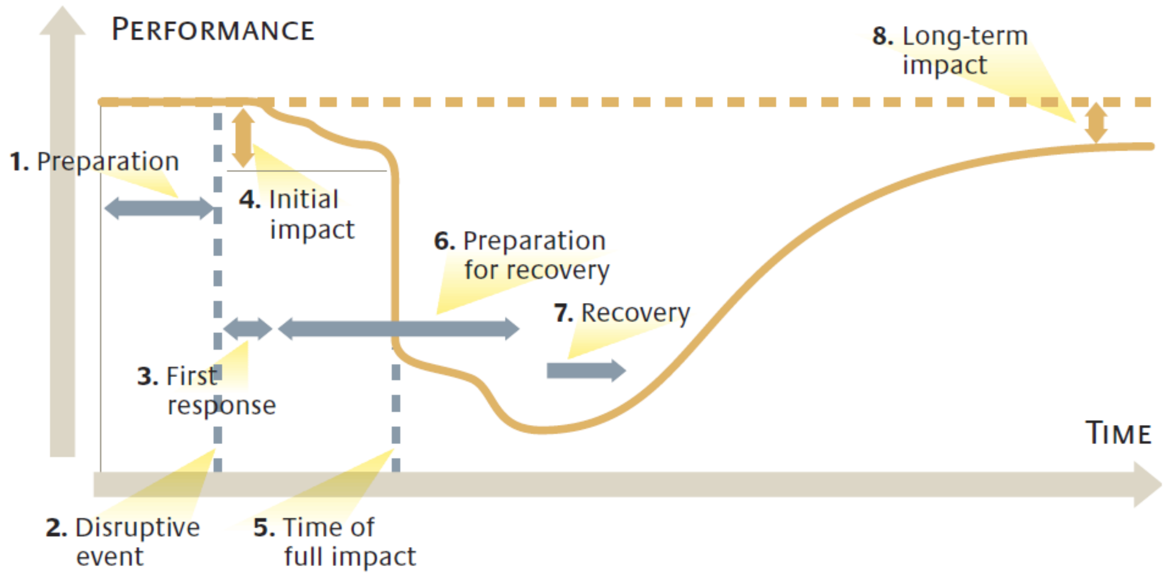
2.3 Resilience Management: Managing Robustness and Flexibility

The intention of resilience management is to systematically asses, develop, implement, apply and improve mechanism and activities that foster an organizations resilience. Although depending on context like business or social, production or service, there are several approaches for resilient management. The basic path is always to start with assessing the targets and vulnerabilities of an organization. Then the outcome is prioritized, ranked and categorized. According to the categorization and importance of found vulnerabilities adequate respond strategies are developed and standardized. Those respond strategies can be preventive or reactive and may also consider chances evolving from changes in business environment. Whilst preventive strategies cope more with risks that can be influenced, like machinery breakdown, reactive strategies are suitable for risk that cannot be controlled or influenced. Resilience management has to continuously grow and improve, or as McManus et al. states:

> "*Resilience Management is designed as an iterative process for long term organizational development and not as a one-off crisis management tool.*"
> (McManus et al., 2007, p.vi)

The association of resilience management with segments of risk-, business-continuity and emergency- management is often highlighted (Mallak, 1998; Brunsdon & Dalziell, 2005; McManus et al., 2007; Preis, 2013). In practice those management systems are not always linked and interconnected to a decent degree (McManus et al., 2007, p.4). To explain how and when resilience management makes a difference, the profile and phases of a disruption as used by Sheffi & Rice (2005, p.42) are explained. A disruption is considered as an interruption of the normal course, that brings disorder to a system (Disruption, 2017). Usually a disruption occurs suddenly or with little prior notice, which amplifies its impact even more. Figure 2 shows the impact of a disruption on performance over time.

Figure 2.: Disruption Profile



(Sheffi & Rice, 2005, p.42)

Phase 1 – Preparation

The disruption has not yet occurred and the organization does not know when or probably if the event will happen. By assessing possible turbulences in advance, the company is aware of the risk of it to happen. That means they can take preparation activities to avoid or prevent the disturbance as long as possible. This is usually done by robustness mechanisms like safety stock or other kind of backups.

Phase 2 – The Disruption hits

If the stress cannot longer be endured by preparation, or the unforeseen happens suddenly, the disruption hits the system.

Phase 3 – First Response

After the disruption hits and is therefore recognized by the company, first activities to cope with the changed environment and circumstances are taken. Often, even in companies that do not yet enforce some kind of resilience or risk management, there are emergency plans. Those plans are guidelines whom to inform, what to prioritize, etc. This phase is crucial for a company's vulnerability. The more organized a disruption is managed, the better the chances to keep the initial impact low.

Phase 4 – Initial Impact

Depending on type of disruption and the company´s business the initial impacts vary. In some cases, the full immediate impact shows in a few hours, others take days. The initial impact is the corresponding decline of performance caused by the disruption.

Phase 5 – Point of full Impact

At this state, the disturbance has hit with full impact and performance dropped significantly.

Phase 6 – Preparing for Recovery

As shown in the figure, this phase often starts parallel or directly after phase 3. Strategies for fast and strong recovery are developed and activities to get back on track are planned. This phase is crucial to match the “bounce back” character of resilience. Management has to foster recovery by initiate standardized processes and creativity adapted to the turbulent circumstances. In general, the more the company has put thought in this scenario before it happened, the faster this phase is done.

Phase 7 – Recovery

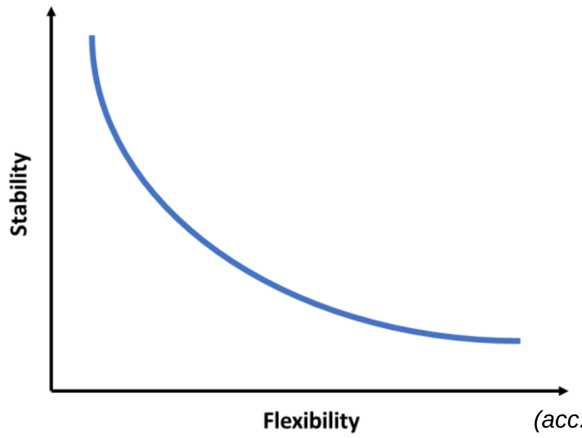
In this phase, the predetermined activities are taken and the recovery strategy is enforced. Depending on the severity of the impact caused by the disturbance this may take some time. The goal of recovery is to always go back to pre-disturbance performance as quick and sustainable as possible. If the disturbance injured machinery or significant resources, it is possible that the performance stays lowered even after recovery.

Phase 8 – Long-Term Impact

The difference of performance before the impact and the level of performance that is achieved after recovery is over, is considered as long-term impact.

These 8 phases explained by Sheffi & Rice (2005, p.42) show how crucial it is to be prepared. This means to prepare to avoid disturbances as long as possible and if they hit, have predetermined strategies to cope with them and accelerate recovery as much as possible. This ensures, that the initial and full impact are minimized and the overall damage to the system is kept low. The avoidance of risks, the enduring of such and recovering is the main contribution resilience management does to an organization. For example in a production system: If a machinery breaks down, it can be made sure, that all relevant spare parts are on stock to repair it and other machines can be adapted to produce the affected product. By performing frequent preventive maintenance, the break down can be avoided. As for example Sheffi & Rice (2005) and Wieland & Wallenburg (2012) describe, resilience management is often a combination of robustness (redundancy) and agility (flexibility). Wieland & Wallenburg (2012) show that in supply chain context robustness supports the proactive capabilities and stability of an organization, whilst agility fosters reactive actions. Beside safety stock and others, a way to achieve stability is the standardization of processes and responsibilities. Guidelines dictate who does what when how. This may ensure high compliance with standards, but does often also limit the creativity of individuals. On the other hand, creativity supports flexibility and agility. Individuals that are required to act agile and flexible in crises need to be able to improvise. This trade-off between stability and adaptability is also shown by Schuh et al. (2013).

Figure 3.: Trade-Off between Stability and Flexibility



(acc. to Schuh et al. 2013, p.147)

Another aspect to consider when designing a management system for resilience is, that stability in regards redundancy is often connected to costs. Flexibility has more leverage on the resilience capabilities of an organization with much lower costs. The ability to respond quickly in turbulences can also be a chance to get competitive advantage against competitors. This requires high awareness at the closest level to disruptions (Sheffi & Rice, 2005). To support individuals in their contribution to overall organization resilience, they need access to resources to live this agility (Mallak, 1998).

As with many management systems there are also standard frameworks for developing and integrating resilience management systems: the ASIS Organizational Resilience Standard ASIS SPC.2-2014 (ASIS, 2014), the CERT Resilience Management Model (CERT, 2010) and the newest ISO 22316:2017 (ISO, 2017). The concepts of these standards are built around identifying, assessing and managing vulnerabilities to enforce resilience. All approach a concept of the 4 R´s which stand for Reduction, Readiness, Response and Recovery (Brunsdon 2005, McManus et al. 2007). Those are considered as a step by step approach to cope with disruptions and manage resilience. Reduction can by transferred to stability and robustness and parts of readiness. Response and also readiness are covered by agility. Recovery can be a mix of predetermined activities and situation depending flexibility.

The current research and knowledge on resilience concludes, that one has to be aware of what parameters and processes of a system have to function at which values to still achieve goals in the best way possible - even under turbulences. This shows, that to measure, design and implement resilience into a production planning system, it has to become measurable and finally controllable. Therefore, control systems in terms of resilience aim to *“…detect a disruption quickly and to foster speedy corrective actions.”* (Sheffi & Rice, 2005, p. 47). To achieve that, critical performance indicators and their interdependence to set objectives have to be determined and used in regards management control.

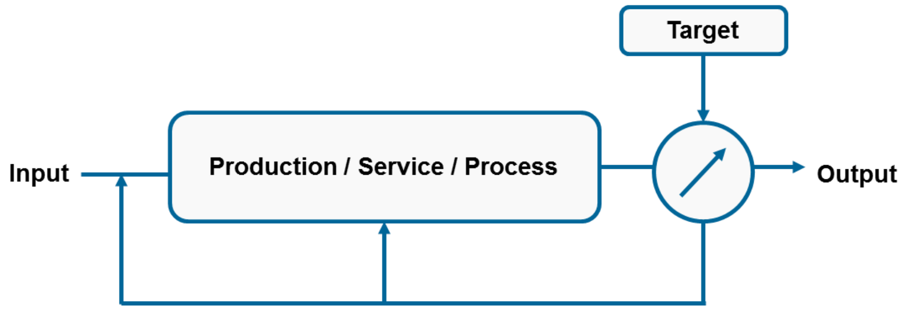
2.4 Diagnostic Control Systems: Feedback as Management Tool

In 1995 Robert Simons introduced „levers of control“ (Simons, 1995), where he describes the 4 levers successful managers use to control and enforce strategic goals. These 4 levers work as a balanced force-field in management control systems. Simons defined management control systems as “*…formal, information-based routines and procedures mangers use to maintain or alter patterns in organizational activities*” (Simons, 1995, p.5). Considering the tasks and goals of production planning and controlling systems, they are an own management control system inside the production part of the organization, as they plan, monitor and strive to control the activities of the production process. More specific, PPC systems fit the category of diagnostic control systems as defined by Simons (1995). Such diagnostic control systems typical show the following characteristics (Simons, 1995, p.59):

- *“The ability to measure the outputs of a process*
- *The existence of predetermined standards against which actual results can be compared*
- *The ability to correct deviations from standards”*

He pictured this characteristics in a simple figure (figure 4).

Figure 4.: Diagnostic Control Systems



(Simons, 1995, p.60)

This figure shows all 3 characteristics as stated above. The diagnostic control systems set up around a specified system. This can be any kind of production, service or process with measurable variables. The system has at least one input and output. Also, there is a target set for this system on how to perform it quality- and/or quantity-wise. The fulfillment of this target is measured continuously. This part fits the “diagnostic”. If the target is not met, there are variables that can be changed to alter the system towards the desired target. This is the “control” part of diagnostic control systems. A simple example for a diagnostic control system would be the temperature of a room measured and controlled by the thermostat of the heating system. The thermostat periodically measures the actual room temperature and compares it to the target room temperature. If the temperature is too low, it will give a signal to the heating system to match the target temperature of the room. Controlling a system can either be achieved by adjusting the system itself or its input. The targets set for a system will be linked to a certain strategy. Achieving them leads to implementing this strategy into the system and the organization to succeed.

Setting such a target requires measurements of variables. These variables have to relate directly to a strategic goal and have to be controllable. Simons (1995) calls these variables "critical performance variables". It is important to consider, that not everything that is measurable is a suitable performance variable. Effectiveness and efficiency of the chosen variables have to be taken into account. If the performance variables increase the probability to achieve targets they are effective, if they have potential for high impact with low effort they are efficient. Before critical performance variable can be identified, the strategy of the organization has to be clear. Then the goals embedded must be determined and afterwards the corresponding measures of such. When the suitable measure for this critical performance variable is found, a target-value (including tolerance) has to be set. Therefore, management does not have to pay attention to every single variable all the time. Only if a variable is out of tolerance an action from management is needed. This way the allocation of resources from the responsible manager is focused on areas where things are off course and need to be corrected. Critical performance variables can be separated into 4 categories (Simons, 1955, p.68):

- *Financial Measures*
- *Customers Measures*
- *Internal Business Measures*
- *Innovation and Learning Measures*

Those 4 groups describe the concept of the "balanced scorecard", introduced by Kaplan and Norton (1992). According to them, a successful diagnostic control system is set up with several critical performance variables in each of the 4 groups and then applied simultaneously to achieve the intendent strategy. A big advantage is, that managers can work with high autonomy if their scorecard is covering all important areas of their responsibility, as long as they match those goals. This of course concludes that the determination of critical performance variables and their target values has to be well thought and carefully balanced between different management areas and departments. Simons (1995) further points out, that managers are mostly involved in the design of diagnostic control systems when setting and negotiation their goals, receiving updates and exception reports and following up on significant exceptions. When negotiating and setting individual goals, it is important that the goal is challenging enough to motivate managers to strive for achievement. If the goal is too easy, managers lack motivation and pay not enough attention. If the goal is to difficult, they tend to give up, because they feel overwhelmed. Updates and reports ensure, that all variables are monitored and controlled frequently to adjust and manage in time if necessary. If major deviations occur, the managerial attention has to focus on aligning this critical performance variable with target again.

As diagnostic control systems are based on comparing actual to desired outputs by measuring variables, it is crucial that the measurements fit the cause and context of the target that shall be achieved by the system. Referring to Lawler and Rhode (1976, p.42) Simons (1995, p.76) determines that ideal measurements should have 3 key characteristics. They should be:

- *Objective*
- *Complete*
- *Responsive*

Although Simons provides a solid basis for building management control systems in production related context, it has to be adapted to fit for a resilience integration framework. It is necessary to not only consider process- and activities-based information, but also find indicators that can be used as risk-based information and variables.

2.5 Risk Information: Categorizing Risk Types

As shown such control system only works, if the information and data that is diagnosed fits the control systems´ purpose. The purpose of a production control system is to ensure compliance with the production program given by the production planning system. To design a production controlling system with resilient characteristics, one has to consider which risks threaten the fulfillment of targets, set with the production program and from production management. Therefore, it is necessary to predict risk events or at least sense their happening before they hit.

