Buffer management at ASML
transparent buffer management system for ASMLs product generation process

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Buffer Management at ASML

Transparent Buffer Management System for ASML's Product Generation Process

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ABSTRACT

The aim of this Master Thesis is to investigate the crucial success factors concerning the design and implementation of a buffer management system for ASML’s Product Generation Process. This will be done for ASML’s Design & Engineering Department, within the context of the iTCM project that is aimed at improved planning and prioritization of projects to synchronize and allocate their capacity to product development activities and in line with ASML’s business strategy, and will result in a high-level buffer management design proposal and a set of recommendations for implementation. This resulted in the insight that the implementation of adequate buffers at ASML reduces the negative effects of changes enabled by issues and risks and thereby reduces the contamination of projects. Thus, buffers partly prevent that changes to a project do not influence other projects’ triple constraint.
MANAGEMENT SUMMARY

PROBLEM STATEMENT AND AIM OF THIS STUDY
This study will investigate the crucial success factors concerning the design and implementation of a buffer management system for ASML’s Product Generation Process. This will be done for ASML’s Design & Engineering Department, within the context of the iTCM project and will result in a high-level buffer management design proposal and a set of recommendations. The following problem statement leads this research:

ASMLs highly ambitious product portfolio and business strategy in combination with a lack of a uniform way of working, in-transparent project information and poor project plans, leads to a constant struggle amongst D&E projects for scarce resources (staff) and poor quality of project plans. This leads to the situation in which project managers hide buffers in their plan by using all their resources without providing transparency regarding their buffers. Thus, current resource allocation depends on the ability of project managers to hide their buffers and bargain for resources, which also decrease the quality of project plans at the D&E department and leads to unpredictable project plans.

Leading to the following main research question:

How can buffers reduce the negative effects of risks and project issues that lead to constant changes in project plans at ASML’s D&E department?

ASML AND ITCM PROJECT
ASML is the world’s leading provider of lithography systems for the semiconductor (microchip) industry that manufactures and services these advanced systems to its customers, which are the major global semiconductor manufacturers, and thereby enables them to create chips that power a wide array of electronic, communications and information technology products.

ASML’s iTCM project is targeted towards the Product Generation Process, which is a multi-stakeholder process that uses Key Decision moments to align, validate and
plan contributions of involved sectors on multiple products. The iTCM project aims at improved planning and prioritization of projects to synchronize and allocate their capacity to product development activities and in line with ASML’s business strategy. This should increase the quality of information and overall transparency and thereby increases project plan quality and consequently provide higher quality products. The most important concept within this iTCM project is the triple constraint (3C): iTCM aims at balancing these from product level down to sub-PBS item level, which increases transparency that allows for more realistic scenario analysis and transparent definition of buffers.

TRIPLE CONSTRAINT AND BUFFERS

One of the core areas of project management is the 3C, which is a traditionally widely-accepted criterion for measuring the performance of projects. First, time is concerned with the processes that are needed for timely completion of the project. Secondly, costs are concerned with estimation, budgeting and controlling costs in order to keep them within the approved budget. Third, scope refers to the processes that ensure all the required work is included in the project and controls the aspects that were originally not included within the project. When these constraints are not managed effectively, this may result in schedule slippages, cost overruns or deliverables that do not meet the criteria and this will consequently result in project failure. Balancing these constraints involves making continuously trade-offs amongst them throughout the project life cycle. Moreover, there can be defined buffers, which are effective means for protecting project plans from issues and risks in NPD environments, based on the triple constraint:
• Effort: financial or labor
• Timing: slack in project plans
• Scope: over-dimensioning solutions with regard to the product requirements

CONCLUSION
• Buffers (partly) prevent that changes to a project do not influence other projects’ 3C. This also prevents bargaining for resources due to chronic resource shortage.
• The iTCM project reduces the negative effects generated by risks and project issues within projects, because less project plan changes are needed.
• Implementing a formal buffer allocation process that supports a transparent discussion between bottom-up and top-down responsibilities increases the level of control. Each level of buffer responsibilities has advantages and disadvantages and finding a balance, adjusted to ASMLs particular situation, is crucial for successful buffer implementation.
• PM training offers support to the implementation of buffers and the iTCM project. It indirectly increases solution support and clarity of decision criteria and thereby increases the chance for successful implementation.

RECOMMENDATIONS
• Buffer management involves major changes regarding the current way of working and therefore the introduction should be done gradually in combination the implementation of PM tools such as CCM, TOC and PERT and top management commitment.
• Before ASML begins with the implementation of a buffer management system, the iTCM project, which demands large changes in ways of working, should be implemented and thoroughly tested.
• The buffer management system should strike the balance between control and flexibility. Flexibility will be maintained through the informal resource allocation cycle (simplified version of the formal process) that will be based on 3C-scenario proposals. The formal allocation process is used for the RFF and in case of an impact that involves major changes in boundaries.
• PM training should be developed by dedicated teams aimed at teaching stakeholders how to deal with soft skills and several PM tools such as CCM, TOC and PERT, which enable adequate buffer allocation.
PREFACE

This Master of Science (MSc) thesis is the result of my graduation project. This graduation project finalizes my study, the master program Innovation Management at the faculty Industrial Engineering and Innovation Sciences, at Eindhoven University of Technology. This master thesis was carried out at ASML Netherlands B.V. from December 2012 to May 2013.

First, I would like to thank Erik Mijnsbergen for giving me the opportunity to do my graduation project at ASML, introducing me in the iTCM project, mentoring me throughout the complete project by giving advice and direction and thereby preparing me for “the real deal”. Second, my thanks go out to Jimme Keizer for his close involvement and providing me with counsel and good advice. Third, I would like to thank Fred Langerak for his final remarks that gave this thesis its final appearance. Special thanks go out to my team at ASML: Erik Mijnsbergen, John-Pierre Minten, Wolfgang van Os, Rik ten Have and Paul Bruggeling. I really enjoyed being part this team!

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<td>3C</td>
<td>Triple Constraint</td>
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<tr>
<td>3ITB</td>
<td>Three In the Box</td>
</tr>
<tr>
<td>AIR</td>
<td>ASML Issue Resolution (name of process as well as tool)</td>
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<tr>
<td>D&amp;E</td>
<td>Development &amp; Engineering</td>
</tr>
<tr>
<td>DM</td>
<td>Department Manager</td>
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<tr>
<td>GL</td>
<td>Group Leader</td>
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<tr>
<td>IH</td>
<td>Immersion Hood</td>
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<tr>
<td>IRR</td>
<td>Issue and Risk Register</td>
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<tr>
<td>iTCM</td>
<td>Integrated Triple Constraint Management</td>
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<td>KD</td>
<td>Key Decision</td>
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<td>PBS</td>
<td>Product Breakdown Structure</td>
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<td>PCM</td>
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<td>PDM</td>
<td>Product Development Manager</td>
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<td>PG</td>
<td>Product group</td>
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<td>PGM</td>
<td>Product Group Manager</td>
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<td>PGP</td>
<td>Product Generation Process</td>
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<td>PL</td>
<td>Project Lead</td>
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<td>PM</td>
<td>Program Manager</td>
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<td>PMO</td>
<td>Project Management Office</td>
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<tr>
<td>RFF</td>
<td>Rolling Financial Forecast</td>
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<tr>
<td>SDS</td>
<td>System Design Specification</td>
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<td>SE</td>
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<td>SP/EP</td>
<td>Sharepoint/Enterprise Project (Microsoft software)</td>
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<tr>
<td>SPS</td>
<td>System Performance Specifications</td>
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<tr>
<td>SVP</td>
<td>Senior Vice President</td>
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<td>TCM</td>
<td>Triple Constraint Management</td>
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<td>TL</td>
<td>Team Lead</td>
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<td>WBS</td>
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CHAPTER 1: INTRODUCTION

Risks are inherently part of the NPD activities of high technology firms and managing them effectively requires the generation of a risk environment which enables conscious decision making. This means that these firms must have the processes and tools available that can deal with a wide variety of risks. This study will research how ASML, which is a world leading high tech company within the semiconductor industry, should organize the risk management activities within their Development and Engineering (D&E) department, which is responsible for the production of new technical solutions that drive a generation of products. The aim of this research is the development of a design proposal which contains several tools and processes aimed at handling risks within ASML’s D&E department.

This chapter starts with a short description of ASML and their D&E department, since this department represents the environment in which the case that is investigates in this study is situated. Additionally, some concepts and theory from scientific articles is described that provide background information that gives guidance to and is necessary for understanding the problem statement and research design. The final section describes the initial problem statement, which serves as input for the research design that is described in chapter 2.

1.1 BACKGROUND & RESEARCH CONTEXT

The background against which this study is situated is ASML’s D&E department. ASML is the world’s leading provider of lithography systems for the semiconductor (microchip) industry. Their customers, which are the major global semiconductor manufacturers, use these systems to create chips that power a wide array of electronic, communications and information technology products. Some key points in ASML’s business strategy are technology leadership and cost of ownership, while maintaining a flexible cost structure, a high market share and a low break-even point. These strategic drivers put pressure on ASML’s D&E department, which roughly consists of a hardware and software cluster that is concerned with the design, development, testing and integration of the complete hardware and software packages that drive a generation of ASML products. These clusters are arranged
around a multitude of projects that are dedicated to the development of these products. In the current circumstances, D&E experiences difficulties maintaining these ambitious drivers, since the combination of high technological demand along with maintaining a high market share, which enables high time pressure, leads to a constant struggle amongst D&E projects for scarce resources (staff). Other project management practices that enable and reinforce this struggle are the lack of a uniform way of working and in-transparent project information. Consequently, this affects the project plan quality, which is generally poor due to these aspects. Consequently, project risks materialize and projects run into project issues, such as escalation of project resource boundaries or insufficient resources, which could have been resolved earlier or avoided altogether (iTCM Requirements document, 2013). ASML recognizes the problem stated above and therefore started with the implementation of the integrated triple constraint management (iTCM) project, which is aimed at improved planning and prioritization of projects to synchronize and allocate their capacity to product development activities and in line with ASML’s business strategy. This should increase the quality of information and overall transparency and thereby increases project plan quality and consequently provide higher quality products. The most important concept within this iTCM project is the triple constraint (3C), which can be defined as a project’s time, cost and scope. Moreover, it is the most widely accepted criterion for measuring project performance. First, time is concerned with the processes that are needed for timely completion of the project. Secondly, costs are concerned with estimating, budgeting and controlling costs in order to keep them within the approved budget. Third, scope refers to the processes that ensure all the required work is included in the project and controls the aspects that were originally not included within the project (PMBOK guide, 2012). The iTCM project aims to balance this 3C within D&E’ projects, which means that managers make continuous trade-offs amongst the constraints throughout the entire project life cycle. Additionally, this project aims to define and implement a set of work descriptions and tooling that should lead to efficient and more balanced decision making within D&E’s Product Generation Process (PGP) projects by providing integrated information about the 3C (iTCM Requirements document, 2013).
Another aspect of the iTCM project is that it enables the implementation and may improve other project management processes and tooling. Factors that play a role in this matter are the uniform and transparent information in schedules, a standardized way of working and a balanced 3C. In this context, another important concept of this thesis, which usefulness for ASML’s D&E department will be explained into more detail in section 1.2, is buffer management. In short, buffers are resources that are dedicated to protect project schedules (plans) from risks and to lower the negative impact of project issues. In the iTCM context there can be defined buffers on the three constraints:

- **Effort**: financial or labor (Leach, 1999; van de Vonder et al, 2004)
- **Timing**: slack in project plans (Leach, 1999; van de Vonder et al, 2004)
- **Scope**: over-dimensioning solutions with regard to the product requirements (Bhattacharya et al, 1998)

