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Reducing and absorbing variations in a manufacturing context

- A capacity management perspective

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Abstract

Variations can have substantially negative effects on performance and it is therefore important to investigate how the variations can be reduced or absorbed in an appropriate way for competitiveness. Manufacturing companies are daily exposed to variations and operations managers need to take capacity management decisions with this in mind to secure the delivery capability. The current body of knowledge mainly focus on techniques for root cause analysis for reducing variations, especially in the manufacturing processes, neglecting the fact that both internally and externally generated variations are more or less possible to affect. Buffers are traditionally associated with waste and unfavourable performance, while the right buffers can be of strategic importance. The purpose of this research is therefore to increase the understanding of causes for variations, actions to reduce variations and how buffers can be used to mitigate negative effects of variations related to capacity management in a manufacturing context.

Three research studies have been conducted, including four appended papers, to fulfil the purpose. These studies encompassed different combinations of traditional literature reviews, conceptual research with logical reasoning and case study research. The findings demonstrate that working on mitigating negative effects of variations is a complex challenge and not just about choosing to reduce or absorb the variations. In general, it is concluded that the variation management and buffer management include several aspects to consider with implications for the capacity management. In addition, the results indicate that the decisions in manufacturing companies tend to be based on intuition and previous experience due to a lack of decision support. Furthermore, the participating companies perceive that several of their internal routines contribute to their prevailing variations. This research contributes to an awareness of causes for variations that are possible to affect, possible actions to reduce the variations and the purposes of different buffers to absorb variations. This is sought to facilitate a systematic way of working with reducing and absorbing variations, creating support in the variation management and the buffer management from a capacity management perspective.

Keywords: capacity management, variation management, buffer management, manufacturing companies, manufacturing planning and control

Sammanfattning

Variationer kan medföra negativa effekter för en verksamhets prestation och det är därmed viktigt att utforska hur variationerna kan reduceras eller absorberas på lämpligt sätt för att verksamheten ska vara konkurrenskraftig. Tillverkande företag är dagligen exponerade för variationer och produktionschefer behöver beakta detta i kapacitetsadministrationen för att säkerställa leveransförmågan. Befintlig litteratur fokuserar främst på tekniker för att analysera grundorsaker inom tillverkningsprocesserna och ignorerar det faktum att både internt och externt genererade variationer är mer eller mindre påverkbara. Buffertar associeras traditionellt med oönskat slöseri fastän rätt buffertar kan vara av strategisk betydelse. Syftet med denna forskning är därmed att öka förståelsen för orsaker till variationer, åtgärder för att reducera variationer och hur buffertar kan tillämpas för att överkomma negativa effekter av variationer i relation till kapacitetsadministration inom en tillverkningskontext.

Tre forskningsstudier, innefattande fyra publikationer, har genomförts för att uppfylla syftet. Dessa studier består av en kombination av traditionella litteraturstudier, konceptuell forskning med logiska resonemang och fallstudier i tillverkande företag. Resultaten visar att arbetet med att hantera negativa effekter av variationer är en komplex utmaning som stäcker sig bortom valet av att reducera eller absorbera variationerna. Generellt dras slutsatsen att det är flertalet aspekter att beakta för variationsadministration och buffertadministration med implikationer för kapacitetsadministrationen. Det visade sig att besluten tenderar att vara baserat på intuition och erfarenheter i tillverkande företag, mycket till följd av en avsaknad av beslutsstöd. Vidare framgår det att de medverkande företagen upplever att flera av deras interna rutiner bidrar till upphovet av variationer. Denna forskning bidrar till en ökad medvetenhet om orsaker till variationer som är påverkbara inom företag, möjliga åtgärder för att reducera variationerna och syftet med olika buffertar för att absorbera variationer. Detta är avsett att underlätta ett systematiskt arbetssätt för att reducera och absorbera variationer, samt utgöra ett stöd för variationsadministration och buffertadministration från ett kapacitetsadministrationsperspektiv.

Nyckelord: kapacitetsadministration, variationsadministration, buffert-administration, tillverkande företag, material- och produktionsstyrning

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During the time period as a PhD student I have received support from many people. I would hereby like to take some time to express my gratitude to some of these people that have helped me throughout the licentiate thesis. I would like to express my deepest gratitude to my supervisors, Joakim Wikner and Stig-Arne Mattsson, for continuously challenging and encouraging me towards greater work. I am humble for the possibility I have had this far working with you, experiencing the endless expertise and ideas that both of you provide. Thank you for being my biggest inspirations. One day I hope that I can become just a fraction as great as you are – until then I will try to keep you happy by bringing home-made pastries from time to time.

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Lisa Hedvall
Jönköping, April 2019

List of appended papers

Paper I

Hedvall, L., Wikner, J., and Hilletofth, P. (2017). Introducing buffer management in a manufacturing planning and control framework. In H. Lödding, R. Riedel, K-D. Thoben, G. von Cieminski, D. Kiritsis (Eds.), *Advances in Production Management Systems: The Path to Intelligent, Collaborative and Sustainable Manufacturing*, Vol. 514, 366–373. Springer International Publishing. *Proceedings of the APMS Conference, Hamburg, Germany, 3-7 September, 2017*.

Paper II

Hedvall, L., and Mattsson, S-A. (2019). Addressing the causes of variations to reduce the need for buffers in manufacturing companies. Working manuscript.

Based on Hedvall, L., & Mattsson, S.-A. (2018). Orsaker till variationer och åtgärder för att minska behovet av buffertar. In *Proceedings of the Plan Research Conference, Jönköping, 23-24 October, 2018.* (pp. 95–110).

Paper III

Hedvall, L., Mattsson, S-A., and Wikner, J. (2019). A framework of buffers for absorbing variations in demand related to capacity management in manufacturing companies, Working manuscript.

Paper IV

Hedvall, L. (2018). Buffers in Capacity Management: A multiple case study. *Proceeding of the 25th International Annual European Operations Management Association (EurOMA) Conference, Budapest, Hungary, 24-26 June, 2018*

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1 Introduction

This chapter includes a description of the background to the research with capacity management, variation management and buffer management, followed by identifying the research gaps. This leads to the purpose and research questions in focus of this thesis. At last, the scope of the research is conferred before presenting the outline of the thesis.

1.1 Background

A competitive delivery capability is important for succeeding in a market no matter if a company competes with short delivery time, low price or high quality (Orlicky, 1975). The fundamental part is, as the basic rule of logistics, to deliver the right product, in the right quantity and quality, to the right place, in the right time and to the right customer at the right price based on what is required in the market (Swamidass, 2000). In order to do this, companies need to balance supply and demand that in general represent requirements of resources balanced with availability of resources for supply in any manufacturing setting (Deif and ElMaraghy, 2007). Capacity management is a central part in balancing supply and demand as it is about the establishment, measurement, monitoring and adjustment of capacity levels to execute all manufacturing plans at different planning and execution levels (APICS, 2016). Van Mieghem (2003) argues that the amount and types of resources in a company are prime economic factors and decisive for the manufacturing abilities and limitations. This means that capacity management impact the ability to attend to demand, with the aim to do this in the most efficient way possible (Klassen and Rohleder, 2002, Raval *et al.*, 2018). The global market with continually changing conditions is increasingly making it harder to achieve this aim (Samson and Gloet, 2018), where companies strive for high utilisation of resources for efficiency in the same time as changing conditions in the market require the ability to be responsive to changing needs in lead-times, products and quantities (Chopra and Meindl, 2016). In addition, capacity is applied on some type of input materials in manufacturing companies and lead-time comes into play as a significant resource for the timing of materials and capacity. All these resources (materials, capacity and lead-time) are therefore important to consider in relation to capacity management for questions regarding resource availability to fulfil demand requirements. However, to decide an appropriate availability of resources becomes a challenge due to variations.

Variations imply changes in data, characteristics or functions due to different causes (APICS, 2016). Changing requirements in demand for lead-times, products and quantities represent variations in demand that inevitably create uncertainties in the requirements of resources for supply. This leads to challenges in securing stable flows of materials with an even capacity utilisation (Crandall, 1998), where the challenge increase if there are also variations in the availability of resources. If variations are not managed properly the manufacturing system is exposed to uncertainties and the delivery capability may be compromised (Slack and Lewis, 2001). This means that there is a risk of failing to match supply and demand that can lead to severe consequences as loss of business and ultimately the termination of the company (Bourne and Mura, 2018). Thus, to consider the impact of variations is of outmost importance as it can have negative effects on competitiveness (Hayes and Wheelwright, 1984). There are in principle two different approaches for mitigating negative effects of variations. The first approach is to take action against the variations with the aim to eliminate variations (Hurley and Whybark, 1999), here referred to as variation management. The second approach is to establish buffers that can absorb the variations (Shoaib-ul-Hasan *et al.*, 2018) and reduce their effects on performance (Mattsson, 1995), with the management of these buffers referred to as buffer management. In practice, it is usually not possible to eliminate all variations or use extensive buffers and a trade-off must be established that consider the costs together with the potential benefits (Hopp and Spearman, 2004).

1.2 Problem statement

When it comes to variations the challenge is that there can be variations caused by multiple parties as customers causing variations in demand, suppliers causing variations in delivery of input materials and companies themselves causing variations within their value-adding processes. This means that variations can originate internally as well as externally from a company that are more or less possible to affect directly or indirectly (Hopp and Spearman, 2004, Shoaib-ul-Hasan *et al.*, 2018). There are several methods and techniques to reduce variations in line with the first approach (Nikulin *et al.*, 2018). Both lean and six sigma are examples of such methods with focus on reducing uncertainties and variations to create a predictable manufacturing system (Raval *et al.*, 2018). However, the methods are most focused on the own value-adding processes and the system is still exposed to external variations. For variation management it is important to start investigating causes for variations that companies can affect, both internally and externally. In this regard it is important to extend the view of actions to reduce variations beyond the value-adding processes, especially as external variations can to a large extent be reduced by using appropriate policies and procedures in the way in which companies work (Sandvig and Allaire, 1998).

Existing variations should be investigated and reduced to the extent possible, while remaining variations need to be absorbed to secure the delivery capability. A common approach is to use buffers in form of material, capacity or lead-time for this purpose (Caridi and Cigolini, 2002, Hopp and Spearman, 2004). However, the cost of buffers needs to be put in relation to the protection they provide (Chu and Hayya, 1988, Guide and Srivastava, 2000). This is especially the case as buffers imply an addition of resources, which consume time and money, two of the most important assets of a profitable business. However, buffers of the right type, size and position can absorb variations and contribute to a competitive delivery capability (Chu and Hayya, 1988). The literature is vast for material buffers, while it for capacity and lead-time buffers are not as obvious. The impression is enforced by a case study conducted 2016, where 14 manufacturing companies expressed a lack of support in capacity decisions (Hedvall and Sollander, 2016). Buffers within capacity management have received relatively little attention in existing literature, even though the operations capacity, available materials and lead-times have a direct impact on the operational performance and delivery capability (Slack and Lewis, 2001). Van Mieghem (2003) exemplify the complexity by explaining that trade-offs need to be considered for capacity utilisation (e.g. of regular time and contingent resources as overtime or subcontracted time), amount of inventory, service level and degree of responsiveness that together determine the amount of backlogs and lost sales. It is therefore important, as a complement to variation management, to investigate how buffer management could be performed in a systematic manner to develop a competitive delivery capability. Traditionally, buffers have been handled within, but not limited to, manufacturing planning and control where decisions are differentiated based on the time horizon concerned (Jacobs *et al.*, 2011). An important part of how the buffer management related to capacity management should be performed is to understand what should be considered in the decisions.

1.3 Purpose and research questions

The intention of this research is to fill a part of the gap in understanding how a competitive delivery capability can be ensured by reducing and absorbing variations. A first step, that is approached in this licentiate thesis, is to investigate some fundamental aspects to consider in order to mitigate negative effects of variations in manufacturing companies. The purpose of this research is therefore:

> *To increase the understanding of causes for variations, actions to reduce variations and how buffers can be used to mitigate negative effects of variations related to capacity management in a manufacturing context.*

In order to fulfil the purpose, it is necessary to understand the alternatives to mitigate negative effects of variations in a manufacturing context. To increase the understanding of causes, actions and buffers for this purpose, there is a need to first understand the main parts of buffer management in manufacturing planning and control frameworks as it sets the preconditions for what to consider in the decisions for both variation management and buffer management. This leads to the first research question:

> *RQ1. What constitutes buffer management in manufacturing planning and control frameworks?*

As already mentioned, a competitive delivery capability may be compromised due to variations. The existing variations define the need for buffers and may to some extent be self-caused and possible to influence. As buffers represent an addition of resources that devour costs it is important to investigate what causes variations, together with possible actions to reduce the need for excessive buffers. An increased awareness of causes for variations and actions for these causes can enhance the understanding of how variations can be reduced and thereby reduce their negative effects, which is a second step to fulfil the purpose. The second research question is therefore:

> *RQ2. Which are the main causes for variations and which actions are appropriate to consider in order to reduce the variations related to capacity management?*

It is seldom possible to eliminate all variations and it is therefore important to absorb the remaining variations, here investigated by different types of buffers. In order to understand how buffers can be used to mitigate negative effects of variations, it is important to understand what type of buffer should be used for what purpose depending on the type of variation. The third research question is intended to provide answers to understand the selection of different types of buffers and the purpose of each buffer. Thus, the third research question is formulated as follows:

> *RQ3. How are different types of buffers related to capacity management considered to absorb variations?*

The research questions are answered through traditional reviews of literature and based on the experiences of respondents in manufacturing companies. This thesis is therefore also intended to provide answers to how the current state is for variation management and buffer management in manufacturing companies (i.e. the perceived causes for variations and actions taken to reduce variations, and the buffers used for what purposes in manufacturing companies). This research is considered part of investigating the content in order to build a basis for researching the process of variation management and buffer management from a capacity management perspective.