The conceptualization of predictive models regarding risk management and control systems is described by Göstl and Schwaiger (2016) in their research on risk-based planning and control systems, where they consider risk types in context of the individual management domain. They show that to design a risk-based control system, it is necessary to have adequate predictive models. To manage and further attempt to control uncertainties in business and the corresponding risks, one has to ask: which risk shall be controlled? This at first does not mean which specific risk event, it means being aware of the different risk categories as described by Mikes and Kaplan (2014, p.26-27) and also used by Göstl and Schwaiger (2016, p.3). These 3 risk categories are:

I. Preventable risks

They emerge from routine operations on a day to day basis. This could be a breakdown of machinery caused by poor maintenance.

II. Risks from strategy execution

These risks have to be taken to achieve superior success. For example, when making a high financial investment that could generate high returns. The intended strategy is the financial benefits, but the risk of making a wrong investment has to be taken therefore.

III. External risk

External risk occur for example from changing customer demand or volatile raw material prices. They cannot be influenced or prevented, only their impact can be managed.

“The main focus in the mitigation of external risks lies in the cushioning of their negative as well as the fostering of their positive consequences for the case of their realizations” (Göstl & Schwaiger, 2016, p.4)

As explained Categories II and III do not have risks only, they also show opportunities. The opportunity of taking strategy execution risks is to earn return. The opportunity of volatile material prices is to buy and transfer them when low and sell the products when their price is high, so that a higher profit is realized. On the other hand, category I, preventable risks, just shows risk without chances. There is only the risk of a machinery breakdown, if the machine functions proper, that’s the mandatory status. Göstl and Schwaiger (2016, p.5) consider this by further separating this risk categories into speculative risks (category II and III) and pure risks (category III). A pure risk is characterized by its likelihood to happen and its negative impact, whilst additional to its likelihood and negative impact a speculative risk also shows a possible positive impact (Göstl & Schwaiger, 2016, p.11)

Building on these 3 categories and 2 risk types Göstl and Schwaiger (2016, p.3-4) also introduce the approach to categorize a company’s management activities into 3 management domains. They point out that in most companies, even a 1-person enterprise, there is a strategic, financial and operational management. Each of this management domains shows different risks categories and types. This circumstance has to be considered when designing a risk-planned control system for management systems to find the specific corresponding for each risk. Table 2 summarizes risk category, risk type and management domain and their connection.

Table 2: Risks and Management Domain

Management Domain	Risk Category	Risk Type
Strategic	External Risks	Speculative Risks
Financial	Strategy Execution Risks	Speculative Risks
Operational	Preventable Risks	Pure Risks

Considering the linkages between management domain, risk category and risk type shown in table 2, it shows that operational risks are a pure risk type and also mainly preventable. To eliminate these risks, it is necessary to prevent them or at least detect them before they happen. This can be achieved by also considering the likelihood and impact of uncertain events in advance. Thus, a proactive risk control system can be established. If then the pro- and reactive management systems are combined, operational risks can be control and managed. One way to do so could be the design of a risk limit system (Göstl & Schwaiger, 2016, p.8), where the value of a parameter is linked to risk as risk indicator. As long as the parameter is within its limits, the corresponding risk is in its predetermined limit and no corrective actions need to be taken. Another approach is a risk-based performance management system (Göstl & Schwaiger, p.8), where a target risk value is set and the corresponding indicator is controlled towards it. If the risk value is beneath its limit, risk can be added. Such risk-based performance management systems are also applicable for speculative risk in financial management. Since speculative risks that emerge from external risks in the strategic management domain can only be managed regarding their impact, but not in their likelihood to happen (Göstl & Schwaiger, 2016, p.11), risk-based control systems as suggested for operational and financial domains are not relevant.

For such external risk scenario planning tools as introduced by Shoemaker (1995), are more suitable. Shoemaker explains a simple, structured approach to develop and analyze possible future scenarios in 10 steps. In the first step, the scope is set. This includes the timeframe (when could it happen) and the department of the company (e.g. sales, purchasing, R&D, etc.). In a second step, the major stakeholders are determined. This shows who will be affected by the scenarios according to the scope. To give context and contrast to the uncertainties, basic trends are identified in step 3, as it can be assumed that such will most probably continue. In step 4 the major assessment of uncertainties is performed. Key uncertainties that represent all kinds of influences on possible events and the current situation are identified. The construction of initial scenario themes is done in step 5. Therefore, uncertainties and possible events are narrowed down to more concrete scenarios. Before continuing with step 7, scenarios are checked for possibilities in step 6. In step 7 learning scenarios are developed by intensively studying scenarios and group them to clusters. If further research is needed to reduce uncertainties, this is done in step 8. Step 9 is optional. Here quantitative models are developed, if necessary or even possible. The last step summarizes step 1 to step 9. All scenarios are evaluated and compared to the initial scope. They are analyzed for helpful outcomes and lessons learned. Applying these 10 steps can also help to develop risk scenarios, especially for external, speculative risks and afterwards determine the adequate correspond. This fosters the preparation for external risks and if they occur the handling of their impacts. Combining all these risk management control strategies an organization can cope with risk (and chances) in a structured and standardized way.

To build a risk-based management control system according to Simons diagnostic control systems it is crucial to define the relevant risk information. This risk information helps to find the correct predictive model after setting limits for risk. It has to represent the corresponding risk that needs to be managed and is later integrated into the planning and control system. For the control process, it is crucial to have an adequate predictive model to forecast the effect of the control activities on a process (Otley & Berry, 1980, p.236). As with any control system a desired outcome value for the risk information is set. This value is frequently compared to the actual value. If there is a mismatch that is out of tolerance a control action is initiated. This action depends on the risk type and therefore the predictive model. Usually, especially in operational management, for example quality management, the risk control systems tend to be reactive risk limit systems. Corrective actions are taken when quality characteristics are out of limit.

As Göstl and Schwaiger (2016, p.12) point out, the importance of risk information is also highlighted in ISO 3100:2009 (ISO 2009, p. 8f), although ISO does not clearly describe the importance of adequacy. COSO (COSO, 2004) integrates risk information by defining risks and chances that influence the achievement of objectives. In operational and financial management risk information can be proven regarding accuracy and validity frequent business cases. The forecasting can then be improved iteratively. In strategic management risks that emerge in strategic management can be linked to a risk information that is scaled qualitative. Also, some indicators that tend to reflect changes in business environment in advance can be found and monitored to detect signs of scenario deviations.

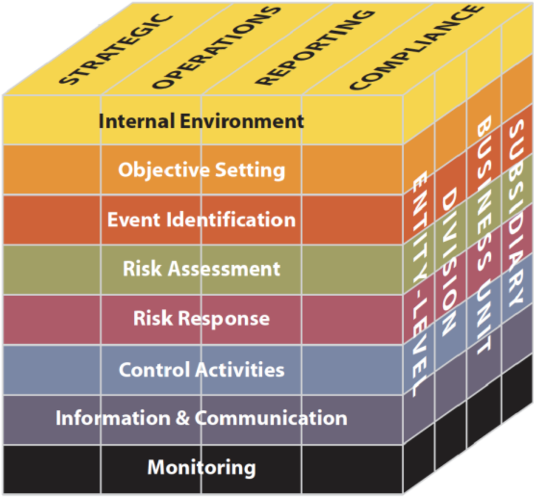
2.6 Risk Management: ISO and COSO

As already described, resilience deals with uncertainties and risks. Resilience management is therefore closely related to risk management. Brunsdon & Dalziell (2005, p.28) describe resilience is applied by *"…combining a strategy of managing identified risks with an ability to respond effectively when a crisis actually happens."*

In general, risk management frameworks focus on reducing and preventing risk as resilience management does. The main difference is that resilience also includes recovery activities and therefore adds crises and business continuity management. This is also found by Preis (2013, p.70). The most commonly used standards for risk management are the ISO 31000:2009 (ISO, 2009) and the COSO Enterprise Risk Management (ERM) standards (COSO, 2004). ISO 31000:2009 structures their risk management framework in relation to a plan-do-act-check cycle. The foundation of this are 5 key components that ensure the commitment of the management and set up activities for designing, implementing, monitoring and improving risk management (ISO, 2009, p.8f). The ISO 31000 framework is not restricted to any specific industry or management area and can be applied in various contexts.

The framework that fits the purpose of this thesis better is COSO ERM (COSO, 2004), as it has an alternative risk understanding. COSO focuses more on targets and objectives, and then in retrospective asses which risks threaten their achievement and which chances enforce or even leverage such. Therefore, COSO is more suitable to build and integrate risk management for different business units inside a company separately, such as the production planning and control system covered in this thesis. They consider risk management to be implemented on entity-level, division, business unit or subsidiary. The COSO ERM Framework also addresses different categories of objectives. To manage risk management control activities, they divide a company's goals into strategic-, operations-, reporting- and compliance-goals. Over this grid of company-level and goal category COSO lays a sequence of 8 activities that represent the steps that have to be performed to apply the framework. This framework can be pictured as a 3-dimensional figure, the COSO-Cube (Figure 5). As the risk and resilience management part of the framework created for this thesis are leaning to the COSO ERM Framework (COSO, 2004), the 8 components are explained in an overview.

Figure 5.: The COSO-Cube



(COSO, 2004, p.7)

Internal Environment

The internal environment of an organization represents its culture and values. It is the internal structure of ethics, decisions making, authority and history. Also, it describes the risk management philosophy of a company and which competences participants have regarding risk and opportunity management. This needs to be analyzed when starting with the framework.

Objective Setting

After the internal environment is analyzed, the goals that are set in strategy are transferred to operations, reporting and compliance objectives. These are later linked to risk events.

Event identification

The identification of events does not only focus on negative events, but does also look for opportunities that evolve from specific events. Whilst risks are managed with respond and control activities, opportunities can be transferred back into strategy planning to reevaluate objective settings. COSO does suggest different tools to identify relevant events. Depending on context of the organization and scope of the assessment, there are different techniques that range from widely creative to strictly structured. After Events are identified, they suggest to categorize them in groups as basis for the risk assessment.

Risk Assessment

After risks are identified, the extent to which they impact the fulfillment of set targets is considered. This can be done by estimating the probability of these events to happen and their impact when they occur. Also, relationships and interdependencies of single events are analyzed.

Risk Response

When risks are identified, assessed and grouped if possible, adequate respond strategies are developed. Therefore, responses are categorized in 4 groups: Avoidance, Reduction, Sharing and Acceptance. Avoidances aim to minimize risks if possible, by exiting causes for this risk. Reduction is connected to taking actions that reduce either the impact or the likelihood of a risk. If the respond strategy to risk is set to be sharing it means, that the likelihood or impact of a risk events is not directly reduced in total, but shared with other organizations or departments. This way the risk is reduced for each individual unit.

Control Activities

The strategies and guidelines determined for risk response need to be transferred into standardized procedures and policies. To enforce compliance to such standards, various control activities are established. This can for example be in the form of approval steps, performance reviews or verifications.

Information and Communication

This activity is mandatory for the viable implementation of risk management into the organization. The gathering of information regarding risks, responsibilities and the communication of such is crucial to demonstrate the importance of the developed management system. Communication has to flow thru all levels and hierarchies of the organization to ensure commitment of all participants.

Monitoring

By frequently evaluating the accuracy and effectiveness of the established risk management system its performance is monitored. The scope and frequency of such evaluations can differ and should be planned to ensure efficient reporting. The monitoring is important to continuously improve the management of risks, risk responses and control activities.

In general, the COSO and ISO Framework obviously focus more on enterprise risk management and less on resilience itself, especially in planning and controlling systems. Both emphasize the importance of risk assessment and managing in advance but less on managing the organization in presence of occurred turbulences in the sense of resilience. This shows that although parts and suggestions of COSO and ISO can be used to design a resilience framework but need to be adapted and combined with other approaches.

2.7 Summary Chapter 2

In chapter 2 of this thesis, theoretical considerations, used to build the framework as artifact in a further step where shown. The purpose and the main components of a traditional production planning and control system where explained. These components where determined to be order generation, order release, order sequencing and production control. This configuration of a PPC serves as basic understanding for the modeling of the framework that this master´s thesis strives to provide. The purpose of a production planning was found to be the linkage between customers or sales and production. Following, the principals and definitions of resilience where described and compared to literature. The summarized understanding of resilience is that is the ability of as system to avoid and endure disruptions as long as possible and recovery quickly to keep the severity of the impact low. As this framework aims to make an existing system resilient, characteristics of a resilient system where defined. To show the application and contribution of resilience, resilience management was explained. Therefore, the phases of a disruptive event and its impact on performance was shown. As it was found that to introduce and enforce resilience in an existing system it is necessary to make this system measurable and controllable, diagnostic control system where introduced. With this model of management control, it is possible to measure, monitor and control a systems performance to achieve targets implemented via critical performance variables. As resilience was determined to deal with managing risks and controlling their probability and impact, an approach to categorize and plan risks and their corresponding risk information was explained. This risk information and the control systems are the basis for developing and integrating resilience in this framework. To also consider a standardized approach of how to structure and perform a risk assessment and concluding risk management, two common standards, COSO ERM and ISO9100, where mentioned. As the structure provided by the COSO ERM Framework suits well for the context and scope of this thesis, the suggested steps where explained. The combination of these theoretical considerations will be the background of the framework for the integration of resilience into a traditional production planning and control framework.

3. Modeling a traditional PPC Framework

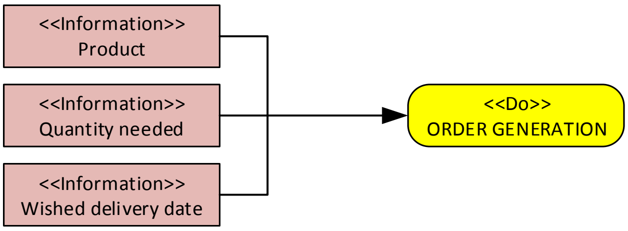
When researching for state of the art knowledge on resilience in organization and production systems it was found, that many highlight the importance of transparency of processes and corresponding responsibilities when building up resilience in existing systems. Schuh et al. (2013) state, that the lack of understanding, due to transparency issues often leads to false control decisions. They show, that the structure of the formal decision process and the transparent communication of how and where information is stored and available, as well as the awareness of process targets is a key to resilience. Wieland & Wallenburg (2012) also found that agility, which they consider as one of two dimensions of resilience, requires visibility. This also includes activities and information processes have to be visible for all participants. Heinicke (2014) shows, that by at first mapping the key processes of production planning and control and building on that identifying route-cause of risks resilience can be designed and integrated.

3.1 Functional Map: The Process of Production Planning

As explained above a production planning and control system is responsible for generating, releasing and scheduling production orders to either directly satisfy customer demand or produce on stock for future demand. In the following a traditional production planning and control system is modeled in regards of its processes, step by step, considering activities, information and resources. This functional map that is created with orientation to activity charts according to unified modeling language (UML) will serve as an example illustration of a traditional production planning and control systems. The modelling and illustration of the functional map of a production planning and control system as suggested by Heinicke (2014) will contribute to making this system transparent for further building the framework for resilient production systems.