### 1.2 PROBLEM STATEMENT

This section describes the problem statement, which forms the motive for the aim and main research question of this research. Currently, ASMLs highly ambitious product portfolio and business strategy in combination with a lack of a uniform way of working, in-transparent project information and poor project plans, leads to a constant struggle amongst D&E projects for scarce resources (staff) and poor quality of project plans. This poor quality is depicted by the fact that information regarding the triple constraint is currently managed for a large part separately and in inconsistent granularity, which leads to problems such as uncontrolled balancing between scope, time and effort (iTCM Requirements document, 2013). In other words, there are no guidelines and uniform way of working regarding aspects that concern the 3C. Second, the struggle for resources in combination with in-transparent information in project plans forces program managers, that need additional resources to solve project issues or meet tight deadlines, to take the resources from projects where this does not immediately lead to problems. For instance projects that seem to have less time pressure due to long lead times or transparent contingencies. However, in the current situation project managers hide buffers in their plan by using all their resources without providing transparency regarding their buffers. This creates the situation in which program managers are
forced to cut resources away from projects that are not allocated within buffers. Thus, current resource allocation depends on the ability of project managers to hide their buffers and bargain for resources. The result is that projects that did not get sufficient resources or did not plan for sufficient resources run into issues and require additional resources. Consequently, project managers are constantly ‘fighting’ over resources, which also decrease the quality of project plans at the D&E department (iTCM Requirements document, 2013). Summarized, the following problem statement can be formulated:

**ASMLs highly ambitious product portfolio and business strategy in combination with a lack of a uniform way of working, in-transparent project information and poor project plans, leads to a constant struggle amongst D&E projects for scarce resources (staff) and poor quality of project plans. This leads to the situation in which project managers hide buffers in their plan by using all their resources without providing transparency regarding their buffers. Thus, current resource allocation depends on the ability of project managers to hide their buffers and bargain for resources, which also decrease the quality of project plans at the D&E department and leads to unpredictable project plans.**

Part of the problem stated above will be handled through the iTCM project. More details regarding this project and in which manner it contributes to a solution for the problem statement is described in chapter 3. Another part of the problem describes the current lack of transparent buffers that can protect project schedules (plans) from risks and lower the negative impact of project issues. Moreover, there is currently barely insight into how buffers are deployed at the D&E department and to what degree they are available in project plans. Using buffers can offer benefits, as scientific research indicates that buffers are effective means for protecting project plans from risks and project issues, for facilitating the allocation of scarce resources to activities and improving the planning, control and scheduling of project activities (Leach, 1999; Vonder et al, 2004). This information, in combination with the problem statement, leads to the following main research question:

**How can buffers reduce the negative effects of risks and project issues that lead to constant changes in project plans at ASML’s D&E department?**
Consequently, this study will investigate which critical success factors play a role in the implementation of buffers in the NPD project plans of ASML’s D&E department. This leads to the aim of this study:

This study will investigate the crucial success factors concerning the design and implementation of a buffer management system for ASML’s Product Generation Process. This will be done for ASML’s Design & Engineering Department, within the context of the iTCM project and will result in a high-level buffer management design proposal and a set of recommendations.

This buffer management design proposal in combination with the recommendations serves as a starting point for the implementation of a buffer management system at ASML. This system encompasses several parts and processes (success factors) and their interconnectivity seen from a high-level perspective and aligned with factors that play a crucial role within the iTCM project. Thus, a system is in this case an interdependent group of items forming a unified pattern. High level refers to the level of detail of the design proposal. This study aims at the identification of these factors and defining their relations and behavior, which enables the development of a system level design proposal. This means that these factors require, with respect to their detailed content, more substantive research before actual implementation by managers at ASML’s D&E department. However, the information provided by the buffer management design proposal is a starting point and enabler for the creation of a normative model that is aimed at the implementation of buffers at ASML’s D&E department. The following research questions, based on the problem statement and iTCM project information, aims to identify the factors that play a crucial role for the development of a buffer management design proposal:

- Were lies the responsibility for defining, managing and deploying buffers at ASML’s D&E department?
- What are the critical success-factors concerning the design of buffer management at ASML’s D&E department?
- Which structural changes should be made in the iTCM TO-BE situation in order to successfully implement a buffer management system?
CHAPTER 2: RESEARCH DESIGN

The design of this study, which should be able to deal with the exploratory and design oriented nature of this study, is based on the regulative cycle of van Strien (1997) and fits within the larger scope of the reflective cycle of van Aken et al (2007) (figure 1).

The reflective cycle aims to close the gap between existing theory and practice through the execution and evaluation of multiple case studies. Repeating this cycle, while eliminating the case specific knowledge, enables the generation of design knowledge which can be used for the development of general theory. However, this study focuses on the execution of the first three steps and the preparation of the implementation of van Strien’s regulative cycle.

![Figure 1: Reflective Cycle (van Aken et al, 2007) and Regulative Cycle (van Strien, 1997)](image)

The first step of this problem-solving cycle, which is suitable for dealing with the individual and case-specific approach of this study, is described in section 1.1 and section 1.2 and encompasses the problem statement and project approach. In this case, the iTCM project plays a major role regarding the determination of the context and approach. The project approach describes the manner in which the diagnosis and design are approached within this specific case. Next, a diagnosis of the current context-specific situation will be provided that is in line with the previously stated problem statement and which describes the investigated topics within ASML from different stakeholder perspectives. The next stage of the study is the design
plan-stage, which uses information gathered within the diagnosis-stage and in which a design is developed that is suitable for dealing with the context-specific problems stated in the first two stages. Finally, this plan will be tested through expert’s opinion. This input will be used for the final recommendations and for improvement of the final design plan.

2.1 PROJECT APPROACH

The project approach is an important part of the problem statement-phase as described in the regulative cycle and is concerned with the theory-based and case-specific context of this business-problem-solving project. The research model (figure 2) depicts how ASMLs case-specific knowledge is generated that makes use of context-specific knowledge and a theoretical framework. The steps are based on the regulative cycle (van Strien, 1997) and a project management research framework of Ahlemann et al (2013) and the content is derived from the iTCM requirements document (2013) and section 1.2.

Figure 2: Research model
The box at the left of Figure 2 depicts ASML’s iTM project and a practical assignment, which provide input for the study on the buffer management system. Besides the value for the iTM project, carrying out the practical assignment improves the flow of crucial information on the iTM project and enables building relationships with stakeholders. The right side of Figure 3 shows the first 4 phases of the regulative cycle which are aimed at developing the design proposal that is stated in chapter 1.2. The boundaries, direction and information-input of this research are mainly provided by the iTM project and the theoretical framework. Moreover, the diagnosis is performed through a series of interviews amongst key-stakeholders of the iTM project and enables the initial design of the final object design. To conclude, this initial design is evaluated by experts in order to improve the final object and to increase the internal validity and the probability of acceptance. This results in the deliverance of the final object design and recommendations.

2.2 STRUCTURE
This section describes the following chapters of this study. Chapter 3 describes an overview of the iTM project, which contains four parts: general project information which describes part of the iTM TO-BE situation, a description of the AS-IS situation, a description of the main objective and crucial changes (TO-BE situation) and an overview of the practical assignment within the iTM project which the researcher of this study executed at ASML. Next, chapter 4 addresses a theoretical framework which revolves around three major topics. This framework should be seen as illustrating and scoping the scientific area and providing the scientific context. In other words, it illustrates and provides context to the first two chapters and provides theoretical input for chapter 5, 6, 7 and 8 and builds up a scientific viewpoint against which this thesis should be viewed. The main topics of this framework are project management, triple constraint management and risk management and buffers. Chapter 4.5 discusses systems thinking, which is method which is suitable for developing constructs for theory and practice. This method will be used for the analysis of chapter 5 and the design proposal of chapter 7. Chapter 5 provides an overview of the results of the interviews. The results are analyzed and synthesized according to systems thinking methods, in which holistic perspectives are combined with circular causal effects and indeterminism. Next, chapter 6 describes an answer
to the main question and sub-questions and thereby draws conclusions based on the data analysis. Chapter 7 describes the proposal of a design for ASML’s buffer management system, which is based on the data analysis (chapter 5), iTCM project information, expert’s opinion, additional literature, the theoretical framework and the conclusions. To conclude, the final chapter of this study encompasses the discussion, which discusses the wider implications of this study, the agreement and disagreement with previous studies and the broader implications of the results. Furthermore, the recommendations provide input that increases the reliability of project plans and provides input for the implementation of the design proposal. To conclude, chapter 8.3 address the limitations of this study and elaborates on avenues for future research.
CHAPTER 3: ASML AND ITCM PROJECT

3.1 ASML: COMPANY DESCRIPTION
This chapter describes the context of this study, which encompasses a description of ASML and a detailed description of the iTCM project.

3.1.1 GENERAL INFORMATION
ASML, founded in 1984 and headquartered in Veldhoven, is the world's leading provider of lithography systems for the semiconductor (microchip) industry and has over 60 facilities in 15 countries in Europe, Asia and the US. ASML manufactures and services these advanced systems to its customers, which are the major global semiconductor manufacturers, and thereby enables them to create chips that power a wide array of electronic, communications and information technology products. ASML’s guiding principle and mission is providing smaller, cheaper, more powerful and energy-efficient semiconductors to customers with leading edge technology that is production-ready at the earliest possible date. Driven by Moore’s Law, which describes a trend where microchips’ functionality increases through doubling the number of transistors per chip every two years, new-generation chips become increasingly complex.

The key points in ASML business strategy are technology leadership, cost of ownership and customer service, while maintaining a flexible cost structure, a high market share and a low break-even point. This is partly achieved through ASML’s dual product leadership strategy: on the one hand, boosting productivity and overlay accuracy of its TWINSCAN NXT immersion lithography systems for volume chip production, on the other hand continuing the development of EUV, the next-generation technology.

3.1.2 SEMICONDUCTORS: ROLE OF ASML’S LITHOGRAPHY SYSTEMS
Semiconductors are produced through a multistep process which is depicted in figure 3. This 6-8 week manufacturing process consists of several photolithographic and chemical processing steps that enable the gradual creation of electronic circuits on a wafer of pure semiconducting material (Hubert, 2008).
Figure 2: Semiconductor manufacturing process

Lithography, which is depicted in step 5 of Figure 3, is arguably the most important and critical step in the semiconductor production process, since (1) it determines how much circuitry can be packed onto a chip by controlling the size and shape of all chip components, connections and contacts and (2) it makes every layer of the chip by selectively growing, modifying and etching out the features in every chip during a 30-step process.

3.1.3 ASML: RISK & ISSUE MANAGEMENT

Buffer management is the main topic of this study. Since buffers are part of the risk management system of ASML, this chapter briefly addresses some of the key issues concerning ASML’s issue and risk management system, which can be seen as an overarching system that encompasses buffer management.

ASML’s internal risk management system monitors and reports operational reviews and is based on identifying external and internal risk factors that can influence operational and financial objectives. Crucial input is provided through a review of ASML’s management board which focuses on five major risk factors; economic conditions; product demand and semiconductor equipment industry capacity; worldwide demand and manufacturing capacity utilization for semiconductors; manufacturing efficiencies; new product development; customer acceptance of new products. The final output is an overview-report of the key strategic risks and their accompanying mitigation actions. These strategic risks and other structural problems
are logged in ASML’s Issue Register (AIR). This tool enables one way of working and offers capabilities to prioritize, classify, assign, track, monitor and report issues. In other words, it promotes ownership, issue transparency and one way of working regarding issue resolution (iTCM Requirements document, 2013). However, in the current circumstances AIR is not coupled to EPM schedules or resource management tooling, which contributes to the non-standardized, not centrally stored collection of 3C agreements.

3.2 iTCM PROJECT

This section provides an overview of the iTCM project and consists of four parts: general project information which describes part of the iTCM TO-BE situation, a description of the AS-IS situation, a description of the main objective and crucial changes (TO-BE situation) and an overview of the practical assignment.

3.2.1 iTCM: SCOPE AND GENERAL INFORMATION

ASML’s iTCM project is targeted towards the Product Generation Process (Figure 4), which is a multi-stakeholder process that uses Key Decision moments to align, validate and plan contributions of involved sectors on multiple products which are generated simultaneously. The involved departments need planning and prioritization processes to synchronize and allocate their capacity to product development in line with ASML’s business strategy. In this case, the iTCM project will be initially launched in the D&E department due to its leading role in the production of new technical solutions that drive a generation of products. In the current situation
D&E experiences difficulties maintaining the ambitious strategic drivers (section 3.1.1), since the combination of high technological demand in combination with maintaining a high market share, which enables high time pressure, leads to a constant struggle amongst D&E projects for scarce resources (staff). Other project management practices that enable and reinforce this struggle are the lack of a uniform way of working and in-transparent project information. Therefore, ASML is currently starting with the launch of the iTCM project, which process framework consists of three areas of the PGP: Boundary Management, Solution Delivery and Control & Reporting.