1.4 Scope of the research

The research presented in this thesis focuses on aspects to consider in order to mitigate negative effects of variations. This is done from the perspective of a single unit, for example a company, meaning that focus is on variations that affect the company and not how variations within the company affect customers or suppliers. However, the considered variations can be both internally and externally generated. This implies that variations in demand, delivery from suppliers and in the own value-adding processes are included. Either the companies need to search for ways to reduce the variations by finding the causes for the variations and taking action or adding resources as buffers that can absorb the variations. Both these approaches are important and investigated in this research.

It is easy to confuse symptoms as being the actual causes for variations. This research, especially the answer to RQ2, aims to look beyond the symptoms to find the actual causes and potential actions to reduce the variations. To enable this, only causes that are possible to affect are considered. The second approach, using buffers, is investigated in terms of the main parts that need to be considered in the decisions (RQ1) and what the actual buffer alternatives are (RQ3). Buffers in form of material, capacity and lead-time are included but only the buffer selection and purpose are considered, meaning that buffer positioning and buffer dimensioning are excluded. All these descriptions indicate that the research is content based, hence that a process for variation management and buffer management is beyond the scope of this research. The included case studies are based on the current state and the research is therefore considered to be more of descriptive character, with an ambition to approach research of normative character in future studies. In addition, this research is based on investigations in a manufacturing context. The research results are therefore only claimed to be applicable for similar contexts as the participating companies. However, it is possible that the results are applicable in other contexts as for example service industry but to investigate that applicability is beyond the purpose of this research.

1.5 Thesis outline

This licentiate thesis consists of five chapters and include four appended papers. A brief description of each chapter is presented below to provide an overview of the structure and content.

First, in **Chapter 1: Introduction**, a short background is provided of variations and buffers. A research gap with regards to how negative effects of variations can be mitigated from a capacity management perspective is highlighted, leading to a presentation of the purpose and research questions of this research. This is followed by a description of the research scope.

Thereafter, in **Chapter 2: Research design**, the design of the performed research is presented. First, the research design is explained, followed by the research approach and strategy. The data collection and analysis procedures are then delineated for the three research studies, which consist of the four appended papers. The chapter ends with a discussion of research quality and ethical considerations.

In **Chapter 3: Frame of reference**, previous research within the research area of interest is summarised as a theoretical background that is used as support for the findings of this research. The chapter can therefore partly be seen as a recapitulation of the literature used in the appended papers. The topics encompassed in chapter 2 in general capture parts of manufacturing planning and control, capacity management, variation management and buffer management.

Chapter 4: Summary of papers contain subchapters devoted to each of the four appended papers, where the purpose of each paper and the main empirical and theoretical findings are conferred. After the summaries the findings are linked to the research questions in this thesis to outline how each appended paper contributes to understanding the important aspects to consider in variation management and buffer management, from a capacity management perspective.

At last, in **Chapter 5: Discussion and conclusions**, a discussion is provided based on the findings presented in Chapter 4. The results are further elaborated in terms of purpose fulfilment, followed by theoretical and practical implications and considerations of limitations. The chapter ends with proposing further research before outlining the main contributions in some concluding remarks.

2 Research methodology

In this chapter the research methodology is delineated. First, the research design is described followed by the research approach. Then the research strategy, data collection and analysis of the research are presented. At last, a short discussion is provided regarding the research quality and ethics.

2.1 Research design

The research until licentiate degree was conducted between August 2016 and April 2019. Most of the research is part of the research project KOPability, with the intention to contribute to both practical interests (e.g. how to make appropriate decisions in variation management and buffer management) and the creation of scientific knowledge (e.g. contribute to theory by new methods concerning variation management and buffer management).

This research is focused on the understanding of how variations can be reduced and absorbed to mitigate negative effects related to capacity management in a manufacturing context. Three research questions have been formulated within the scope of the purpose, covered by three studies and four papers (Figure 1). In Figure 1 the dotted arrows represent implicit connections between research question and study, while filled arrows represent explicit connections.

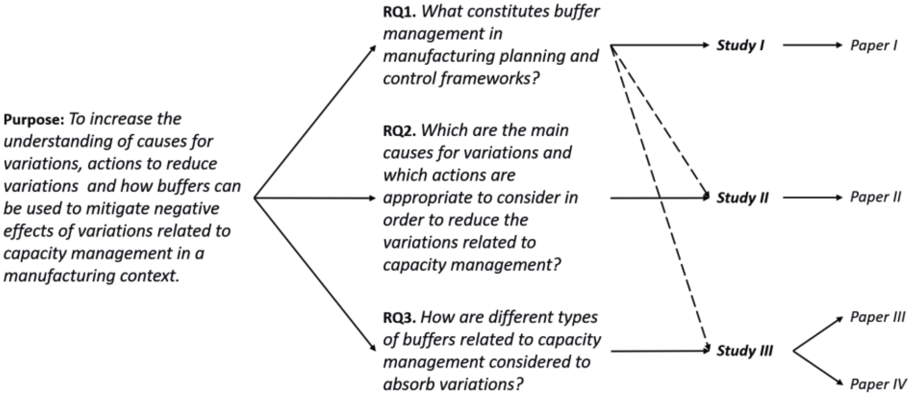

Figure 1. Connection between RQ´s and research studies

Figure 1 represents the main focus and research carried out until licentiate degree, which is the first part of the third cycle study program. This research was carried out by three research studies, all that are intended to increase the understanding of variation management and buffer management by important aspects to consider in the decisions. The studies are arranged in an order based on what is logical in relation to the research questions, meaning that the order is somewhat different than the chronological order for when in time the studies were conducted. To exemplify, Study II was conducted last but the researchers in KOPability discovered that variations is arguably the logical starting point before buffer management, which initiated the study, and is therefore also presented before Study III in this thesis.

The first study was conducted through analytical conceptual research as a strategy, outlining a refined MPC framework that explicitly highlights variations and buffers. Study I increased the understanding of buffer management and the significance to consider different variations in MPC based on different management perspectives, conducted with RQ1 in mind and resulted in the creation of Paper I.

The second study concerns RQ2 with a minor contribution to RQ1 and highlights the importance of investigating the causes for variations and potential actions. This was done through a traditional literature review and a multiple case study. The intention of this literature review was to capture a snapshot of the diversity of studies conducted in the field, with special interest in internally generated variations that affect the consequent requirements for buffers.

The third study aimed to investigate buffers and their purposes in relation to capacity management, conducted through a traditional literature review and a multiple case study. Study III is represented by Paper III and Paper IV and contributes to answer parts of RQ1 and is the main contributor to RQ3.

2.2 Research approach

The research approach reflects the methodological direction of the research. This research follow a qualitative methodological direction, which is common when the research aim to investigate a phenomena in itself (Easterby-Smith *et al.*, 2015). The qualitative direction was considered as an expedient choice as it enabled the possibility to explore and generate in-depth knowledge about variation management and buffer management. The overall aim of the studies in this research is to identify and describe key aspects and variables, which is a typical characteristic in theory building research (Voss *et al.*, 2002).

In this research, the contribution to knowledge with both managerial and theoretical implications have been the core value. A collaborative research approach was chosen for this intension, which is an approach based on co-production and joint learning with the generation of new insights that drive action and theory development (Adler *et al.*, 2003). Collaborative research is here seen as an umbrella term with different levels of collaboration, ranging from low collaboration to high collaboration. This means that the research can be collaborative even if the only collaboration is a joint identification of a research problem relevant for practice. On the other side of the scale, the collaboration could be for every single step in the study, ranging from identification of research problem to analysis of results (Phillips *et al.*, 2013). The level of collaboration for this research varied for the different studies, which is described further in conjunction to the description of each study in chapter 2.4.1-2.4.3.

For the case studies within KOPability, the collaborative research approach has mainly been by a setup with workshops that has enabled an interactive atmosphere between academia and practice, where knowledge and experiences have been exchanged. This exchange of knowledge has also been present between the different companies, not just between academia and practice. The workshop setup for co-production and joint learning can be illustrated as in Figure 2, which Ellström (2007) refer to as the process of the interactive research approach. The interactive research process in Figure 2 illustrates joint learning in the interaction between researchers and practitioners and by learning cycles for the research and practice systems. The learning cycles have revolved around workshops in KOPability together with interview sessions and assignments between workshops. The assignments have consisted of questions based on the theme of the workshop, where the participating companies have discussed the questions internally and then presented the work at the workshop. More information of the specific workshops as data collection method connected to Study II and Study III is presented in Chapter 2.4.2-2.4-3. The collaborative research approach has been the foundation for this research, where the research strategy varies slightly between the different studies.

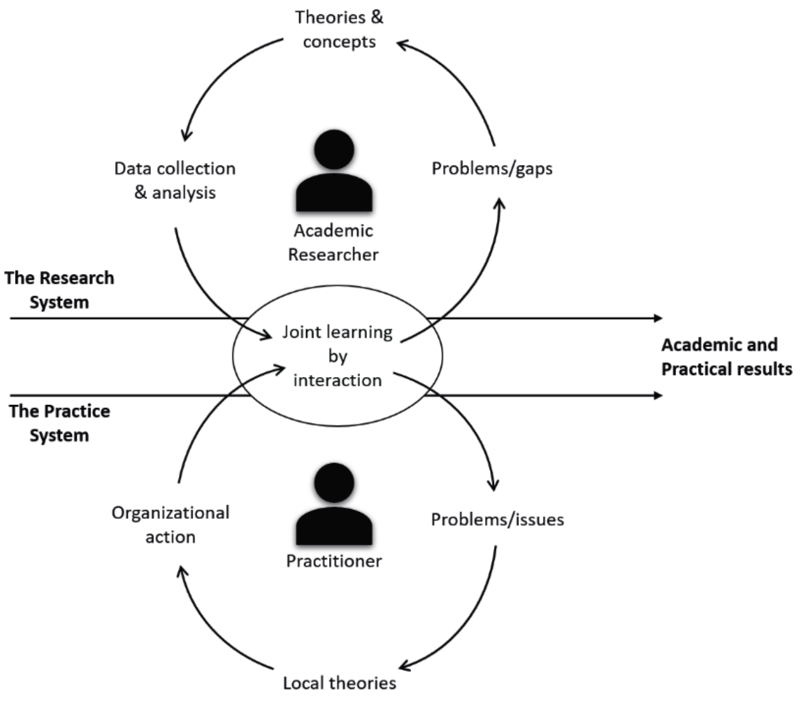

Figure 2. The interactive research process

Note: adapted from Aagard Nielsen and Svensson (2006, p. 245) and Ellström (2007, p. 5) .

2.3 Research strategy

To select research strategy is mainly about issues of how to conduct the research in a way that is sought to answer the established research questions. Different research strategies are more qualitative or quantitative in their nature. In this research, the research questions were sought to be answered through analytical conceptual research, traditional literature reviews and the conducted case studies. The selected research strategies will be described further in the following subchapters. In Table 1 an overview is provided of the publication(s), purpose, research strategy, data collection and data analysis connected to each research study.

Table 1. Overview of research strategies

	Study I	Study II	Study III
Publication	Paper I	Paper II	Paper III & Paper IV
Purpose	Outline refined framework for MPC, highlight the significance of imbalances between supply and demand	Investigate causes for variations and potential actions to reduce the variations and consequently the need for buffers	Identify buffers related to capacity management and investigate the purpose, in theory and practice
Research strategy	✓ Analytical conceptual research	✓ Traditional literature review & logical reasoning ✓ Multiple case study	✓ Traditional literature review & logical reasoning* ✓ Multiple case study**
Data collection	✓ Database searches	✓ Database searches ✓ Workshop ✓ Semi-structured interviews ✓ Documents	✓ Database searches* ✓ Workshops** ✓ Semi-structured interviews** ✓ Documents**
Data analysis	✓ Content analysis	✓ Content analysis ✓ Open, axial and selective coding	✓ Content analysis* ✓ Open, axial and selective coding**

* Applies to Paper III
**Applies to Paper IV

2.3.1 Analytical conceptual research and traditional literature reviews

Logical reasoning provides opportunities to express conceptual perspectives on theory for increased understanding of relationships (Wacker, 1998). This is here seen as an important part of analytical conceptual research, with an intention to better explain and integrate underlying theories. In particular, conceptual research (in Study I) and logical reasoning (In Study II and Study III) have been used in this research to gain new insights by investigating relationships in existing literature.

Traditional literature reviews have been conducted and constitute parts of Study II and Study III. These reviews have aimed to be an identification, evaluation and interpretation of the existing body of knowledge. In this research it was of interest to capture the development and diversity of studies for the management of variations and buffers related to capacity management until this point in time. Contributions to theory development can be achieved by identifying the conceptual content of the field (Meredith, 1993), where literature reviews are important in identifying patterns, themes and issues (Seuring and Müller, 2008). Seuring and Müller (2008) emphasize that it is impractical to read everything and that literature reviews can facilitate to identify relevant literature for the research area of interest. The process of a review normally consist of three stages; planning, conducting and reporting (Ashby *et al.*, 2012). The planning stage was mainly about the formulation of purpose and research questions. The conducting stage consisted of searches for relevant literature and performing analysis. Finally, the reporting stage was about the formulisation of findings and recommendations (as described by Tranfield et al., 2003).

2.3.2 Case studies

In Study II and Study III, case study research was the adopted research strategy. In the field of operations management, case research is seen as one of the most powerful methods (Voss *et al.*, 2002), especially in the development of new theory and ideas (Barratt *et al.*, 2011). Among the advantages in case study research (described by e.g. Voss et al., 2002), this research strive for the potential to new and creative insights and high validity among practitioners. The potential advantages are captured by Van de Ven (1989), p. 486: “Nothing is so practical as a good theory”. Siggelkow (2007) also address this by explaining that research should provide new insights about the world and not just about literature. Finally, Sousa and Voss (2001) recommend the case study as a research methodology when the nature of the research question is exploratory or embodies an exploratory component. The overall research purpose of this research is considered to be of exploratory nature with theory building intensions and the case study as a research methodology was therefore considered appropriate.

