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VISIBILITY AND VARIABILITY IN INDUSTRIAL OPERATIONS

Master's Thesis in

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ABBREVIATIONS

ROI	Return on investment
WIP	Work in progress
ROI	Return of investment
KPI	Key performance indicator
KRI	Key result indicator
RI	Result indicator
PI	Performance indicator
SPC	Statistical process control
UCL	Upper control limit
LCL	Lower control limit
VSM	Value Stream Map
TOC	Theory of constraints
OTD	On time delivery
CONWIP	Constant work in progress

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ABSTRACT

Protection and promotion of flow is the fundamental principle that businesses and the rules and tools they use should be built upon. Flow of information and materials must be relevant to the required output of the system. Visibility means relevant information for decision making. Variability is summation of differences between plans and what happens. Improved flow results from less variability. A change in variability is caused by a change in visibility. Variation experienced by an organization decreases when access to relevant information increases. Variation experienced by an organization increases when visibility is blocked or inhibited, or irrelevant information for decision making is generated. The importance of visibility for flow based operating models is only rarely addressed in literature. With a constructivism approach, this thesis investigates how visibility is understood and implemented in the relevant literature and in the operations of the case company. The results of the research are represented according to a conceptual framework that is developed based on the review of relevant literature of the subjects of visibility and variability. The research is concluded with a proposal for potential future developments in the case organization and in relevant literature. The potential development areas are specific for the operations of the case company business units but generalizable for other organizations and studies.

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Teknillinen tiedekunta

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Tutkinto	Kauppatieteiden maisteri
Tutkinto-ohjelma	Tuotantotalouden maisteriohjelma
Pääaine	Tuotantotalous
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TIIVISTELMÄ

Virtauksen suojaaminen ja edistäminen on liiketoiminnan ja siinä käytettyjen toimintatapojen sekä työkalujen keskeinen periaate. Informaatio- ja materiaalivirtojen pitää olla relevantteja järjestelmän vaaditulle tuotokselle. Näkyvyys tarkoittaa relevanttia informaatiota päätöksentekoa varten. Vaihtelu on suunnitelmassa tapahtuvien muutosten summa. Virtauksen parantuminen johtuu pienentyneestä vaihtelusta. Muutos vaihtelussa johtuu muutoksesta näkyvyydessä. Yrityksen kokema vaihtelu laskee, kun näkyvyys parantuu. Yrityksen kokema vaihtelu kasvaa, kun näkyvyys on estetty tai rajoitettu, tai jos päätöksentekoa varten kehitetään irrelevanttia informaatiota. Näkyvyyden merkitys virtaukseen keskittyvissä toimintamalleissa on vain harvoin osoitettu kirjallisuudessa. Tämä diplomityö pyrkii konstruktivistisen lähestymistavan avulla tutkimaan, miten näkyvyys ymmärretään, ja on implementoitu relevantissa kirjallisuudessa sekä case-yrityksen liiketoiminnassa. Tutkimuksen tulokset esitetään konseptualistisen viitekehyksen avulla, joka on kehitetty relevantin, näkyvyyteen ja vaihteluun keskittyvän, kirjallisuuskatsauksen perusteella. Tutkielma päätetään case-yritykselle ja relevantille kirjallisuudelle ehdotettavilla potentiaalisilla kehitysalueilla. Nämä potentiaaliset kehitysalueet ovat spesifejä case-yrityksen liiketoiminnalle, mutta yleistettävissä muiden yritysten ja tutkimusten käytettäviksi.

1. INTRODUCTION

This thesis studies visibility and variability in the operations of an industrial organization. The literature review and empirical study of this thesis are conducted in the context of operations and supply chain management. Operations management addresses the way organizations produce and deliver goods and services to the customer. (Porter 2009). Supply chains encompass activities that are *"associated with the flow and transformation of goods from raw materials stage (extraction), through the end user, as well as the associated information flows"* (Seuring & Müller 2008). In supply chain management, customer and economic value is generated by examining and managing the networks related to the transformation and flow of goods and information (Zigiaris 2000). This chapter introduces the research motivation, case organization, research process and thesis content, research objective and scope of the thesis.

1.1 Research motivation

The motivation for the research of this thesis was initiated from the way relevant information for decision making was generated and used in the operations of the case company business units. During the implementation of improvement activities in the case company, it was often evident that the current way of working seemed to encourage and reinforce behaviours that block the flow of information and materials. In practice, this was often evident as long lead times, large amounts work in progress, high utilization rates altogether, sub-optimization and quality nonconformities. It was evident that for future improvement activities in the case company, it would be beneficial to generate a manner of approach that is built around the purpose of achieving, protecting and encouraging flow.

The review of relevant literature on flow provided justification to select the topic of visibility as the basis for the study. During the review, it was evident that the approaches of previous studies often did not comprehensively explain reasons behind the phenomenons evident in the case company. The research topic therefore stems to some

extent from the outcome of the literature review but initially from the observations of the operations of the case company. The final validation of the topic was concluded when reviewing material from Smith & Smith (2013b, see Figure 5), where the formula for flow is combined with formula of visibility and variability. The formula of visibility and variability provided the scope for the thesis.

In flow based operating models, the benefits of successful operations of a company are determined based on the speed of flow of relevant information and materials (Ptak & Smith 2016: 18). Driving shareholder equity is the fundamental objective of all for-profit entities. Flow of material, flow of information and flow of cash are the basis of manufacturing and supply chains. Large variety of products, materials, technology, machines and people skills are all comprised within a manufacturing and supply chain processes. These principles are articulated in the first law of manufacturing by George Plossl: *"all benefits are directly related to the speed of flow of information and materials"* (Ptak & Smith 2016: 15).

Organizations today are covered in large amounts of data with information that cannot be effectively utilized for decision making and large inventories of unnecessary materials. Moving information and materials quickly through a system will not alone create success. Flow of information and materials must be relevant. Relevancy of information and materials is determined by the required output of the system, the actual demand. The prerequisite to having the right materials is to have the right information. (Ptak & Smith 2016: 18.) Based on this prerequisite, the first law of manufacturing can be amended: *"all benefits will be directly related to the speed of flow of relevant information and materials"* (Ptak & Smith 2016: 18).

In this thesis, the definition of visibility is *"relevant information for decision making"* (Smith 2015). Increased visibility can enhance operational performance, flexibility, decision making and coordination. Encouraging, measuring, and making flow visible can align the objectives of a company's functions to the goal of maximizing shareholder equity (Ptak & Smith 2016: 17). Despite well-grounded literature on the subject of

visibility, the underlying capabilities of systems that claim to deliver visibility for operational processes are often vague. (Gaupner, Urbitsch & Maedche 2015.)

Improved flow results from less variability (Ptak & Smith 2016: 17). In this study, variability is *"the summation of the differences between our plan and what happens"* (Smith 2015). Increased variability degrades the performance of systems. Reducing variability is essential because variability is the source of various problems in manufacturing. Examples of what variability causes include losses in throughput, congestion, large amounts of work in progress (WIP) and extended lead times. Variability in manufacturing system is distinguishable from the way it propagates in an amplified manner downstream the system, eventually causing flow variability. (Deif 2012.)