![iTCM Process Framework](image)

**Figure 4: iTCM Process Framework (iTCM Architecture Document, 2013)**

First, the Boundary Management process, which consists of the sub-process Update Product Roadmap and Define Product & Projects, defines the 3C boundaries on all program levels through a scenario management process in which each constraint of the 3C sets the boundaries for the levels below. Initial boundary-setting is done by the RFF, which is a boundary management process that is executed every 6 months and defines the development budget for the 7-12 months period, based on the prioritization of the product portfolio. Boundary-changes may be inflicted by roadmap-adjustments or through Issues and Risks. Solution Delivery, which consists of the sub-processes Scheduling (defining and assigning activities) and Execution (per-
forming activities), will be discussed in more detail in chapter 3.2.5. Finally, the purpose of Control & Reporting is to monitor and control trend reports, providing decision support information and increase information traceability (iTCM Architecture Document, 2013).

Another important component of the iTCM project is the demand (program organization) – supply (Line organization) model, which is depicted in Figure 6. The responsibilities of these organizational units, as defined by ASML’s works committee and agreed upon by the board of management in May 2011, are the following:

- The line organization takes responsibility for functional ownership, quality, effort estimates and timely delivery.
- The program organization selects and prioritizes the proposed solutions, coordinates delivery and integration, makes commitments to external stakeholders and manages risks.

Figure 6 illustrates the Line versus the Program view. Program has primarily focus on when what is available. Line has primarily focus on how solutions are developed (engineering method) and by whom (responsible). Thus, Line and the Program organization have different information needs and order to facilitate interaction between them and they must have insight in each other’s information: The Line needs current allocation information to take decision on future allocation of staff to projects, assign staff to tasks and to manage predictable solution delivery. The Pro-
gram needs information to know when what solution is available for what project (iTCM Requirements document, 2013).

3.2.2 ASML’S AS-IS SITUATION
Currently, ASML’s PGP is a highly complex and dynamic undertaking, and in combination with high technical risks due to advanced technology, requires a constant balancing of the 3C. However, the information regarding the 3C is currently managed for a large part separately and in inconsistent granularity, which makes it in practice difficult to take decisions based on the 3C. Moreover, the lack of 3C-integration leads to uncontrolled balancing and a mismatch between the components and unpredictable plans (iTCM Requirements document, 2013).

A detailed description of the causes and effects of this problem are graphically depicted by the fishbone diagram in figure 7 and is composed of information from the iTCM requirements (2013) and architecture document (2013). The bottom half of figure 7 depicts the causes and effects that encompass the origination of the 3C-uncertainties that lead to the problem statement as presented in Figure 2 and 10. On the other hand, the top half of the diagram depicts the causes which lead to problem (effect) that is encountered within the current buffer management system. In this case, the tension and balance between uncertainties and buffers should be determined by ASML’s Demand-Supply-Model. Especially within the current situation, in which project managers hide buffers in their plan, which forces program managers to cut resources away from projects that are not allocated within buffers. Thus, current resource allocation depends on the ability of project managers to hide their buffers and bargain for resources rather than facts. This results in the fact that projects that did not get sufficient resources run into issues and require additional resources. Consequently, project managers are constantly ‘fighting’ over resources. This problem is aggregated through the fact that there is there is insufficient communication and transparency of the Program, (which is responsible for determining the buffer strategy) towards the Line organization. Moreover, there currently is no consistency regarding the division of responsibilities among the Line and the Program. Consequently, instead of communicating about solutions there are discussions about resource allocation (iTCM Requirements document, 2013).
3.2.3 ASML’S TO-BE SITUATION

This chapter provides an overview of the objective and key changes that the iTCM project introduces in order to tackle part of the problem as stated in chapter 1.2. Moreover, as depicted in Figure 2, this TO-BE situation facilitates the practical assignment which has implications for both the final design and implementation of the iTCM project and hereby the final design of the buffer management system.

The main objective of the iTCM project is the integration of the 3C in order to provide higher quality product generation and thereby reducing the negative effects of uncontrolled balancing of the 3C. This should lead to changes, which are backed up
by a set of work descriptions and tooling that, if supported the D&E organization, will lead to efficient and more balanced decision making on D&E’s Line- and Program level. The most crucial changes introduced by the iTCM project are:

- **Integrated triple constraint management**, containing scope, effort and timing of solutions, from product level down to sub-PBS item level: This increases the transparency which allows for more realistic scenario analysis and transparent definition of buffers. Sub-PBS items are work packages defined in such a manner that they have a clear contribution to the system specifications, and also a clear owner in the line. Each sub-PBS will have its own 3C, meaning they will have a clearly defined scope, total effort estimate and timing. The triple constraints on these sub-PBS items can then be rolled up to project and product level.

- **Enhance demand-supply model in PGP**: Program and Line (D&E) discuss and agree on the delivery of solutions rather than the allocation of resources (see Figure 7). In the AS-IS situation, this policy is not accepted in practice, but the Program still delivers the solutions and the Line is merely an “ennobled” resource provider. The iTCM philosophy should provide support which encourages the acceptance of this way-of-working in which responsibilities are taken by representatives from Technology, Line and Program organization:
  - **Technology (Program SE/Product SE/Architect)**:
    - Defines feasible solutions and alternatives and maintains architectural integrity.
  - **Line organization (VP/DM/FO/GL/TL)**:
    - Provides knowledge, people, methods and estimates for the solutions, reviews development and ensures timely delivery of solutions by teams.
  - **Program Organization (PM/PDM/PCM/PL)**:
    - Reviews effort estimates and feasibility of solutions and is responsible for the coordination of timely execution, integration and staying-within-budget of agreed solutions.
On all levels in the organization decisions are taken with joined responsibilities by representatives from Technology, Line and Program organization. Operationally, execution of these responsibilities is done by the 3 in the box (3ITB), consisting of Technology, Line and Program. Realization of PBS items usually requires different competences, or even disciplines, and therefore under responsibilities of different group leads. The Function Owner is the Group Lead who is in the lead for realization and coordinates delivery of the solutions by the other groups. Each of these roles has an escalation line in case of conflicts to the next level in their organization who will resolve this with counterparts in the other organizations (iTCM Requirements document, 2013).

Figure 8: TO-BE situation - Organizational Structure (iTCM Requirements document, 2013)

3.2.4 PRACTICAL ASSIGNMENT
The practical assignment, which is done within the iTCM project at ASML, consists of 3 phases: analyzing a real-case project plan and configuring it according to iTCM philosophy, filling EPM/Sharepoint software with configured project data and de-
signing use case scenario’s and assisting in presenting iTCM real-life examples to ASML stakeholders. The main purpose of this assignment is to show the practical implications of the iTCM project to stakeholders within the iTCM project. The emphasis lays on explaining the way of working by showing a real-life example while using the tools that should support these practices.

First, the real-life project example which was chosen for showing the practical implications of the iTCM project is the project plan of the Immersion Hood. The immersion hood is a component of the NXT3 machine. The first objective of this assignment was to bring together the 3C (time, cost and scope) data of the Immersion Hood project, which is currently fragmented amongst different tools such as the FTE-tool (effort), the EPS tool (time) and the PBS tool (scope) and to reconfigure the project-data by ‘breaking’ down the total work into WBS units according to the manner depicted in Figure 9. This Figure shows that there exists a ‘split’ at sub-PBS level, which means that team schedules and work packages are managed within TCE and higher level boundaries are managed within SP/EP. Thus, information from the Immersion Hood plan will be partially transferred to EP/SP and partially to TCE. These separate plans were used for the design of use case scenario’s that depict the way of working of the iTCM project and the functionality of these software tools. An example of such a use case scenario is described in Appendix B. The most important aspect of these scenarios is that they provide means by which D&E can balance the 3C in a transparent manner. Meaning that the responsibilities are defin-
ed and that the triple constraint of plans at all levels can be re-balanced when the project plan is distorted by risks or project issues. The scenarios show different examples by which the 3C can be re-balanced by exchanging the values of time, cost and scope amongst each other. The result of the final step of this assignment, showing the practical implications to stakeholders within D&E, resulted in an investment in the iTCM project in February 2013. This resulted in the fact that as from May 2013, ASML started with a pilot launch of the iTCM project at the D&E department.

3.2.5 AS-IS AND TO-BE
This section summarizes the most crucial information of this chapter and thereby serves as a guide for chapters 5, 6, 7 and 8. Figure 10 depicts a framework of ASML’s current TCM situation (AS-IS) and the desired situation as described by the iTCM project (TO-BE), for which information is derived from the Requirements and Architecture document of the iTCM project.

![Figure 10: Framework of AS-IS and TO-BE situation](image-url)
CHAPTER 4: THEORETICAL FRAMEWORK

4.1 THEORETICAL RELEVANCE
This chapter provides a theoretical framework which revolves around three major topics that are introduced during the first 2 chapters. This framework should be seen as illustrating and scoping the scientific area and providing the ‘detour’ of science as depicted in Figure 2. In other words, it provides theoretical input for chapter 6, 7 and 8 and builds up a scientific viewpoint against which this thesis should be viewed. The main topics are project management, triple constraint management and risk management and buffers. To conclude, chapter 4.5 elaborates upon systems thinking, which is a conceptual framework which is suitable for developing constructs for theory and practice. This framework will to present the results and provide insight in the interviews and situation as described in chapter 1 and 2.

4.2 PROJECT MANAGEMENT
Practically, project management it is the application of knowledge, skills and tools in order to meet or exceed stakeholder needs and expectations while taken into account that its main characteristics are that tasks are performed by people, it is constraint by limited resources and encompasses several phases such as initiating, planning, execution and controlling and closure (Fitsilis, 2008; PMBOK guide, 2012; Naqvia et al, 2011). The core area of project management are the 3C and encompass the project’s time, cost and scope.

4.2.1 PROJECT STAKEHOLDERS AND STRUCTURE
Stakeholders are the persons and organizations that are actively involved in the project and influence the project deliverables and this makes stakeholder identification crucial for the performing organization (Smudde & Courtright, 2011; PMBOK guide, 2012). Examples of stakeholders are customers, sponsors, the project team and the public. Identifying the range of individual responsibilities and authority of the stakeholders is in this case critical for project success, since acknowledging their relative impact on the project increases transparency and aids in balancing and managing the stakeholder’s expectations and interests (PMBOK guide, 2012). However, viewpoints of client and project team on project-success are fundamen-
tally different since the former is focused on the deliverables and the latter is focused on the means by which the deliverables are created (Rad, 2003). Thus, in order to increase the efficiency of these actions, organizations should maintain and improve these relationships through proactive stakeholder management in which ethical communication strategies and tactics, that are directed to indicate opportunities for probable success, minimize weaknesses and screen threats to achieving success, play a vital role (Smudde & Courtright, 2011).

Other factors that influence project outcomes are organizational influences such as culture, style and structure. Norms and culture, which determine the organization’s working-approach, can be defined as the shared visions, expectations, beliefs, policies, procedures, authority relationships and work ethic. In this case, senior management is responsible for defining tasks and setting specific and challenging strategic goals (vision), which according to goal setting theory leads to higher performance, enables strategic renewal, reduces conflict and thus increases the efficiency of the stated policies and procedures (Ho and Tsai, 2011). Moreover, a supportive organizational culture in which the patterns of behavior, attitudes and feelings that characterize an organization and a supportive climate is crucial in the sense that a collective tacit understanding provides structure in the group level and increases the transparency of knowledge sharing (Bertels et al, 2011). On the other hand, structures can be defined as an “enterprise factor which can affect the availability of resources and influence how projects are conducted (PMBOK guide, 2012).” These structures range from functional to project-based. The main difference is that functional structures are arranged according to specialty (departments such as marketing, R&D and sales) and functional managers and projected-based structures are arranged around project teams, which increases the influence of project managers. Research by Hobday (2000) identifies the latter structure as ideally suited for managing increasing product complexity, fast changing market and technology uncertainty through its potential to foster innovation, combining and sharing resources across other project stakeholders and the promotion of effective leadership across business functions. However, there is a range of possibilities to blend these struc-
tures into a matrix structure that delegates different levels of responsibilities to functional and project managers.