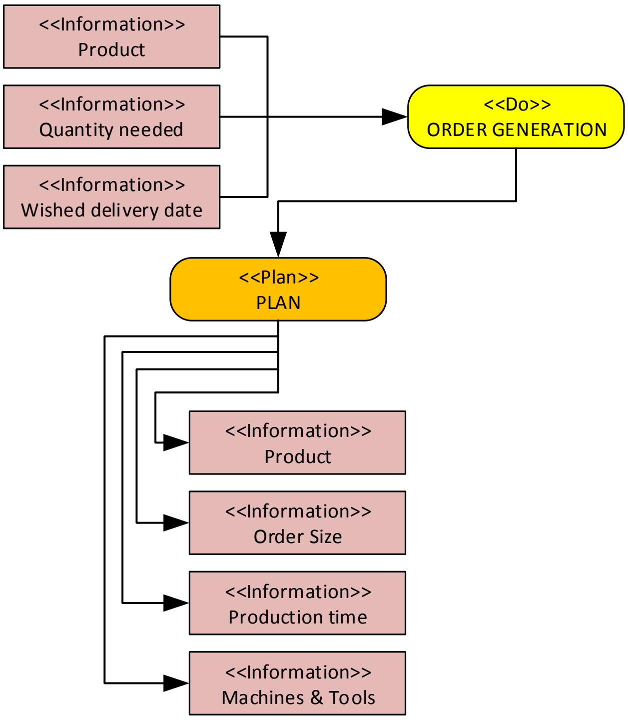
The process starts with a customer ordering a product that is not on stock and only available after production. It is considered that the customer places his order and the sales department then translates this order into the information the production needs to generate a production order. This means that the initial input for this example process is the request for a production and the information which product is required at which quantity for which wished delivery date. That information will be the basis for the order generation

Figure 6.: Customer Order as Input for Order Generation



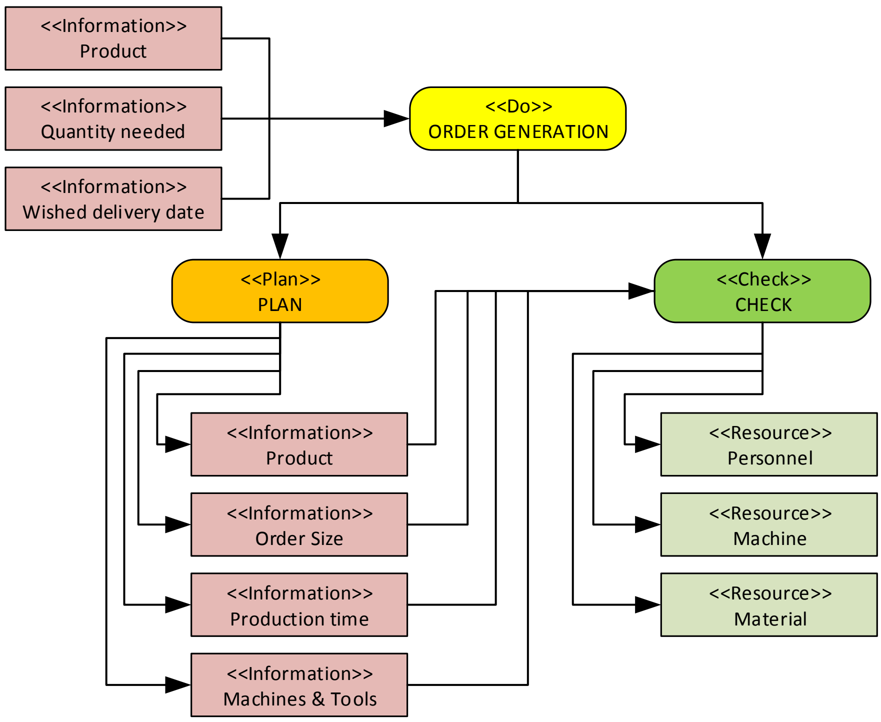
Now that the order generation is initiated, a plan-activity is started. The information about the ordered product is transferred into production information about this specific product. The demand from the costumer is considered when planning the quantity for production. This quantity can differ from the ordered quantity for example due to minimum order sizes concluded from efficiency aspects, as well as planned future demand. From this order sizes, the production time that is needed to produce this quantity is conducted and also the machinery and equipment that is necessary to fulfill this order.

Figure 7.: Transferring Information at Order Planning



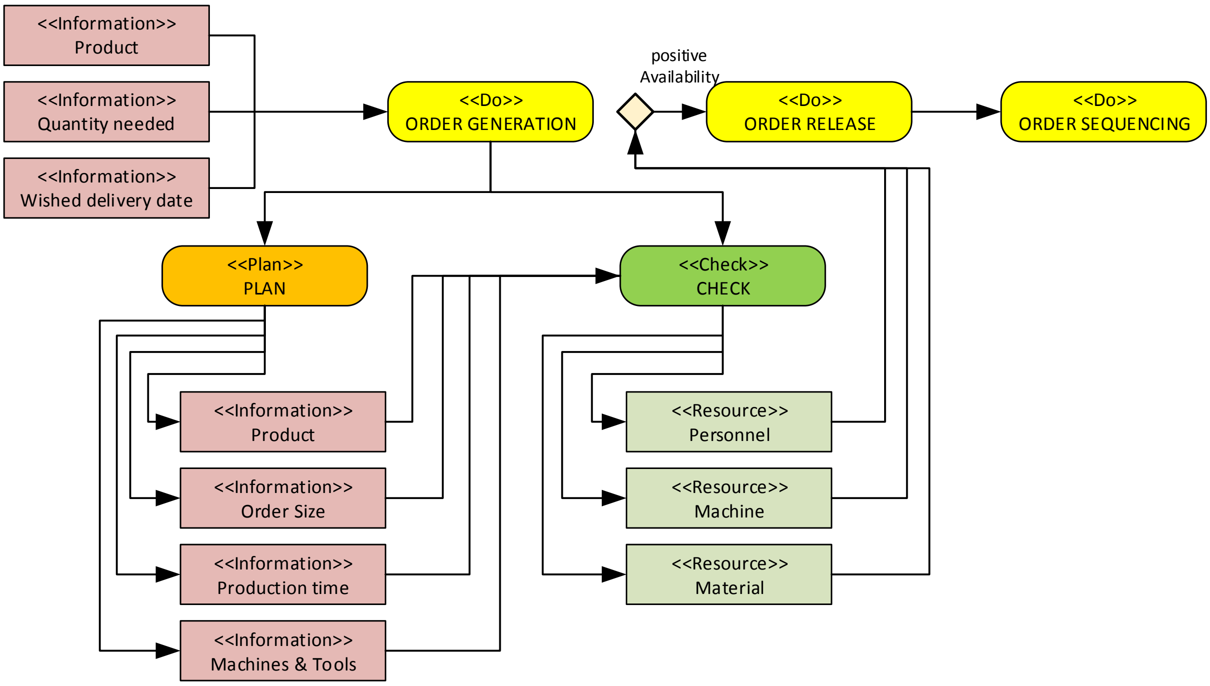
The information from this plan-activity is then forwarded to the check-activity where the resource demand regarding material, machinery and personnel is checked against actual stock and availability. The resource in terms of material, such as raw-material, additives, packaging, etc. is checked according the products receipt. The personnel availability and free machine capacity is checked against the current production and staff plan.

Figure 8.: Checking Resources According Order Planning



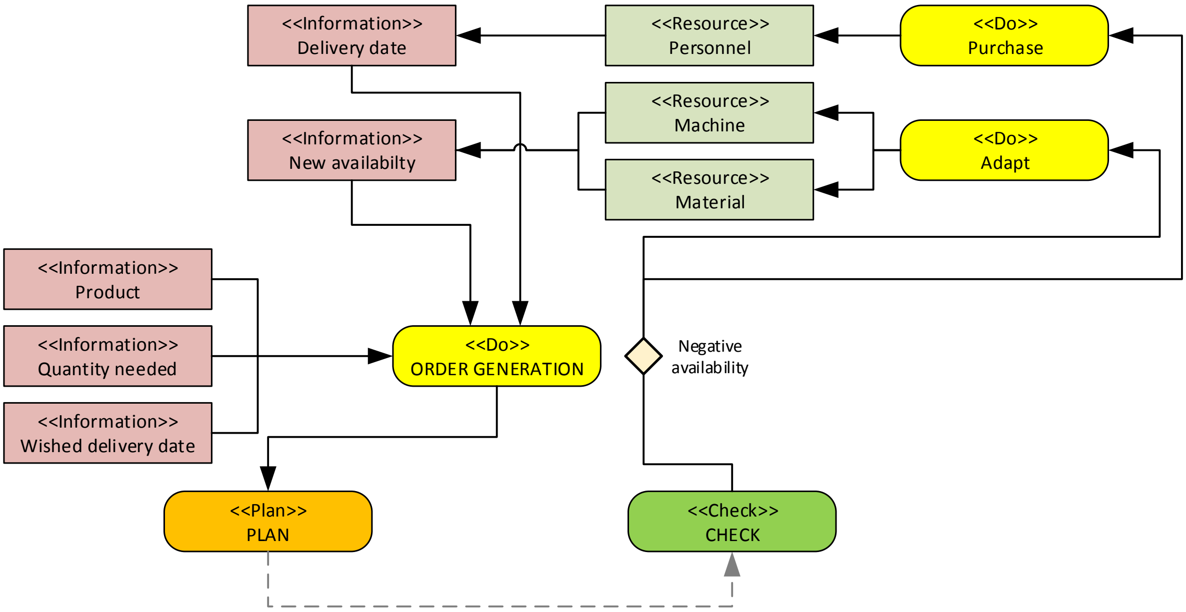
If all resources required for this specific production order are available, the order generation, consisting of order planning and order checking, is finished and the order is released.

Figure 9.: Order Release to Order Sequencing



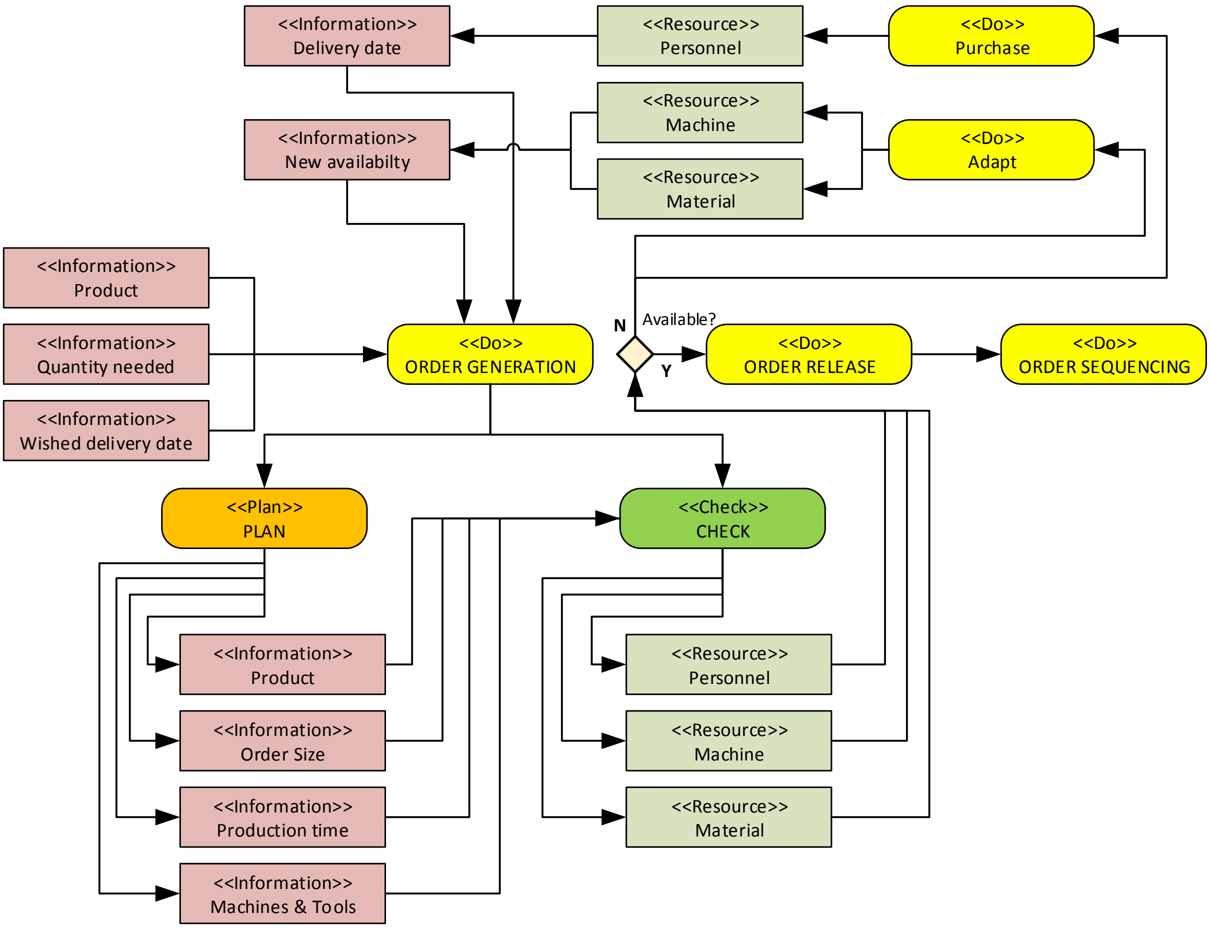
The released order then has to be fitted into the schedule of the production program. This is done in order sequencing. If the availability check of resources is negative, additional activities have to be performed before releasing the order. If to little personnel resources are available, then typically there is the possibility to temporary order support from external personnel suppliers, or adapt current resources to new priorities. The last one, also goes with availability of production machines and equipment. If machines that are mandatory to produce this certain product are occupied at the targeted time when planning the order, the availability can be replanned and adapted. This purchasing of material, or the adaption of machinery and personnel leads to new information like alternative availability or delivery date of material, which is then considered again when the plan and check cycle of order generation starts again.

Figure 10.: Adapting and Replanning Availability of Resources



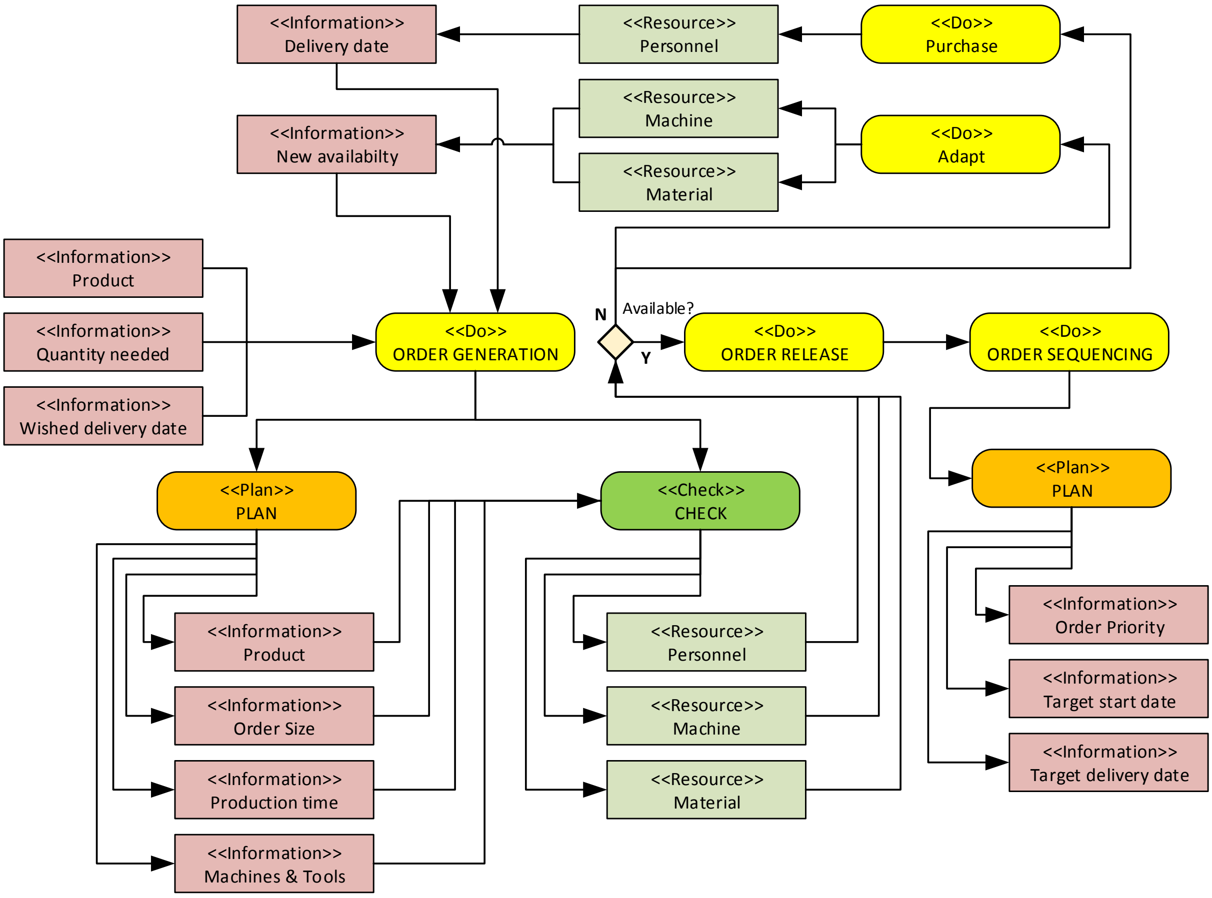
If this loop of adapting and purchasing is successful, the resources are available when needed, the order is released and moves on the order sequencing.