Inherent level of variability is present in any environment (Ptak & Smith 2016: 30). According to Smith & Smith (2013a), a change in variability is caused by a change in visibility. Variation experienced by an organization decreases when access to relevant information increases. On the other hand, variation experienced by an organization increases when visibility is blocked or inhibited, or irrelevant information for decision making is generated. Inversely, a change in ROI also follows the change in variation. (Smith & Smith 2013a.)

1.2 The Case Organization

The case company is a global leader in advanced technologies and complete lifecycle solutions for the marine and energy markets. The case company has three key business areas providing solutions for marine and energy industries as well as services to their solutions. The mission of the case company is to support the marine and energy markets with advanced technologies and focus on lifecycle performance, to enhance customers business and benefit the environment. The strategy of the case company aims at profitable growth by providing advanced technologies and lifecycle solutions to its marine and energy market customers.

1.3   Research objective

Derived from the motivation for the research, the objective of the research is to conduct a descriptive single case study (with three embedded units) on the effects of visibility to variability in the flow based operating models of an industrial organization. "*A descriptive case study is used to describe an intervention or phenomenon and the real-life context in which it occurred*" (Baxter & Jack 2008). Single case study with embedded business units enables the comparison of the embedded units with each other and the larger system. In this method *"data can be analysed within the subunits separately (within case analysis), between the different subunits (between case analysis), or across all of the subunits (cross-case analysis)"* (Baxter & Jack 2008). Finally, the analysis is returned to address the initial, global issue. (Baxter & Jack 2008.) Derived from the motivation for the research, the following research questions are formulated.

Question 1. *How visibility and variability in flow based operations are understood in the relevant literature?*
This is answered by conducting a literature review on the concepts of this thesis. Based on the literature review a conceptual framework is developed.

Question 2. *How visibility is currently understood and implemented in the case company business operations?*
This is answered by conducting the case study and analysing the case company data based on the conceptual framework.

Question 3. *How visibility can be further improved in the case company based on conceptual framework?*
This is answered by developing a conceptual framework from the literature and comparing it with case company data. Improvements are then proposed for the future.

The research questions provide guidance for the literature review, empirical study and discussions. The literature review investigates the requirements for relevant information for decision making (visibility) and variability control and reduction, thus providing a

structure for the conceptual framework. The conceptual framework is the basis for the empirical part, which answers the second research question. The empirical study is done to analyze the generation and usage of relevant information for decision making and to highlight challenges. Finally, the findings are concluded in the final chapter and focus areas for future development and study are provided.

1.4   Scope of the Thesis

The research is narrowed to the operations of selected case company business units and initiatives within these businesses. This thesis focuses primarily on the relationship between visibility and variability in flow based operating models. Flow is the enabler for the objectives of most functions in a company including marketing, sales, planning, operations, quality and finance (Smith 2016). This is essential because *"the performance of any component is to be judged in terms of its contribution to the aim of the system"* (Lazko & Saunders 1995: 35). Optimizing and focusing on individual profits of a single component or department with inconsistent competitive measures often leads to system sub-optimization (Lazko & Saunders 1995: 35).

The relationship between flow and ROI (return on investment) is not studied in this thesis. The relationship between flow and ROI is already articulated in the first law of manufacturing by George Plossl in Orlicky's Material Requirements Planning: *"all benefits are directly related to the speed of flow of information and materials"* (Ptak & Smith 2016: 15). Ptak & Smith (2016: 13) point out that the appreciation for information and material flow is a unifying concept between disciplines of Dr. Eliyahu Goldratt (the creator of Theory of Constraints), Taiichi Ohno (Toyota Production System) and Dr. W. Edwards Deming (14 points for quality). In addition on how flow affects ROI, the relationship between variability and flow is also not required to be thoroughly studied in this thesis because *"the one thing most process improvement philosophies agree on is that the No. 1 enemy of flow is variability"* (Smith & Smith 2013a).

The scope of the thesis.

$\triangle$ VISIBILITY $\longrightarrow$ $\triangle$ VARIABILITY $\quad\longrightarrow\quad$ $\triangle$ FLOW $\longrightarrow$ $\triangle$ CASH VELOCITY $\longrightarrow$ $\triangle$ ROI

VISIBILITY = Relevant information for decision making
VARIABILITY = The sum of differences between plan and what happens
FLOW = The rate at which a system converts material to product
CASH VELOCITY = The rate of net cash generation
ROI = Net profit / investment

George Plossl's first law of manufacturing:
"All benefits are directly related to the speed of flow of information and materials."

Figure 1. The scope of the thesis visualized in a formula provided by Smith & Smith (2013b).

1.5 Research process and thesis content

The thesis begins with a review of relevant literature on the subjects of visibility, limited visibility, visual representation and variability. A conceptual framework is generated based on the literature review. An empirical study is conducted based on the findings in the review of relevant literature. The research material of the empirical study is gathered based on the topics of the conceptual framework. Finally, based on the analysis of the research material, discussion chapter provides an overview of the research with focus on key development areas. The following illustration presents the research process.
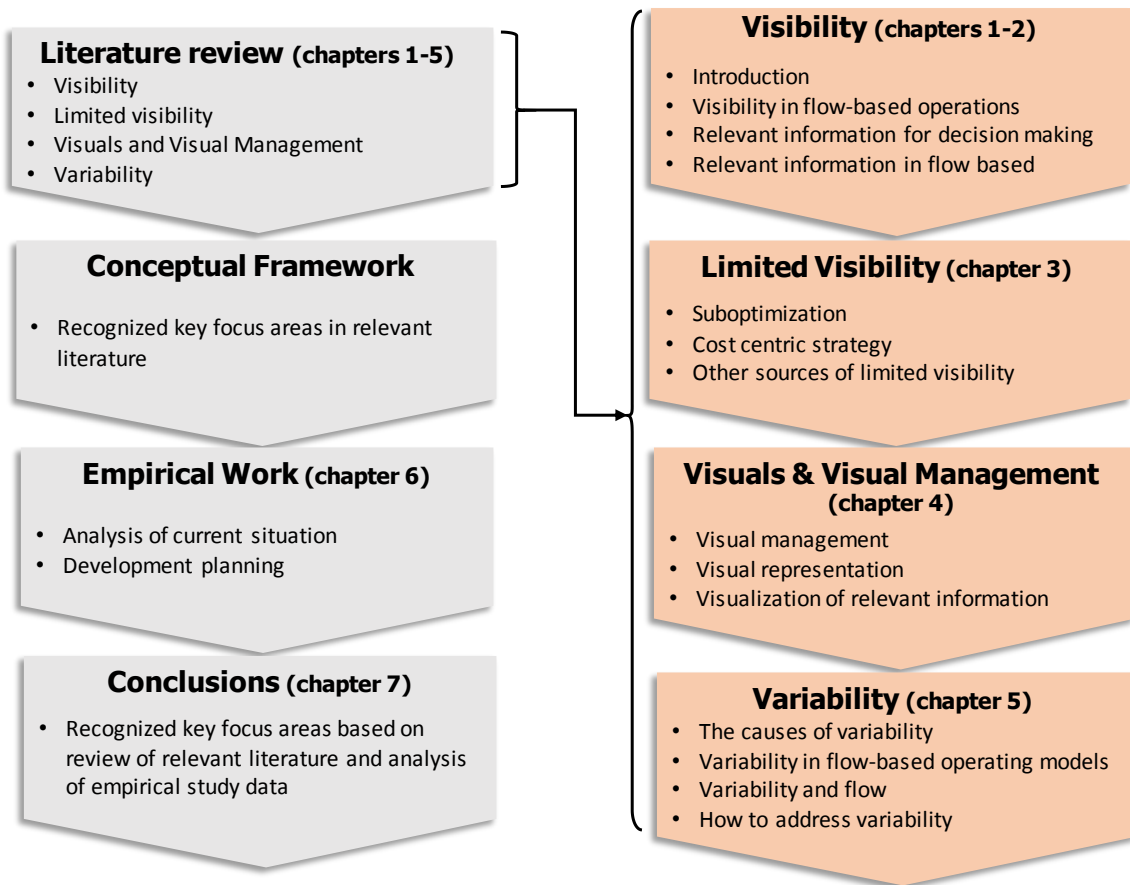
Figure 2. The research process and structure for literature review.