4.2.2 PROJECT MANAGEMENT FORMALITY
The project management method, which is characterized by its structured and well-defined task definitions, processes and activities, is considered by academics and scholars as generally useful for managing NPD projects (Barczak and Kahn, 2012; Sandmeier et al, 2004). NPD projects are projects which processes and activities are directed towards conceiving, developing and launching new products (Cooper, 2008). However, the complex interrelated activities, high levels of uncertainty and complex information processing circles that characterize NPD, are not completely addressed within some areas of project management. An example is that current Project management practices are based on output control through targets and management by objectives and this is considered as inhibiting innovation by some researchers. However, other research indicates that formalization and output control enhances innovation (Cardinal, 2001). Moreover, project management requires relatively complete initial definition of outcomes and scope, which can be problematic for NPD’s dynamic scope (Pons, 2007).

4.3 TRIPLE CONSTRAINT MANAGEMENT
One of the core areas of project management is the 3C, which is displayed in figure 11, is a traditionally widely-accepted criterion for measuring the performance of projects (Atkinson, 1999; Jha and Iyer, 2007). First, time is concerned with the processes that are needed for timely completion of the project. Secondly, costs are concerned with estimation, budgeting and controlling costs in order to keep them within the approved budget. Third, scope refers to the processes that ensure all the required work is included in the project and controls the aspects that were originally not included within the project (PMBOK guide, 2012). Thus, when these constraints are not managed effectively, this may result in schedule slippages, cost overruns or deliverables that do not meet the criteria and this will consequently result in project failure (Anbari et al, 2008; Davidson, 2002). Balancing these constraints involves making continuously trade-offs amongst them throughout the project life cycle. This will be discussed in chapter 4.3.4.
4.3.1 TIME

One of the crucial problems regarding time is the intrusion of bias, which can exhibit itself in the over- or underestimation of the time required to complete the activity and this requires project managers to be vigilant towards biases such as overconfidence, motivation and stereotyping (Vose, 1996). In dealing with time during a NPD project, it is necessary to monitor the degree of work-completion and schedule-completion. This requires managers to rely on member’s own judgment of task-completeness from the range 0% to 100% (Pons, 2007). However, a gap remains’ between this judgment about reality and reality itself: an error. This can be defined as “the state or condition of being wrong in conduct or judgment” (The Oxford Dictionary). Methods that can assist project manages in dealing with these errors are the project evaluation and review technique (PERT) and critical chain methodology (CCM), which can provide some support regarding the robustness of scope-estimations (Sonnemans et al, 2003).

4.3.2 COST

Cost management involves the cost-estimation, production of a baseline (life cycle cost for NPD project) and cost control activities during the project. In case of NPD projects, managers should be aware of the product-differentiation when choosing a cost strategy, since a focus on target costing may distract designers away from product-values such as technology, time-to-market and customer satisfaction (Pons, 2007). A crucial problem within NPD projects are the labor costs, which include the budgeted project-work but not include the slack time. However, in reality this may be actual project costs and could be better handled by software such as MS project (Pons, 2007). Another problem is the fact that NPD involves both ex-
penses and income, while project management has costs as a primary focus in the life cycle. This conflict increases the confusion risks and error and requires software improvements that can deal with the several metrics of financial performance (Pons, 2007).

4.3.3 SCOPE
Scope management within NPD project deals with scope-definition and the creation of the work breakdown structure (WBS) down to the level of work packages. However, the full scope of the project can often not be anticipated beforehand, especially not within radically new projects and therefore prescribes the scope definition and materially affects the work breakdown structure. Therefore, managers need to set clear and stable overall goals while avoiding unrealistic expectations (Barczak and Wilemon, 2003). In this case, the stage-gate model, if implemented in such a manner that it can deal with aspects such as rework activities, multiple partial solutions, changed scope and different stakeholder views, can provide a road-map for the project’s scope, WBS and work packages (Pons, 2007).

4.3.4 BALANCING TIME, COST AND SCOPE
In order to effectively manage these balancing acts, project managers must identify other important project aspects. Namely, one of the main tasks of the project manager concerning the triple constraint is prioritizing the relations between the constraints with respect to the stakeholder’s expectations and needs. Thus, which intrinsic or implicit metrics by which a project is judged are most crucial according to stakeholders (Anbari et al, 2008)? Project managers must identify, through customer interactions and involvement, which constraints are of crucial importance for the project and which are of lower significance in relation to customer expectations and needs (Anbari et al, 2008; Atkinson, 1999; Davidson, 2002). Research of Anbari et al (2008) indicates that a combination of quality tools, audits and the quality function deployment (QFD) tool, which identifies customers’ expectations and translates them into technical requirements, is an effective method for identifying these expectations and ‘translating’ them towards the triple constraints. Ultimately, this will result in the identification of the so-called strong, middle and weak constraints. The strong constraints, which are identified as most crucial according to
stakeholders’ project expectations, are in this case considered as less flexible as the middle and weak constraints, which are related to their less crucial expectations. Thus, project managers must continuously be aware of these aspects when making trade-offs amongst them throughout the project life cycle (Dobson, 2004).

4.4 RISK MANAGEMENT AND BUFFERS

4.4.1 RISK MANAGEMENT SYSTEM

Project Risk Management, according to the PMBOK guide (2012), includes the processes of conducting risk management planning, identification, analysis, response and monitoring and control on a project. According to Flanagan and Norman (1993) it is “a system which aims to identify and quantify all risks to which the business or project is exposed so that a conscious decision can be taken on how to manage the risks.” Risks can be defined as “the possibility that events, their resulting impacts and their dynamic interactions will turn out differently than anticipated” and is generally described in statistical terms (Miller and Lessard, 2008). The contemporary risk management-life cycle is generally considered to consist of 5 steps:

- Risk identification
- Risk estimation
- Risk evaluation
- Risk response
- Risk monitoring

Figure 12: Risk management life-cycle (Baker et al, 2012)

Figure 12 displays the risk management life-cycle in which the risk identification and estimation come under the broader title of risk analyses. Furthermore, risk analyses and risk evaluation can be grouped under risk assessment (Baker et al, 2012). Risk identification determines which risks possibly affect/influence the project and registers characteristics (Mojtahedi et al, 2010). The project team should be closely involved in the iterative identification process, in which new risks can continually pop up during the project’s life cycle, since responsibilities regarding these risks and associated risk responses should be determined (Mojtahedi et al,
2010). With respect to project risk identification it is important to mention that some risks cannot be identified beforehand: Known-unknown risks are risks of which the project team beforehand knows that they could occur, but their exact timing and form is not clear. On the other hand, unknown-unknown risks are risks for which cannot be planned, since their occurrence was deemed impossible beforehand. Thus, they fall outside the initial scope of the project plan (Pich et al, 2002). Next, project risk assessment measures the impact and priority of the identified project-risks and facilities the allocation of resources to support management’s action decisions (Cooper et al, 2005). Firms can assess the priority of risks, their impact on project objectives and the risk tolerance of the triple constraints (time, cost and scope) by using qualitative risk analyses techniques such as scenario planning (Ebrahimnejad et al, 2010). To conclude, project risk monitoring is concerned with the implementation of risk response plans, tracking identified risks, monitoring residual risks and evaluating risk process effectiveness throughout the project. Purposes of monitoring are the determination of the validity of project assumptions, checking if the nature of risks has changed and the concurrent actions made upon this assessment and guaranteeing that policies are being followed (PMBOK guide, 2012).

4.4.2 RISK RESPONSE STRATEGIES
Risk response strategies are concerned with the identification, evaluation, selection and implementation of strategies which should reduce the likelihood of occurrence of risk events and/or lower the negative impact of issues to an acceptable level and this includes the documentation of the crucial actions, responsibilities and risk handling costs (Fan et al, 2008). The choice of such a response (handling) strategy, which actions should reduce the level of risk, is contingent on the both the project characteristics and the risk situation. Fan et al (2008) propose a framework (figure 7) in which the decision of risk handling strategy is made upon the key parameters project characteristics, controllability of risk event and the risk handling costs. The primary purpose of this framework is enabling managers to quantify parameters, analyze alternatives and choose a risk response strategy that deals with a certain risk event while minimizing risk response costs.
Figure 13: Risk response strategy conceptual framework

Generally, project characteristics encompass project size, technological complexity and the external economic environment. Furthermore, controllability of risk events is concerned with “the likelihood of changing the probability distribution of the event and is used to define the nature of the risk situation” (Miller and Lessard, 2001). High degrees of risk controllability are associated with technical, scheduling and budget risk events, while a low degree of controllability is associated with aspects such as economic conditions and therefore potentially affects the choice of a risk handling strategy. In case of extremely high or low controllability, the choice for a handling strategy is often quite obvious, but in case of non-extreme situations, the associated handling costs could play a more profound role in the ultimate choice of strategy (Fan et al, 2008). Examples of risk response actions are (1) the enhancement of control and communications and the development of a contingency plan to provide design flexibility in case of alternations in project scope or budget and the preparations of budget-reserves to deal with inflation-occurrence. Moreover, the phases of risk identification and risk assessment could provide the project team with information that can be used as input for identifying the project characteristics and the controllability of risk events, since aspects as the general risk-level and pattern and the high risk items should be identified and assessed within these phases (Cooper et al 2005). Risk-handling costs can be defined as “the expenses incurred in implementing a selected strategy that would reduce risks to an acceptable level (Fan et al, 2008).” Low handling costs are associated with higher levels of controllability and high handling costs with lower levels of controllability. However, project managers still must judge whether the costs of choosing and implementing a certain strategy that deals with a risk event are balanced against the benefits this could create for the project (Miller and Lessard, 2008).
Risk-handling strategies can be grouped into two categories: risk prevention strategies and risk adaption strategies. Risk prevention strategies involve actions implemented during the project planning phase which are aimed to reduce the probability of occurrence of risk events and are associated with risk events with high levels of controllability. Risk adaption strategies’ actions are planned through the project budget and schedule and implemented during the execution phase in order to alleviate and reduce the negative impacts of project issues (Fan et al, 2008).

4.4.3 STRONG, MIDDLE AND WEAK CONSTRAINT
In order to effectively manage the balancing acts, companies must prioritize the relations between the constraints and identify the strong, middle and weak constraints with respect to customers’ needs and expectations (Anbari et al, 2008; Atkinson, 1999; Davidson, 2002). Therefore, companies should start by engaging in risk-identification and risk-assessment activities, which could provide them with an overview of the general level and pattern of risk facing the triple constraints, a list of the (possible) risk events and input for the controllability of risk events. The main emphasis of these activities should lay in stage 2 (Figure 13) since in this stage the project plan is created in which the important 3C-activities, interrelations between the triple constraints and uncertainties that affect project outcome are identified (Cooper, 2005). However, identifying and assessing risks should also be addressed within the later stages when new risks and uncertainties arise due to new developments in the NPD activities.

4.4.4 3C-BUFFERS
This chapter gives examples of time-buffers, cost-buffers and scope buffers. Moreover, some project management-tools and techniques are discussed that enable managers to effectively manage these buffers.

- Including slack in projects, which provide focus and clear decision criteria for project managers, is an example of a time buffer. A widely used tool for assisting managers in managing slack is critical chain project management. The critical chain methodology focuses on the project schedule through specifying
the critical chain of tasks in which the projects’ resource dependencies are included (Leach, 1999).

- A scope-buffer in NPD is the definition of a performance level into the product that is higher than initially thought necessary. In this manner, managers can diminish the project scope in order to accommodate multiple possible outcomes of risk events without endangering the project scope initially agreed upon (Bhattacharya et al, 1998).