In this research, the unit of analysis was limited to variations affecting a production unit. This has been investigated at several companies under study were each has its own context, which allow cross-case comparison (Williamson, 2002). The multiple case research is beneficial when a phenomenon is investigated from different perspectives to detect patterns and gain deeper understanding (Blumberg *et al.*, 2011, Yin, 2014). Further, it can contribute to more reliable findings (Yin, 2014) and enhance the research transferability (Ellram, 1996). To conclude, a multiple case design was considered appropriate for this research in order to identify similarities and differences in how different companies work with variation management and buffer management.

Case selection

Regarding the number of cases, there is no ideal number. However, between four and ten cases is a guiding principle (Eisenhardt, 1989). The fewer cases, the greater opportunity for in-depth observations (Voss *et al.*, 2002). However, multiple cases typically provide a stronger base for theory building as it leads to more robust findings when the propositions are grounded in a varied empirical evidence (Eisenhardt and Graebner, 2007). In this research, six companies participated in Study II and four companies in Study III. In Table 2 an overview of the participating companies is provided in terms of main product, turnover and number of employees.

Table 2. Participating companies

Company	Main product	Turnover (th EUR)	Employees
Company A	Gas turbines	1,152,233	2588
Company B	Luminaries	142,816	564
Company C	Heat exchangers	42,904	117
Company D	Aerospace components	796,335	2012
Company E*	Metal cutting tools	1,513,796	8000
Company F	Metal cutting tools	587,372	1406

Note: Data is gathered from the database Amadeus for the fiscal year 2017.
* Numbers retrieved from company, n.a. in Amadeus.

Company A-D have been involved in the research project KOPability, while Company E-F have been added by the researcher herself. This means that four companies have been provided through the research project, where the researcher has made a choice to only include the manufacturing companies from the research project for the work connected to this thesis. Hence, a form of theoretical selection has been applied for company selection in this research, which implies that the selection builds on the researchers own assessment of cases that are expected to provide important contributions (Eisenhardt, 1989). According to Voss *et al.* (2002) and Williamson (2002), the research questions are essential for appropriate case selection. In this research, the most essential thing was that the companies work with finding an appropriate balance of supply and demand in their capacity management and that they actively work with reducing and absorbing variations by variation management and buffer management.

Four of the participating companies in the research project KOPability are manufacturing companies, which were of interest for this research, both in Study II and Study III. Two additional companies were added for Study II. The different types of companies gave insights on variation management and buffer management decisions from different perspectives, creating a richer data set. The companies face different challenges which can contribute to a wider understanding, however many aspects of variation management and buffer management have been similar. It was considered preferable to explore the research area of interest over different contexts without constraining it to a certain market to get a general understanding of how manufacturing companies work to reduce and absorb variations. Multiple respondents have been involved in all participating companies in order to provide a deeper understanding, a greater breadth and better validity. The functional representation varies as variation management and buffer management are important at all hierarchical levels (to different degrees and of different kind). In KOPability one main respondent at each company has had the main responsibility to involve respondents for each workshop and interviews depending on the questions of interest. In Study II, the additional companies were asked to involve respondents that have a holistic understanding of the manufacturing in terms of planning and control, preferably with knowledge of the supplier and customer interfaces as these parties are connected to the input to, and output from, manufacturing. This could be for a single respondent or several respondents that together could provide answers to variations in demand from customers, in manufacturing and from suppliers. To include different organisational positions/roles was considered as an expedient choice as it enables the possibility to get a general understanding of the phenomenon, see all respondents in Table 3.

2.4 Data collection and data analysis

Theoretical data was gathered mainly by traditional literature reviews and empirical data to Study II and Study III was gathered essentially through workshops, followed by semi-structured interviews and document studies (as described by Yin, 2014). The latter two are what Voss *et al.* (2002) describe as some of the most common sources of data in case studies. The interviews were audio-recorded and relevant information was transcribed, which provide an accurate rendition of what has been said and is certainly a benefit when the exactness of what has been said is important (Voss *et al.*, 2002). Before an interview session, the respondents received information of importance in order to make proper preparations. Additional discussions have been conducted to clarify issues when considered necessary.

Ketokivi and Choi (2014) stress that the basic scientific mode of inquiry calls for transparency. A part of transparency in case studies is to present and explain how data has been collected. The interaction with the respondents in the participating companies, in form of physical meetings, is presented in Table 3 to show the organisational position of the respondents for each company, together with information of Study II and Study III in terms of the method (workshop or interview), involved respondents for each method and study (designated by "R" together with the respondent number) and time duration. The time duration for the workshops in Table 3 (10h) represents the total time of the workshops including Company A-D, divided on two working days from lunch to lunch. More detailed information of how all three studies have been conducted is presented in section 2.4.1-2.4.3.

Table 3. Data collection from participating companies

Company	Respondents	Study	Method	Involved respondents	Time
Company A	1. Manager Sales and Operations 2. Procurement Director 3. Leader Logistics Development 4. Capacity Planner	Study II	Workshop	R1 & R4	10 h
		Study III	Workshop 1	R1, R3, R4	10 h
			Workshop 2	R1-R4	10 h
			Semi-structured interview	R1	2 h 10 min
Company B	5. Team leader Planning 6. Production Planner I 7. Logistics developer 8. Production Planner II	Study II	Workshop	R5 & R8	10 h
		Study III	Workshop 1	R5 & R7	10 h
			Workshop 2	R5 & R6	10 h
			Semi-structured group interview	R5, R7, R8	2 h 30 min
Company C	9. Supply Chain Manager 10. Production Planner	Study II	Workshop	R9	10 h
		Study III	Workshop 1	R9 & R10	10 h
			Workshop 2	R9	10 h
			Semi-structured interview	R9	2 h 45 min
Company D	11. Senior Specialist Logistics 12. Process developer	Study II	Workshop	R11 & R12	10 h
		Study III	Workshop 1	R11 & R12	10 h
			Workshop 2	R11 & R12	10 h
			Semi-structured group interview	R11 & R12	3 h 10 min
Company E	13. Logistics Planning Manager 14. Senior Planner I 15. Senior Planner II 16. Supply Chain Planning Manager 17. Process expert 18. Global Supply Planner	Study II	Semi-structured group interview	R13, R14, R15	4 h 30 min
			Semi-structured group interview	R16, R17, R18	2 h
Company F	19. Manager Supply Chain Planning 20. Supply Chain Planner	Study II	Semi-structured group interview	R19 & R20	2 h

2.4.1 Study I

In Study I different management perspectives were investigated to highlight the significance of imbalances between supply and demand based on existing knowledge within manufacturing planning and control (MPC). The purpose was to outline a refined framework for MPC that highlight the significance of these imbalances and the consequent requirements for buffers. The idea for the study came already in the initiation of the research project KOPability based on practical observations of challenges with capacity dimensioning. Hence, the research problem was partly made in collaboration with practice with practical relevance even though this particular study is an analytical conceptual study. Four management perspectives were integrated to provide a refined framework for manufacturing planning and control, which illustrate preconditions for variation management and buffer management. The four management perspectives constituting the foundation are: 1. Balance management represent the need to balance supply and demand which leads to the second management perspective, 2. Resource management representing the requirement of resources defined by demand that needs to be balanced with the availability of resources for supply, 3. Risk management representing the control of expected and unexpected events in supply and demand for different resources, and 4. Hierarchical management representing decision making related to different time horizons. The results from Study I is presented in Paper I.

2.4.2 Study II

The second study of this research had a starting point in causes for variations in demand, capacity requirements, capacity availability and delivery lead-times from suppliers. Study II therefore represents a fundamental standpoint why variation management and buffer management are needed and how the material flows can be stabilised through actions against these causes, resulting in a reduced level of variations and reduced requirements for buffers. The process of Study II consisted of two main process steps: 1. Create a framework based on literature and conceptualisation/logical reasoning, 2. Investigate which actions are used for what purpose in manufacturing companies today. These steps are explained further below.

A traditional approach for reviewing existing literature has been applied due to the diverged nomenclature in the subject area of interest. The purpose of the literature review was to identify causes for the four types of variations and proposed actions against the causes that are provided in the existing body of knowledge. The data collection was mainly through title searches of potentially relevant publications in reference lists, starting with three articles that touch upon the topic and continuing searching interesting references in these reference lists. In total, three levels of references were studied, meaning that a reference found from level 1 (the three starting articles) was further investigated and resulted in additional references to investigate from level 2. The review has then been complemented with additional searches in Scopus and in major journals in the operations management field to enhance the confidence in that influential publications are included. Search words and search strings connected to causes and actions against variations were used to specify the literature of interest. In particular, the inclusion criteria were to only include publications in Swedish and English without time limitations for publication date. This resulted in an inclusion of journal articles, conference papers, books and reports. The output from the traditional literature review was synthesized into a framework for theoretically identified causes and actions. Some causes and actions have not been explicitly explained as causes and actions for variations in the literature but have been included based on logical reasoning for connections in traditional problems.

The second part of the study was mainly a way to investigate the actions that companies use in order to reduce the variations. The initial framework was discussed with the participating companies, mainly through an interactive workshop with the four manufacturing companies in KOPability and semi-structured interviews with the two additional companies (see Table 3). Before the workshop, the companies were asked to scrutinise the framework in terms of causes they recognise as apparent in their business and which actions they use for these causes. A special notion was given to analyse if important actions were missing in the framework and if the already included actions made sense. This work resulted in feedback of how the framework could be revised.

Before the interviews with the two added companies, a semi-structured interview guide was established based on recordings from the workshop and by studying the participating companies´ presentations. This was done to ensure that all parts covered in the workshop would be covered in the interviews and to include remaining questions. The compiled documentation from the participating companies´ preparations for the workshop together with the interviews constituted important input for analysis. Additional questions arising after the two rounds (workshop and interviews) have been handled by further contact with the respondents. The output from Study II is presented in Paper II.

2.4.3 Study III

Study III started with the intention to identify the purpose of capacity management, buffer management and safety capacity in general by a traditional literature review. Explicit explanations were found to be scarce but different types of buffers were found. This led to the identification of three main types of buffers (material, capacity and lead-time) that could be used to protect or compensate for inadequate capacity. The purpose then became to identify buffers related to capacity management and their purposes for theory and practice.

A first workshop (WS1 in Table 3), was initiated where the participating companies were asked to analyse what types of buffers exists in their manufacturing systems and for what purposes. The outcome did not land on the level of detail as wished, probably due to the fact that it has been unclear what a buffer really represents. This initiated a need to provide a structure in order to investigate the buffers used in practice. Preliminary findings from the literature review and analytical conceptual ideas were collocated into a framework of buffers with buffer types, purposes and descriptions. The companies then received the same questions to discuss internally before a second workshop, this time with the framework as support in the discussions. During the workshop the companies presented their answers and work connected to the questions. The compounded presentations have constituted important documentation for Study III, which have been scrutinised together with recordings from the workshops to ensure coverage of remaining questions in the interviews with company representatives. The participating companies have had the chance to review and propose changes to the framework, not just answering which buffers they have in practice, which illustrates co-production as a part of the collaboration.

In Study III main concepts related to buffer management were used in the literature searches. When the main concepts were identified, these constituted the set of search terms to be combined with truncation, wildcards and phrases to ensure inclusion of alternative spellings. In addition, search terms were combined to create search strings using Boolean logic. To run the search, evaluate the results and to modify the search was done in an iterative loop, with adjustments of for example subject area in the search. Seuring and Gold (2012) consider this to be part of ensuring that the identified papers address the topics of interest. The evaluation of the search was based on the number of retrieved records and the relevance of records for the search string. In addition, citation and reference searches were done to find relevant publications. The results from Study III resulted in Paper III and Paper IV.

2.4.4 Data analysis

Sousa and Voss (2001) provide a general description of data reduction and analysis, that starts by data reduction with reduction of research control data and classification for reduction of contextual data. This is followed by data analysis where associations between variables and constructs are investigated, continued by finding explanations and discussion of what has been concluded from the analysis. In general, this approach to data analysis has been adopted in this research but with some adaptions based on the research strategy in each study.

For the literature reviews, the evaluation of material strives for structured and theory driven comprehension of data and interpretations. In this research, the categories were often derived from the data itself rather than being assessed before data analysis. This implies that an iterative process of category building, testing and revision has been employed, where the final categories were derived from this constant comparison of categories and data. This approach is closely related to what Seuring and Gold (2012) describe as the second level of content analysis where latent content of text is analysed to understand the underlying meaning of terms and arguments.

Ellram (1996) recommend that case study analysis should consist of three steps; open coding, axial coding and selective coding. The open coding process aim to examine, compare, contrast and categorise data, followed by axial coding where preliminary connections among categories are done to be finalised in the selective coding where the theory is integrated into a cohesive whole. The open coding is a way to summarise segments of data, that Miles *et al.* (2014) call a first level coding. This was an iterative process where empirical data from the participating companies in the case studies were treated separately before comparisons to each other, defined by Eriksson and Kovalainen (2008) as *in-case analysis* and *cross-case analysis*. By first making an in-case analysis a holistic configuration has been created and used to compare to other cases, which facilitate to distinguish case specific findings from generic findings across all cases (Voss *et al.*, 2002, Merriam, 2009). In general, this was sought to enable extraction of relationships across cases and abstract peculiarities from individual cases. The open coding should mainly allow the reader to compare similarities and differences among cases (Ellram, 1996).

The axial coding in turn was done to summarise the identified issues in the open coding into themes, with categories and even subcategories for some parts of this research. At last, the selective coding was done in similar manner as the axial coding but aiming at a higher, more holistic level of analysis. Due to the complexity and volume of data in case studies, a consequence is that the analysis is iterative and begins simultaneously in the data collection. It is therefore beneficial and useful to record ideas and impressions as soon as they occur (Voss *et al.*, 2002). This was done in this research by field notes with separations of what is said and what is observed or interpreted, to push the own thoughts forward.