1.6 Literature review introduction

The literature review on visibility, limited visibility, visuals and visual management and variability is conducted in the context of supply chains and operations management. The chapter on visibility distinguishes the importance of visibility, what are the key characteristics of it and what it should address in flow based operations. The chapter after visibility emphasizes the corrosive effect of limited visibility, while providing practical examples on how to avoid limited visibility. The chapter after limited visibility separates the concepts of visual representation and visual management from the concept of visibility, while simultaneously providing guidance on how to utilize visibility effectively in decision making. The final chapter of the literature review focuses on variability in the context of the study, with focus on the characteristics of variability in flow based

operating models and methods on reducing and controlling variability in the operations of the case company. The chapter on variability therefore provides guidance on how could visibility be generated and utilized in a way that variability is reduced and controlled in the context of flow based operating models and in the operations of the case company.
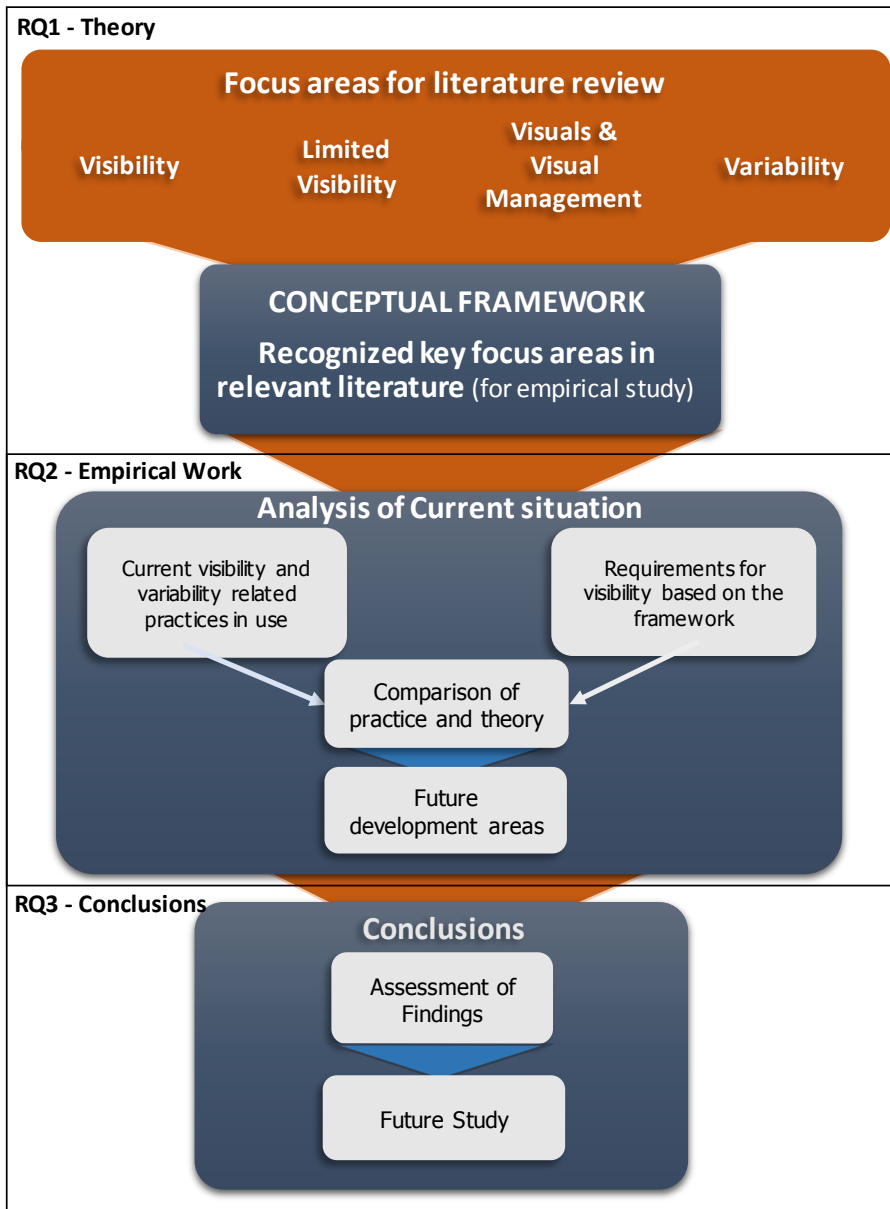
Figure 3. Content of the thesis

2. VISIBILITY IN FLOW BASED OPERATIONS

Driving shareholder equity is the fundamental objective of all for-profit entities. Flow of material, flow of information and flow of cash are the basis of manufacturing and supply chains. Return on investment (ROI) increases when revenues grow, inventory is minimized and unnecessary expenses are eliminated. *Protection and promotion of flow* is therefore the fundamental principle that businesses and the rules and tools they use should be built upon. (Ptak & Smith 2016: 15-16.)

Flow is the movement of information and materials (Goldratt 2008). George Plossl's first law of manufacturing articulates that material, information and cash flow determine how shareholder equity is driven in supply chains and manufacturing systems. *"All benefits are directly related to the speed of flow of information and materials"* (Ptak & Smith 2016: 15-16). All benefits encompass:

- **Service:** Consistent and reliable results as well as quality are enabled by a system that has good information and material flows.
- **Revenue:** Growth of market share is enabled by higher and better service.
- **Quality:** Good flow minimizes confusion and expediting and thus mistakes.
- **Inventories:** The less time it takes to flow between and through the system the less the total inventory investment.
- **Expenses:** Additional expenses occur when closing the gaps of poor flow.
- **Cash:** Materials that are paid for convert to cash at fast and consistent rate when flow is maximized.

$$\triangle \text{FLOW} \longrightarrow \triangle \text{CASH VELOCITY} \longrightarrow \triangle \text{ROI}$$

FLOW = The rate at which a system converts material to product
CASH VELOCITY = The rate of net cash generation
ROI = Net profit / investment

Figure 4. The formula for flow (Smith 2015).