- Stochastic networks such as PERT and GERT allow managers to identify the critical path for projects and for making resource proposal’ scenarios. This increases project transparency and enables adequate resource allocation amongst the 3C. Thus, these tools can visually support the time, resources and scope that a project will consume according to several scenario’s (Pich et al, 2002). PERT’s are typically useful in organization where the duration times are hard to define and the relationships between the tasks are complex. Each PERT has a starting point after which each subsequent task is connected to the other tasks. Each task contains a best, worst and average duration time-scenario and the people that are needed per scenario. An additional option is the coupling of scope to these scenarios.

4.5 SYSTEM THINKING

According to research by Kapsali (2011) provides systems thinking the flexibility to manage innovativeness, complexity and uncertainty in innovation projects more successfully. System thinking is a conceptual framework which is suitable for developing constructs for theory and practice and complements conventional research styles in certain ways; it suggests different levels of analysis and synthesis for different problems; it complements reductionism, cause-and-effect thinking and determinism (delusion of complete control) with synthesis (holistic system-view), circular causal effects and indeterminism (emergence and probabilistic thinking); it constructs holistic, contingent perspectives and practices by making use of different theories, tools and techniques; it works on high levels of abstraction and is suitable for depicting mental models that are inclusive of the complexity of stakeholders’ interpretations, which increases understanding project management boundaries and striking balances (Kapsali, 2011).
As previously mentioned, is System thinking (dynamics) concerned with identifying common patterns of behavior for business processes and incorporating process structures which can generate these patterns of behavior. Usually this requires that the investigation of how one or more variables of interest change over time. A large number of patterns of behavior are caused by feedback, which is the phenomenon where changes in the value of a variable indirectly influence future values of that same variable. Causal loop diagrams are a manner of graphically representing feedback structures in a business process, because causal loop diagrams suggest the possible modes of behavior for a process. In other words, a feedback loop is a closed sequence of causes and effects. Thus, after common behavioral patterns are discovered, one can identify the system structure which causes that pattern. Consequently, modifying this system structure enables the possibility of permanently eliminating the problem pattern of behavior. Four patterns of behavior are shown in Figure 14. In this figure, “Performance” refers to a variable of interest (Richardson & Pugh, 1981).

![Figure 14: Four patterns of behavior](image-url)
• Exponential growth means that an initial quantity of something starts to grow, and the rate of growth increases.
• With goal-seeking behavior means that the quantity of interest starts either above or below a goal level and over time moves toward the goal.
• S-shaped growth starts with exponential growth and is followed by goal-seeking behavior which results in the variable leveling off.
• Oscillation means that the quantity of interest fluctuates around some level.

A diagram of the feedback structure of a management system is a starting point for analyzing what is causing a particular pattern of behavior (see chapter 5 for examples). These diagram include elements and arrows linking these elements together and include a sign (either + or −) on each link. These signs have the following meanings:

• A causal link from one element A to another element B is positive (+) if either (a) A adds to B or (b) a change in A produces a change in B in the same direction.
• A causal link from one element A to another element B is negative (−) if either (a) A subtracts from B or (b) a change in A produces a change in B in the opposite direction (Kim, 1992).

In addition to the signs on each link, loops are also provided with a sign. The sign for a particular loop is determined by counting the number of minus (−) signs on all the links that add to the loop:

• A feedback loop can be seen as positive, indicated by an R sign, if it contains an even number of negative causal links.
• A feedback loop can be seen as negative, indicated by a B sign, if it contains an odd number of negative causal links (Kim, 1992).
CHAPTER 5: DATA COLLECTION AND ANALYSIS

Data for this study are acquired through iTCM project-data sources (Requirements and Architecture documents), literature which is discussed in the previous chapter and a series of interviews. As discussed in section 2.1, are these interviews part of the diagnosis phase and provide in-depth input for the conclusions and the high level design of the buffer management system and recommendations.

5.1 INTERVIEW SET-UP

Interviews aim to gather knowledge on goals, experience and expectations of the involved stakeholders. In this case, the semi-structured interview is used for uncovering information, since this type of interview is suitable for obtaining information that lies beyond the specific answers to the questions. Moreover, it takes the own interests/viewpoint of the different stakeholders into account and allows for the acquisition of more in-depth information. This type of interview can be considered suitable for uncovering detailed information within the specific ASML-context, since buffer management is currently seen as a complex subject within ASML due to aspects such as responsibilities, formality and power. By conducting a semi-structured interview, which allows for pre-defined questions and specific (not prepared) questions that are customized to the specific viewpoint of the stakeholder, both general information relevant to specific issues and specific quantitative and qualitative information can be uncovered. Ultimately, this will uncover the different needs, priorities and preferences of stakeholders.

Since this study is done within the context of the iTCM project. Meaning that iTCM is one of the enablers and influencing factors of the buffer system design proposal. Therefore, the interviewees that are selected are stakeholders and champions within the iTCM project. Moreover, in order to get a wide overview of the study object, a wide range of people from different positions is interviewed. This resulted in a list of 8 persons which are interviewed: 2 PL’s from D&E, 2 project planners, 1 GL of the Project Management Office, 1 DM of the Project Management Office, 1 PCM of D&E and 1 PDM of D&E. Thus, both people form the Line and the Program are interviewed and from different hierarchical levels.
5.2 VALIDITY AND RELIABILITY

This study uses two types of triangulation, which is a method used to check and establish validity in qualitative research from multiple perspectives in the sense that findings reflect the situation in an accurate manner (Guion et al, 2011). The types of triangulation which this study encompasses are: data triangulation and theory triangulation. The first type of triangulation is using different sources of information to increase validity of the study. In this case, stakeholders from multiple departments, hierarchical levels and programs are used to extract information from. In this case, depth-interviews are conducted to gain insight into the different perspectives of these stakeholders, who have both areas of agreement and areas of communality (Guion et al, 2011). Other sources of data that have been used in this study are literature and iTCM project data. The second type of triangulation is theory triangulation and this method involves that multiple perspectives are used for the interpretation of a single set of data. This means that people from different disciplines and positions are involved in the data gathering and analysis process (Guion et al, 2011). Thirdly, this study conducts an expert’s opinion in order to check the data analysis presented in figure 4. These two experts are both from different departments, disciplines and programs which again involve multiple perspectives into this study and increase the reliability and validity of the proposed design solution and recommendations. Furthermore, the research question, problem statement and the construction of the interview protocols are partly based upon data that is extracted from the iTCM project. This data is already thoroughly on tested on validity and reliability within a wide range of ASML staff. This aspect also adds to the reliability and validity of this study, since the iTCM project can be seen as an enabler and information-provider of this study. To conclude, research by Mayring (2001) regarding qualitative content analysis was used for the analysis of the qualitative results. This research distinguishes four advantages for grounded analyses: fitting the material into a model of communication, devising the material into content analytical units, logical sequence of causes and effects (feedback loops) and carrying out checks of reliability through triangulation and inter-coder reliability. The inter-coder reliability is defined as: “the extent to which independent coders (referred to as interviewees) evaluate a characteristic of a message or artifact and
reach the same conclusion.” Mayring (2001) states that the standard of coder agreement should be 0.7 or higher, which means that in this study factors that are identified by 5 or more people are seen as reliable, since the number of interviewees is 8. The results of the final step of this content analysis can be found in appendix C.
5.3 INTERVIEW ANALYSIS

This part provides an overview of the results of the interviews. The results are analyzed and synthesized according to systems thinking methods, in which holistic perspectives are combined with circular causal effects and indeterminism. Moreover, as indicated in chapter 4.5, this method depicts mental models that are inclusive of the complexity of stakeholders’ interpretations, which increases understanding of project management boundaries and striking balances (Kapsali, 2011).

5.3.1 CURRENT BUFFER SITUATION

The first aspect of this interview analysis is the current situation regarding buffer management (figure 15). This aspect has a direct relation with the problem statement (section 1.2) and adds more in-depth knowledge to the situation as described in the iTCM requirements document.

![Figure 15: Causal loop diagram of current buffer situation](image-url)
Figure 15 depicts the current situation regarding the use and determination of buffers during ASML’s PGP within the D&E department. There is currently not a formal policy that describes buffer management procedures. Therefore, figure 15 describes the informal system of current buffer practices at ASML. Momentarily, the driving factors behind the determination and use of buffers are project risks and project issues that are identified and materialize in between the RFF’s. In general, project risks play a crucial role after the annunciation of the quarterly rolling financial forecast (RFF) in which the resource allocation (staff) of the individual projects, clusters and programs is determined. These project risks, which consist of the risk impact and risk occurrence and is determined through various risk identification and estimation techniques/ methods, have an impact on the size of the project resources, issues and indirectly on the project buffers. The reason is that higher-risk projects need a larger number of resources and safety measures such as prototyping in order to meet the project terms agreed upon upfront. Moreover, a higher risk is linked to a larger number of project issues. In this case, risks and issues are defined as negative, which means they have a negative impact on the project. For a certain amount of project risks which are identified upfront contingency plans and safety measures are installed within the project plans which are not part of the project buffer. However, for a certain amount of issues (usually known unknowns) a project buffer is reserved. In other words, project issues that materialize after the determination of the project resources are the main drivers of buffer use. The methods that are used by PL’s to determine and use their buffers will be discussed later in this chapter. Other crucial factors that influence the project resource allocation are project size and resource availability. The resource availability is limited because of the finite number of available engineers. At ASML, these engineers are considered a scarce resource since hiring and training them is a cost-intensive undertaking. It should be noted that the buffer management and reservation process as described above does not happen in a transparent manner. In practice, this means that buffers are not allocated separately to projects, but are ‘extracted’ from the assigned resources and incorporated in the (project) plans by the PL in an intransparent manner. As indicated by a PL: “You do not get a buffer, but use your own resources as buffers.” A negative implication is that there are certain PL’s that
neglect to define buffers in their plans and instead make unrealistic plans, which do not contain buffers and are highly likely to fall outside the 3C project-boundaries.

As illustrated in Figure 15, the project resources are influencing the project scope. An increase in scope means an increase in PBS items within a project, whereas a decrease entails that less PBS items can be fulfilled. The higher the scope, the technically more advanced the final project will be. However, there exists a balancing loop between project scope and project issues:

- An increase in scope will increase the project issues and this triggers, amongst other things, a decrease in scope. The consequence is that there will be a decrease in project issues and this enables an increase in project scope.

A large influence in this loop is reserved for the system engineering department, which determines if the total scope of the product fulfills the requirements as promised beforehand to the customer. Thus, there may be some ‘space’ to decrease the project scope as long as the complete system delivers as agreed. Thus, the PL does not have the power to use this ‘buffer’ without consent of system engineering, which is displayed in figure 8 in the Technology-column. Therefore, PL’s are focused to have sufficient project resources to reach the targeted scope and time as agreed upon during the negotiation phase in which the PBS-items and crucial milestones were defined. In order to make a profound resource claim, PL’s should be preparing a project plan for after the annunciation of the RFF in which they sufficiently take account for the identified and estimated risks. However, in the current situation at ASML there are multiple processes that co-exist regarding the resource allocation. In this case, a crucial factor is the way of working of the PCM and PM, which has an impact on how realistic the project plan is. Figure 16 displays a simplified process that should be followed during the RFF or large changes that occur in between the RFF and have a big impact on multiple layers, but in practice often is (partly) neglected. Thus, this formal resource allocation process is not yet fully adopted by the D&E department.
A scenario that often occurs is that the process described above starts with the creation of a program proposal, which is directly derived from the results of the RFF. This implies a top-down way-of working, whereas the process described above starts with a bottom-up resource proposal. The process by which this process enrolls influences the quality of the project plan, the strength of the resource claim and the number of project resources. Moreover, a realistic project plan in which is accounted for the risks by installing safety measures such as buffers has a higher predicting value and suffers less from the impact of project issues. Thus, this process is also suitable for determining the buffers during the RFF.