2.5 Research quality and ethical considerations

2.5.1 Construct validity

Construct validity address to what extent a study investigates what it claims to investigate and leads to accurate conception of reality (Gibbert and Ruigrok, 2010). To use multiple data sources enhance the construct validity by looking at the phenomenon from different angles, using different data collection strategies and sources (Voss *et al.*, 2002). This is also referred to as triangulation where similar results from different sources enhance the confidence in the findings (Eisenhardt, 1989). In this research, the multiple sources of evidence from data collection were in terms of method triangulation and source triangulation (as described by Williamson, 2002) as different data collection methods have been used (workshops, documents, interviews) and different respondents within the same company were interviewed (for the conducted interviews).Triangulation can also be to check the consistency in the findings between researchers. Multiple researchers have been involved in the case studies, which enhance the creative potential of the study as there is often complementary insights that add to the richness and increase the likelihood of capitalising novel insights in the data (Eisenhardt, 1989). Hence, consistency in the findings enhance the probability of an accurate conception of the studied phenomenon.

A second element of construct validity is about to allow the reader to reconstruct how the researcher went from initial research questions to final conclusions (Ellram, 1996). This include to explain the research process with a reflection of the planned versus actual process for the data collection and data analysis procedures (Gibbert and Ruigrok, 2010). This is sought to be addressed by reviewing logic, content and clarity in written documents in the research. In addition, by providing a reflection on difficulties and how these have been contained and handled is considered to strengthen the construct validity.

Finally, key informants reviewing compiled documentation by researchers can verify that case facts from case studies are accurate. The results from the studies have been presented at workshops, where corresponding respondents have had the chance to read through compiled documentation and provide comments, reducing the risk of researcher bias and misunderstandings.

2.5.2 Internal validity

Internal validity is about the establishment of causal relationships between variables and results (Voss *et al.*, 2002). Decisions regarding internal validity are made in the design of case studies but it refers to the phase of data analysis (Gibbert and Ruigrok, 2010). The strategies to enhance internal validity are about to formulate a clear research framework where the causal relationships are demonstrated in relation to certain conditions, to compare observed patterns with predicted ones or patterns in previous research, and triangulation to verify findings by adopting multiple perspectives (Gibbert and Ruigrok, 2010). In this research, the internal validity is considered enhanced primarily by discussion of relationships between empirical data and previous research and in some studies there has been multiple methods, respondents and researchers involved for triangulation. In theory building research, the comparison of emerging concepts, theory or hypotheses with extant literature is an essential feature (Eisenhardt, 1989). In general, this involves asking what the results are similar to, what it contradicts and why. This is an important part that have been kept in mind in this research, since the point of theory building research is to develop or at least begin to develop theory by presenting new, and perhaps frame breaking, insights.

2.5.3 External validity

External validity address the generalisability of findings beyond the immediate case study (Voss *et al.*, 2002). In case study research it is not about statistical generalisation of a population, rather it is analytical generalisation that refer to generalisation from empirical observation to theory (Gibbert and Ruigrok, 2010). Replication of case studies refers to investigation of other cases that should be comparable (McCutcheon and Meredith, 1993) . This is addressed by a rationale for case study selection that allow the reader to understand the sampling choices and by including multiple cases and respondents for theoretical replication (as described by Yin, 2014).

2.5.4 Reliability

Reliability is about the extent to which a study can be repeated with the same results (Stuart *et al.*, 2002). It is mainly about if subsequent researchers gain the same insights if they conduct the same steps (Gibbert and Ruigrok, 2010). In order to increase the reliability of this research, audio recordings and transcribing are important parts that could be used by others to proceed the same analysis and hopefully result in similar results. A case study protocol has been established with documentation and clarification of research procedures, which together with a case study data base are keys to reliability (Stuart *et al.*, 2002).

2.5.5 Ethical considerations

Bryman and Bell (2015) propose key principles in research ethics, where the principles of no harm of participants, informed consent and respect of privacy are mainly considered in this research. No harm of participants is addressed by carefully maintaining confidentiality of records and by respondent anonymity. This is closely connected to informed consent, which is to inform the participating respondents about the research, their role in it as well as potential risks and benefits (Easterby-Smith *et al.*, 2015). To ensure informed consent the respondents have received relevant information in order to decide if they want to participate or not. The provided information was in terms of, for example, the purpose of the study, the favourable and expedient type of respondent(s) and type of questions to be addressed. Furthermore, information has been provided before interviews as preparation. Obtained information has been treated confidentially and sensitive information has been removed or normalised in written publications for respect of privacy.

3 Frame of reference

In this chapter the theoretical foundation for this research is provided. First, manufacturing planning and control is introduced, followed by a description of capacity management in this context. The chapter then continues with an introduction of different types of variations, variation reducing activities by causes and actions, and finally absorbing variations by different types of buffers.

3.1 Manufacturing planning and control

Manufacturing planning and control (MPC) revolves around the managerial concerns of planning and controlling all aspects of manufacturing (Hayes and Wheelwright, 1984). It includes planning and scheduling manufacturing by managing materials and capacity, as well as coordinating suppliers and key customers (Vollmann *et al.*, 2005). MPC systems aim to provide support for managers to manage the operations and meet customer demand. The work with meeting customer demand within MPC systems can be divided as activities for different time horizons (Slack and Lewis, 2001). Roughly three different time horizons are concerned: long term, medium term and short term. The long-term priorities are decisions on appropriate amounts of resources to meet future market demands (including buildings, geographical location, equipment, personnel, suppliers and so forth) (Vollmann *et al.*, 2005). The fundamental issue is to match supply and demand, on intermediate term in terms of volume and product mix by providing appropriate levels of material and capacity for the requirements (Vollmann *et al.*, 2005). It may require decisions on employment levels, overtime possibilities and subcontracting needs (Van Mieghem, 2003). Another task for this time horizon is providing customers with expected delivery lead-times and communicating with suppliers regarding order quantities and delivery lead-times for material supply (Vollmann *et al.*, 2005). In the short term, it is required to establish detailed resource schedules involving personnel, time, equipment, and materials. The MPC system should for this time horizon provide information on important measures of the performance as resource utilisation, material consumption and delivery performance (Arnold *et al.*, 2008). This information is especially important for strategic improvement work.

Many details of MPC evolve over time due to changes in knowledge, technology and markets, but many essential activities in MPC remain the same (Vollmann *et al.*, 2005). In general, MPC is performed on different hierarchical levels including key activities as sales and operations planning (S&OP), master production scheduling (MPS), material requirements planning (MRP) and production activity control (PAC). S&OP include decisions on how to balance sales plans with available resources, creating plans for the manufacturing in meeting business strategies (Olhager *et al.*, 2001). The MPS is a disaggregated plan from S&OP, deciding the products to manufacture in the future. These plans need to be integrated with some form of resource planning to provide required capacity for current and future situations. MPS plans are directly fed into the MRP, where the plans are on a level of detail for material requirements of products and parts. The MRP plans are time-phased for all raw materials and components required based on the MPS plan and can be used for detailed capacity planning of labour and equipment requirements. Finally, PAC, depicts execution of the plans and represents a control phase for work on a daily basis (Arnold *et al.*, 2008). Here it is a high level of detail, concerning individual components, workstations and orders. Independent of what the different planning levels are called for the activities within MPC, the hierarchical levels of decisions differ in terms of the level of aggregation for time (daily, monthly, yearly), products (components, products, product families) and resources (equipment, production facilities, networks).

In a general sense the resource decisions are made at all hierarchical planning levels (Tan and Alp, 2009), where higher level decisions affect lower levels of planning and control (Hedvall *et al.*, 2017). Capacity management is therefore a fundamental part of MPC for these concerns.

3.2 Capacity management

Capacity management is a response to demand rather than an attempt to steer demand (Klassen and Rohleder, 2002). Hence, in general the purpose is to attend to demand in time and the most efficient way possible with the available resources (Adenso-Díaz *et al.*, 2002). Some researchers even argue that a successful capacity management is the most critical factor for long-term success in businesses (Wu *et al.*, 2005). Existing literature suggests several objectives or purposes with capacity management, some authors explicitly state the objective while others reveal their view by the measured values in simulations and calculations. Several papers point at the objective to minimise costs (Armistead and Clark, 1994, Bradley and Glynn, 2002, Van Mieghem, 2003). However, there are many additional objectives, as for example; to minimise customer waiting time (Larsson and Fredriksson, 2014), minimise inventory levels (Steele and Papke-Shields, 1993), enable high delivery performance (Atwater and Chakravorty, 2002), maximise operating profit (Goodale *et al.*, 2003), minimise backlogs (Hurley, 1996), maximise throughput (Cook, 1994), increase quality performance (Ng *et al.*, 1999), reduce lead-time (Fry *et al.*, 1994) or maximise utilisation (Gunasekaran *et al.*, 2001). It is not unusual that several of these are mentioned in the same article as objectives or purposes with capacity management.

The capacity management decisions cannot only consider capacity as a resource due to trade-offs between different resources. Van Mieghem (2003) explains that there is a great complexity to consider several trade-offs in the decisions, for example between capacity utilisation (e.g. decide amount of regular time, overtime and subcontracted time), amount of inventory, service level and degree of responsiveness that together determine the number of backlogs or lost sales. In addition, there are variations to consider that adds to the complexity.

3.3 Variations

One important notion is that variations, independent of source, can have different characteristics depending on the time horizon concerned. In general, the variation characteristics a company is exposed to can be classified as systematic or stochastic variations in supply and demand. Systematic variations tend to be of long-term character, for example following trends or seasonality, but it could also be on weekly basis for requested service depending on the day of the week (Wikner and Mattsson, 2018). The key characteristic for the systematic variations is that it follows certain patterns of period by period character, with on average basically constant requirements. For demand, the systematic variations are typically considered as stationary and the average demand per period as deterministic. Forecasting in different forms are often used to estimate expected requirements per period for systematic variations during a number of periods into the future.

The stochastic variations are more of short-term character, superimposed the on average estimated requirements per period. In other words, stochastic variations represent random variations, often estimated as ranges in percentage around net requirements (e.g. in demand) or calculated as a measure of dispersions (for instance the standard deviation). How well a process is studied and the information available determines the possibility to identify variations. To be aware of the existing variations is a first step to take appropriate measures (Hurley and Whybark, 1999), here considered by variation reducing and variation absorbing activities.

3.4 Variation reducing activities

All companies are to some extent exposed to variations. Variations have been the focus of attention in for example quality management literature due to the acknowledgement that variations exist in all sort of processes and that it is a source to quality problems (Melnyk *et al.*, 1992). However, variations in demand seems to be the variation most addressed in existing literature for good reasons, as it is often regarded as the most difficult origin of uncertainty with high impact on business performance (Caridi and Cigolini, 2002). The total amount of variations can have a significant impact on performance and it is therefore important to map existing variations, monitor the effects and reduce the variations if possible (Palmatier, 1988). In this research, the management of variations is referred to as variation management with focus on variation reducing activities. The origin of uncertainty, the causes and the actions for existing variations have been identified as three fundamental parts for variation reducing activities and will be explained further in the three following sections.

3.4.1 Origin of uncertainty

Van Mieghem (2003) explains that most models considering variations in capacity management does not specify the origin of uncertainty but emphasize that general models can capture variations in demand, supply, processing, cost and similar. Caridi and Cigolini (2002) specify processing further by dividing it into variations in machine availability and equipment performance. In general, all these proposed origins of uncertainty can be regarded as variations in supply and demand, representing both variations internally and externally in relation to a company. External variations are foremost associated with variations in demand of products from customers (Palmatier, 1988), but can also include variations from suppliers in terms of e.g. varying delivery lead-times, order fulfilment quantities or product quality (Weng, 1998). Variations in demand contribute to variations in capacity requirements to perform value-adding manufacturing processes. In addition to the requirements that are externally generated, there can be internally generated capacity requirements due to variations in the manufacturing (e.g. a need for rework because of quality problems). There can also arise variations in available capacity for the resources used in value-adding processes. In this research, two external and two internal origins of uncertainty will be considered: Variations in demand, variations in internally generated capacity requirements, variations in available capacity and finally variations in delivery lead-time from suppliers.

3.4.2 Causes for variations

To identify the origin of uncertainty is a first step to reduce variations but it does not automatically reveal the cause that triggers the variations. External variations are often generated by customers and suppliers but this does not automatically imply that they are unavoidable (Mattsson, 2007). Both the internal and external variations are to some extent possible to affect by the rules, routines and behaviours employed in the own manufacturing processes, and in the relations with other actors in the supply chain the company is part of (Hopp and Spearman, 2004).

Causes for variations in demand

Variations in demand emerge for natural causes as end customers consume in irregular patterns that inflate the demand variations upstream the supply chain (i.e. the bullwhip effect, see e.g. Disney and Towill, 2003). However, there are several causes that contribute to the variations. Large order quantities constitute one of the most decisive causes to unmanageable variations in demand as it increase the irregularity of demand (Williams, 1991). Outliers, or exceptionally large order quantities, can create substantial problems not least due to that the fact that the larger quantities the larger variations tend to be (Lee *et al.*, 1997). Changed delivery lead-times to customers can also amplify demand variations, especially when customers perceive the changes as delivery problems and start to order larger order quantities or in advance than actual requirements to secure their own deliveries (Christopher and Lee, 2004). Budget and target-related behaviours are common, but it can also create periodic behaviours leading to variations in demand during the planning period as the hockey stick effect/end-of-the-month syndrome (Olson, 1998, Sanches and Lima Jr., 2014). Up to 20% of all demand variations are accounted as caused by periodic behaviour (Laseter and Stasior, 1998), that generally have a limited connection to demand variations from customers.