2.1 Why visibility is important?

Increasing visibility is critical for improving operational performance, agility and responsiveness of complex, and often global supply-demand networks. Before a company can improve the operational performance, it needs visibility to it. (Aberdeen Group 2013.) Organizations today are covered in large amounts of data with information that cannot be effectively utilized for decision making and large inventories of unnecessary materials. Moving information and materials quickly through a system will not alone create success. Flow of information and materials must be relevant. Relevancy of information and materials is determined by the required output of the system, the actual demand. The prerequisite of having the right materials is to have the right information. (Ptak & Smith 2016: 18.) Based on this prerequisite, the first law of manufacturing can be amended: *"all benefits will be directly related to the speed of flow of relevant information and materials"* (Ptak & Smith 2016: 18).

The relationship between visibility, variability, flow, cash velocity and ROI can be expressed by the formula below. Visibility and variability describe the core problem area of generating and using relevant information. The definition of visibility is *"relevant information for decision making"* (Ptak & Smith 2016: 17). Variability is *"the summation of the differences between our plan and what happens"* (Smith 2015). Operating to flow is impossible if relevant information is not generated, used and made available. Therefore, the formula starts with relevant information. (Smith 2015.) Encouraging, measuring, and making flow visible can align the objectives of a company's functions to the goal of maximizing shareholder equity. (Ptak & Smith 2016: 17).

PROBLEM AREA

△VISIBILITY ⟶ △VARIABILITY ⟶ THE FIRST LAW OF MANUFACTURING

△FLOW ⟶ △CASH VELOCITY ⟶ △ROI

VISIBILITY = Relevant information for decision making
VARIABILITY = The sum of differences between plan and what happens
FLOW = The rate at which a system converts material to product
CASH VELOCITY = The rate of net cash generation
ROI = Net profit / investment
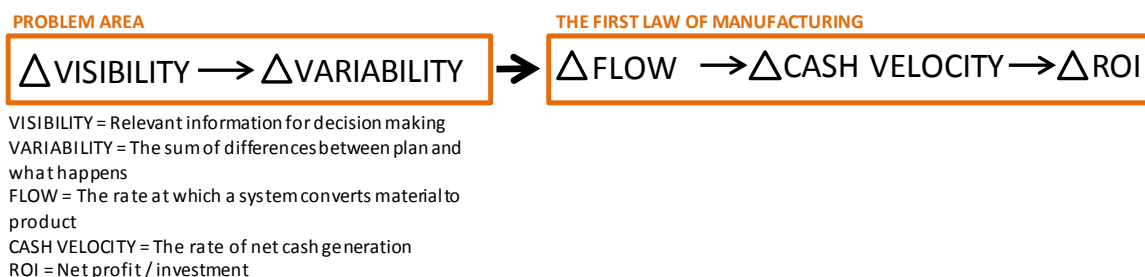
Figure 5. Visibility, variability, flow and ROI (Smith & Smith 2013b).

Visibility helps deciding on where to focus efforts within a system. Veryard (1986) defines a system as an artefact-in-use in which mechanisms, activities and procedures are connected into a group. Visibility improves control by demanding attention to the relationship between the system and the user or community of users. Control includes the following elements:

- Setting expectations.
- Measuring achievements.
- Comparing achievements with expectations.
- Taking corrective actions where and when needed. (Veryard 1986.)

According to Veryard (1986), visibility enables organizational and individual learning because the impact of it encompasses local property and single systems. "*Visibility in one place may improve understanding elsewhere*" while poor visibility affects people within the system in a non-favourable way (Veryard 1986). Logically structured and easy to understand visibility brings with it the loss of innocence because the assumptions it is based on are brought out for everyone to see. Overall, the advantages of making systems visible are related to utilizing the intellectual input from each employee as efficiently as possible. Enhancing relevant information for decision making makes a system cheaper to maintain by improving simplicity and documentation of it. Effectiveness and productivity of the system are also improved. Inaccurate data is more likely to be corrected and symptoms of faults are more likely to be diagnosed more quickly. (Veryard 1986.)

As terms, visibility and transparency are often used interchangeably in literature and in everyday business. However, visibility is different from transparency. According to Veryard (1986), the term *transparency* is ambiguous because it can refer to the user seeing into the system and understanding what happens inside it. This is also the objective of visibility. Transparency can also mean that the user sees *through* the system and ignores what actually happens inside it, which is the opposite for the first one. Transparency is *"the property of an object alone"* whereas *"visibility is a property of an object in relation to an observer"* (Veryard 1986). In visibility, the observer can see relevant information for decision making if needed, but need not. In transparency, seeing through the

transparent object is not a choice of the observer. (Veryard 1986.) According to Tezel Koskela & Tzortzopoulos (2009a), transparency is one of the functions of visual management. Transparency can be achieved by publicly displaying all of the flows within a system in an understandable way. (Tezel et al. 2009a). *"Transparency facilitates management by sight, which requires understanding of the workplace at a glance by the superior"* (Tezel et al. 2009a).

2.2   What is relevant information for decision making?

Visibility only to delayed metrics inhibits improvements. According to Manufacturing Enterprise Solutions Association (2011), employees in most manufacturing companies *"do not have visibility into performance to change outcomes during their work shift, or even at the end of it."* The reason why relevant information for decision making is often not provided quickly enough due to the following issues.

- Companies find that an analyst is needed to cleanse the data required for decision making prior to analysis.
- Companies find that it is time consuming to analyse and set up the data for visualization.
- Companies do not provide information that helps to predict problems (*leading metrics*) but only reporting of what has already happened (*lagging metrics*). (Manufacturing Enterprise Solutions Association 2011.)

Measurable information does not require extensive analysis and cleanse of data to achieve reliable and objective result of measurement. Timely information can be analysed and set up within appropriate ranges of time for decision making. Predictability means focusing on information that enables sound decisions that help to predict potential future outcomes.

Either objective metrics or subjective judgement can be used to demonstrate changes in performance. Production rates, volumes of sales, efficiencies, market shares, quality metrics or scorecard systems are all used for performance measurement in a variety of ways across companies. (Thekdi & Aven 2016.) *"In general, the practice of using data-based metrics encourages standardization and objectivity"* (Thekdi & Aven 2016).

Predictions of future performance are hard to conduct based on historical data based metrics. (Thekdi & Aven 2016.) *"Measurements that capture the past are rear-view mirrors"* (Zeithaml, Bolton, Deighton, Keiningham, Lemon & Petersen 2006).

2.2.1 Key performance indicators

KPI's are quantitative information used to illustrate the structures and processes of companies. When implemented correctly, *"KPI's tell you what to do to highly increase performance"* (Badaway, El-Azis, Idress, Hefny & Hossam 2016). The true nature of KPI's is often misunderstood and many companies work with the wrong measures. Key performance indicators should be differentiated from other types of performance measures. Key result indicators (KRI) are used to describe how something has been achieved, result indicators (RI) describe what has been done and performance indicators (PI) are used to describe what needs to be done. (Badaway et al. 2016.)