In the current situation, in which the quality of project plans is often insufficient due to reasons described above, there exist 2 loops in which the bargaining for resources plays a crucial role:

- Unrealistic project plans have a low predicting value, which leads to more issues that materialize during the PGP-process. Hence, more buffers need to be used, which increases the perceived project risk. The perceived project risk are the risks that are not based on risk identification and risk estimation techniques, but merely based on PL’s immediate resource need due to resource shortage. Reasons for this shortage are stated in chapter 1 and 2. This increases the bargaining
for resources, based on highly informal processes, which decreases the
reality of the project plan, since schedule adjustments need to be
made which deviate (largely) from the initial project plan. Hence, a re-
inforcing loop that decreases the predictability of project plans and in-
creases project issues due to factors such as unrealistic planning is the
result.

- Another loop exists due to the constant process of bargaining over re-
sources. A decrease in buffer resources and an increase in perceived
project risk create an increase in bargaining for resources and project
buffer resources. Hence, buffer resources increase again and due to
the constant “fighting”-over-resources game there exists a balancing
loop. Moreover, due to this highly informal bargaining-process, the re-
inforcing loop stays intact and projects with chronic resource shortage
are enabled to continuously contaminate healthy projects that have
predictable project plans and sufficient resource buffer and slack.

To conclude, project slack is something which almost never does occurs until the
first shipment. The timing of all projects is based on the milestones from the prod-
uct master plan and integration plan, which states how the deliverables of the pro-
jects fit together into one machine and when these deliverables need to be inte-
grated into the machine. ASML’s strategy is based on fast development cycle times
and first-mover advantages makes that until the first shipment there is little room
for slack.

5.3.2 BUFFER RESPONSIBILITIES: CENTRAL VS. DECENTRAL
The Line is solution provider according to the current policy (see figure 6). Howev-
er, in practice the Program carries the solution provision responsibility and the Line
is responsible for resource (staff) allocation. The main reason of this discrepancy is
the fact that in the past the Program always has been in charge of the solution and
this power-balance is anchored within the ASML culture. A PCM indicated that “The
Program has the credit card and the Line has the resources.” Because the Program
is still responsible for solution delivery (scope), the resource capacity does matter,
since more resources increase the likelihood to deliver a higher project scope. How-
However, with the Line as solution provider the resources would not matter to the Program because only the solution availability (when and what) would matter. Moreover, the majority of the interviewees indicate that the GL should support the PL’s project management activities such that the way of working is embedded properly into the different projects and project-plans. Thus, GL as solution provider does currently not work according to a large part of ASML’s management. This can be seen in the responses regarding where the responsibility and allocation should be, since everyone indicated that the program should be held responsible.

Figure 17: Buffer responsibilities

However, there are some differences regarding the opinion regarding centrality of buffer responsibility. Therefore, figure 17 displays the advantages and disadvantages of central and de-central buffer responsibility. This picture makes clear that both extremes impact the time of completion and resource use through both positive and negative mechanisms. Central responsibility means that there is a higher degree of overview and allocation flexibility, which leads to less buffer fragmentation and more effective buffer attention. On the other hand, central responsibility means that PL’s are forced to continuously share their project issue details with higher management, which not only occupies higher management, but also tremendously increases the information stream. Moreover, there is a decrease in the self-empowerment of PL’s.
5.3.3 ITCM AND BUFFER MANAGEMENT SOLUTION SUPPORT
This chapter elaborates upon the solution support of buffer management in the context of the iTCM project. Figure 20 highlights the most important influences that were introduced by the interviewees and partly derived from the iTCM requirements document (2013). First, a factor that has a direct influence on the solution support is the software complexity. This means that engineers from the D&E department want the least possible amount of software tools to work with. Moreover, if new software is introduced, engineers will be inclined to work around them if they do not see the personal usefulness of the software. Thus, a connection with the current way of working can be seen as a factor that positively influences solution support.

![Figure 18: iTCM and buffer solution support](image)

Next, a reinforcing feedback loop that can be identified is displayed in the top of figure 18. Interviewees indicated that the iTCM project has the potential to increase the insight in the triple constraint, which increases transparency and increases the clarity of the decision criteria. On the one hand, this clarity enables an open discussion between the involved parties regarding the pending discussions and on the other hand reduces the impact of bargaining for resources. The main reason is that
insight in the 3C and increased clarity on business such as resource allocation leaves less room for bargaining ‘outside the boundaries’. Thus, this way of working enables PL’s to think about their 3C balance and boundaries and increases insight of PL quality regarding their project management skills. Another important influence is project management training, which not only increases the project management skills of planners, PL’s and GL’s, but can increase management’s soft skills, which enables more clarity.

5.3.4 FLEXIBILITY MATRIX
This final chapter of the analysis briefly discusses the flexibility matrix of the time, cost and scope of projects at the D&E department. Figure 19 provides an overview of the results.

![Flexibility Matrix Diagram]

*Figure 19: Buffer-Flexibility matrix*

One must keep in mind that these results are a generalization of the flexibility matrix of D&E projects and that each project has its unique matrix. In general, at the start of a project lifecycle there are not yet made harsh commitments to customers regarding the final delivery and product requirements. However, there are made internal agreements regarding the effort, based on the RFF. However, as the lifecycle continues, ASML will make harder commitments to their customers regarding delivery dates and requirements, which results in a less flexible scope and time. Consequently, the effort that has to be adapted to these commitments becomes more flexible. Next, a change exists after KD11. Mostly, products do not fully meet with the set requirements, which make scope the least flexible. On the other hand, since customers already have a working product in-house (although with less than agreed scope) which they can use for testing, time becomes more flexible. At the
final stages of the lifecycle effort is often the least flexible, because commitments to other projects are already made, which makes it more difficult to re-allocate effort.

5.5 REQUIREMENTS FOR DESIGN PROPOSAL

By making the step from data collection to design analyses one should consider some requirements to which the design proposal has to abide. First, the main research question has to be answered. This gives direction to the main purposes and way of working of the design proposal. The implication of this question is that the analyzed data must be verified by making use of other sources in order to filter the factors that are undermined or missing in the current situation as described in figures 16-18. Data sources that are used in this case are the theoretical framework, a second literature scan and data from the iTCM project. This verification results in a list of subjects that in combination with the results from chapter 6 should be included in the design proposal. In this case these subjects are described in the first paragraph of chapter 7. Another important fulfillment of the design proposal is the user requirements. This entails that the end users need to be able to not only understand but also implement the final design at ASML. This type of verification is done through an expert opinion as described in chapter 5.2.
CHAPTER 6: CONCLUSION

The first section of this chapter describes the main conclusion that can be drawn from the interview analysis and provides an answer to the main research question. The sub-question will be partly answered and partly in the recommendations of chapter 8.

First, as indicated in the interview analysis, is bargaining for resources leading to a decrease in quality of project plans, which leads to continues schedule adjustments. This in turn leads to a reinforcing loop that decreases the predictability of project plans and thereby increases project issues. This reinforcing loop is kept intact due to inadequately assignation of or a complete lack of resource buffers and slack (balancing loop). The result is that projects with chronic resource shortage are enabled to continuously contaminate healthy projects. The conclusion is that an implementation of adequate buffers can reduce the negative effects of changes that are enables by project issues and risks and thereby reduce the contamination of healthy projects. In other words, buffers prevent that changes or schedule adjustments to projects do not influence other projects triple constraint. This also prevents bargaining for resources due to chronic resource shortage of certain projects. However, the implementation of buffers does not mean that project cannot fall outside their 3C boundaries, because there are project issues and risks which are inherent to ASML’s high technology and complex industry. An example is technical uncertainties that can hardly be correctly estimated in project plans due to their low controllability.

Second, the iTCM project integrates 3C information and thereby reduces the negative effects of uncontrolled balancing of the 3C. This leads to changes, which are backed up by a set of work descriptions and tooling that will lead to efficient and more balanced decision making and more realistic project plans. Thus, the iTCM makes 3C information available, which currently stays hidden due to inefficient control mechanisms, tooling and guiding principles, and thereby is the enabler of buffer management. The reason is that buffers cannot be implemented without the existence of transparent project information. This means that the iTCM project reduces
the negative effects generated by risks and project issues within projects, because less schedule adjustments and project changes are needed.

Third, there is currently not a formal policy implemented that describes buffer allocation procedures. This results in a wide variety of buffer allocation techniques or a complete lack of buffers. Top-down central resource allocation process during the RFF in combination with informal bargaining for resources lead to assigned resources from which buffers are taken. The analysis does not describe a straightforward answer regarding the responsibilities of buffer allocation. Central responsibility leads to a higher degree of overview and allocation flexibility, which leads to less buffer fragmentation and more effective buffer attention. However, decentral responsibility leads to insight into project issues, which reduces escalation of problems to higher management and additionally decreases the information stream and increases the self-empowerment of PL’s. From the aspects described above can be concluded that the implementation of formal procedures for buffer allocation based on transparent information made available by iTCM, enables a transparent discussion between bottom-up and top-down responsibilities that provides higher levels of consistency and control to buffer allocation. Hereby, since each level of buffer responsibility has its own advantages and disadvantages, ASML must find a balance between them that is adjusted to their particular situation. This is crucial for successful assignation of buffer allocation responsibility.

Fourth, project management training increases the project management skills of planners, PL’s and GL’s and increases management’s soft skills, which enables more clarity. Thus, project management training offers support to the implementation of buffers and the iTCM project, since it indirectly increases solution support and clarity of decision criteria. This means that the adoption of training increases the chance for successful implementation of buffers and the iTCM project.
CHAPTER 7: DESIGN PROPOSAL OF THE BUFFER MANAGEMENT SYSTEM

This chapter elaborates on the proposal of a design for ASML’s buffer management system, which is based on the data analysis, iTCM project information, the theoretical framework, a second literature review and the conclusion. The combination of these sources indicates that there exist several factors that came up that should be improved or introduced within ASML and included in the design of the buffer management system, of which this chapter describes the following factors; (1) how critical chain methodology can initiate a liable way of working in combination with buffer management (2) Complexity versus creativism and the role of formality; (3) Project management training. Section 7.1 combines these factors along with the main conclusion from the previous chapter, into a high-level design proposal for a buffer management system at ASML.

7.1 DESIGN PROPOSAL

This chapter discusses the high level design for a buffer management system at ASML. Moreover, this implies that part of the aim of this research will be presented. Figure 20 graphically represents this design. The core message of this design is based on the following factor:

- Resource buffers and slack are risk adaption strategies that protect the original project plan from deviations by absorbing issues that cannot be solved within the 3C-boundaries set within the RFF through a formal allocation process. Thereby, buffers prevent that changes or schedule adjustments to projects do not influence other projects triple constraint.

Figure 20 depicts both a formal buffer resource and slack allocation process and a more informal resource and slack allocation process. The formal process is depicted in the blue box which is also shown in figure 16 and involves multiple steps and approval from multiple management levels (3iTB). This formal process should be used for determining the 3C boundaries and during this process risks are identified and assessed, which influences the 3C boundaries and buffers. Moreover, higher-quality formal processes lead to better identification and assessment of project risks. This
increases the predictability of project plans, decreases the number of project issues due to unrealistic planning and thereby reduces the use of buffer. This formal allocation process should be used during the RFF or in case of major changes to projects, clusters or programs. In case of ASML, these usually occur during KD’s. Especially after KD11-first shipment, this formal process should be used to reset the 3C boundaries and buffers, since after this KD there is a major shift in the flexibility matrix that makes the project scope the least flexible and project time the moderate flexible constraint. Methods and processes which can support this formal process are the critical chain methodology, TOC, PERT and the iTCM processes and tools.