Figure 11.: Order Release to Order Sequencing



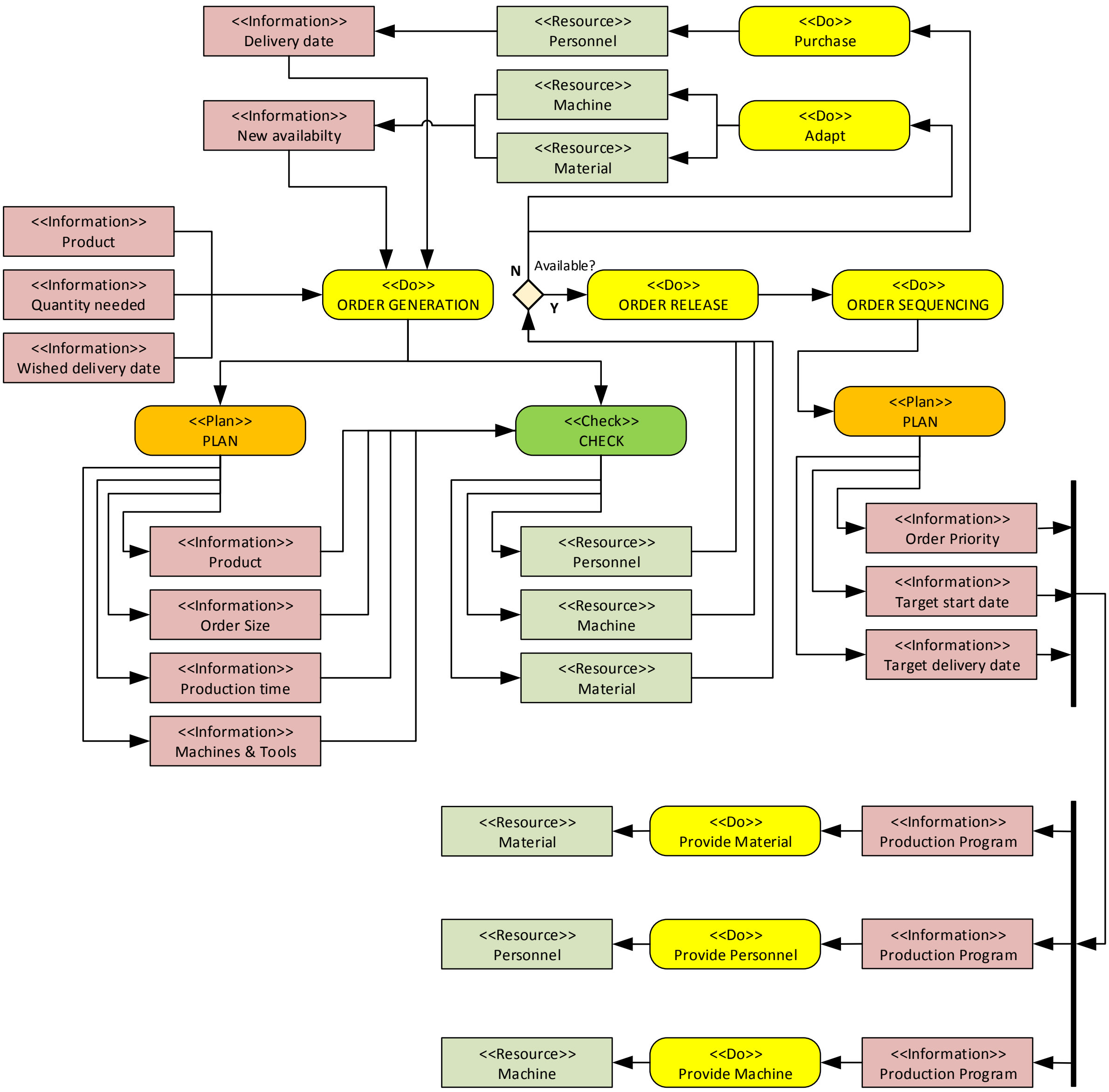
The order generation and following order release activities will possible be performed several times a day for several different products. This leads to many released orders, waiting in line for production. The order in which those products get produced is determined with the order sequencing activity. This prioritization and sequence of orders can have different reasons. It could be to meet a fixed delivery date or to ensure high utilization of production equipment by combining the production of similar products to minimize downtime due to set up time needed to change tools. The output of order sequencing is the production plan.

Figure 12.: Order Sequencing to Planning



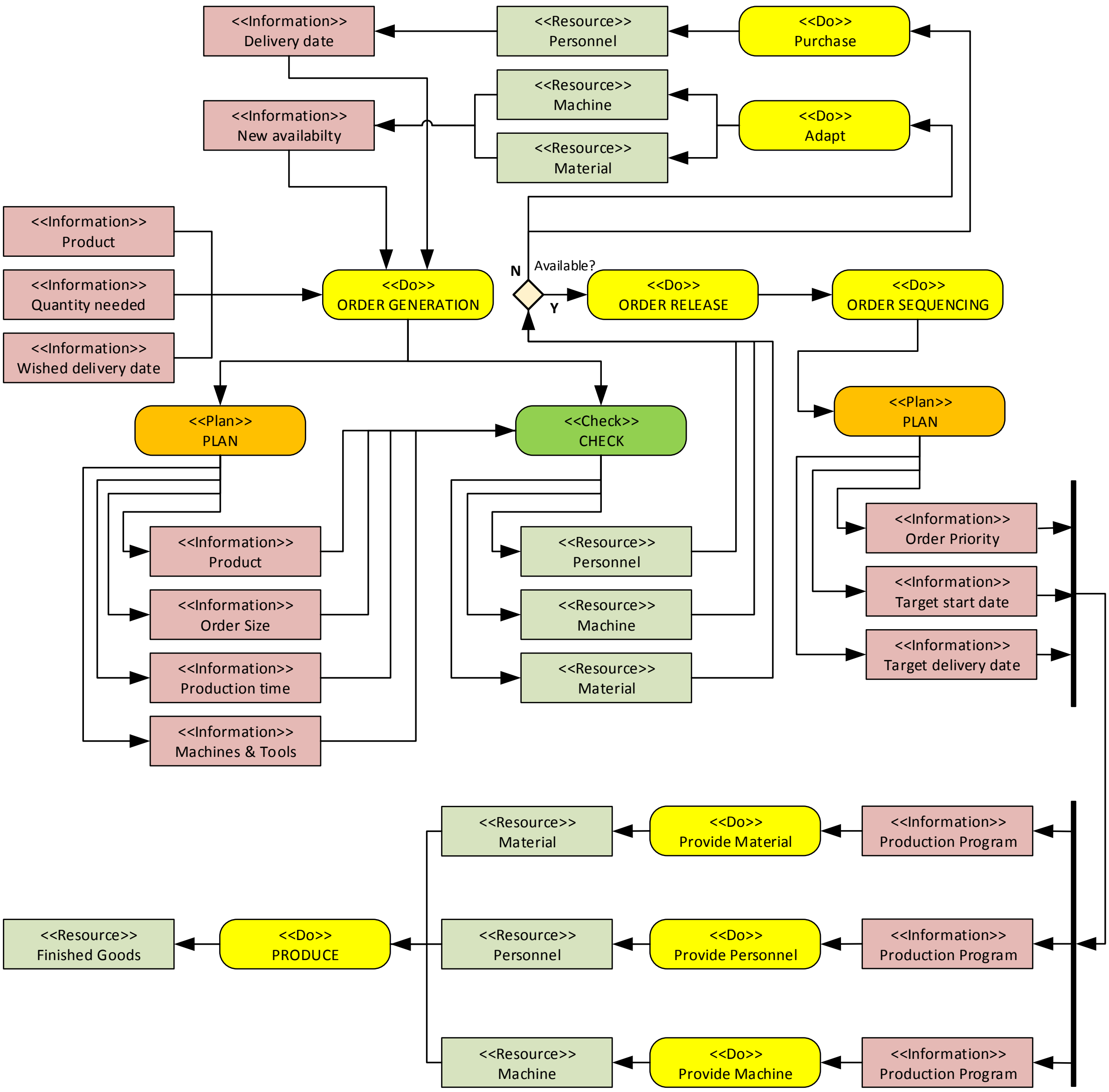
The production plan shows which product should be produced in which quantity with which production machine and personnel demand in which time following what previous production order. This can also be called the production program. This program is the basis for material handling, production management and mechanics to show them when and where they have to provide the resource they are responsible for.

Figure 13.: Transfer to Production Program



If material, personnel and machinery are available and set up according the production program, these resources are transferred into the finished good in the production-activity. This finished good is then usually handled by the logistics department and prepared for delivery to the customer.

Figure 14.: Functional Map of PPC



The activity chart shown above now summarizes the main steps and activities performed in a production planning and control system, although the focus is more on the production planning part. The production control´s responsibility is to control all these activities and ensure their compliance to the production program and their contribution to achieving the overall goals for the production system. These responsibilities are spread amongst different roles inside the production systems, with different tasks for each.

3.2 Preparing for Route-Cause: Roles and Responsibilities

As suggested by Heinicke (2014) the next step for a transparent functional map is to apply roles and hierarchies to the activities of production planning and control. Since the functional map used in this thesis differs from the one shown by Heinicke, also alternative roles and hierarchies are applied. Again, the suggested roles and activities serve as example to illustrate the development if the framework. The importance of this transparency in regards resilience is also highlighted by McManus et al. (2007) in their research.

"Many organisations do not have an accurate vision of their own importance in the community. Following a crisis most organisations expect that support would be immediately available; extra staff, water supplies, builders, insurance assessors. Other organisations that do have an important role to play in community recovery had poor knowledge of this role and how to manage community expectations."

McManus et al. (2007, p.v)

The context of McManus et al. research was several organizations that have a role in public and federal communities in terms of service and support. This can be transferred to roles of departments inside the production system, so the organization would for example be the material handling and the community the production planning and control system. The importance of the awareness at the hierarchic level where resilience is needed in case of a disturbance is also underlined by Sheffi & Rice (2005). This shows that to enforce resilience later in the framework, every participant of this production system has to be aware of its roles and responsibility in this construction. Therefore 5 key roles in the production system are established.

Production Planning

As already explained in detail above, the production planning generates, releases and sequences production orders. Their input are customer demand and sales forecasts. They strive to accomplish high utilization of machinery, short production- and down-times and cost-efficient allocation of resources. The production planning is responsible for generating the production program.

Material Handling

The material handling provides and manages the raw and packaging material to produce the products according to the production program. They have to make sure, that the required material is provided in time at the correct production machine and that the material stock is kept in order. Also, they handle the finished goods in terms of warehouse management and delivery.

Production Management

The production is usually managed by foremen and shift operators. They manage the production staff and operate the machinery and therefore provide the personnel resources to actually perform the production of products. The production management is mainly responsible to produce the products according to the production program. They are also responsible to produce the products compliant to quality standards and customer requirements. Their goal is usually to produce as much as possible in a minimum of time with minimum personnel and resource demand. This also includes the goal to produce as less scrap as possible.

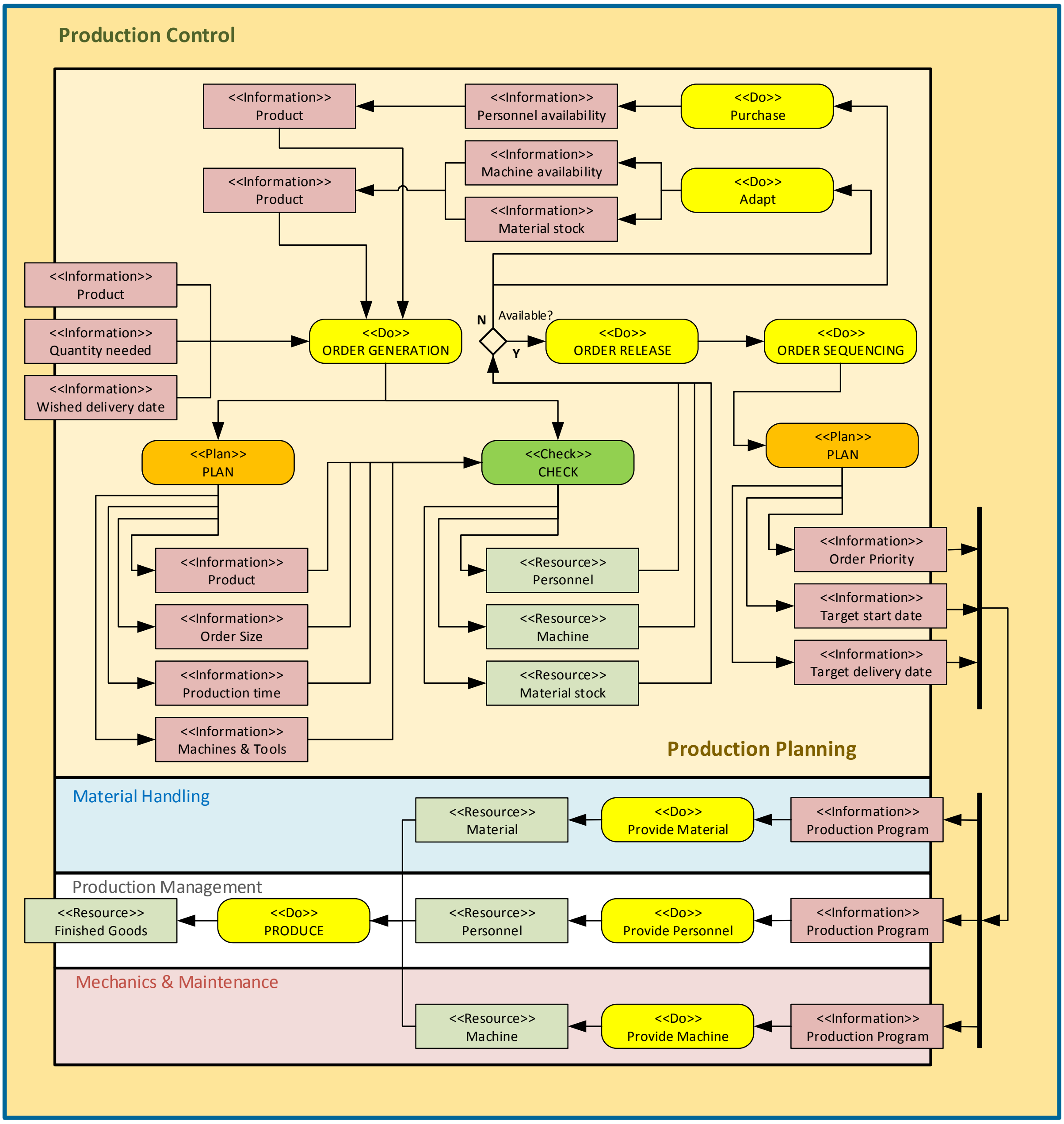
Mechanics & Maintenance

This department supports the production in operating the machinery. The mechanics are responsible for setting up machines with the right tools and equipment to produce the products according the production program. The maintenance department services and checks the machinery and equipment to keep it operating as long as possible. They perform frequent, planned maintenance as well as repairs in case of a break down.