Causes for variations in internally generated capacity requirements

Variations in capacity requirements are directly influenced by the demand variations, but there are also some internally generated causes that are possible to affect. Rework is one of these causes that emanate from quality problems and scrap (Raval *et al.*, 2018), leading to higher requirements of capacity for the additional work. This is closely related to scheduling, where established methods and procedures can create additional variations in capacity requirements, particularly if scheduling is not unified with divisions of responsibility and decisions are made without a broader understanding. It could for example be that scheduling is done for one production group in a sub-optimised manner without considering the consequences for other production groups. The capacity requirements can also vary due to inadequate planning data or bill of materials (Pendleton, 1988), meaning that there might be needs to have more capacity than planned for if the planning data differs significantly from actual data (Melnyk *et al.*, 1992).

Causes for variations in available capacity

If the available capacity for value-adding processes varies there is variations in available capacity. One main cause for these variations is temporary capacity losses due to short-term absence of personnel, repair requirements and machine failure or breakdown, that can cause great difficulties for the delivery capability (van Kampen *et al.*, 2010). Variations in available capacity may also occur due to inadequate planning, as if the planning is based on a capacity level that does not correspond to the actual available capacity or if indirect time is incorrectly estimated. Finally, variations in available capacity can emerge due to unstable support processes in terms of material supply or other preparations that does not work as intended. This would then imply that capacity can be starved and cannot be utilised to the fullest potential.

Causes for variations in delivery lead-time from suppliers
Variations in delivery lead-times from suppliers can emerge before and after ordering. Before order a measure of how consistent the supplier is in keeping stable delivery lead-times can be used to address variations between expected versus confirmed delivery lead-times (Mattsson, 2017). The second variation, after order, represents a difference between confirmed and actual delivery lead-time, and is often used to measure delivery accuracy (Mattsson, 2017).

3.4.3 Actions to reduce variations

Several methods are proposed in current literature for reducing internal variations in manufacturing processes. Six sigma is probably one of the most recognised philosophies for variation reducing activities, with a general process inspired by the Deming cycle (plan-do-check-act) called DMIAC (define-measure-analyse-improve-control), see e.g. de Mast and Lokkerbol (2012). Within the improvement cycles there are several quality-management tools utilised, as for example: 5 whys, control charts, Pareto analysis, root cause analysis, Ishikawa diagrams and quality function deployment (QFD). However, most of the tools are focused on identifying the cause for variations or monitoring the existing variations but some focus on the actions. Independent of the method or selection of tools used, the fundamental part is the process of continuous improvements for reduced variations (Hurley and Whybark, 1999). Even though these methods and tools are often of generic character to find appropriate solutions, with special focus on internal variations, there are some actions proposed in the current literature for internal and external variations.

Actions for variations in demand
Variations in demand can be significantly reduced by using appropriate policies and procedures (Sandvig and Allaire, 1998). To avoid that customer order quantities becomes too large and lead to demand variations it is possible to facilitate ordering by e.g. EDI (Mattsson, 1995), refrain from set-up overheads (Mattsson, 2017) and rationalise order administration (Cachon and Fisher, 2000). All these factors impact the ordering costs and increase

economic order quantities, that by extension increase the variations in demand. For extremely large orders, it is recommended to minimise the occurrence through dialogue with customers or propose partial deliveries (Sandvig and Allaire, 1998).

To temporarily change the delivery lead-time to customers (e.g. due to capacity problems) can create a customer behaviour that leads to demand variations. To avoid this, it is recommended to communicate with the customers, investigate possibilities for temporarily reduced order quantities or partial deliveries (Mattsson, 2017), and to be restrictive in parameter updates (Disney and Towill, 2002). There are also several other actions for variations in demand, as for example: to adapt routines and the way obtained measures are evaluated to reduce the hockey stick effect (Sanches and Lima Jr., 2014), induce customers to send delivery plans or stabilise their need to reduce system nervousness (as explained by e.g. (van Donselaar and Gubbels, 2002)); and work with ensuring quality in the manufacturing processes to reduce reclaims and product returns.

Actions for variations in internally generated capacity requirements

Rework increase costs and inefficient material flows (Angulo *et al.*, 2004). Rework is proposed to be reduced by quality initiatives in the manufacturing processes. For inadequate production planning data, product structures and scheduling there are several actions proposed, for example: improve quality/content of basic planning data (Melnyk *et al.*, 1992), clarify responsibilities and implement uniform planning methods and procedures.

Actions for variations in available capacity

It is recommended to perform activities that reduce short-term absence of personnel, and preventive maintenance to reduce the risk of unexpected manufacturing disturbances (Assid *et al.*, 2015). To plan for preventive maintenance, include indirect time in the planning and routinely have team meetings can also reduce the variations in available capacity by temporary capacity losses. For planning, the proposed actions are to work with ensuring correct capacity estimates including indirect time, structure indirect time to avoid variations that lead to variations in available capacity, prepare setup activities before manufacturing is planned to start and work with improving the planning processes in general (Melnyk *et al.*, 1992).

Actions for variations in delivery lead-times from suppliers
To reduce variations before ordering (i.e. variation between expected and confirmed delivery lead-times) it is possible to enter into agreements for fixed delivery lead-times, enter into VMI solutions (Fox, 1996, Angulo *et al.*, 2004), continuously communicate with supplier regarding current delivery lead-times and update inventory control based on this, or in the extreme case change supplier (Pannesi, 1988, Angulo *et al.*, 2004). For variations after order (i.e. variation between confirmed and actual delivery lead-times), the delivery monitoring in different forms are possible: before or after agreed delivery lead-time for all orders, unreliable suppliers or for shortage risk situations.

3.5 Buffers for mitigating effects of variations

Variations that can, should or are decided to not be reduced may erode competitiveness if not managed properly. If it is hard to detect causes and address these for reduced variations, or if the actions to reduce the variations imply significant costs, then it might be better to consider holding buffers that can absorb variations and thereby reduce impact on the delivery capability. Buffers are sometimes only considered as waste and a symptomatic treatment as they do not reduce variations (Mattsson, 2006). However, they can reduce the effects of existing variations. The management of buffers is important to find an appropriate balance between costs and risks (Chu and Hayya, 1988), referred to as buffer management with focus on absorbing variations. One important notion is that buffers can be of different types and be used to absorb different types of variation, which will be described further below.

3.5.1 Buffer types

The traditional stream of literature associate buffers with inventory (i.e. materials) and safety stocks in particular. This is also reflected in some dictionaries, as an example the APICS dictionary define a buffer primarily as a quantity of materials awaiting further processing (APICS, 2005). However, there are some researchers that particularly highlight that buffers can be in terms of materials, capacity and lead-time (Caridi and Cigolini, 2002, Hopp and Spearman, 2004). It can therefore be argued that not just materials, rather that materials, capacity and lead-time are three main buffer types. As earlier mentioned, there can be variations of systematic and stochastic character. The buffers can therefore be categorised as buffers for systematic variations for concerns of trends and long-term variations and buffers for stochastic variations for issues of random and short-term character. This implies that there can be different buffers for different situations. These buffers will be presented in the coming subchapters.

3.5.2 Buffers for systematic variations

For periodic variations in demand there are needs to either adjust the capacity in line with requirements or to build additional inventory in advance based on anticipation of peak demand (Atamtürk and Hochbaum, 2001). To build this type of periodic inventory for systematic variations is often referred to as an anticipation inventory (Olhager *et al.*, 2001, Axsäter, 2015) or seasonal inventory (McClain and Thomas, 1977). Another alternative for systematic variations is to have additional capacity added to the net requirements, partly to meet changed demand patterns, and partly to keep the utilisation rate within manageable levels to avoid long queue times and lead-times (Atwater and Chakravorty, 2002). There is an assumption that capacity must meet or exceed demand (Bean *et al.*, 1992), but it is most likely that capacity will be insufficient for some instances when demand is uncertain and when adjustments in capacity are not instantaneous (Van Mieghem, 2003). Companies must then decide how to handle this imbalance, with one alternative in terms of backlogging (Bish *et al.*, 2005), implying that supply that is not fulfilled in one period is transferred to be fulfilled in the next planning period (Wikner and Mattsson, 2018).

If demand is instead expected to increase there are different strategies to approach this. Lead and lag strategy are commonly discussed as two fundamental capacity investment strategies (Hayes and Wheelwright, 1984). The lead strategy implies that investments in capacity are made in advance of realised requirements (Hill and Hill, 2009). This means that available capacity will be higher than capacity requirements until the demand increase is realised (Stonebraker and Keong Leong, 1994). This additional capacity then represents a capacity buffer for systematic variations in demand. However, the capacity can also be in terms of external resources, where variations are mitigated by flexibility in for example dual-sourcing and subcontracting (Pinker and Larson, 2003, Tan and Gershwin, 2004). This is part of what Van Mieghem (2003) refers to as operational hedging.

3.5.3 Buffers for stochastic variations

The probably most recognised buffer for stochastic variations is the safety stock, that is commonly used in manufacturing companies (Hu *et al.*, 2003). Safety stocks represent additional amounts of materials to mitigate risks of stockouts and can be in terms of raw materials, components and semi-finished or finished products. This indicates that the safety stock can be positioned in different parts of the flow, mainly on an inbound side from external supply and on an outbound side before delivery to customers.

Fry *et al.* (1994) argue that additional capacity to net requirements can also hedge unexpected variations in the flow of materials and peak demand, with the primary difference of additional flexibility and risk of resource loss compared to safety stocks. This type of capacity buffer has varied nomenclature in the literature, with safety capacity (Hu *et al.*, 2003), protective capacity (Atwater and Chakravorty, 2002), capacity cushion (Blackstone Jr., 2013) and capacity buffer (Bradley and Glynn, 2002) as a few examples. Another form of capacity is also highlighted in the literature as essential for efficiency and high service performance, namely capacity flexibility (Betts *et al.*, 2000, Pagell *et al.*, 2000). Capacity flexibility can refer both to resources capable of working with different types of products and opportunities to utilise additional resource options (Gupta *et al.*, 1992). For internal resources, this can be regarded as internal capacity flexibility and include for example the authorisation of overtime to increase capacity when needed.

The incorporation of queue times into manufacturing processes work as a hedge against unexpected events (Vollmann *et al.*, 2005), representing the waiting time before value-adding processing and implies that an addition of lead-time is added in the manufacturing. The actual queue times are influenced by the resource utilisation rate and impact the ability to be responsive to changes in customer demand (Gunasekaran *et al.*, 2001). Another important lead-time buffer mentioned in literature is the safety lead-time, incorporated to hedge variations in supply and demand (van Kampen et al., 2010). Hariharan and Zipkin (1995) define safety lead-time as the difference between release date and due date subtracted with the time required to manufacture the order. However, in a more detailed perspective the safety lead-time can be regarded as the addition of lead-time for variations in supply or demand before manufacturing is planned to begin or after manufacturing and before delivery. To exemplify, before manufacturing in an MRP environment the planned lead-time can be equal to a contractual or forecasted lead-time multiplied by a security coefficient (to create a safety lead-time in procurement). This is emphasized by Louly and Dolgui (2013), where the more unreliable the supplier is, the larger the safety lead-time should be.

4 Summary of appended papers

Summaries of the appended papers are provided in this chapter. First, each paper is summarised in terms of purpose, findings and the researcher's contribution. Thereafter, the contribution from each paper is put in relation to the three research questions.

4.1 Paper I - Introducing Buffer Management in a Manufacturing Planning and Control Framework

The purpose of Paper I (i.e. study I) was to outline a refined framework for MPC that explicitly highlights the significance of imbalances between demand and supply and the consequent requirements for buffers. Buffer management was highlighted as an important part of MPC as buffers can be used to mitigate imbalances, where the contribution needs to be weighted to the costs involved to maintain a competitive business. In the paper, buffer management embrace four management perspectives related to a transformation flow: balance management, resource management, risk management and hierarchical management.

A fundamental principle in any manufacturing company is to balance supply and demand, where balance management refers to the management of this balancing act. It was argued that balance management is a challenge due to variations in requirements of supply and demand, where decisions for buffer selection, dimensioning and positioning are decisive to mitigate imbalances.

Requirements of resources are defined by demand that needs to be balanced with availability of resources for supply. Resource management was emphasized as concerning the management of resources in the transforming processes, where different resources are important for buffer management. To simplify matters, the resources concerned were considered in terms of objects being transformed (i.e. materials) and objects performing the transformation (considered in terms of their capacity), with the management of these resources referred to as materials management (MM) and capacity management (CM).

It is fundamentally important to identify and manage risks in a system, where risk management was considered to include variations of both systematic (illustrated with μ) and stochastic character (illustrated with σ). An important part to consider is risks for variations in supply and demand for both resources being transformed (materials) and resources performing the transformations (capacity). Depending on the type of variation and resource concerned, the risk management varies to some extent and is therefore an important concern for buffer management.

Hierarchical management was considered as the management of decisions relating to different time horizons. In total, four different hierarchical levels were identified, including three planning levels and one execution level. The highest planning level was referred to as the Structural Level (StL) and concerns long-term decisions as positioning of sites with regards to markets. The next logical issue is the dimensioning of resources at each node in the network of sites, with the planning referred to as belonging to the Aggregate Level (AgL). The AgL set the possible volumes to produce, hence the focus shifts to the mix of output for the next planning level. The planning for the mix of output concerns the coordination of resources for detailed planning and scheduling to fulfil customer orders. This planning level was therefore referred to as the Detailed Level (DeL). At last, the plan is executed and only leave room for short-term reactive measures for unforeseen events. This was referred to as the Execution Level (ExL). In total, the four management perspectives were combined to unfold the significance of buffer management, creating sixteen components possible as unit of analysis (Figure 3).