The informal allocation process is depicted by the balancing loop. In this case, informal means that a simplified process that involves less stakeholders. This process is intended to manage resource buffer and slack allocations that have small impact on the overall project, cluster and program levels. Allocation decisions are based on transparent information that is made available through iTCM processes, the CCM methodology and PERT. However, PL’s and PCM’s do not need to go through the entire formal process, but can quickly allocate extra resources by discussing with higher management when projects or clusters fall outside their resource or time boundaries and buffers. This allocation is now enabled through scenario propositions that link project buffer resources to slack and scope. In other words, PCM’s can quickly determine whether to increase the buffer and slack of the PL’s project plans in order to maintain the originally set project scope and PDM’s can determine this for the PCM’s clusters. This increases flexibility as described in chapter 5.2. Finally, project management training should be installed in order to increase the efficiency by which the iTCM project processes and tools, CCM/TOC methodology and PERT are implemented and used. This training positively influences the project plan, project management methodologies and the iTCM project, which ultimately have a positive impact on the buffer management system.
7.2 CRITICAL CHAIN METHODOLOGY

Research by Cohen et al (2004) indicates that the most important trade-off in organization’s management is between resource utilization and project throughput time. Moreover, this research indicates that higher resource levels will lead to more traffic intensity, longer throughput time and lower predictability of project plans. The critical chain methodology, that aims to develop sound project schedules by using time and resource buffer management against schedule variation, has been
identified by interviewees as a critical factor regarding buffer implementation at ASML. As indicated in chapter 5.3.1, there are hardly possibilities for time buffers due to aggressive milestones. However, implementation of iTM will increase resource and time transparency of schedules, which makes the ‘hidden’ buffers visible. An example of a risk-response method currently used by PL’s at ASML is spreading (buffer) resources by assigning more buffer to tasks than predicted. This means an increases occupation of both resources and time. Cohen et al (2004) and Patrick (1998) indicate that this increases Parkinson’s Law, which states that work expands to fill the time given for the execution. CC methodology in combination with Goldratt’s Theory of Constraints (1997) that is suitable for managing multi-project environments, offers a formal method regarding buffer allocation and control which can co-exist and cooperate with iTM and could improve the transparency of the current way of working. Table 1 provides a brief high level overview of what the general implications and steps of these methods are.

<table>
<thead>
<tr>
<th>CC</th>
<th>The chain of precedence and resource dependent activities that determines the overall duration of a project. (Figure 22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOC</td>
<td>Every system must have at least one constraint and the existence of constraints represents opportunities for improvement. The largest constraint, the bottleneck, is the activity/project that has the largest negative impact on the program. In case of ASML, the most constraining resource is time until first shipment (see Figure 21).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steps</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single project</td>
<td>Reduce activity durations by eliminating safety margins that are made transparent by iTM.</td>
<td>Identify the critical chain while taking both precedence dependencies and resource boundaries into consideration. Again, iTM provides transparency.</td>
<td>Create project buffers that protect the due dates against variations in CC activities.</td>
<td>Create feeding buffers in in non-critical activities, which protect the critical chain from variations in tasks.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steps</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple projects (TOC philosophy)</td>
<td>Identify bottleneck activities and ensure that bottleneck The high-level overview is provided through iTM’s EPM/Sharepoint.</td>
<td>Add time buffers in between bottleneck activities of successive projects. iTM’s EMP/Sharepoint will be able to make this transparent.</td>
<td>Buffer control: In case of project issues that are (threatening to get) outside their boundaries, buffers will be allocated according to the following priority:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Bottleneck resources of projects on critical chain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• CC-Activities of projects with buffer utilization</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Activities of projects with highest feeding buffer utilization</td>
</tr>
</tbody>
</table>

Table 1: CC and TOC (Cohen et al, 2004; Patrick, 1998; Vonder et al, 2004)
Figure 21: CC buffer management

The steps that are described in table 1 can be seen as high-level guidelines that provide ASML stakeholders with an initial direction of how to allocate buffers efficiently.

7.3 FORMALITY

This chapter discusses the level of formality that is suitable for ASML’s buffer management system and which tools and processes could aid in striking the difficult balance between managing complexity and innovation. First, the high-tech NPD project portfolio of ASML’s D&E department is extremely complex. Research by Teller et al (2012) indicates that with rising complexity, the benefits of formalization become even stronger, since this is connected with higher speed of resource allocation, reliability of commitment and the reduction of conflicts in resource allocation. However, when high levels of creativity are required, as is the case with ASML’s D&E projects, formalization may systematically create barriers to innovation and reduce opportunities for creativity (Bonner et al., 2002; Sethi and Iqbal, 2008). Moreover, no clear guidelines can be offered for project portfolios that are both complex and highly innovative due their conflicting implications. Thus, this requires a careful balance and consideration of moderation effects and the interaction of complexity and innovation. In other words, too much formality and structure will retain the uncertain, high-tech innovations, but too little focus on processes can lead to inefficient processes and continuously repairing errors and chaos (van Aken, 2004).

From an ASML viewpoint is the challenge of finding the appropriate balance of formality regarding buffer management within D&E, one of introducing and implementing formal control tools and processes which can control high complexity and
provide more transparency into the project plans and way of working as such that buffer management can function in an effective manner. The current way of working at ASML is highly informal, of which bargaining for resources is a striking example. However, introducing formal tools and processes should not destroy the positive aspects such as high levels of creativity and innovation. Moreover, the introduction of standardized routines and processes should take place at both single and portfolio project management level and the formalization of single project management should be integrated within the overall formalization of the project portfolio (Teller et al, 2012). In order to yield maximum benefit from this connection, ASML should give Line-management an advising role that closely adheres to the formalization requirements of both levels. Practically, formal processes and methods that are suitable for ASML’ buffer management are CC methodology, PERT and the RFF resource allocation process as displayed in figure 17.

7.4 PROJECT MANAGEMENT TRAINING
Several interviewees indicated the importance of project management training for PL’s, GL’s and planners. Especially amongst the planners, who should support PL’s with making plans and identifying risks, there exists a wide range regarding the quality and knowledge of project management skills. In this case, training in the following methods/process can be seen as useful for effective adoption of a buffer management system:

- Critical Chain methodology and Theory of Constraints
- Sharepoint/EP and Teamcenter
- PERT

Research by Buganza et al (2013) showed the positive impact of training effectiveness on project management competencies and the moderating role of role-training and environment. This means that ASML should decide which roles needs which competences and to what degree. Moreover, the impact of environmental factors such as management commitment, IT infrastructures and the degree of collaboration of the functions involved, must be mapped before setting up project management training.
CHAPTER 8: DISCUSSION, RECOMMENDATIONS AND FUTURE RESEARCH

This chapter consists of three sections. First, a discussion about the wider implications of this study, the agreement and disagreement with previous studies and the broader theoretical implications of the results will be provided. Second, some recommendations, based on the conclusions of chapter 6 and the design of the high level buffer management system at ASML, will be provided. Additionally, a summary of the data analysis, conclusions and the recommendations is described in appendix D. To conclude, chapter 8.4 address the limitations of this study and elaborates on possibilities for future research.

8.1 DISCUSSION

The most important result of this study is depicted by chapter 7 and figure 20. The design proposal is constructed by combining data collected from interviews, the theoretical framework and additional literature, information from the iTCM project and the conclusion. Moreover, the recommendations are partly derived from this high-level design. The main message that this design carries is the fact that within ASML’s high tech PGP, buffers are effective means to protect the project plan from deviations caused by issues and risks, of which the negative impact can be further reduced by: making realistic project plans, installing project management training and finding a balance between formal and more informal, continues resource allocation processes.

That buffers are effective means for protecting project plans from issues and risks in NPD environments has been widely accepted by both practitioners and academics. However, there can be identified several approaches for finding the balance between formal control and flexibility within project management. Namely, majority of the currently used project management methods focus on control rather than flexibility (Keegan & Turner, 2002; Lenfle and Loch, 2010). These methods are characterized by its structured and well-defined task definitions, processes and activities and are considered by academics and scholars as generally useful for managing NPD projects (Barczak and Kahn, 2012; Sandmeier et al, 2004). However, several studies indicate that in case of highly innovative NPD projects, which are character-
ized by high levels of uncertainty and complex information processes, formal output control methods are considered as inhibiting innovation and they systematically create barriers to innovation and reduce opportunities for creativity (Bonner et al., 2002; Sethi and Iqbal, 2008). On the other hand, research by Cardinal (2001) indicates that formalization and output control enhances innovation and research by Teller et al (2012) indicates that the benefits of formalization become even stronger with rising complexity, since this is connected with higher speed of resource allocation, reliability of commitment and the reduction of conflicts in resource allocation. Teller et al (2012) also indicates that when creativity is required, too much formalization may create barriers to innovation. This last research is part of the third group that emphasizes the importance of a careful balance between formal control and flexibility to cope with unforeseen events. Thus, companies should be able to continuously deal with the interaction of complexity, innovation and creativity when dealing with managing projects and risks (Aken, 2004; Osipova & Eriksson, 2012).

The main theoretical contribution of this study is the design proposal of this particular ASML case. This design shows how a high-tech company can deal with high levels of project complexity and at the same time maintain their flexibility in order to deal with unforeseen issues and risks through the use of buffer management and project management methods such as CCM and PERT. Moreover, it introduces moderating factors such as project management training and information transparency (through the iTCM project). Thus, this means that this study builds upon the research findings of Teller et al (2012) by providing a real case example that depicts on a high level how to balance control (formality) and flexibility within risk and project management activities and processes.

8.2 RECOMMENDATIONS
The recommendations that are provided below are part of the design plan stage of van Strien’s regulative cycle and a preparation for the implementation stage. Thus, these recommendations describe how the design proposal can be implemented within the current situation of ASML and contain the following factors:

- The objectives of this implementation
- A description of the main changes
The actions that must be taken

Before ASML begins with the implementation of a buffer management system, the iTCM project should be successfully adopted by ASML’s D&E department, since this ensures information transparency, balanced decision making through 3C integration and scenario building and project management tooling. Since this involves a large step which demands large changes in ways of working at D&E, it is recommended that iTCM is implemented and thoroughly tested before embarking on the implementation of buffers. In other words, if iTCM is not accepted and adopted completely, buffer management cannot work.

One of the most difficult aspects of the implementation of the buffer management system is striking the balance between control and flexibility. Currently, the culture and way of working within D&E are primarily directed towards maintaining high levels of flexibility which enables creativity. This flexibility will be maintained through the informal resource allocation cycle that will be based on transparent information. This should be used in combination with the formal allocation process, which is used for the RFF and in case of an impact that involves major changes in (high-level) boundaries. However, the manner by which this will practically work has to be carefully monitored and based upon this information and increased experience from the involved stakeholders, ASML should be able to move in the direction of a more balanced buffer situation. Practically, this means that the responsibility for defining, managing and deploying buffers at ASML’s D&E department lies with several hierarchical levels within the Program and Line. The levels that should be included from the Program are the PL, PCM and PDM due to their task responsibilities and level of overview. The reason that higher hierarchical levels are not included has to do with the fact that their responsibilities and activities take place at product and roadmap level, which are too abstract for dealing with buffers, since this requires more in-depth knowledge. Another level from the Line that has to be included is the GL, since the GL is responsible for providing people and methods for the solutions and ensuring timely delivery of solutions by teams. The Technology need only be included when changes regarding scope are made. Figure 16 depicts a high level
overview of how these responsible levels interact during the half-yearly RFF or in case of major boundary changes. Therefore, the responsibility for defining, managing and deploying buffers occurs according to the 3iTB principle which is depicted in chapter 3.2.3. Another implication is that each level has the authority over its own buffer, as such that the positive and negative aspects of both central and decentral buffer responsibility, as depicted in chapter 5.3.2, are present.

Sufficient project management training should be available and committed to, since it has a positive impact on project management competencies and can therefore increase the effectively of the overall solution as depicted by figure 18. This training should be developed by dedicated teams that are familiar with the iTCM project and directed towards teaching PLs, PCMs, PDMs, GLs and planner. This training teaches them how to deal with several PM tools such as CCM, TOC and PERT, which are suitable for managing and guiding buffer allocation processes and determining the buffer location and size in project plans. This training should be given gradually to D&E and planners, during a time span of several months, in order for them to continue their daily activities without a large degree of distortion.