Production Control

Finally, the production control controls all those roles and responsibilities and that they perform according the given production program. If any deviation from this plan is detected, it changes and adapts accordingly. Figure 15 shows the active chart as developed above combined with the explained roles and their location in the process.

Figure 15.: Functional Map of PPC with Roles and Responsibilities



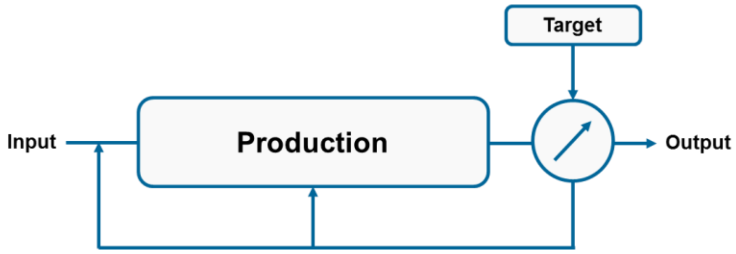
3.3 Diagnostic Control Systems: Modelling Production Planning and Control

The activity chart combined with roles and responsibilities now pictures a traditional production planning and control system. This system has to be transferred into a diagnostic control system according to Simons to make it controllable in terms of management controls. To make it controllable, it has to become measurable at first. As Simons determined, a diagnostic control system shows the following characteristics (Simons, 1995, p.59):

- *"The ability to measure the outputs of a process*
- *The existence of predetermined standards against which actual results can be compared*
- *The ability to correct deviations from standards"*

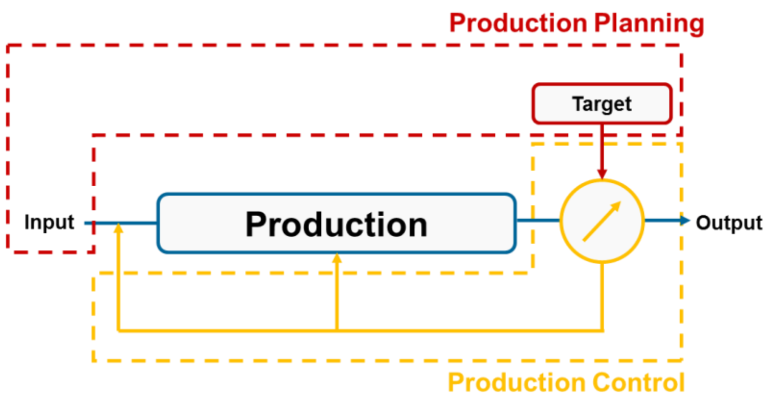
To model a production planning and control system as diagnostic control system, the figure of a single loop control system as shown by Simons (1995, p.60) is used. The system, process or service that is controlled is the production. This brings the simple illustration as shown in figure 16.

Figure 16.: PPC as Diagnostic Control System



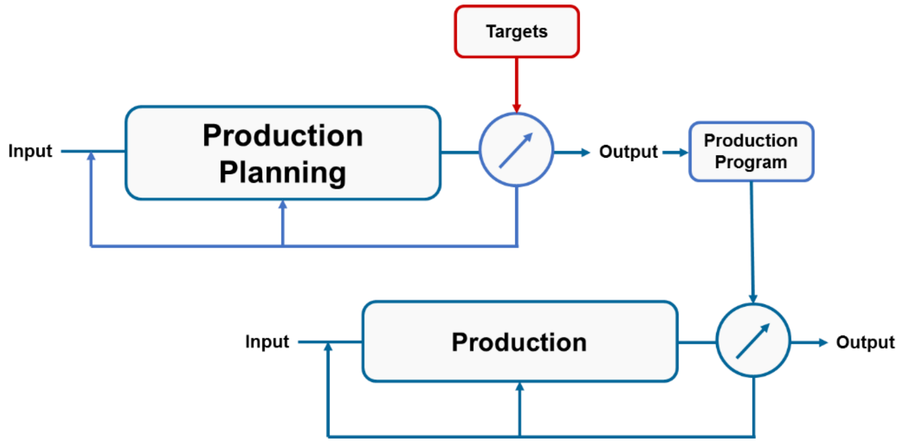
As explained, the production planning and control is responsible for generating the production program and ensuring that the production system operates accordingly. Therefore, the production planning generates the target for the production which is the production program and the production controlling controls the operating of the production. Therefore, the first adjustment to figure 16 can be made.

Figure 17.: Separating Planning and Control in Diagnostic Control Systems.



This shows, that the production planning itself is an own diagnostic control system. The output of this system is the production program which again is the target for the production control system.

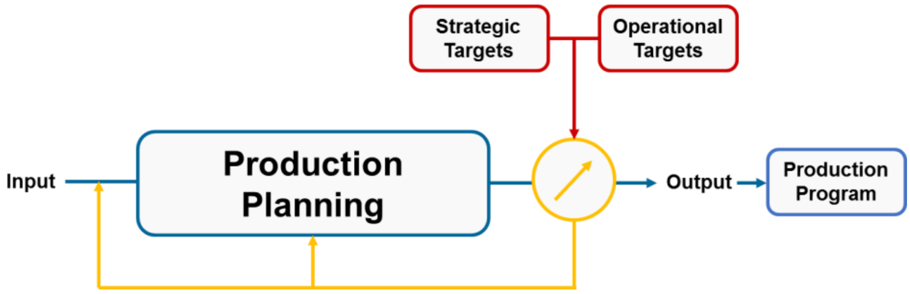
Figure 18.: Modeling Production Planning as Control System



Starting with the input for this production planning diagnostic control system the production planning is performed. The inputs can be forecasted demand, customer demand, etc. The target set for the production planning consists of many different objectives. Those have to be studied more in detail.

As explained with risk types and critical performance variables, the targets set for a production planning system can be categorized. In general, it can be separated between operational targets and strategic targets. Those targets are set from management and are the overall targets for the whole production system. All other targets derive from them. The main task of the production planning is to translate this goals into targets for production and production control and embed them in the production program. This ensures a top-down management of objectives.

Figure 19.: Separating Target Types



Strategic targets are considered as targets that are not directly related to every-day operating and do focus more on long term direction of the production and enterprise, as well as the mastering of business environment challenges. On the other hand, operational targets are dealt with on a daily basis during regular production processes. To further model the production planning and control system as diagnostic control system an assessment for each operational and strategic target has to be done. Then critical performance values as explained by Simons have to be determined for every single target. Together with the corresponding measurement, which have to be objective, complete and responsive, this completes the modeling.

3.4 Targets in Production Systems: Variables and Measurements

As targets are various, a few examples are taken to resume the modeling as explained above. For demonstration purpose, typical targets for a production system are selected.

T1: Target 1 – Secured Material Supply Chain

This target aims to secure the supply of material for production. This means, that in any scenario the material required for production will be available for production at the moment it is needed according to demand forecasts and the production program.

T2: Target 2 – Efficient Production

Efficiency is key. Often efficiency refers to output per input. This could for example be units produced per hours of production, which is in terms of efficiency the higher the better.

T3: Target 3 – High Machinery Utilization

Especially in mass production machines should produce as often and long as possible to keep unit costs low and avoid unnecessary down time. Depending on shift model for personnel, holydays and mandatory maintenance there is a number of hours that is theoretically available for operating the machine and producing units. If every single hour of this available time is used for production the utilization level would be 100%. This means, that there is no break down, unplanned repairs or adjustment during production. The target of high machinery utilization is to operate the machinery as much as possible in the available time.

T4: Target 4 – Low Personnel Costs

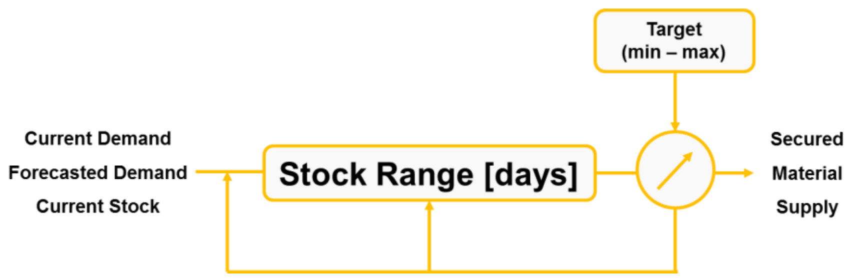
The target to keep the expenses for personnel costs in budget is often crucial for a cost efficient and competitive production. This does not mean to fire all employees, or break any laws, but encourages production managers to carefully manage their staff resources. Often this is supported by hiring temporary personnel if the production is depending on seasonality. Therefore, managers can achieve to exactly have the personnel resources they need, which is even more important in production systems with a low level of automatization.

After defining targets, now the critical performance variables that represent those targets have to be determined to continue with transforming the production planning and control into a diagnostic control system. When the variable is found, the adequate measurement has to be identified. By categorizing the target type in strategic or operational it will be easier to afterwards find the corresponding risk type. If then a target value for the critical performance value is set, each target can be pictured in a diagnostic control system.

T1: Secured Material Supply Chain – Critical Performance Value and Measurement

A secured material supply chain depends on demand, supply and current stock of materials. As Simons suggests a practical way to find adequate performance values for a target is to ask what was the reason it went wrong when a target is failed to achieve. So, if the organization failed to secure material supply for production in case of higher demand or a missed delivery from a supplier it would suggest that they had to less stock range to endure this. This concludes that an adequate critical performance value for the target of securing material supply for production is “stock range”. Stock range describes how long a production can be satisfy its demand of raw materials from current stock. This could be measured in days. The calculation of stock range is done by setting the current stock quantity in relation to demand, which could be a monthly average or real-time demand from running production. A stock range of 30 days shows, that the material supply for production is secured for 30 days. By assessing how long it takes to find as alternative supplier or get a new delivery a target value for this stock range can be determined. The lower limit of this target is represented by the minimum time to get new supplies, whilst the upper limit is based on stock capacity and economic considerations. The securing of materials supply is a strategic target. It aims to continue the operations over long terms to fulfill every customer order and ensure revenues from sales of products. Figure 20 shows target 1 modelled as a diagnostic control system. To make sure, the chosen measurement is in accordance with the characteristics suggested by Simons it is tested regarding its objective, complete, responsive properties. The measurement of stock in days is objective. It can hardly be interpreted wrong as demand and stock and therefore their relation is set. It also represents a complete measurement for material supply. It takes demand and supply and therefore considers input and output of the supply chain. The responsiveness is influenced by the frequency of it being measured. As long as current stock and material need are known, it can be calculated in real-time. The stock range can for example be controlled by ordering new material supplies if needed, canceling planned deliveries or adapting production order volumes.

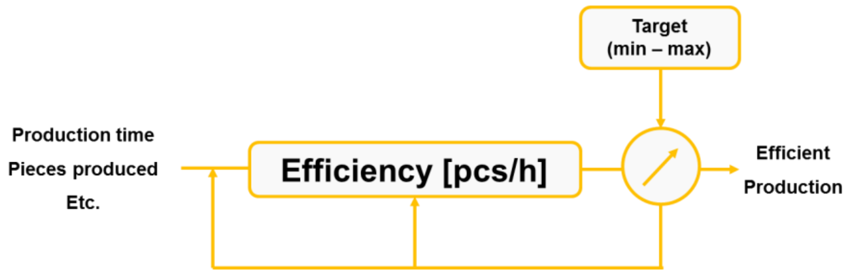
Figure 20.: Control Loop for Example Target 1



T2: Efficient Production – Critical Performance Value and Measurement

The critical performance variable for this target is addressed in the target description. Efficiency in production can be quantified by measuring output unit per input unit. Therefore, an output unit that describes the process it represents best has to be taken. The input unit can be raw material, time or monetary. Taking a manufacturing of assembled parts as an example, the measure would be produced pieces per hour. To specify this, only pieces that pass the quality testing that is performed after assembling are counted. This means, if the efficiency measurement shows a low value, there is a critical amount of parts that are produced not fulfilling quality standards. The control-activity would then be to assess the process in detail and analyze the cause of such negative performance. The target value is determined by benchmarking former calculated efficiency values. The lower limit is set due to economic aspects, for example by calculating the resulting costs per unit with minimum efficiency and comparing it to target profit. The upper limit might not be necessary in this example. This target can be pictured as shown in figure 21. Since this target primarily focuses on how the production is operated, it is considered as operational target. Again, the measurement must be checked regarding the 3 characteristics of adequate measurements for diagnostic control systems.

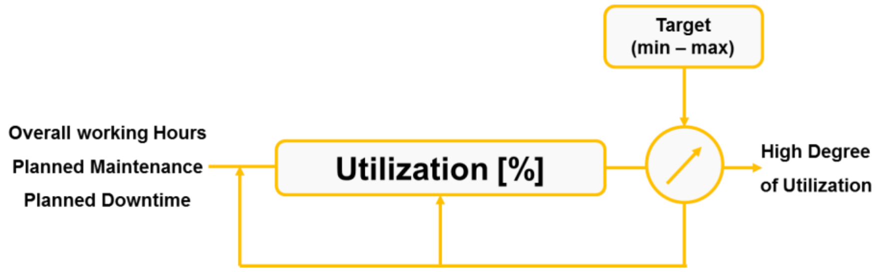
Figure 21.: Control Loop for Example Target 2



T3: High Machinery Utilization – Critical Performance Value and Measurement

As already explained above, a high degree of utilization is achieved by making sure, every available hour of a production machine is used to manufacture products. The critical performance value is again imbedded in the target formulation. The measurement for machinery utilization is degree of utilization in percent. If the utilization rate is 100% every available minute of production is used. The target value is again best identified by comparing and benchmarking. The range can for example be starting with minimum of 70% and be capped with 100%. The amount of available time has to be calculated for every machine by deduction planned maintenance and adjusting time from overall working hours. This target represents a productivity goal and is categorized as operational. The responsiveness of this measurement is ensured by its calculation. Every available minute that is not utilized for production lowers the degree of efficiency. This fulfillment of this target can be controlled by exactly managing maintenance and adjustment time, so that the production machines do stand still as little as possible. This target and its measurement are objective, responsive and complete.

Figure 22.: Control Loop for Example Target 3



T4: Low Personnel Costs - Critical Performance Value and Measurement

This target emerges from executing the strategy of keeping operating costs as low as possible, to stay competitive. It is therefore a strategic target. The critical performance variable for this target are the expenses for personnel in production. The measurement can be EUR per month and/or EUR in total as cumulative number. The objectivity of personnel expenses is simple. As soon as 1 EUR is paid for salary or other staff related expenses it is considered in this measurement, therefore no subjective interpretation is necessary. The responsiveness is also ensured by the frequency of payments for staff or for example the reduction of personnel costs by avoiding night-shifts and weekend-hours. To be complete, all expenses that are related to operating the machines for production have to be considered. The target value is set in the budget for the production department. This critical performance value is interconnected to a lot of other objectives. If the degree of utilization is low because maintenance and down time are longer than planned, production staff is waiting to operate the machine. If efficiency is low because a high number of not conform pieces is assembled, more working hours than planned are required to fulfill order sizes. This would all result in higher than planned personnel expenses. Ideally, the personnel expenses can be put into relation to units produced to take a higher than budgeted output of units into account.