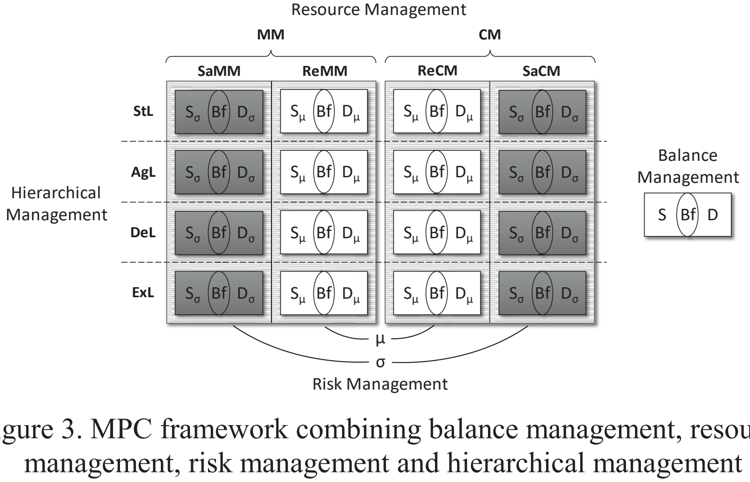

Figure 3. MPC framework combining balance management, resource management, risk management and hierarchical management

Figure 3 explicitly highlights the need of covering uncertainties for both systematic and stochastic variations. The distinction between the expected regular level (ReMM and ReCM) and the safety level (SaMM and SaCM) is often implicit in the literature on materials management and hardly present in the literature on capacity management. This led to an identification of a knowledge gap about buffers, especially for stochastic variations, in capacity management.

Researcher´s contribution: Hedvall and Wikner co-initiated and wrote the paper together. Hedvall contributed foremost with insights from an earlier conducted case study and Wikner added theoretical knowledge to find the four management perspectives. Hedvall had the main responsibility to write the paper and Wikner provided comments and made improvements. Hilletofth has been involved as a discussion partner and providing comments. Hedvall is the corresponding author and presented the paper at the international APMS conference, Hamburg, Germany, 3-7 September 2017.

4.2 Paper II - Addressing the causes of variations to reduce the need for buffers in manufacturing companies

The purpose of Paper II (i.e. study II) was twofold, first to develop a framework of causes for variations and potential actions for each cause to reduce variations, and second to study to what extent the proposed actions are utilised in practice.

The starting point of the study was that variations create challenges in maintaining a competitive delivery capability and that variations should be reduced by identifying causes and taking action against the causes. This is sought to reduce the need for buffers and was the approach considered in Paper II. Two internal and two external types of variations were investigated: variations in demand, variations in internally generated capacity requirements, variations in available capacity and variations in delivery time from suppliers (see Figure 4).

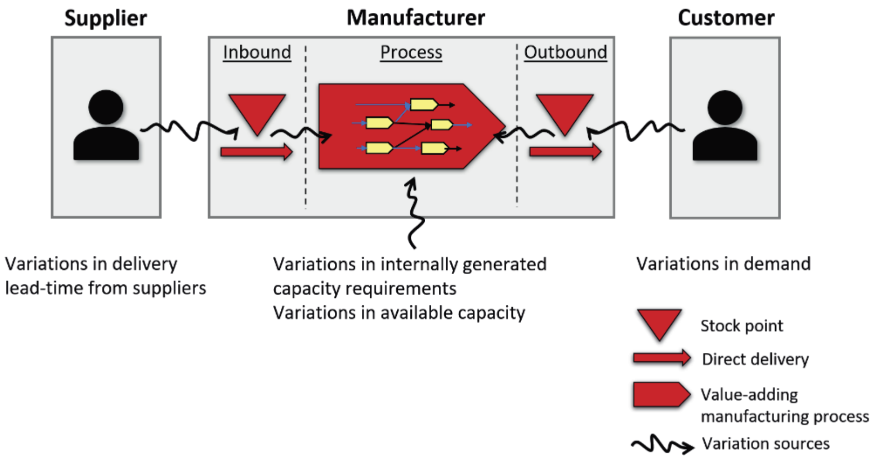

Figure 4. Variations that affect a company

Paper II was sought to create a greater understanding of what cause variations in companies that are possible to affect and establishing a framework that support practitioners identifying possible actions and facilitate a systematic way of working with reducing variations. In total, 22 different causes for variations were identified and 61 actions proposed and synthesized into a framework. All the causes were more or less recognised in the six participating companies. For the proposed actions, the utilisation in practice varied. To exemplify, for variations in demand only one proposed action (out of 25 actions) was applied in all the companies and four actions were not even mentioned by any of the companies. Hence, there is a gap between theory and utilisation of some proposed actions in practice. On the other hand, many of the proposed actions for variations in available capacity are utilised in practice. This was apparent as half of the companies mentioned all twelve actions as utilised in their companies.

To summarise, it is the combination of existing variations that induce a need for buffers. An increased awareness of the existing variations and causes that contribute to the variations, together with potential actions, can increase the understanding of how the variations can be reduced. The study gives a perception of how companies work to reduce variations and consequently reduce the requirements for buffers. The study indicate that the requirement of buffers can be reduced by simple matters with small changes in the way the company work internally and externally with other actors in the supply chain.

Researcher´s contribution: Hedvall and Mattsson initiated the paper. Hedvall was responsible for planning the case study, data collection and analysis. Hedvall and Mattsson collected data from the four companies in the research project, while Hedvall collected the data from the two additional companies and analysed all data for the paper. Hedvall wrote the main body of the paper together with Mattsson, where Mattsson had special responsibility to review and provide comments for improvements. Hedvall is the corresponding author and presented an earlier version of the paper at the Swedish conference PLANs Forsknings- och tillämpningskonferens, Jönköping, Sweden, 23-24 October 2018.

4.3 Paper III - A framework of buffers for absorbing variations in demand related to capacity management in manufacturing companies

The purpose of Paper III (in Study III) was to take a holistic perspective on different types and subtypes of buffers in relation to capacity management and how these buffers can be used in manufacturing companies for different types of variations in demand. To attend to demand in the most efficient way possible is often seen as the overarching purpose of capacity management (Adenso-Díaz *et al.*, 2002). Buffers can be seen as an important enabler to contribute to the purpose of capacity management but the purpose of buffers in relation to capacity management is not explicitly elaborated in the literature. Hence, the purpose was partly to elaborate on the purposes of different buffers to handle imbalances from a capacity management perspective, for both systematic and stochastic variations in demand. Buffer types in form of additional materials, capacity and lead-time were studied from a flow perspective together with their purposes to identify different subtypes of buffers related to capacity management. The buffers were categorised as inbound, process or outbound buffers. To simplify matters the inbound buffers can be described as placed before value-adding processes, the process buffers as within value-adding processes and the outbound buffers as placed after value-adding processes.

For the systematic variations, six different buffers related capacity management were identified. First, there is a need in capacity management to adjust capacity utilisation for demand patterns as seasonal types of variations.

When building inventory in advance to meet the requirements at peaks in demand the additional inventory for seasonal variations were considered and referred to as an inbound seasonal inventory buffer for a matter of input materials, and an outbound seasonal inventory buffer for finished products. The third identified buffer related to strategies for when and how to respond to systematic changes in demand. For a lead strategy with an investment for expected future demand, the additional capacity was seen as an anticipation capacity buffer that can provide opportunities to gain market shares and securing the delivery capability. The anticipation capacity buffer is an investment for an expected increase in demand, that might not occur. A similar buffer was identified, with a different purpose, referred to as a delivery lead-time protection capacity buffer that is supposed to ensure short and reliable deliver lead-times. When the additional capacity is added by opportunities of external contingent resources to meet demand increase, by for example long-term contract with labour agencies, it was referred to as an external capacity flexibility buffer. Last but not least, a 'negative' buffer was identified. Most companies will face instances when capacity is insufficient to meet demand (Van Mieghem, 2003), and if the demand is not lost it can be backlogged (Bish *et al.*, 2005). The opportunity to backlog demand was seen as a backlog buffer, a lead-time buffer in terms of a way to ensure more stable and reliable lead-times by a more even capacity utilisation.

Seven different buffers were identified in relation to capacity management to absorb stochastic variations in demand. The inbound buffers for stochastic variations were considered as protecting value-adding processes from capacity losses either by an extra amount of input materials or that the materials are ordered in advance of requirements to have a safety time before manufacturing. These buffers were referred to as inbound safety stock buffer and inbound safety lead-time buffer. Three process buffers were identified. Atwater and Chakravorty (2002) argue for the strategic importance of additional capacity to handle unexpected fluctuations and thus protect the delivery capability. This addition of capacity was referred to as a safety capacity buffer. Various types of flexibility in capacity is also important in the value-adding processes to temporarily increase the capacity available when needed. Contingent resources to temporarily increase the capacity level by internal resources was referred to as an internal capacity flexibility buffer. The third process buffer identified in the study was the queue time buffer, an addition of time in the processes to protect the delivery lead-time. The identified outbound buffers for stochastic variations protect the delivery capability when capacity is insufficient in the processes. In capacity management the outbound buffers were, as for the inbound buffers, in form of material and lead-time. Hence, these buffers were referred to as outbound safety stock buffer and outbound safety lead-time buffer.

All these identified buffers related to capacity management imply additional resources in form of material, capacity or lead-time to absorb variations and maintain a competitive delivery capability. The different subtypes of buffers have different purposes that can protect or compensate for capacity.

Researcher´s contribution: Hedvall, Mattsson and Wikner initiated the paper in collaboration. Hedvall had the main responsibility to write the paper. Mattsson and Wikner have been involved throughout the process contributing with literature, providing comments and making improvements. The result of the paper is based on joint discussions.

4.4 Paper IV - Buffers in Capacity Management: A multiple case study

The purpose of Paper IV (in Study III) was to investigate to what extent different buffers are utilised in practice in relation to a framework of buffers related to capacity management presented in Hedvall and Mattsson (2018). An important aspect of the purpose was to investigate how buffers are used for different types of variation in demand, especially in terms of the main buffers utilised in practice and the purpose of utilising the buffers. All the proposed buffers in the framework by Hedvall and Mattsson (2018) were identified in the multiple case study, where each buffer was acknowledged in at least two out of four companies. Four of the buffers were mentioned by all the companies: queue time buffer, internal and external flexibility buffer as well as outbound safety lead-time buffer. This is not a surprising result as queue time is common practice to include in capacity management (Vollmann *et al.*, 2005) and that various types of flexibility are common to use for short-term requirements caused by demand variations (Betts *et al.*, 2000, Van Mieghem, 2003).

On a general level, protection appeared to be the main purpose of buffers based on the answers from the companies. One of the respondents emphasized that the overall purpose of buffers is to protect processes and activities against variations and should be placed in front of or in the process or activities. Another respondent stated that the purpose is always to protect customer orders, where each buffer might have an explicit purpose for the direct impact and implicitly to protect the delivery capability. However, depending on the type of buffer, the purpose explanation by the companies had some key features. Material buffers were considered to enable high capacity utilisation by placing the buffer in front of processes (protect from capacity losses) or placing the buffer after processes to secure a high service level. The purpose with capacity buffers were often mentioned as an ability to absorb disturbances, protect against capacity losses and to secure the future delivery capability. Finally, the lead-time buffers were often associated with a protection of following processes, both to be able to absorb variations in delivery from suppliers, protecting the manufacturing processes and to absorb variations in the manufacturing processes to protect the process of delivery to customers.

Company D explained that the management of buffers tend to become sub-optimised with decisions made locally without understanding the bigger picture. This is something that all the companies agreed on as a challenge. Thus, some question stated by one of the respondents remain: "*How do we select an appropriate mix of capacity and buffer alternatives? Nevertheless, how do we determine the level of these?*"

Researcher´s contribution: Hedvall initiated, conducted and wrote the paper. Wikner and Mattsson supervised the work and provided comments for improvements. Hedvall is the corresponding and single author and presented the paper at the International EurOMA conference, Budapest, Hungary, 24-26 June, 2018.

4.5 Contributions of the appended papers

In Table 4, the contributions of the appended papers are put in relation to the research questions addressed in this thesis. A main contribution is illustrated with "X" and a minor contribution is illustrated with "x" in Table 4. The main and minor contributions for each paper will be further explained in the four following subsections after Table 4.

Table 4. Connection between research questions and paper contributions

	RQ1: *What constitutes buffer management in manufacturing planning and control frameworks?*	**RQ2**: *Which are the main causes for variations and which actions are appropriate to consider in order to reduce the variations related to capacity management?*	**RQ3**: *How are different types of buffers related to capacity management considered to absorb variations?*
Paper I	X		
Paper II	x	X	
Paper III	x		X
Paper IV	x		X

Paper I – Major contribution to answer RQ1

Paper I contributes to RQ1 by an identification of the building blocks for buffer management. More specifically, four management perspectives were identified that highlight that decisions concern the strive for a balance between supply and demand, the variations (i.e. systematic and stochastic), the resources (i.e. materials and capacity) and different planning levels depending on the time horizon. These four management perspectives characterise and set the preconditions for both variation management and buffer management.

Paper II – Major contribution to answer RQ2 and minor contribution to answer RQ1

The paper contributes to RQ2 by 22 identified causes for variations and 61 proposed actions to reduce variations and consequently the need for buffers. This was done for four different variations that affect and are present in companies. The actions utilised in six companies have been conferred. The paper contributes to RQ2 by causes and actions in theory and relating it to the experiences by practitioners. This is sought to enhance the awareness and facilitate a systematic way of working with variation reducing activities.

Paper II also have a minor contribution to RQ1 by highlighting that variations are important to consider in the buffer management and that there are different origins of uncertainty to consider in the risk management.

Paper III – Major contribution to answer RQ3 and minor contribution to answer RQ1

Paper III contributes to the understanding of what type of buffer could be used for what purpose depending on the type of variation, which is closely connected to RQ3. In total, six different buffers to absorb systematic variations and seven buffers to absorb stochastic variations were identified. These different buffers were in form of either additional material, capacity or lead-time. Trade-offs and relations between these different buffers were elaborated to enhance the understanding of when and how they are advantageous from a capacity management perspective.