KPI's can be divided to leading indicators, lagging indicators and diagnostic measures. Leading indicators are the most powerful metrics. Using leading metrics businesses can significantly affect their future performance. Leading metrics are therefore relevant information for decision making. (Badaway et al. 2016.) They own *"the predictive and insightful causal relationships within the business processes and authorize the actionable course to continue the process improvement"* (Badaway et al. 2016).

Lagging indicators describe the output of past activities. *"A lagging indicator is a measure that only changes after the economy has changed"* (Manuele 2009). Diagnostic measure is neither a leading nor a lagging measure but is used to describe the current status of processes or activities. (Badaway et al. 2016.) For example, *"complex repairs completed successfully during the first time or visit may be a leading indicator of customer relief"* but a lagging indicator of the capability to carry out repairs (Badaway et al. 2016).

2.2.2   Leading indicator metrics as relevant information

Leading indicators are significant predictors of program performance. Leading indicators are measures that are used to evaluate the effectiveness of activities applied on a program. They provide information on the occurrences that affect system performance objectives. *"Measurements that capture the past are rear-view mirrors"* (Zeithaml, Bolton, Deighton, Keiningham, Lemon & Petersen 2006). Leading indicators support management in providing value to customers by predicting the future outcome of system performance based on measures or collection of measures. In order for systems to carry out complex deliveries according to plan and targets, leading indicators and sound risk management practices are essential. They support decision making with visibility. Visibility that is provided by leading metrics is useful in evaluating and predicting potential future outcomes objectively. (Orlowski, Blessner, Blacburn & Olson: 2015.)

According to Sinelnikov, Inouye & Kerper (2015) the basic definition of leading indicators is complicated.

> *"The literature regarding leading indicators is a multifarious compilation of thoughts, opinions, case studies, and some empirical research from a variety of industry, academic and government, and nongovernmental sources"* (Sinelnikov, Inouye & Kerper 2015).

The terms "*upstream, heading, positive and predictive"* are all used in describing leading indicators (Sinelnikov et al. 2015). The term *indicator* can also be substituted for metric, measure, or index. (Sinelnikov et al. 2015.) In this thesis, the terms *indicator* and *metric* are used interchangeably to describe the same conceptual knowledge. The results and outcomes of actions can be presented with *lagging indicators*. Leading indicators are likely to be presented prior to an event described by a lagging indicator. (Sinelnikov et al. 2015.)

According to Sinelnikov (et al. 2015), leading indicators have some key components that characterize them. These include their connectivity to outcomes (described by lagging indicators), reliable and objective measurability, interpretability across organizations and

applicability across company operations. Leading indicators are also easily and accurately communicated (Sinelnikov et al. 2015).

Leading indicators are *predictive*. Predictability of leading indicators means that they provide information that is linked to potential future outcomes. The predictive nature of leading indicators is related to the causal relationship of the result of the indicator and the business process outcomes. Leading indicators are also *actionable*. Actionability means that leading indicators provide the course on where to focus efforts to continue improvements. (Badaway et al. 2016.)

2.2.3 Forward looking information

Short-term financial metrics create myopia in employee decision making (Casas-Arce, Martínez-Jerez & Narayanan 2011). *"In essence, a forward-looking metric is a noisy assessment of future performance that will be superseded at a later day by the actual performance"* (Casas-Arce et al. 2011). Forward looking metric provides higher visibility to an estimated value and thus increases focus on relevant attributes. Forward looking information enables better control over the allocation of long-term and short-term actions. (Casas-Arce et al. 2011.)

2.2.4 Performance management

In order for visibility and correct metrics to contribute to organizational goals, there should be an understanding of what is to be achieved and how on an employee level. A performance management system makes the contribution of employees explicit to organizational goals (Aguinis 2011).

> *"Performance management is a continuous process of identifying, measuring and developing performance in organizations by linking each individuals performance and objectives to the organizations overall mission and goals"(Aguinis 2011).*

Performance appraisal means systematic description of individuals strengths and weaknesses. Performance appraisal does not provide an on-going feedback and coaching. It is also often conducted as an evaluation once a year. Performance management is

different from performance appraisal in that it also provides continuous feedback and coaching to improve performance. Performance management systems generate an explicit link on employee contribution to organizational goals. This generates a shared understanding of what is to be achieved and how. (Aguinis 2011.)

2.2.5 The timeliness of relevant information

Understanding the ranges of time in which assumptions, made based on relevant information provided, are valid is a prerequisite for making decisions. There are two relevant ranges for business decisions, *tactical relevant range* and *strategic relevant range.* Tactical relevant range provides information on short time frames such as hourly, daily or weekly. Strategic relevant range provides information based on longer time spans such as annually, quarterly or monthly. The information and assumptions that are relevant for making decisions vary between these frames of time. For example, forecasts and fixed expense variations are relevant for the strategic range, not the tactical range. Conversely, occurrences such as work order delays and machine breakdowns are relevant for the tactical range, not strategic range. *"Force fitting irrelevant assumptions into the wrong range will lead directly to distortive information, suboptimal decision and actions"* (Smith 2016). In the context of flow based operations and system variability reduction, leading metrics on tactical relevant range are more essential for decision making than lagging metrics on strategic relevant range.

2.2.6 Analysis of relevant information

For shared and analyzed information to provide good visibility, it should be *"accurate, timely, complete and in right format"* (Williams, Roh, Tokar & Swink 2013). The better the visibility, the faster and effective decision making processes for systems are. (Williams, Roh, Tokar & Swink 2013.) Analysis of information has the purpose of translating information into usable knowledge. This knowledge is useful in achieving the purposes of the organization. Analytical tools that require time-consuming analysis are not useful for operational purposes where decisions must be made fast. Data used must be set in the context of the process to transform it into meaningful process information,

such as KPI's (key performance indicators) that provide direct decision making support. (Gaupner et al. 2015.)

Visibility and comprehensibility can be aided by simplicity. Complicated systems are hard to keep track of because of the false impression of the complicated system covering everything. A simple system is easier to follow up. Simplicity can be achieved by streamlining of the number of constructs in the system and by using common sense instead of theoretical models. However, over simplification and flattening of bill of materials should be avoided because over-simple design may not be expressive enough. Systems are made visible with models by separating relevant attributes of an entity from the irrelevant ones. A model is a representation of reality that has a purpose and perspective. Therefore, a model must share some properties of the reality being modelled, i.e. the subject. If all the properties of the subject would be shared with the model, it would be indistinguishable from the subject. (Veryard 1986; Ptak & Smith 2016: 23-32).

2.2.7   An overview of characteristics of relevant information

Based on the review of concepts related to relevant information for decision making, it can be concluded that the key characteristics of relevant information for decision making are as follows.

- Predictability – they are linked to future outcomes.
- Measurability – they provide objective and reliable results of measurements.
- Actionability – they locate the areas where to focus efforts.
- Timeliness – they provide valid assumptions on correct ranges of time.
- Presentability – they can be interpreted throughout the system.

The table below distinguishes the characteristics of relevant information for decision making with key literature explanations and corresponding sources on each one. These characteristics, explanations and sources have been incorporated within the literature review of this chapter.