Figure 23.: Control Loop for Example Target 4

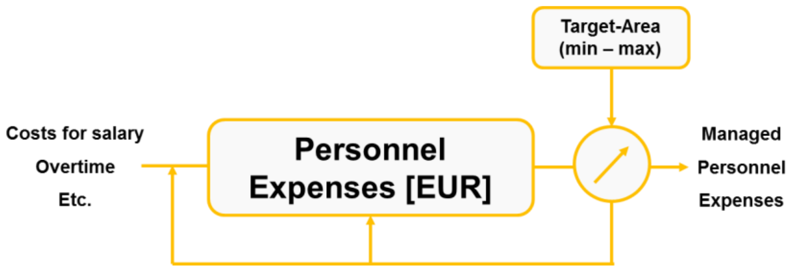
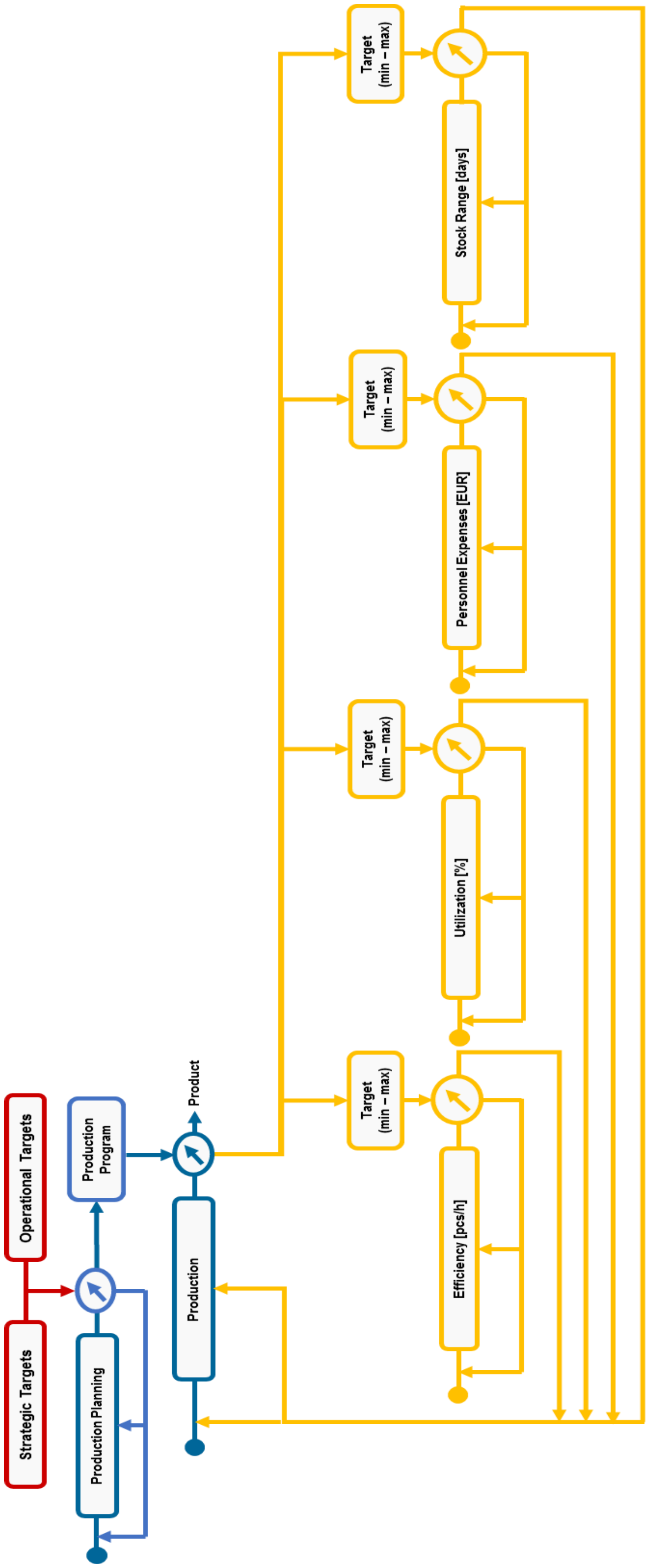


Table 3: Summary of Example Target Assessment

Example	Target	Target Type	Critical Performance Value	Measurement
T1	Secured Material Supply	Strategic	Stock Range	Range in Days
T2	Efficient Production	Operational	Output	Output per Hour
T3	High Machinery Utilization	Operational	Utilization	% Utilization
T4	Low Personnel Expenses	Strategic	Personnel Expenses	Costs for Personnel per Unit

As shown above with 4 examples and summarized in table 3, for every target regarding the production system there is a corresponding critical performance value, a measurement that is objective, responsive, and complete and the possibility to set a target value. By modelling all targets in terms of a diagnostic control system the illustration of figure 18 and 19 can be transferred into a more advanced one that shows that all targets set by management are embedded into the production program by the production planning. Figure 24 schematically shows, that the production controlling considers every single target as a control system with its inputs, outputs, measurements and target values. The summary of all these control loops pictures the production controls overall responsibilities.

Figure 24.: Illustration - Integration of Targets into the Control Loop of Production Control



3.5 Finalizing the Modell: Linking Targets to Responsibilities

After every target is modelled as shown above, the next step to build up resilience is to link targets and their performance variables to the roles and responsibilities inside the production system. Therefore, the inputs, outputs and measurement as explained above in the target formulation can be compared to the tasks and responsibilities as shown in section 3.2. This enables to located their role in the functional map as shown in figure 15.

T1: Secured Material Supply Chain – Responsibility

Considering figure 15 and looking at all activities and resources that are related to material stock and material supply, there are several areas where the fulfillment of this target is influenced. The material handling department provides material from stock for the production. They also are responsible for the physical managing of material stock. The production management consumes the material stock by transferring it to finished goods. The current and forecasted material demand is also influenced by sales and customers. With this example, the interdependence of all departments for the fulfillment of a single goal is clearly evident. Although, one single responsible role has to linked for the achievement of this goal. Bearing in mind that the production planning department is responsible for planning and checking material stock, as well as purchasing and reallocating the materials to enforce orders according their priority, this is the department that is mainly responsible for this target. More specifically this target can be monitored in the activity of order generation. This is where demand is planned and forecasted and current stock is checked. So, the control loop of example target 1 is embedded in this main activity.

T2: Efficient Production – Responsibility

To transfer the input of given resources to a maximum of output underlies the responsibility of production management. Considering that all required resources are provided, the production performs the activity “produce” as shown in the functional map. There the output per input is management. If the machinery and equipment is set up in ideal configuration, a maximum of efficiency is achieved. The responsibility of target 2 is located in the production activity of production management.

T3: High Machinery Utilization – Responsibility

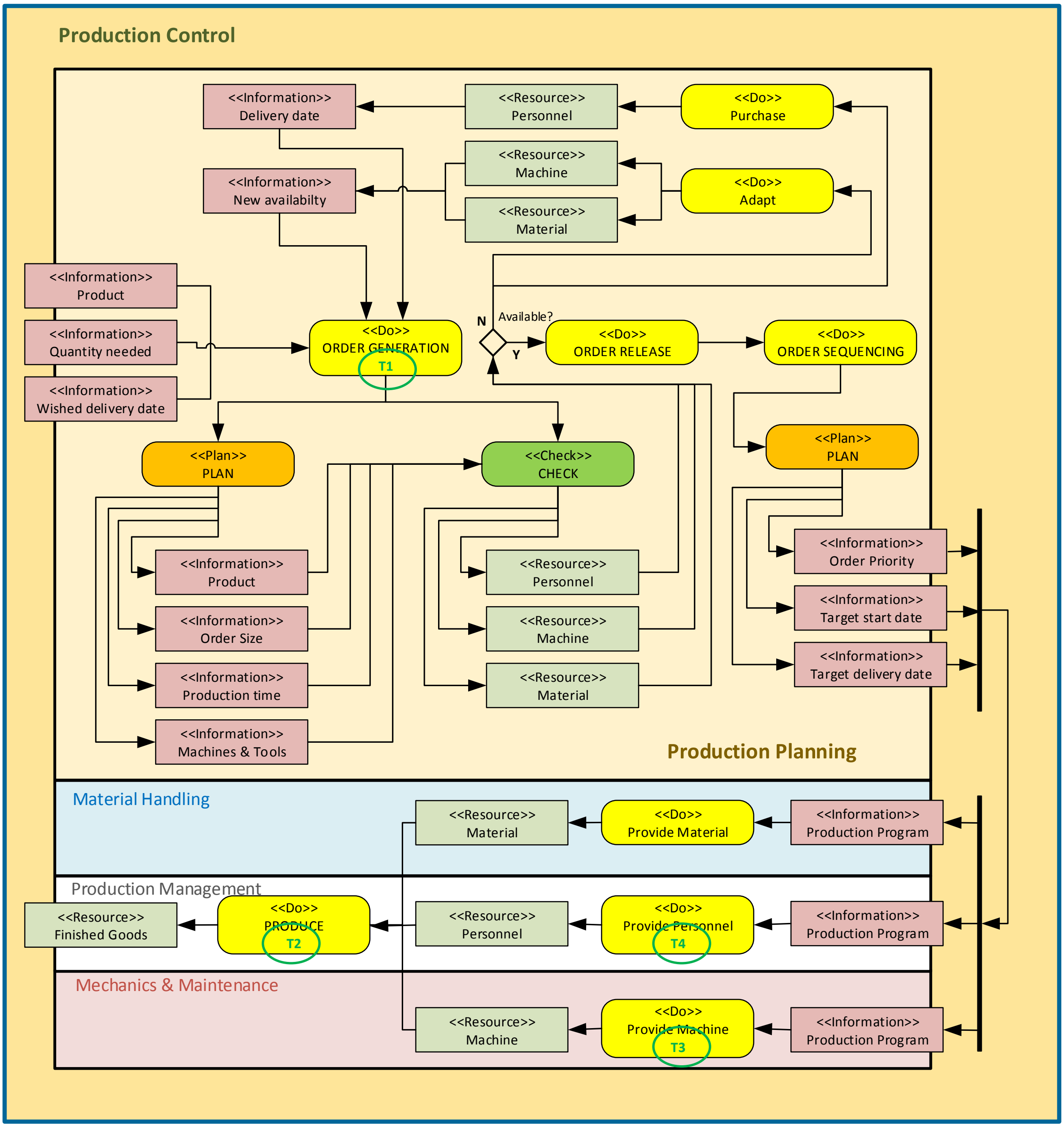
To ensure that the machinery and equipment is available when needed and that no breakdowns occur that could be prevented by maintaining the machines properly is the responsibility of the mechanics and maintenance department. They provide the machines according to the production program and have to take care of repairing and replacing parts in time and set up the hardware and tools to prepare them for production. Therefore, the mechanic and maintenance department is responsible for target 3.

T4: Low Personnel Costs – Responsibility

The management of production personnel requires constant adaption and attention according to the production program and quick adjustment if changes occur. Since production management finally fulfills the production program and is responsible for operating machines and providing personnel, target 4 is their responsibility. More specific, this achievement of this target is controlled on the "provide personnel" activity.

Depending on the number of targets, identified when modeling such a functional map with diagnostic control system, there are different ways to illustrate such a system with one figure. If the targets are numbered and can be linked to one specific activity, it is suggested to include the target number in the functional map. Another approach is to picture it as explosive or assembly drawing. This can then also include the control loop as pictured above. Figure 25 shows the suggested illustration with target numbers included in activity description.

Figure 25.: PPC Functional Map with Target-Responsibilities



3.6 Summary of Chapter 3

In chapter 3 the creation of the framework as artifact of this thesis according to design science research methodology has been started. The functional map of a traditional production planning and control system was developed in orientation to UML charts. Therefore, the processes of order generation, order release and order sequencing that lead to the generation of the production program where illustrated. This was done with considering information, resources, activities and their interconnection. It was shown that several steps are necessary from customer order to finished goods supply. To finish the modelling of the functional map for a traditional production planning and control system, roles and responsibilities where applied. This led to an activity chart that pictures the processes of production planning and control in a transparent way and takes the tasks of different departments into account. Building on this model, production planning and control was considered as diagnostic control system. The planning and the control part of production planning and control where modeled, separated and linked together by the production program. This shows, that the production planning generates the image of the production program with targets imbedded and the production control manages compliance to this image in production. The targets imbedded in the production program are transferred from higher strategic or operational goals. The integration of such into the production program is done by breaking those goals down into smaller, more specific ones. These are then analyzed regarding critical performance variables and corresponding measurements. By introducing 4 example targets this modeling of diagnostic control system with set targets, inputs, outputs, variables and measurements was explained. Each target was also illustrated as a control loop. These control loops were then connected to the tasks and roles of production planning and control system as the ones determined when modeling the activity chart. Finally, a complete image of the production planning and control system by combining functional map and diagnostic control loop models was created. This model shows the activities in the production system, its connection and roles. The roles and activities are further linked to individual targets to show responsibilities and main tasks. The targets are represented by control loops that enable the responsible individual unit to control and manage the achievement of its targets. This transparency communicates a clear understanding of the landscape and responsibilities and is the fundament for the further framework development.

4. Modeling a resilient PPC Framework

Since resilience has to do with avoiding and enduring disruption, one has to think about which disruption can happen to either take preventive actions or otherwise prepare guidelines and structures how to act in the presence of such. As explained in section 2 of this thesis and suggested by several frameworks on risk and resilience management, the creation of resilience frameworks always consist of few consecutive steps. For this framework 6 steps will be performed. At first risks that threaten the production system and the achievement of its goals are identified. Then, these risks are analyzed in terms of probability and impact. After, the corresponding risk information that will serve to control this risk will be determined. By linking the risks to specific targets that will be affected if such risks occur, the linkage between risk, risk information and the main risk holder in the functional map of the production system is drawn. This way, the unit responsible for the target, control loop and risk can be identified. By developing adequate respond strategies, suitable and applicable to the corresponding role in the production system, the requirements of preparedness and flexibility will be fulfilled.

4.1 Identification of Risks

To narrow the scope for the identification of risks, the focus of this assessment is limited to the 4 example targets as exercised before. The goal is to identify events that have a negative impact on the achievement of these goals. Techniques for the event identification are various and can be found in several different frameworks. Also, different approaches can lead to similar risk findings. Therefore, one suitable method that would have led to the found risks influencing the example targets are mentioned for each.

T1: Secured Material Supply Chain – Risk Identification

If the main supplier for a raw material goes out of business without prior notice, or has severe breakdown in his production plant, this would lead to missed delivery dates and shortage of material. This means, that the required and scheduled material delivery according to the production plan is not carried out. Therefore, the material supply is not secured and the fulfillment of target 1 is not achieved. Such a risk scenario can be found with scenario planning as shown by Shoemaker (1995).

T2: Efficient Production – Risk Identification

A condition that can cause that the set target for efficiency is not fulfilled is, if the output of a production machine is lower than predetermined. This is caused by a wrong or at least not ideal setup of machines by operators. If the process parameters (pressure, temperature, speed, etc.) are not set and combined to ensure maximum output. The production machines do not perform at the efficiency level they are capable and the targeted value of pieces per hour is not met. This risk can be identified by interviewing operators and mechanics and analyzing data from past productions.

T3: High Machinery Utilization – Risk Identification

If a machine breaks down due to bad maintenance it needs repair or even worse, cannot be fixed. This immediately lowers the degree of utilization and also influences other objectives. If the machine cannot be utilized for production as planned, the targeted degree of utilization is not matched. This risk can also be identified with scenario planning or interviewing operators and workers.