The most crucial structural changes that should be made to the iTCM TO-BE situation are depicted in chapter 5.3.3. First, the interviewees indicated that there is not enough (higher) management commitment towards project management process changes and management training, as introduced by the iTCM project. A low degree of commitment towards projects such as iTCM, which increases the transparency of information and is of crucial importance for an effective buffer management system, will not stimulate this way of working. This means that there should be a structural change regarding the manner by which (higher) management commits itself to this type of project management projects that have a large impact on the current way of working of PL’s. Secondly, in order to successfully accomplish the critical success factors described in the paragraph above, structural changes to the way of working of PL’s are required. The new way of working requires complete information transparency, which eradicates the current bargaining for resources-process, which is not based on formal guidelines and transparent information.
Moreover, it demands from PLs, PCMs and PDMs that they deliver high-quality plans, which initially will consume more time. The implication is that their occupation with the technical, substantive project content will decrease. Thus, they need to increase the occupation with project management activities, which requires a large culture change at ASML, since PLs are generally technically oriented and have a background in engineering.

The design proposal as presented in chapter 6.1 depicts the elements and their relationships and thus provides a systematic view which indicates what the implications are of changes of the individual elements on the system. In other words, this holistic perspective exhibits a system that forms coherent whole rather than separate elements. Therefore, this design provides a starting point for the implementation of a buffer management system at ASML. Since this design involves major changes regarding the current way of working and requires intensive training of several management layers, the introduction of the buffer management system should be done gradually.

8.3 LIMITATIONS & FUTURE RESEARCH

The results of this study need to be interpreted cautiously, because this study entails some limitations. First, this study concerns qualitative research that encompasses in-depth interviews which are followed by an assessment, interpretation and explanation of thoughts and opinions from stakeholders. Moreover, in this case only a limited number of persons from the departments D&E and PMO were part of this information input-process. Thus, the limited number of scientific methods, excluded from quantitative research methods, in combination with the limited number of interviewees can be seen as a limitation, which was partly influenced by the time frame of this Master Thesis. Next, the case study approach of this study, which is aimed at designing a buffer management system at ASML, provides other methodological limitations. This study takes place in a specific firm and within specific circumstances and is therefore not designed for statistical inference purposes. Rather, this study gives some insights into particular topics, such as risk management and buffer management, which are related to the specific circumstances and chosen study direction.
Further research is recommended for examining the topics and their relationships as presented in the design proposal into more detail through more quantitative and qualitative research. This study is directed towards the identification of the topics that play a crucial role in the implementation of a successful buffer management system within specific circumstances. However, more research should be aimed at the specific content of these topics. An example is the manner by which project management training should be customized towards the different stakeholders in order to increase their project management skills. Moreover, the reflective cycle of van Aken can offer direction towards increasing the robustness of the design. This means that buffer management and related topics as presented in the design proposal should be investigated through a larger number of case studies within NPD departments within high technology companies. Especially the balance between formal and informal 3C-resource allocation methods requires more robust research.
REFERENCES

- Buganza, T., Kalchschmidt, M., Bartezzaghi, E., Amabile, D., Measuring the impact of a major project management educational program: The PMP case
APPENDICES

APPENDIX A: SEMI-STRUCTURED INTERVIEW

SHORT INTRODUCTION OF INTERVIEWER TO INTERVIEWEE

- Context (TUE, iTCM project)
- Purpose and intended uses of data

OPEN QUESTIONS

1. Please explain what the current buffer management policy at ASML entails?
   a. What are the main problems within the current buffer-situation?

2. Assuming you have buffers on the 3C: Which problems have to be dealt with by ASML’s future buffer management system?

3. How (size) and (2) When should buffers be used?
   a. Which type of (risk) situations?
      i. High controllability (technical, scheduling and budget) / Middle / Low controllability
   b. Use buffers for issue resolution & preventing issue escalation?
      i. Active retention vs. Passive retention
4. What are the advantages and disadvantages of central buffer management vs. decentral buffer management?
   a. At which level should the buffer be allocated and who should be held accountable for the buffers? [FILL-OUT FORM]
   b. Top down vs. Bottom up

5. Which aspects should be anchored within the planning-structure, seen from an iTM point-of-view, in order to successfully introduce a buffer management system at AMSL?
   a. Implementation of the critical path analysis (CPA) regarding implementing slack?

6. How does the priority of the buffer constraints (3C: time, cost, scope) change over the project lifecycle (flexibility matrix)? [Fill OUT-FORM]
   a. What should be the ratio of exchange between the buffer-constraints (3C) during a project lifecycle?

7. IN CASE: A new buffer management policy and guidelines are going to be introduced:
   a. How do you ensure that people will comply to this and do not fall into old routines (hiding buffers in plans and ‘firefighting’ over resources)
Figure 22: Flexibility matrix fill-out form
Figure 23: Line vs. Program fill-out form
UC3 IH: Accelerate IH MK606 integration and de-scope MK605

- Higher Management shifts integration-milestone (need date) of prototype MK606 at Master plan level from 16/12/2013 to 25/9/13.
- This milestone ‘cascades down’ to sub-PBS and activity level, which means that the TL has to reconfigure original project plan in order to deliver prototype at 25/9/13.
- TL plan is managed within TCE, in which 3C information is combined. This means that TL can reconfigure plans by rebalancing the 3C.
- In this case, TL and PL which are responsible for delivery of prototype MK606 are also responsible for the delivery of prototype MK605.
- In order to change the team plan, the TL has to make a proposal in the form of (multiple) a scenario, which has to be approved by higher management. (The height of the level depends on to what level the impact of the proposal reaches.)
- In order to shift the forecast date back in time, the solution of the TL is to de-scope the tasks of prototype MK605 (safety features are not fully delivered), which enables extra resources for faster delivery of MK606. -> Rebalancing 3C
- The PL can see the resource implications of this scenario in a resource graph that is a functionality of SP/EP (Appendix).
## APPENDIX C: CONTENT ANALYSIS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Construct and Relation</th>
<th>Confirmed by # interviewees</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5.3.3</strong></td>
<td>Project Management training</td>
<td>Quality of project management soft skills 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quality of GL and planner 6</td>
</tr>
<tr>
<td></td>
<td>Adoption iTCM project</td>
<td>Realistic project plan 8</td>
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<td></td>
<td></td>
<td>Insight 3C 8</td>
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<td></td>
<td>Insight 3C</td>
<td>Bargaining for resources 8</td>
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<tr>
<td></td>
<td></td>
<td>Clarity of decision criteria (formality) 8</td>
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<tr>
<td></td>
<td>Clarity of decision criteria (formality)</td>
<td>Bargaining for resources 8</td>
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<tr>
<td></td>
<td></td>
<td>Mutual trust and solution support 6</td>
</tr>
<tr>
<td></td>
<td>Quality project plan</td>
<td>Predictability value 6</td>
</tr>
<tr>
<td></td>
<td>Predictability value</td>
<td>Bargaining for resources 6</td>
</tr>
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<td><strong>5.3.2</strong></td>
<td>Central buffer responsibility</td>
<td>Insight project issues 6</td>
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<td></td>
<td>PL buffer responsibility</td>
<td>Insight &amp; buffer allocation flexibility</td>
</tr>
<tr>
<td></td>
<td>Insight project issues</td>
<td>Escalating issues to higher management 5</td>
</tr>
<tr>
<td></td>
<td>Insight &amp; buffer allocation flexibility</td>
<td>Fragmentation buffer allocation 5</td>
</tr>
<tr>
<td></td>
<td>Escalating issues to higher management</td>
<td>Project speed 5</td>
</tr>
<tr>
<td></td>
<td>Fragmentation buffer allocation</td>
<td>Prioritize buffer attention 5</td>
</tr>
<tr>
<td></td>
<td>Prioritize buffer attention Project speed</td>
<td>Forecasted completion date 5</td>
</tr>
<tr>
<td><strong>5.3.1</strong></td>
<td>Project issues</td>
<td>Project scope 8</td>
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<td></td>
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<td>Project resources assigned to plan 8</td>
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<td></td>
<td></td>
<td>Project slack assigned to plan 8</td>
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<tr>
<td></td>
<td>Project resources assigned to plan</td>
<td>Project perceived risk 6</td>
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<td></td>
<td>Project slack assigned to plan</td>
<td>Project perceived risk 6</td>
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<td></td>
<td>Project perceived risk</td>
<td>Bargaining for resources 6</td>
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<td>Bargaining for resources</td>
<td>Realistic project plan 7</td>
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<td></td>
<td>Realistic project plan</td>
<td>Project issues 8</td>
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<td></td>
<td>Project risk</td>
<td>Project issues 7</td>
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<td></td>
<td>Project resources</td>
<td>Project scope 7</td>
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<td></td>
<td>Project budget</td>
<td>Project resources 7</td>
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## APPENDIX D: SUMMARY OF ANALYSIS, CONCLUSION AND RECOMMENDATIONS

<table>
<thead>
<tr>
<th>Results from Analysis (Chapter 5)</th>
<th>Conclusion (Chapter 6)</th>
<th>Recommendations (Chapter 8)</th>
</tr>
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<tbody>
<tr>
<td>Bargaining for resources decreases reality of project plan, leading to continuous schedule</td>
<td>Implementation of adequate buffers reduces the negative effects of changes enabled by</td>
<td>The design provides a starting point for the implementation of a buffer management system.</td>
</tr>
<tr>
<td>adjustments. Result is a reinforcing loop that decreases the predictability of project plans and</td>
<td>issues and thereby reduces the contamination of projects. Thus, buffers (partly)</td>
<td>This design involves major changes regarding the current way of working and therefore the</td>
</tr>
<tr>
<td>increases issues.</td>
<td>prevent <em>that changes to a project do not influence other projects’</em> 3C. This also</td>
<td>introduction should be done gradually. Important factors: the implementation of PM tools</td>
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<td></td>
<td>prevents bargaining for resources due to chronic resource shortage.</td>
<td>such as CCM, TOC and PERT, which are suitable for determining the buffer location and size</td>
</tr>
<tr>
<td>Inadequately assigned resource buffer and slack keep bargaining for resources intact (balancing</td>
<td>The iTCM project makes 3C-information available which currently stays hidden and thereby</td>
<td>in project plans and a structural change regarding the manner by which (higher) management</td>
</tr>
<tr>
<td>loop), which in turn keeps the reinforcing loop intact. Result is that projects with chronic</td>
<td>enables buffer management. iTCM reduces the negative effects generated by risks and</td>
<td>commits itself to project management projects.</td>
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<tr>
<td>resource shortage are enabled to continuously contaminate healthy projects that have predictable</td>
<td>project issues <em>within</em> projects, because less project plan changes are needed.</td>
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<td>project plans and sufficient resource buffer and slack.</td>
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<tr>
<td>The iTCM project increases 3C-insight and makes project plans more realistic. Enables resource</td>
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<td>allocation based on transparent information and clear decision criteria.</td>
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<td>Not a formal policy implemented that describes buffer allocation procedures: Top-down resource</td>
<td>Implementing a formal buffer allocation process that supports a transparent discussion</td>
<td>Before ASML begins with the implementation of a buffer management system, the iTCM project,</td>
</tr>
<tr>
<td>allocation process during the RFF in combination with informal bargaining for resources.</td>
<td>between bottom-up and top-down responsibilities increases the level of control. Each</td>
<td>which demands large changes in ways of working, should be implemented and thoroughly tested.</td>
</tr>
<tr>
<td>Central responsibility: higher degree of overview and allocation flexibility, which leads to</td>
<td>level of buffer responsibilities has advantages and disadvantages and finding a balance,</td>
<td>Without iTCM adoption, buffer management cannot work.</td>
</tr>
<tr>
<td>less buffer fragmentation and more effective buffer attention. However, PL’s are forced to</td>
<td>adjusted to ASMLs particular situation, is crucial for successful buffer implementation.</td>
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<td>continuously share their project issue details with higher management, which increases the</td>
<td></td>
<td></td>
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<tr>
<td>information stream and decrease in the self-empowerment of PL’s.</td>
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<td>Project management training increases PM-method skills and soft skills.</td>
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<td>PM training offers support to the implementation of buffers and the iTCM project. It indirectly</td>
<td>PM training should be developed by dedicated teams aimed at teaching stakeholders how to</td>
<td></td>
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<tr>
<td>increase solution support and clarity of decision criteria and thereby increases the chance for</td>
<td>deal with soft skills and several PM tools such as CCM, TOC and PERT, which enable adequate</td>
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<tr>
<td>successful implementation.</td>
<td>buffer allocation.</td>
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