Table 1. Overview of characteristics of relevant information based on literature review.

Chractersitic	Literature explanation	Source
Predictability • Is the information linked to future outcomes?	Information that helps to predict problems.	Material Handling & Logistics (2011)
	Information that provides visibility to expected potential future outcomes.	Orlowski et al. (2015)
	Causal relationship of the result of the information and business outcomes.	Badaway et al. (2016)
Measurability • Does it provide objective and reliable results of measurement?	Information that does not require extensive front end work prior to usage.	Material Handling & Logistics (2011)
	Information with reliable and objective measurability.	Sinelnikov et al. (2015)
	Information that is in the context of the correct process.	Gaupner et al. (2015)
Timely • Does it provide valid assumtions on correct ranges of time?	Analysing and usage of information within appropriate ranges of time.	Material Handling & Logistics (2011)
	Continuously provided information to improve performance.	Aguinis (2011)
	Assumptions based on information that is provided on correct ranges of time.	Smith (2016)
Actionability • Does it indicate where and how to locate efforts?	Information provides course on where to focus efforts.	Badaway et al. (2016)
	Information with control over the allocation of actions.	Casas-Arce et al. (2011)
	Information that indicates what is to be achieved and how on an employee level.	Aguinis (2011)
Presentability • Can it be interpreted throughout the organization?	Information that is interpretable and applicable throughout organizations.	Sinelnikov et al. (2015)
	Visibility to estimated values in order to focus on relevant attributes.	Casas-Arce et al. (2011)
	Information that shares relevant properties of the reality that is modelled.	Ptak & Smith (2016)

2.3 Relevant information in flow based operating models

The interdependence of the components within a system defines the level of cooperation and communication needed between them. Knowledge and visibility of interrelationships between the sub processes is required to manage an entire system. (Lazko & Saunders

1995: 35.) Components of a system must be understood by the whole organization and they must contribute to *"the aim, values and beliefs of the organization"* (Lazko & Saunders 1995: 35).

> *"The performance of any component is to be judged in terms of its contribution to the aim of the system, not for its individual production or profit, nor for any other competitive measures"* (Lazko & Saunders 1995: 35).

The next chapter on limited visibility further explains the importance of systems thinking and the erosive effect of suboptimization.

2.3.1 System flow

An efficient manufacturing and distributing system promotes and protects flow. System flow is the rate at which a system generates products or services. flow is the rate at which the system converts material to products. Decisions and behaviours that block or impede flow compromise ROI and system efficiency. There are three key principles that emerge when the importance of flow is understood company wide. These principles illuminate the fact that *"a company's ability to better manage time and flow from a systemic perspective will determine its success in relation to ROI"* (Smith & Smith 2013b).

1. Time is the most significant constraint.

Without focusing on the time it takes to move through the system, a risk for misusing it arises.

2. The definition and understanding of the system.

In order to determine the capabilities of the system on maximizing flow, there should be specific definitions on how information and materials should flow within the system.

3. The systems linkages and connection points must be smooth.

Flow, cycle time and working capital investments are all heavily affected by the friction between the system points. (Smith & Smith 2013b.)

2.3.2 Actual demand pull

Moving information and materials quickly through a system will not alone create success. Flow of information and materials must be relevant. Relevancy of information and

materials is determined by the required output of the system, the actual demand. (Ptak & Smith 2016: 18.) There are two main categories for production systems: *push system and pull system.* In a push system, work is released according to a predetermined schedule of the predicted demand and when there is an availability for further processing. The push system can show errors in forecasting demand, resulting in excess WIP inventory, utilization problems and problems with meeting the actual market demand. In a pull system, the release of work is triggered when work that is ready or unfinished inventories are withdrawn and replenishments can be made. (Prakash & Feng 2011.) Working with a pull system aligns the flow of information and materials to the required output of the system. A pull system that is triggered by actual customer demand while maintaining minimum queue within the system works according to *demand driven flow.* Demand driven companies use *"build to order"* strategy instead of *"build to forecast"* strategy. (Mendes, Leal & Thomé 2016.)

2.3.3   Protection and promotion of flow

In order to maximize ROI in flow based operating models, all work is required to be synchronized according to *system flow and actual market customer expectation – the demand pull*, which is the required output of the system. This protection and promotion of system flow according to actual market demand requires management of variability on a system level. (Smith & Smith 2013b.)

Improved flow of relevant information and materials results from less variability (Ptak & Smith 2016: 17). *"Variability at a local [process] level in and of itself does not kill system flow. What kills system flow is the accumulation and amplification of variability"* (Smith & Smith 2013b). Methods to reduce and control variability are further explained later on in this thesis.

A system that generates and uses visibility secures system flow by breaking variation and damping its effects. Working according to required output of the system (market demand pull) with good system flow will result in on time deliveries, short lead times and minimum invested capital. (Smith & Smith 2013b.) In flow based operating models

relevant information for decision making should address *system flow*, *demand pull* and *variability*. The following table represents the focus areas of relevant information in flow based operations.

Table 2. The focus areas of relevant information for decision making in flow based operations.

Focus area	Literature explanation	Source
System Flow	Subsystems must contribute to aim, values and beliefs of the system.	Lazko et al. (1995)
	Flow from a systemic perspective will determine the success of a company.	Smith & Smith (2013)
	System must be well defined and understood with smooth linkages.	Smith & Smith (2013)
Demand Driven Flow	A pull system that is initiated by actual customer demand, ie. the required output.	Mendes et al. (2016)
	Work release is initiated by dinished goods or WIP inventories.	Prakash & Feng (2011)
	Maintain minimum queue between individual operations.	Prakash & Feng (2011)
Variability	Improved flow results from less variability.	Ptak & Smith (2016)
	Protection and promotion of system flow requires management of variability.	Smith & Smith (2013)
	The amount of variability that is passed on determines the performance of the system.	Smith & Smith (2013)