T4: Low Personnel Costs – Risk Identification

The negative events that affect this risk can be various and are more indirectly hinder the achievement of this goal. The personnel costs in production are too high, if staff is not managed in accordance with the production output and utilization. This means, that when a machine breaks down, or production volumes are decreasing, the allocation of personnel has to be managed consequently. Otherwise the personnel expenses per unit produced increase and are over budget. To pick one possible example risk event that initiates the risk of being of budget with personnel costs, the breakdown of a machinery that causes a long-time stoppage is considered. If the machine does not produce, no work force is required to operate the machine. This also shows the interconnection of risks and targets.

Table 4 summarizes the above explained risks with one slogan and shows the linkage to the targets.

Table 4: Targets and corresponding Risk

Risk Example	Target	Corresponding Risk
R1	Secured Material Supply	Breakdown at Supplier
R2	Efficient Production	Wrong Machine Setup
R3	High Machinery Utilization	Machinery Breakdown
R4	Low Personnel Expenses	Costs are off Budget

4.2 Assessment of Risks

The assessment of risks as also shown by the COSO ERM Framework, aims to prioritize the determined risks. When this framework is expanded to a real-life production system, many more targets regarding the production system will be managed and consequently also a high number of different performance variables and risks. Then, this step serves to sort these risks according the priority that they should be taken care of. To do this sorting, many approaches exist. For this framework and considering the context, a vulnerability matrix tool is used. In the literature research two references used such a vulnerability framework. McManus et al. (2007) suggests the setup as shown in figure 26. They rate the risks on preparedness for it and the critically of its consequences. The modification that is used for this assessment is in accordance with the one used by Sheffi & Rice (2005). Here the disruption probability and the consequence of the impact are rated (see figure 27). This model is favored because even if events are very unlikely to occur, if their impact is severe, they are managed. This approach is also highlighted by COSO ERM (2004, p. 43).

Figure 26.: Vulnerability Matrix as used by McManus et al. (2007, p.14)

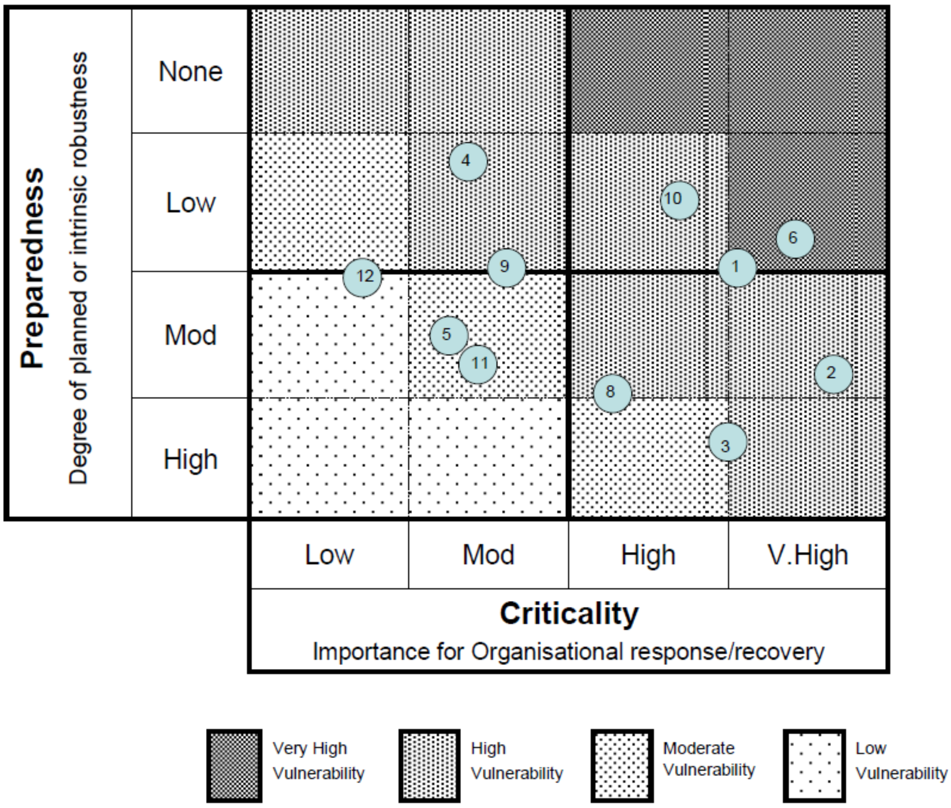
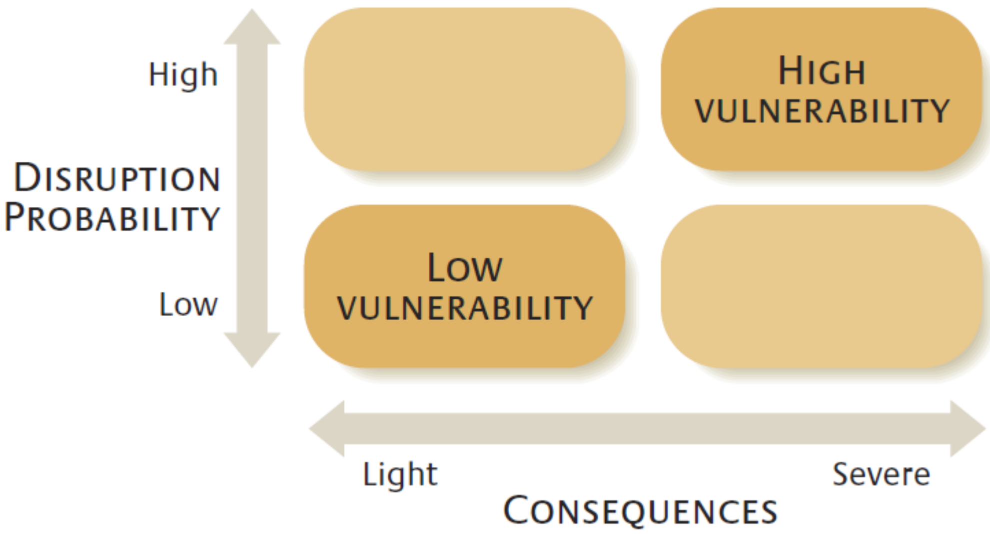


Figure 27.: Vulnerability Matrix as used by Sheffi & Rice (2005, p.43)



The risks will at first be rated regarding their consequences. This will be done on a 3-category scale: light, middle, severe. The translating of this qualitative rating into a quantitative can be done by many approaches. For example, the concluding financial damage to the business can determined for each specific risk. Then these can be clustered in 3 different categories, for example:

- *up to 15.000. EUR = light*
- *16.000 to 50.000. EUR = medium*
- *51.000 and above = severe*

Of course, the range depends on business, production and risk type. The same thing can be done with production down time caused by this risk event, this is also suggested by Heinicke (2014, p.206). Consequently, production down time can also be translated into costs that arise from a stoppage. The probability of the risk to happen has to be estimated. For risks that deal with operational risks that are directly linked to quantitative data like process parameters, this recorded data can be used as basis for the estimation of likelihood. For risk scenarios that deal with more external disruptions, where the probability of occurrence can only be rated qualitative, this is more based on subjective expertise. Risk that show very little consequence and high probability to happen are considered as “daily-business”. Those are the challenges that are faced in the operation system every day. Nevertheless, also for such events standardizing response strategies can be useful. On the other hand, events that are very likely to happen and conduct high impact consequences show high vulnerability.

R1: Breakdown at Supplier

This scenario might ideally be assessed in context of one specific supplier and the concluding product. To rate the probability of a breakdown at a supplier or major disruption in its internal supply chain an audit can be made at the supplier’s plant. Also, if experience shows that it already happened several times in the past, it might be more likely to happen again. The severity depends in this scenario is judged on how long it would take to get supply from another source. This example is assumed to be affecting a key product with special requirements for its raw materials. The consequences are severe.

R2: False Machine Setup

This risk represents a typical every day, preventable risk. In stressful times in production it is highly possible that operators do not or even cannot take the time to set up the machine to ideal parameters and fine tune every production machine to its optimal potential. The consequence is that, although production is running, not the full potential is acquired and the target of high efficiency is not met to a satisfying degree. This concludes probability is high, consequences are medium.

R3: Machinery Breakdown

The breakdown of machinery happens from time to time, even if maintenance is perfumed according to a plan, the risk can never be reduced to zero. The time that is needed to fix a machine ranges, depending on machine and type of breakdown. For this example, a medium probability but severe consequence is assumed.

R4: Costs are of Budget

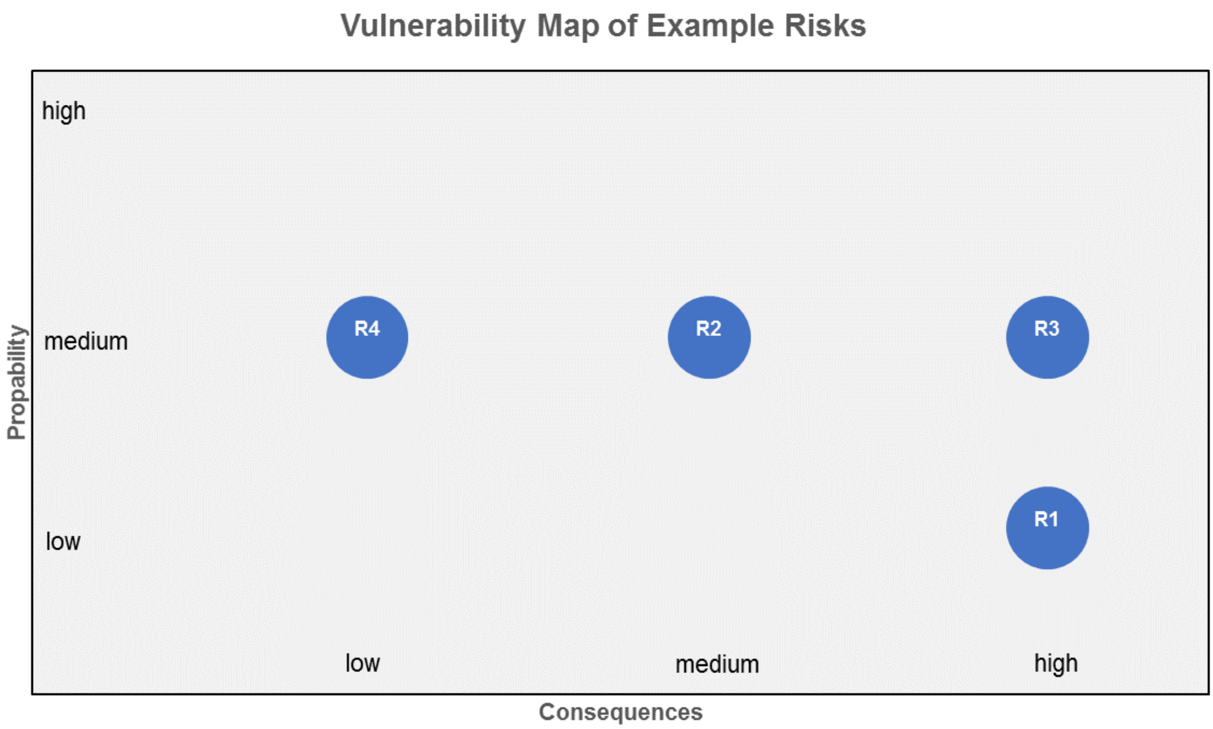
This risk is assumed to be as likely to happen as and machine breakdown, also because this to scenarios are considered to be interconnected. The consequences are low, because experience showed, that this scenario only represents a minimal deviation from budget.

The results of this assessment regarding probability and consequences as applied in orientation to vulnerability frameworks are summarized in Table 5. The illustration is done in a vulnerability map as shown in figure 28. Especially when assessing a lot of risks with various ratings, this illustration can help to structure the outcome of such a framework.

Table 5: Risk Assessment of Example Risks

Risk Example	Risk Description	Probability	Consequence
R1	Breakdown at Supplier	low	severe
R2	Wrong Machine Setup	high	medium
R3	Machinery Breakdown	medium	severe
R4	Costs are off Budget	medium	low

Figure 28.: Vulnerability Map



4.3 Identification of Risk Information

Now that the risks are identified and assessed, the risk information that represents these risks has to be determined. In combination with the target that is affected by them, this enables to link targets and corresponding risks to the model of functional map and diagnostic control system developed in section 3. Additional, the risks are categorized regarding management domain, risk type and risk category as shown in section 2.5.

R1: Breakdown at Supplier

When the purchasing department in production planning orders material from a supplier with specified quantity and delivery date, it receives an order confirmation. The confirmed quantity and date are considered for order generation and also planned stock range. If a confirmed order date is missed by a significant time or is canceled by the supplier, this is an indicator for the detection of the corresponding risk. Therefore, in context with the material and production type, a limit for delivery delay and an alarming for canceled deliveries has to be set. This then serves as risk information. Since this risk represents a disruption from external participant and cannot be influenced it is considered as external, speculative risk, that is anchored in strategic management domain.

R2: False Machine Setup

For every machine and production equipment regarding the production of specific products ideal process parameters are defined. These parameters lead to optimum output and efficiency. When operators or mechanics switch between different products they have to adjust the production machines to match these ideal setup parameters. If this is not done consequently, the machine output is off limits and does not match the required value. Therefore, the risk information for example target 2 is output off limits. This risk represents a typical risk from operational management and is therefore a preventable risk. Since this represents negative consequences only, it is categorized as pure risk.

R3: Machinery Breakdown

The risk information representing this target, is imbedded in the description. If the machine breaks down the identified risk as described above does occur. This means, the risk information is the breakdown itself. A more advanced risk information approach for this event could be to link the breakdown to changing product or process parameters in advance to establish an early warning system. The categorization of this risk matches with risk example 2. It is a preventable, pure risk, managed in operational management.

R4: Costs are of Budget

As described in the risk identification, the risk information announcing this risk event are manifold. For this example, assessment, the connection to a machinery breakdown is picked. Therefore, the risk information that is connected to this risk is also the breakdown of a machine. This concludes, that if a breakdown happens, also the personnel has to be managed and adapted to achieve targets. This risk is considered as risk that evolves from execution strategy in financial management and is a speculative risk.

Now that the risks are identified, analyzed and categorized, Table 6 summarizes all the findings from section 4.1 to 4.3.

Table 6: Risk Information and Categorization of Example Risks

Risk Example	Risk	Management Domain	Risk Type	Risk Category	Risk Information	Probability	Consequence
R1	Breakdown at Supplier	Strategic	Speculative Risk	External Risks	missed or canceled Deliveries	low	severe
R2	False Machine Setup	Operational	Preventable Risk	Pure Risk	Output is off Limits	high	medium
R3	Machinery Breakdown	Operational	Preventable Risk	Pure Risk	Machine Breakdown	medium	severe
R4	Costs are off Budget	Financial	Strategy Execution Risk	Speculative Risk	Machine Breakdown	high	low

4.4 Identification of Risk Responsibilities

As the risks are identified and linked to targets inside the production planning and control system, the can also be linked to the roles inside this system as introduced in section 3.2. above. This way, it can be determined who is responsible for managing the risk that is threating the corresponding target achievement. Since the connection of targets and roles is already done before, the corresponding risk are linked to the roles of production planning and control system as shown in table 7.

Table 7: Connection of Example Risks and Responsibilities

Risk Example	Risk	Responsibility
R1	Breakdown at Supplier	Production Planning
R2	False Machine Setup	Production Management
R3	Machinery Breakdown	Mechanics and Maintenance
R4	Costs are off Budget	Production Management

4.5 Developing adequate Respond Strategies

Now that the location inside the functional map of each risk and each risk holder is determined, the next step is to develop adequate respond strategies. These predetermine how to cope with risks. For this framework, the 4 R´s as suggested by Brunsdon (2005) or McManus et al. (2007) are considered, as this concept deals with preparation, enduring and recovering and therefore meets the requirements for resilience systems as defined in section 2.2 of this thesis.