A small contribution is also made to RQ1 by adding lead-time as a perspective to the resource management consisting of materials and capacity. This means that lead-time buffers are added as important to consider except the already mentioned buffer types in form of materials and capacity.

Paper IV- Major contribution to answer RQ3 and a minor contribution to answer RQ1

Paper IV contributes to RQ3 by enhancing the understanding of how practitioners select different types of buffers and for what purposes, based on an earlier version of the buffers in Paper III. At last, the paper also makes a small contribution to RQ1 in terms of lead-time buffers as a commonly used complement to materials and capacity buffers.

5 Discussion and conclusions

In this chapter the findings from the appended papers are discussed in relation to the three research questions of this thesis, followed by a discussion of implications for capacity management and purpose fulfilment. The main theoretical and practical implications are thereafter presented. This is followed by limitations and future research. At last, conclusions are made by presenting the main contributions together with some concluding remarks.

5.1 Discussion

The purpose of the research presented in this thesis is *to increase the understanding of causes for variations, actions to reduce variations and how buffers can be used to mitigate negative effects of variations related to capacity management in a manufacturing context*. Three research questions were formulated to address this purpose and the research connected to the research questions are discussed further below.

5.1.1 What constitutes buffer management in manufacturing planning and control frameworks?

The first research question (RQ1) aimed to provide a better understanding of the fundamental aspects included in buffer management in manufacturing planning and control (MPC) frameworks. This was mainly examined in Paper I, which indicated that buffer management embrace four management perspectives (balance, resource, risk and hierarchical management). First and foremost, balance management in terms of balancing supply and demand was identified and is the most fundamental part for a successful business (Caridi and Cigolini, 2002). The requirements of supply and demand can be more or less uncertain which is important to consider together with the resources concerned (Hurley and Whybark, 1999, Caridi and Cigolini, 2002). It was highlighted that risk management is needed to manage variations in supply and demand for materials and capacity, in this research addressed by reducing variations and utilising buffers. The types of variations were divided based on their characteristics, with systematic and stochastic variations as two categories. One interesting discussion point is that previous studies have mostly addressed the material buffers (Hurley and Whybark, 1999, Guide and Srivastava, 2000), while both materials and capacity are interdependent in a manufacturing context and can have a significant impact on business performance (Hu *et al.*, 2003). Capacity has been treated as a whole where a separation in systematic and stochastic issues have been neglected. Paper I therefore refines the view of resources in MPC by dividing both materials and capacity into systematic and stochastic concerns. In Paper III and Paper IV, the resources to consider were accompanied by time as a resource, that is also important to consider as a buffer and a trade-off to materials and capacity. Hence, buffers in terms of materials, capacity and lead-time are possible options (Caridi and Cigolini, 2002, Hopp and Spearman, 2004).

Variations were further investigated in Paper II, which scrutinised the causes for prevailing variations and actions to reduce the variations. It was further recognised that the variations in supply and demand can be categorised into four categories of variations affecting a company (variations in demand, internally generated capacity requirements, available capacity and delivery lead-time from suppliers) and that these categories can be related to a flow perspective as inbound, process and outbound. This means that instead of just referring to variations in supply and demand that can be systematic or stochastic (as in Paper I) it is possible to distinguish variations further based on the origin of uncertainty and from a flow perspective (as in Paper II). Paper II also separates variation reducing activities (i.e. variation management) from variation absorbing activities (i.e. buffer management). This means that variation management is distinguished from, but an important complement to, buffer management.

Finally, the hierarchical management was identified for the management of decisions for different time horizons. This management perspective was highlighted as important due to the fact that different information is relevant depending on the decisions (see e.g. Jacobs et al., 2011), since balancing supply and demand is unique for different time perspectives for resources concerned and the risks involved. From a capacity management perspective in the context of manufacturing companies, all these parts are important to consider in the variation management and buffer management.

5.1.2 Which are the main causes for variations and which actions are appropriate to consider in order to reduce the variations related to capacity management?

The second research question (RQ2) focused on causes for variations and actions to reduce the variations, that by extension reduce the negative effects of variations related to capacity management. Causes refer to underlying reasons to the presence of variations. It is further used to describe behaviours and routines utilised within companies and in their relations with other parties in the supply chain that drive variations. Actions refer to activities and changes to reduce variations and is used to describe how manufacturing companies work to reduce variations. The research in Paper II provides an overview of variation reducing activities from a company perspective for variations that are possible to affect. A total of 22 causes and 61 actions were identified for variations in demand, internally generated capacity requirements, available capacity and delivery lead-time from suppliers. 39 out of 61 actions were utilised by at least half of the participating companies. This means that many of the actions are utilised by many of the companies and can be regarded as an indication that the framework is reasonably complete and relevant for practice. In this thesis the focus is on the main causes and actions, selected based on what has been emphasized in theory as causes and actions for these causes based on the utilisation in practice. Only actions mentioned by at least five out of six companies will be discussed here.

Large order quantities were found to be one of the most impactful causes for demand variations that manufacturing companies experience frequently. This is supported by previous research where large order quantities constitute one of the most decisive factors to unmanageable situations for demand variations (Williams, 1991, Lee *et al.*, 1997). The most common action was to facilitate order placement, especially for large customers, that can contribute to more frequent ordering and decreased order sizes (Mattsson, 1995). Interesting enough, most companies have campaigns and offer quantity discounts that induce customers to order more, amplifying order quantities and variations in demand. The consequences might not weight up to the advantages of the temporarily increased sales, especially as it may lead to lumpy demand and challenges to keep low inventories and even capacity utilisation (Croson and Donohue, 2003). If the communication is lacking the increased sales from the promotion might be perceived as gained market shares (Mather, 1996). This happened to one of the participating companies where it went as far that major investments were made to reinforce the machine park. After the promotion the sales dropped radically and resulted in low resource utilisation, where barely one out of four machines were fully utilised. If the communication is lacking internally the manufacturing might not have the required resource availability to manage an increased demand during a promotion period. This could lead to delivery problems and extended delivery lead-times (Mather, 1996), with a domino effect on the variations in demand if customers start questioning the delivery capability and start ordering larger quantities or earlier in advance than required (Christopher and Lee, 2004). Several companies argue that they investigate opportunities of partial deliveries in periods of high demand but that urgent volumes always should be delivered. This is a finding that indicate a need of flexibility and resources that can absorb variations, an argument for the need and purpose of buffers connected to RQ3. In addition, the companies are restrictive to parameter updates in lead-times to not amplify the variations and work with continuous process development to avoid reclaims due to quality problems.

Rework, inadequate planning data and inadequate planning processes were found to be the main experienced causes for internally generated capacity requirements that all participating companies work actively on reducing. In general, the companies work with continuous improvements and promotes a culture of root cause analysis for these issues. This is in line with the general processes proposed in quality management literature, see e.g. (Nikulin *et al.*, 2018). The development work is done so that the same problem should not be repeated for rework, that basic planning data becomes accurate and that planning processes are uniform with clarified responsibilities to avoid sub-optimisations. One of the participating companies exemplified how they work with avoiding sub-optimisation in their planning, pinpointing the importance of creating a holistic understanding for all employees, to work with customer focus and not based on self-interests for what is easiest for themselves. Another company emphasized the need to measure planned and achieved values in order to observe the expected versus actual values, of for example the operating times, to use as accurate parameters as possible in the business systems. This is an important notion, partly because the common mentality "what is measured is what is done" and "you cannot control what you do not measure", but foremost because measuring planned and achieved values is a prerequisite to become aware of deviations, get a better understanding of actual problems (Mather, 1996) and get a starting point as a reference point in improvement work (Palmatier, 1988). Several actions applied in practice point to improve current processes or data. Measurements are therefore considered as fundamental in order to enable this improvement work.

The reliability of resource availability strongly influence the delivery capability (Nikulin *et al.*, 2018), ultimately leading to variations in demand if customers experience delivery problems (Taylor, 2000). This means that one type of variation (e.g. in capacity availability) can impact another type of variation (e.g. in demand). Variations in available capacity is well recognised by the participating companies and is said to occur daily, especially due to temporary capacity losses. Assid *et al.* (2015) emphasize the importance to work with reducing short-term absence of personnel and preventive maintenance as these affect the risk of unexpected manufacturing disruptions. This was reflected in the actions applied in practice, where many actions are applied possibly as the causes often have a direct impact on the daily operations. The actions mentioned by all companies were: to perform activities to reduce short-term absence, plan for preventive maintenance, structuring and including indirect time in the planning, to routinely have team meetings to reduce temporary capacity losses and to prepare setup activities before an order is scheduled to begin to reduce the occurrence of inadequate planning. However, it is not always a matter of technical issues for variations in available capacity. One of the companies mentioned that they have absence in personnel that they know is not a result of sick people, rather it is a matter of soft values that are important to consider in order to find appropriate actions for this type of capacity loss. This level of detail has not been reflected in the framework in Paper II but highlights the importance of soft values.

Several researchers argue that variations in delivery lead-time from suppliers can often have more severe consequences than the length of the delivery lead-time (Lawrence, 1992). It still seems to be a strong focus on short delivery lead-times in both theory and practice, with focus to shorten rather than ensure robust delivery lead-times that has been prevailing for the last couple of decades. This is an interesting notion which contradicts several studies that indicate that businesses generally value secure timing of deliveries higher than short delivery lead-times (see e.g. Keebler and Manrodt, 2000 or Van der Hoop and Pfohl, 1996). The participating companies agree on the importance of reliable delivery lead-times, nevertheless the interesting thing is that their agreements with suppliers are for approved intervals instead of fixed delivery lead-times (i.e. delivery windows as described by Corbett, 1992). A couple of the participating companies do not have any agreements at all but have found this as an important improvement area as they have encountered problems when the supplier performance does not correspond to expectations. The most common actions for variations in delivery lead-times from suppliers were found to be monitoring delayed orders, utilise alternative transport modules (air freight) and to provide technical support to supplier to minimise the prevailing variations. One of the companies even have a proper structure for keeping track on supplier performance internally and keeping pressure on questionable suppliers.

5.1.3 How are different types of buffers related to capacity management considered to absorb variations?

The aim of the third research question (RQ3) was to enhance the understanding of absorbing variations in terms of utilising buffers. In Paper I the importance of considering both systematic and stochastic variations was highlighted, and Paper III covers buffers related to capacity management to absorb both these types of variations in demand. As Paper II suggest, it is an advantage to first address the causes for variations that are possible to affect. However, there will most likely remain variations that need to be absorbed to maintain a competitive delivery capability. This is covered in RQ3, where Paper III provided an overview of the main buffer alternatives for systematic and stochastic variations, while an earlier version of these buffers was investigated in Paper IV for the buffers utilised in manufacturing companies.

Each buffer from the earlier version of Paper III was recognised as apparent in at least two out of four companies in Paper IV. Some companies perceived that almost all buffers are utilised in their businesses while others only have a few different types of buffers. It has been indicated that different strategies are sometimes applied for one and the same type of buffer within companies based on, for example, criticality of materials and geographical distance to customers or suppliers. The participating companies generally acknowledged the purpose of buffers as a protection for different issues by statements as "to prepare [for expected future demand]", "protect against variations", "to protect the flow", "get a reasonable lead-time", "absorb all problems" and "protects delivery". This is in line with what Hurley (1996) emphasize as the purpose of buffers, specifically that buffers are for the protection and not the enhancement of the throughput rate. One of the companies emphasized that the overarching aim is always to protect customer orders, while others added a more detailed perspective in terms of protecting processes and activities against variations. When investigating the different buffer types, the material buffers were considered to enable high capacity utilisation by protecting resources from capacity losses and to secure high service performance. This is in line with the traditional view of material buffers, where efforts have been on economies of scale and that material buffers absorb unexpected fluctuations (Fry *et al.*, 1994), and protecting against potential shortages and uncertainties in supply and demand (Kanet, 2014).

For capacity buffers, which have received less attention in current literature, the companies mention the importance to absorb disturbances for long-term demand patterns and to absorb variations in the value-adding processes. The requirements for capacity buffers have foremost been highlighted by studies investigating the impact on cost and performance depending on the resource utilisation rate (Bradley and Glynn, 2002), where all performance measures deteriorate for high capacity utilisation (Marucheck and McClelland, 1992). Capacity flexibility buffers have especially been argued by the companies to reduce the need for other buffers as they enable short-term opportunities to increase available capacity when needed. This finding is not surprising, previous studies have indicated that many manufacturing companies utilise various types of flexibility for short-term requirements (Hedvall *et al.*, 2017), and that capacity flexibility is essential to achieve high delivery performance and efficiency (Fry *et al.*, 1994, Betts *et al.*, 2000, Pagell *et al.*, 2000). What has not been mentioned by the participating companies is the strategic possibility with capacity buffers, Fry *et al.* (1994) emphasize that it is not merely a cost if the buffer when not used for variations is used for continuous development. This means that capacity buffers can be competitive weapons to reduce lead-time and the need of inventory (Steele and Papke-Shields, 1993) and the total need for buffers if variations are reduced (Lee *et al.*, 1997). Lead-time buffers are, according to the participating companies, mainly perceived as alternatives that protect following processes independent if it is for inbound, outbound or a perspective of internal processes. All the companies have established an outbound safety lead-time buffer as a final protection against any form of variations before delivery to customers. In addition, queue time buffers are present in all the companies, which is not a surprise as it is commonly used in capacity management (Vollmann *et al.*, 2005) and is an important variable to manage in order to keep the utilisation rate within controllable levels (Gunasekaran *et al.*, 2001).