2.3.4 The framework of relevant information for decision making

Based on the literature review on the ideal characteristics of relevant information and relevant information should address in the context of flow based operations, the following framework is generated. This framework provides the basis of the conceptual framework of the research. This framework illustrates what needs to be taken into account when generating visibility in flow based operating models. Firstly, the characteristics of relevant information need to be addressed in order to assure that the information that is generated is correct. Secondly, for visibility to exist in the context of flow based operating models, system flow, demand driven flow and variability must be addressed.
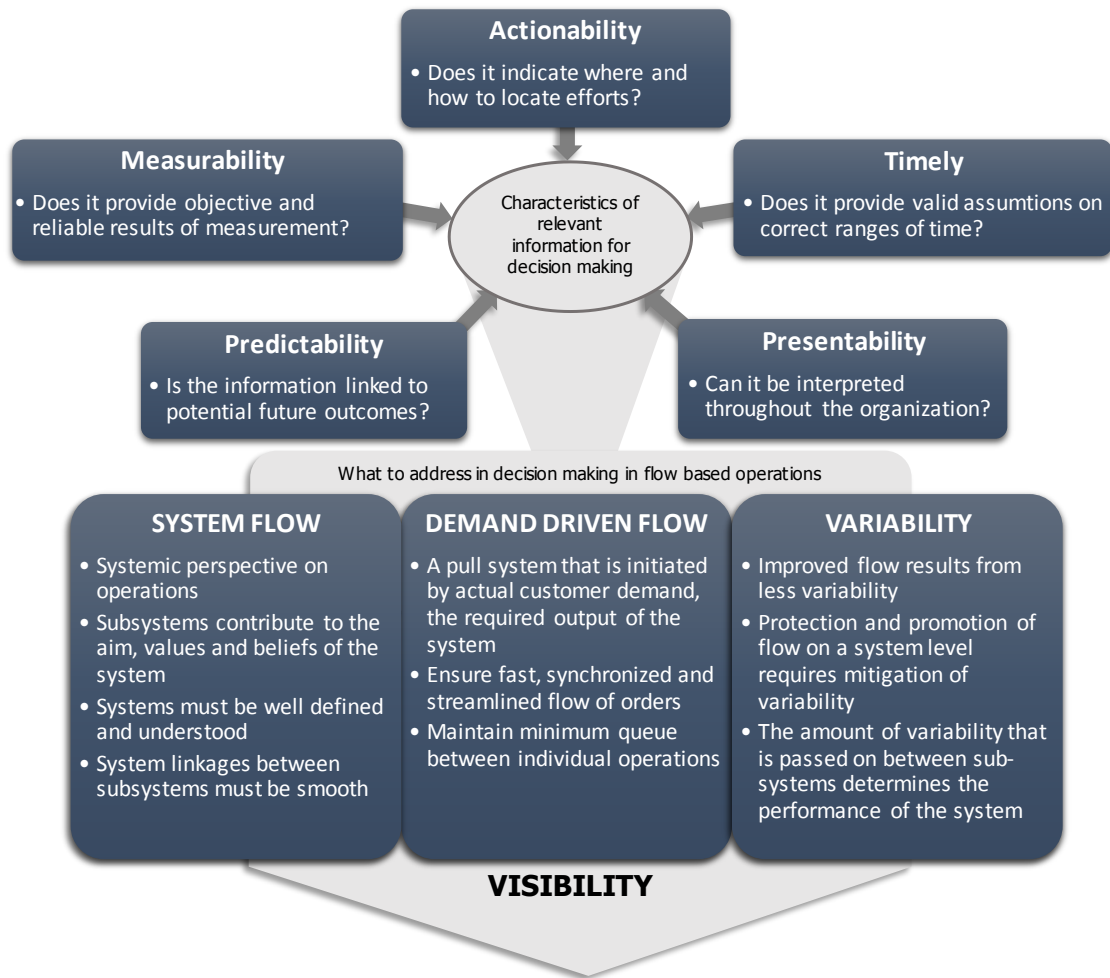
Figure 6. The framework for relevant information for decision making in flow based operations.

3. LIMITED VISIBILITY IN FLOW BASED OPERATIONS

"A system is a series of functions or activities within an organization" (Latzko & Saunders 1995: 35). It includes components that are interdependent and required, but alone insufficient, for accomplishing the goals of the system. (Latzko & Saunders 1995: 35.) A system is more than just a collection of its parts. In systems thinking, inferences are made based on the understanding of underlying structures. (Arnold & Wade 2015.)*"Systems thinking is, literally, a system of thinking about systems"*(Arnold & Wade 2015).

An alternative to visible system is a less reliable *"black box"* system that encapsulates information and raises suspicion, dislike and distrust due to the difficulty to check whether it is working or not. Therefore, systems should not only work. The intentions, workings and structure of any system should also be seen to work. Systems of all kinds are evaluated, selected, designed and improved by interdependent criteria such as effectiveness, efficiency, reliability, stability and measurability. Visibility ranks alongside these system criteria. (Veryard 1986.)

3.1 Sub-optimization and limited visibility

Optimization of single component or department often results in system sub-optimization. Sub-optimization is costly because it excludes the effect of one component or department on other stages of production. Businesses generally have a high degree of interdependency. Activities of each component should be coordinated to contribute to the aim of the entire system. This is a challenging task for the management because incentives such as bonuses are often based on the performance of individual business units and different entities within an organization are ranked against each other. (Lazko & Saunders 1995: 35-36.)

Controlling an organization with inconsistent indication of performance creates functions with islands of data separate from each other. This results in friction, conflict and

communication difficulties between each function. These functions, or *"silos"*, cannot relate their actions to the flow of relevant information and material in the system. This is because actions are taken to meet primary objectives of each function, which creates conflicts between the metrics in use. These objectives can be aligned with the system goal of maximizing return on shareholder equity by encouraging, measuring and making flow of relevant information and materials properly visible. Flow should therefore be made *visible* and incorporated into the metrics in use to protect it. (Ptak & Smith 2016: 16-17; Charlton 2010.)

The challenge of building links between islands of data and disparate systems is due to lack of visibility and collaboration (Charlton 2010). Businesses processes can be implemented in multiple systems across organizational units. To create a unified end-to-end visibility of processes, there needs to be an ability to collect and integrate the right information from various internal and external sources. This enables effective processing of information. (Gaupner et al. 2015; Smith 2015.)

3.2   Cost centric strategy and limited visibility

Companies seek for accurate profitability information about their products, customers and markets to face the competition of globalized markets. This cost behaviour is driven by the need for understanding how costs are consumed by different activities and structures of products. (Novák & Popesko 2014.) According to Brierley (2013), cost calculations are used in decision making to support profit motives and to control costs. Accurate product costs are used to make decisions on, for example, make-or-buy situations, pricing, introduction, discontinuation and competition. Cost data is also used to analyse feasibility of current product mixes, usage of resources and decisions regarding reduction or expanding of capacities. (Brierley 2013.) Maximizing ROI by minimizing unit costs is often seen as the truth that dictates operational decision making and behaviour. This truth is the basis for the way information systems are often arranged to gather cost related and resource utilization measurements. A system working according to this truth cannot

provide relevant information in an appropriate period for decision making in flow based operating models. (Smith & Smith 2013a.)

According to Smith & Smith (2013a) cost related calculations are not expressive enough for decision making.

> *"The current rules that generate the cost and reporting information industry uses to judge performance and make strategic and tactical decisions simply don't reconcile well with what's required to drive ROI in today's market environment"* (Smith & Smith 2013a).

This is due to two principles.

1. The flow of materials and information form the basis of supply chains and manufacturing.
2. The complex non-linear nature of the flow of information and materials create variation that is a challenge for productivity and is hard to manage and limit. (Smith & Smith 2013a.)

Companies will not be able to focus on flow performance if relevant information for decision making is not generated and used (Smith & Smith 2013c). Measurements such as unit costs are not relevant for decision making in the context of flow based operations. The policies, rules, measures and tactics used when working according to cost-centric measures are in direct conflict with the first law of manufacturing. They do not provide relevant information for decision making in flow based operations in a valid ranges of time. (Smith & Smith 2013c.) The following tables illustrate the significant differences of working according to system flow and working according to unit-cost focused measurement.

Table 3. Comparison of cost- and flow-centric strategies (Smith & Smith 2013c).