R1: Breakdown at Supplier

The reduction of the risk impact can be achieved by acquiring an alternative supplier for the specific material. Therefore, the material can be ordered from a different source if the main supplier struggles with delivery. To be ready for this risk event the constant management of stock is necessary. In case of risk impact, it can be detected early. If the risk impact advances, resources need to be relocated according to order priorities. For this purpose, these priorities have to be visible for all participants. If the material is available after the shortage, stock needs to be filled and if the former main supplier is out of business or experiences severe damage to its machines additional suppliers need to be approached.

R2: False Machine Setup

By ensuring high order volumes in terms of quantity the risk of false machine setup can be reduced. If production orders last longer and adjustment and setup does not need to be done frequently, the risk of false setup is decreasing. Of course, the setup parameters for each product and machinery needs to be optimized and then standardized. A frequent check of machine and product parameters can be linked to being ready for risk detection. The response of course is the setup according to standardized parameters. If the risk of false machine setup occurs, a way to still ensure high efficiency is the increasing of volumes to benefit from scale of production effects.

R3: Machinery Breakdown

The risk of a machinery breakdown can be reduced by performing regular maintenance. If still a breakdown happens, common spare parts can be hold on stock to be ready for response. The immediate respond is the fixing of the breakdown to again utilize the machine as fast as possible. If the breakdown concludes that the planned maintenance was not sufficient, the plan needs to be adapted.

R4: Costs are of Budget

As costs need to be managed permanently, this risk is managed in day to day business. The hiring of temporary personnel is a way to reduce the risk of unnecessary high personnel costs if a severe breakdown of machinery happens. By monitoring overtime and rest periods of temporary and permanent workers current staff can be reduced quickly in compliance with legal restrictions. If the risk impact turns out to be vehement, the number of temporary workers can be adapted. If personnel cannot be adapted as required from financial point of view, these resources can be utilized to operate productions on alternative machines, that initially were scheduled for the near future. This serves to produce now and save in the future.

Table 8 summarizes the 4 R´s for every example target.

Table 8: Respond Strategies for Example Targets.

Risk Example	Risk	Risk Reduction	Risk Readiness	Risk Response	Risk Recovery
R1	Breakdown at Supplier	secure alternative Supplier	manage Material Stock Range	relocate Material Resources according Priorities	purchase material to refill stock or approach additional supplier
R2	False Machine Setup	ensure high Order Volumes, Standardize Setup	Frequent Check of Parameters	improve Production Parameters	increase Volumes
R3	Machinery Breakdown	preventive, planned Maintenance	hold common Spare Parts on Stock	repair, fix Machinery	reschedule Maintenance Plan
R4	Costs are off Budget	temporary Personnel	monitor Overtime and Rest periods	adapt Number of temporary Workers	save Expenses in following Months

Although the identified risks and respond strategies do not represent complex events or targets, they illustrate how to approach and perfume the assessment as provided by this framework. It is very important for resilience to become alive in an organization to involve all participants and individuals that need to perform according the activities standardized in the resilience management system. All those strategies and control system developed in theory need to be applied in real practice. People need to have a clear understanding of what to do in case of crises. The guidance provided by the respond strategies is crucial for fast respond and recovery. McManus et al. (2007) observed:

"*A few groups were observed to be very proactive, but in their rush to make and implement decisions quickly they failed to fully scope the full implications of the crisis. Often this meant they 'solved the wrong problems', highlighting the value of time taken to identify the full scope of potential impacts before moving onto solutions*"

McManus et al. (2007, p.v)

They also point out the importance of sorting out a clear view on respond and recovery priorities and therefore minimum operating requirements. Resilience applied in practice needs to be understood as constant learning. If crises occur, respond strategies are applied. This serves as feedback loop to improve for the next time such an event happens. It is therefore mandatory to talk to all key participants and explain and demonstrate the framework. Only with clear communication of targets, responsibilities and vulnerabilities as described, the mechanisms of this resilience system can be put to live.

4.6 Integration of Resilience

Considering the primary research question, the integration of resilience into a traditional production planning and control system is the aim of this thesis. Consequently, this section summarizes the framework and describes how it is integrated into the production planning and control system. The modeling of the functional map and the diagnostic control systems combined with roles and responsibilities introduced a transparent and structured landscape of the production planning and control system. Therefore, all participants in this system are aware of the variables and indicators that need to be monitored and managed. By identifying risks, their connection to strategic and operational targets imbedded in the production program and the corresponding risk information the risk awareness was integrated. To finish this complete framework the main characteristics of resilience management beside risk awareness where addressed by standardizing guidelines and activities to enforce risk reduction, readiness, response and recovery.

Combining the production planning and control model with this risk strategies leads to a new system that deals with risks and disruptions in an optimized, organized and standardized way. The reduction and readiness strategies are part of the daily managing attention. If a risk that was identified occurs, there are responds and recovery strategies that already provided by the resilience management system. These predetermined actions enforce the “bounce back quickly when hit” of a resilience system, whilst the constant managing according to the diagnostic control systems model meets the “avoid disruptions as long as possible” characteristic of a resilient system. To finalize the demonstration of the integration of resilience the developed system is compared to the determined characteristics of a resilient production planning and control system as explained in section 2.2:

1. The organization knowns its main targets and vulnerabilities.

By applying diagnostic control systems, building the functional of the existing system, combining and linking those to roles and responsibilities the organization is aware of its responsibilities and how they contribute to the achievement of determined targets that are integrated into the production program. The identification of risks and the assessment of those as shown in section 4.1 ensure the awareness of the organizations vulnerabilities.

2. **The organization has determined and implemented corresponding strategies to cope with those risks.**

By establishing critical performance variables, analyzing their input as well as controllability and linking those to identified risks, activities and guidelines where developed to cope with every identified risk.

3. **Those strategies focus on preventing, reducing, enduring and recovering from disruptions.**

As the framework uses strategies for the reduction, readiness, response and recovery regarding risks, the characteristics of resilience systems regarding preparedness and reactivity are met.

4. **The organization understands its resilience management as continuous process that is developed iterative.**

As processes are constantly changing and new products are going into production frequently the control systems are constantly under development. The framework shows the basic guidelines and construction of resilience and enforces adapting and learning.

5. **The resilience management involves individuals and does consider their capabilities as well as their responsibilities.**

The explained functional map and the integration of roles and responsibilities focuses on individuals and their tasks in the production system. Targets, measurements and risk strategies are designed with considering those roles. By interviewing individuals to identify risks as explained in section 4.1. the commitment and understanding of them is taken into account in the framework.

The characteristics are matched by the framework and provide an approach that cumulatively fulfills these requirements. This proofs that by applying the developed framework a traditional production planning and control system can be rebuild and structured to become a resilient production planning and control system.

4.7 Summary Chapter 4

In chapter 4 the framework for the integration of resilience into a traditional production planning and control system was completed. The chapter is structured to install resilience, basing on the model of production planning and control as designed in chapter 3. For this installation of resilience 6 consecutive steps where established that are orientated to common risk management approaches. At first, risks where identified. Therefore, the before introduced targets were taken to set a scope for this risk identification activity. It was shown, that with scenario planning, interviewing of individuals or analyzing historical data risks can be identified and directly linked to a risk that they affect. To show the further development and application of the framework example risk were introduced. These risk types represented different risk types and categories. After the risks were identified and categorized, an assessment in regards probability and impact of those was performed. Therefore, the likelihood of each risk to happen and the conducted severity of the impact where analyzed. This was done in accordance with the vulnerability matrix framework as used in research. The likelihood was rated by considering data from past risk events and process parameters, or if available simply qualitative. For the rating in terms of impact different approaches where explained. Either by taking caused down time in production into account or by estimating financial impact the risks were classified. This assessment shows individual results regarding vulnerability for each example risk. To link these example risk to the production planning and controls roles the corresponding risk information for each risk was identified. The risk information, its interdependence to performance variables and goals allowed the connection to the responsibilities as introduced in the modeling of in section 3. Since the complete process landscape as explained in chapter 3 and the imbedded targets and corresponding risk where determined, adequate risk respond strategies where developed. To meet the requirements of a resilient system in regards preparedness and agility strategies for risk reduction, risk readiness, risk response and risk recovery where explained. Combining all these coping strategies for each individual example risk, the application of the framework was shown. This finalized the targeted framework for the integration of resilience into traditional production planning and control systems. The integration of all these activities performed when creating and applying the framework into an existing production system represents the answer to the main research question of this thesis.

5. Conclusion

By successfully applying design science research methodology to solve the problem as stated, a framework for the integration of resilience into a traditional production planning and control system was developed. The chosen methodology was proven to be suitable for this process. First the problem was defined and objectives for a solution were concluded. Then the design process of the targeted framework was shown in section 3 and 4. By comparing the result to the before set objectives the evaluation activity of design science research was fulfilled. This evaluation shows that a framework for the integration of resilience was created as an artifact and an existing traditional system can be made resilient by applying it. The scope of this thesis on traditional production planning and controls system, where still a lot of human interaction is required, was considered when modeling the functional map and diagnostic control system of an example production system. The thesis gives the reader a brief introduction into production planning and resilience in the context of such. It shows and explains how resilience mechanism work in case of disruptions and how it contributes to an organizations competitive advantage.

By illustrating practical examples for processes, targets and risks the designing, implementing and demonstration of a resilient system was shown. By completing the developed framework, the advantage of resilience in production planning and control systems was conducted. This represents the closing of the research gap as determined in the problem statement. The creation of the framework as artifact and application of it by structuring the production planning system with functional maps and diagnostic control systems with consideration of roles and responsibilities and linking them to targets, risks and risk coping strategies for avoiding, enduring and recovering from disruptions shows how existing, traditional production planning and control system can be made resilient. This answers the main research question of this paper. The example illustration of a production system with combination of predetermined risk strategies to match the characteristics of resilient systems as defined for this thesis, shows how resilient production planning and control systems look and work.

The integration of resilience by applying functional map and diagnostic control systems and imbedding targets and risk strategies in each responsible hierarchical level explains how resilience can be integrated in the context of this thesis. These results answer the additional research questions. The result, which was expected to be a combination of selected approaches and tools from production-, process-, risk- and resilience management- as well as management control to design a framework that fits the research scope and answers the research question. The artifact developed for this master´s thesis can be also used for other systems, preferably with supply chain context. It can be adapted in regards control systems and roles and responsibilities to fit other configurations.

6. Further Research

As shown, the created framework achieves the objectives that where targeted for this master´s thesis. A complete, practitioner oriented framework for the integration of resilience into production planning and control systems was developed. Further research in context of this thesis could be done by also considering the quality control department into the production planning and control model as a source of control feedback and measurements. Also, the consideration of management control systems could be expanded to other levers of control as suggested by Simons (1995). With current revisions in risk and resilience management standards, these could also be researched more to potentially refine this framework. If the framework is proven to be applicable in practice without major adaptions, it could also serve as basis for business analysts to create a IT-based model of such.

7. Summary

This master´s thesis is written with the headline of integration of resilience into a traditional production planning and control system. It is structured in 6 chapters. In chapter 1 the scope and motivation of this paper where explained. The research scope was defined to be on traditional production planning and control systems and an applicable framework for the integration of resilience into such. To identify state of the art knowledge on this topic a literature research regarding resilience, supply chain and production control was conducted. It was found, that several references show segments and approaches that can be used for the targeted framework, but none does match the requirements of a complete, practitioner-oriented concept. From this, the problem statement was concluded. It states, that yet research does not supply a framework that:

- ✓ Gives a brief introduction into production planning and control and resilience in context of such.
- ✓ Shows how resilience mechanism can work.
- ✓ Guides the reader thru the process of defining, designing, implementing and testing a resilient system
- ✓ Uses practical examples
- ✓ Shows the advantage of resilience in production planning and control systems

Therefore, the aim of this thesis is to develop such a framework and answer the research questions, that where defined to be:

- ✓ "How can an existing, traditional production planning and control system be made resilient?"
- ✓ "How does a resilient production planning and control system look like?"
- ✓ "How can resilience be integrated into an existing system?"

To create the framework, show its viability and answer the research question, design science research methodology was applied as research methodology for this thesis. This methodology is structured in 6 activities. First the problem to solve is identified and the motivation to do so is explained. Then, the objectives of this solution are specified. The main contribution is the creation and demonstration of an artifact that achieves the objectives stated before and closes the research gap. After the artifact is demonstrated, its feasibility is evaluated. The last activity according to design science research is the communication of the results and findings of the research. All these steps were performed as described, which concludes the structure of this thesis. The expected result of this paper was determined to be the creation and demonstration of a framework according to the research scope and problem statement by combining segments of different frameworks and suggestions from research.

To further explain the context of this research and show the segments and objectives for the solution according to the research methodology, the theoretical considerations of production planning and control as well as resilience, risk and management control where described. The purpose, tasks and process steps of a traditional production planning and control system where explained to picture the understanding of such a system before resilience is integrated. Then, resilience was described. Different definitions and descriptions from literature where stated, which show, that resilience is the capability of a system to avoid and endure disruptions and recover quickly when hit. This definition of resilience was further transferred into the explaining of resilience management, where the benefit of dedicated resilience management was shown with a disruption profile. As it was identified that to enforce resilience and establish a resilient management system, it is necessary to provide a system to measure and control processes and their corresponding risks, diagnostic control system where introduced. Diagnostic control systems aim to plan, monitor and control management system such as a production planning and control system. By transferring goals into critical performance variables and establishing adequate measurements, the achievement of goals is controlled. To manage the risks of dissipations an approach to identify corresponding risk information depending on management domain was described. By separating risks type, risk category and management domain the linkage of risk and risk information representing a specific risk in a management system can be achieved. To close the compilation of theoretical considerations, risk management standards where described.

In chapter 3 of this thesis, the development of an artifact was initiated. To picture the processes of PPC more in detail, a functional map was created. By building this map step by step, the configuration of an example production planning and control system was shown. By introducing the roles and their responsibilities in such a PPC the functional map was finalized in terms of its transparency. Further, production planning and control was modeled as diagnostic control system by at first separating the planning and the control segment and then modeling targets imbedded in the production program as individual diagnostic control system. This modeling showed, that the production planning transfers strategic and operational targets from higher management goals in the production program and the production control strives to control their fulfillment. By introducing example targets and identifying their critical performance variables and measurements, those where pictured as diagnostic control systems. Combining the functional map and designed diagnostic control systems, the critical performance variables and their measurement where linked to the roles of the production system. This modeling accomplished to illustrate the PPC landscape in a transparent map and standardizes responsibilities for target achievement.

Building on this, resilient management was applied to identify and analyze risks and determine respond strategies. For this, components of COSO and other resilience management approaches where combined. The modeling of a resilient production planning and control system was structured with 6 steps. At first, risks threatening the achievement of stated targets where identified. Then this risks where assessed regarding their probability and their impact on performance. Further the corresponding risk information representing these risks where identified and linked to measurements and responsibilities. To determine adequate respond strategies in terms of resilience it was considered to develop strategies that focus on reduction, readiness, response and recovery. Finally, all this was combined. The respond strategies were linked to the risks they aim to manage. The risks were linked to targets, critical performance variables and those to their measurements. These where then viewed as their diagnostic control system. By connecting those control systems with their responsible role inside the production system, their location in the functional map of the production planning and control modeled was determined. This represents the integration of resilience into a traditional production planning and control system.

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