Moreover, the findings from Paper IV indicate that buffer management in manufacturing companies are characterised by intuitive and experience-based decision making, mainly due to a perceived lack of decision support. This has also been noted by previous researchers, who emphasize that an intuitive approach is common, especially when there is a lack of theoretical knowledge of how to evaluate the impact of different strategies (Krajewski *et al.*, 2010). However, the buffer type that is best depends on surrounding circumstances and aims. The combinatorial effects of the total selection of buffers has been highlighted as a complex problem by Hurley (1996), which have led to a tendency to simplify matters in most literature. One of the companies raised concerns that the management of buffers tend to become sub-optimised, where many decision makers make decisions locally without a holistic understanding. The other participating companies agreed that this is a challenge, partly because there is a lack of established structures in the companies that guide the buffer management and partly because the lack of responsibility and ownership of the buffers. Inevitably, this is leading to accumulation of buffers where everybody tries to secure their own performance measures. One of the companies raised concerns that this has resulted in major challenges to maintain buffers for their purposes, especially lead-time buffers, as they often become utilised for other issues when there is time available.

5.2 Connecting the discussion to implications for capacity management and fulfilment of purpose

The discussion started off by stating the purpose of this research that was *to increase the understanding of causes for variations, actions to reduce variations and how buffers can be used to mitigate negative effects of variations related to capacity management in a manufacturing context*. The three research questions were discussed, where the researcher started by investigating the perspectives of buffer management in MPC frameworks as it impacts the variation management and buffer management. Then the focus shifted to the causes for variations and actions to reduce variations, followed by the buffer types and purposes from a capacity management perspective. To fully relate the findings in the discussion to capacity management in a manufacturing context, as indicated by the purpose, this will be elaborated further below based on the three research questions.

Capacity management is primarily about balancing availability of resources with the requirements of resources as this is fundamentally important for competitiveness (Van Mieghem, 2003). In a manufacturing context, the capacity management is foremost about the resource capacity in manufacturing but is affected by, dependent of, and needs to be weighted with materials and lead-time. Already here it becomes complex to consider trade-offs between resources (Hu *et al.*, 2003) and then systematic and stochastic variations need to be taken into account beyond this, making the decisions even harder. In order to mitigate negative effects of variations and make well-informed decisions in capacity management in a manufacturing context, there are different types of resource and variations concerned, together with different data to consider depending on the time horizon. Hence, all the four management perspectives (balance management, resource management, risk management and hierarchical management) covered in RQ1 by Paper I are important to consider in capacity management with implications for the variation management and buffer management.

There are many causes for variations that affect companies. The causes that are internally generated were investigated in RQ2 and Paper II. The awareness of that several internal rules, routines and behaviours impact variations and thereby also the requirements of resources shows the importance to consider actions to reduce variations as it has a direct impact on capacity management. In other words, in a manufacturing context the reduced variations reduce the need for buffers (Hurley and Whybark, 1999), enable a more even capacity utilisation and lead to more stable flows of materials. In general, the proposed actions that are most used in manufacturing companies are connected to communication, the policies and procedures, system support, agreements and incentives. From a capacity management perspective, it is important to be aware of both the causes and actions and make changes when needed for improved competitiveness. With this said, there is not always a need to make changes, especially since a variation can be intentionally generated. It could for example be that a certain set of resources are not utilised to the desired extent and that a campaign is released to increase demand and resource utilisation. One of the companies mentioned the importance to discuss these issues internally in the company to better understand the causes for variations.

They considered to have a workshop with several departments to get a common understanding of how negative effects of variations can be reduced without sub-optimisations.

The remnant variations, no matter if the variations have been reduced or not, may have negative effects on competitiveness. In RQ3 by Paper III and Paper IV, the buffer alternatives to absorb variations were investigated from a capacity management perspective. Each buffer purpose was therefore directly related to capacity issues, with the intention to protect or compensate for capacity. How performance is measured can contribute to the causes for variations, as described in RQ2, but it can also affect the choice of buffers. One example is that accounting systems usually report unused capacity as a cost (Steele and Papke-Shields, 1993), that easily can lead to a preference to use other buffer types. This research contributes to an increased understanding of the possible buffers and their purposes, from a capacity management perspective, to facilitate and increase the awareness of when a certain buffer is preferable. In other words, an attempt to look beyond performance measures and instead think of what is of most strategic importance.

To conclude, this research can increase an awareness of how variations can be reduced and absorbed, leading to an awareness in decisions for how the variation management and buffer management affect and have implications for capacity management. All these aspects are therefore considered to be of fundamental importance for mitigating negative effects of variations in manufacturing companies.

5.3 Theoretical and managerial implications

The research presented in this licentiate thesis contribute to increasing knowledge of reducing and absorbing variations in a manufacturing context, by investigations from a capacity management perspective. The theoretical and practical findings from appended papers provide descriptive insight into the current state of variation management and buffer management in manufacturing companies. Specifically, the research enhances the understanding of variations affecting companies and that are possible to affect by reviewing internal routines, rules and behaviours (as proposed by Sandvig and Allaire, 1998). Potential actions have been identified that can be utilised in the variation reducing activities. This has been complemented with investigating the buffer alternatives that can absorb and reduce the effects of existing variations. Different buffer types and subtypes have been identified together with their purposes in practice, providing an increased understanding of absorbing variations by the use of buffers. The theoretical contribution is foremost in terms of highlighting the importance of all these aspects for capacity management, creating a more integrated perspective for variation management and buffer management, and providing insights into the importance of handling systematic and stochastic variations as separate issues for all types of resources. Furthermore, the research combines current knowledge for different origins of uncertainty and buffers to provide a more holistic picture for variations and buffers related to capacity management.

Moreover, the theoretical and empirical findings can be used by manufacturing companies to enhance their awareness of their situation and how other companies work to reduce and absorb variations. This, together with the established frameworks in the papers, can assist in guiding companies to become more systematic in their variation management and buffer management. Established frameworks can be used by companies to map current state and therefore also be used in analysing potential improvement areas when comparing to desired situation. As the frameworks include several sources of uncertainty (for the framework of causes and actions for variations in Paper II) and several buffer types and subtypes for different types of variation (for the framework of buffers established in Paper III), it is sought to enhance the understanding of decision makers that decisions need to consider several parts to avoid sub-optimisation. This is sought to enhance the understanding of the complexity of variation management and buffer management, calling for better decision support to be established.

5.4 Limitations

As commonly said “nothing is perfect”, nor is this research. This subchapter is devoted to some of the imperfections that might have affected the research results. First of all, the methodology chosen impacts the scope of possible conclusions. This research is based on a case study methodology, conceptual research and literature studies. The generalisability of results in case studies are often considered dependent on the number of studied cases (Voss *et al.*, 2002), with a rule of thumb that between 4-12 cases are appropriate (Eisenhardt, 1989). In Paper II six companies participated and four companies in Paper IV. Some perceive the number of cases as “the more the merrier” to increase the confidence in the findings. However, more cases reduce the possibility to dig into depth and the balance of available resources with data quantity resulted in six and four companies for this research. However, the participating companies are within different industries with different types of products and the case selection rationale and generalisability of results could therefore be targets for criticism. Other studies more focused on a specific industry could of course be valuable but considering the maturity of knowledge the goal was here to get a general understanding of the current state in variation management and buffer management in manufacturing companies, independent of the type of product. An interesting notice is that the companies themselves have expressed that they are more alike each other than first perceived, especially that they experience the same type of challenges independent of industry.

Another important thing to mention for case research is the researcher's role and potential implications on research results. Most of this research is conducted within a research project (i.e. KOPability), where the participating companies are involved and interacting with the research group for a long time period (for three years). This enable building close relations and trust, in the same time as the risk increase that the respondents get influenced in the way they think, answering questions based on knowledge established from interaction in the research project. In the same time, it is easy to draw conclusions too fast because as a researcher you get to know the data well and might think what the respondents "probably thought or meant" something but in fact they did not. For the latter concern, the recordings have been of high importance to reduce the risk of researcher bias. However, there are always risks of misinterpretation even though recordings are available. Documents have therefore also been used as support when possible.

This far, the discussion has focused on limitations connected to the case research but there are also some important remarks for the literature studies. The review of literature in this research can be considered as traditional literature reviews, which is frequently criticised as an approach with a lack of thoroughness (Seuring and Gold, 2012). However, a fully systematic approach has not been considered applicable in this first phase of the research due to the divergent nomenclature within the subject area of interest. To exemplify, in the beginning of the research project the focus was foremost on capacity buffers and safety capacity in particular, but the search results did not provide much that pinpointed exactly the topic of interest. This could of course be connected to limited skills in database searches but as a young scholar without previous knowledge of other connected, relevant search words it could be destructing to follow a fully structured literature review approach at first. Just by going back and forth searching in reference lists and citations there were several words corresponding to safety capacity as for example hedge capacity, protective capacity and capacity cushion. There are potentially relevant concepts and terminology that have been missed, which is a limitation of this research as it prevents to provide a complete overview of previous research. A structured approach is of course preferable, and this is something that will be strived for in further studies when the researcher has built up a more thorough knowledge base of the research area and topic.

5.5 Future research

In Paper II several causes for variations were identified and actions proposed to reduce the variations and thereby the need for buffers. However, whether or not the proposed actions result in reduced variation has not been studied. Further studies could focus more on the assessment of realised changes in variations depending on selected action. This would facilitate the decision making with an appropriate selection of actions based on cause-effect, where the action with least investment and largest effect would be highest prioritised. The most appropriate actions would of course depend on the surrounding circumstances and it is therefore also proposed that further studies focus on the establishment of a process for the variation reducing activities. This process could guide practitioners of how to work with the already established framework of causes and actions in Paper II. Both these suggestions would complement and enrich the research presented in this licentiate thesis.

This research has also focused on the content of buffer management in a manufacturing context. Buffer management includes buffer configuration, that includes decisions regarding buffer type (selection), place (positioning) and size (dimensioning). This research has touched upon the buffer selection for the type of buffer in Paper III and Paper IV. Still, several paths for continuation are open for all these three parts of buffer configuration. Questions remain for how to choose between different buffer alternatives, especially for different types of flexibility. Further it would be interesting to investigate the trade-off between the required capacity level for fixed capacity versus flexible capacity. For buffer position, questions remain where buffers should be positioned for biggest effect. Literature on material buffers are extensive, while lead-time and foremost capacity buffers have received little attention in previous research. The importance and trade-offs between these three different types of buffers have been highlighted in this research but many questions are still to be answered. How should the identified trade-offs be considered in the buffer management? How does the combinatorial selection of buffers affect the delivery capability? How can lead-time and capacity buffers be dimensioned in an appropriate way to sustain a competitive delivery capability? Last but not least, how can we develop decision support in capacity management that include the main parts of buffer configuration?

Addressing research gaps in line with proposed above could contribute to increase knowledge and develop decision support that enhance practitioner's ability to reduce and absorb variations. It would also be a step from focusing on content to study the process of mitigating negative effects of variations.

5.6 Conclusions and concluding remarks

The underlying foundation for this research builds on RQ1 that clarify the essential parts of buffer management in manufacturing planning and control frameworks, where different types of variations, resources and planning levels are fundamental for both reducing and absorbing variations in the balancing act of supply and demand.

The answer to RQ2 provides a set of proposed causes and actions for variations in demand, internally generated capacity requirements, available capacity and delivery lead-time from suppliers. This is sought to enhance the awareness of which internal routines, rules and behaviours that can contribute to variations and how this can be avoided by proposing different actions. Henceforth, the work with variation reducing activities can be done in a more systematic manner, where conventional and established methods for root cause analysis and continuous improvements can be used in combination with the framework of causes and actions in Paper II. The research has indicated that one type of variation can have direct or indirect impact on other types of variations. It is proposed that companies work with variation reducing activities in a systematic manner, starting with becoming aware of challenges in current situation, creating consensus in the organisation of future desired situation and establishing an action plan for how to reach the goals. It has been interpreted that measurements are not always done for relevant information for variation management and buffer management and this needs to be in place in order to understand the impact of current problems. It could even be argued that this is decisive for the success of the improvement work and future competitiveness. This is not least as fundamental parts need to be robust in order to gain advantages of future requirements, as for example upcoming technologies with digitalisation striving for Industry 4.0.

Paper III provides a set of buffers related to capacity management to absorb both systematic and stochastic variations in demand. The answer to RQ3 is sought to enhance the understanding of buffer alternatives and purposes in theory and practice for buffer types in form of materials, capacity and lead-time. This research has indicated challenges in a selection of an appropriate set of buffers, when to use which buffer and how combinatorial effects of buffer selection should be considered to achieve desired performance. In addition, the empirical findings indicate that the variation management and buffer management tend to be based on intuition and experience rather than based on formal methods and procedures. Moreover, issues have been raised for challenges in avoiding sub-optimisations and to maintain that established buffers are used properly based on their purposes and not for other issues. Hence, there is still much research to be done to bridge gaps between theory and practice, especially to increase an awareness of the theoretical possibilities for practice and to make methods easily applicable for practitice.

To summarise, this research has emphasized that both internal and external variations are important to consider, with different origins of uncertainty that can cause systematic or stochastic variations. These variations have further been investigated by the causes that are internally generated and possible to affect in order to find appropriate actions to reduce them. This has been complemented with the purposes of different buffer types that can absorb systematic and stochastic variations, independent of the origin of uncertainty and cause for variation. Furthermore, the decisions need to be done on different hierarchical levels to consider the level of detail of relevance for the time horizon concerned in order to successfully balance supply and demand.

To conclude, this research has indicated the need of both variation reducing activities and absorbing variations by buffers, none which in general is superior without the other for business competitiveness. Two take-aways are: first that variations create a need for buffers and if a company is not satisfied with the size of the buffers, they need to reduce the variations, and secondly that the buffers should be selected based on the requirements of the company to satisfactory absorb variations. There is however much more research to be done to establish a solid foundation for decision support in variation management and buffer management. This thesis is therefore a step forward by investigating the content (in a descriptive manner) to study the process (in a normative manner) of variation reducing and absorbing activities.

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