	Cost Centric Strategy	Flow Centric Strategy
Goal of the Strategy	Increased ROI through unit cost reductions.	Increased ROI through protection and increase of flow of relevant information and materials.
Key characteristics	Resource efficiency and utilization. Minimizing unit costs by planning and scheduling of resources.	System flow that is aligned with market pull.
In practice	Focus on (eg.) labour savings, machine utilization and inventory reductions to reduce costs and increase ROI.	Focus on synchronizing demand and supply signals between critical points to protect and promote flow.
Objectives of metrics	Gross profit margins for products Standard costs on products Working capital efficiency Cost reduction initiatives Targeted resource cost efficiency	Reliability - Execution consistency Stability - Variation in system Speed - Time through system / pass the right work on as quickly as possible Improvement - Point out and prioritize opportunities Strategic contribution – Maximize Throughput Operating expense – What is the minimum amount that captures opportunities?

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Table 4. Conflicts of tactics and actions of cost- and flow-centric strategies (Smith & Smith 2013c).

	Cost Centric Strategy	Flow Centric Strategy
Machine and labour efficiency	Resource efficiency by larger batches, longer forecasts and by optimizing resources.	System efficiency by protecting limited resources and reducing batch sizes.
Budget performance protection	Focus on achieving standard unit costs.	Focus on achieving flow to the market.
Margin	Focus on achieving lower unit costs of products.	Focus on improving service for the customer and utilizing constrained resources.
Inventory	Minimal inventories, overall reductions, low cost purchasing and discounts through bigger volumes.	Strategic stock positioning with purchasing based on quality, reliability and lead time.
Volume	More volume through price reductions and minimum order quantities.	More volume through better service, shorter lead times and lower minimum order quantities.
Margins	Actions focused on lowering unit costs.	Actions focused on increasing throughput.
Improvement	Focus on achieving and identifying unit cost reductions by increasing resource efficiency.	Focus on shorter lead times and lower buffer investments by identifying variation sources.

3.3   Other sources of limited visibility

According to Hendrix (2002), there are unifying characteristics in the measurement problems of product and service companies that lead to limited visibility. *"Visibility is determined by the measurement system and practices of an organization – what gets noticed, captured, analysed and acted on"* (Hendrix 2002). Leading organizations recognize and understand current and possible future situations in their area of business by utilizing relevant information for decision making. (Hendrix 2002.)

Table 5. Measurement problems that lead to limited visibility (Hendrix 2002).

Problem	Description
Unused information	Despite the use of analytical techniques and data warehouses, significant information is missed because the original data is aggregated and discarded.
Organizational silos	Measurements do not flow freely within or across organizations due to silos of information.
Disconnected measures	Measures are captured at different times and for different purposes without establishing cause and effect with one another.
Latency	The time it takes to detect an occurrence, measure it, report it and response to it is too long due to lags and delays.
Lagging indicators	Lagging indicators make it challenging to identify and adjust to changes in demand and force executives to manage *"through the rear view mirror."* Lagging indicators are used because of latency.
Indiscriminant measurement	Ignoring the fact that some information may be more relevant and useful than others.
Scorecard mentality	Unreasoned emphasis on scorecards leads to behaviours such as gaming and hoarding that distort measurement and reduce visibility.
Problems with analyzing information	Distorted interpretation of data that leads to difficulties in recognizing, accepting and responding to changes in a market.

Despite limited visibility, companies might still succeed and prosper. The importance of visibility is crucial in less favourable times and in turbulent conditions when vulnerabilities are exposed. This is a similar situation as when receding tide reveals rocks beneath the surface. To maintain and improve visibility even in less favourable and turbulent environments, organizations are enhancing their ways of working with measurements and extending their expertise to adapt more effective metrics. (Hendrix 2002.) This is accomplished in ways described in the following table.

Table 6. Suggestions on how to achieve better visibility (Hendrix 2002).

Suggestion	Description
Capture information	Capturing and leveraging insights generally lost. This requires a disciplined and structured recognition of sources of relevant information to avoid information overload.
Measure real time	Capturing, dissemination and measurement of sources of relevant information in a way that enables real time monitoring of performance, problems and opportunities.
Align measures	Alignment of internal metrics with external customer outcomes. This provides the foundation for target setting, performance tracking and better results.
Open collaboration	Visibility improvement through close cooperation with the stakeholders of the company.
Co-opt customers	Usage of innovative methods and tools to encourage customers to provide better understanding of their preferences, behaviours and other key information.
Leverage technology	Usage of technology to detect, measure, and response to events and developments. For example, sensors can be useful in capturing information previously unavailable and caputre unused information described earlier.
Tune in to informative sources	Relevant information gained by paying close attention and focusing measurement efforts to lead users, demanding customers and other informative sources.
Calibrate cause and effect	Measurement of the effectiveness of suggestions described above.

4. VISUAL REPRESENTATION OF RELEVANT INFORMATION

Visibility means focusing on not only on how the systems work but also on how the visual representation works (Veryard 1986). Visual representation of relevant information can reduce biases in decision making and judgements as well as help in facilitating the processing of statistical information. This is because good visual representations are concrete, and therefore easy to understand. (Gamliel & Kreiner 2013.) Visual representation can help displaying complex relationships in a way that allows easier comprehension of complex phenomena as well as relatively quick pattern recognition. (Geraldi & Arlt 2015: 17).

4.1 Visual Management

Visual Management is the usage of cognitively effective visual tools to filter quality information from the environment in a way that it flows for people to carry out day-to-day work transactions (Tezel, Koskela & Tzortzopoulos 2009b). *"Visual Management is a highly practical and intuitive solution for different operational and managerial problems"* (Tezel et al. 2009b). Visual Management is the usage of cognitively effective visual tools to filter quality information from the environment in a way that it flows for people to carry out day-to-day work transactions. Visual Management aims at improving performance through alignment of critical organizational visions, values, culture, processes, elements and stakeholders. It attempts to manage project and people with visual clues. Visual Management takes place in visual workplaces, where visual devices are used to communicate with the people. It strives for a workplace that is "*self-explanatory, self-ordering, self-regulating and self-improving*" (Tezel et al. 2009b). Ideally, the elements of visual management allow people can withdraw information that aids decision making simply by looking around. (Tezel et al. 2009b.)

"Visual Management is a highly practical approach with numerous visual solutions for different management practices" (Tezel et al. 2009b). Many terms are used to describe the concept of visual management. The terms used to describe the same conceptual

content include "*visual workplace, visual control, visual factory, shop floor management, visual tools and visual communication*" (Tezel et al 2009b). The following table represents the other functions of visual management. Transparency is *"the ability of a production process (or its parts) to communicate with people"* (Tezel et al 2009b).

Table 7. The functions of visual management (Tezel et al. 2009b).

Function	Definition	Alternative practice
Transparency	How well a production process can communicate with people.	Information in people's minds not available for all.
Discipline	Maintaining correct procedures.	Warnings, punishments, dismisses etc.
Continuous Improvement	Focused and sustained improvements throughout the organization.	Static organizations or improvement leaps through big investments.
Job Facilitation	Offering visual aids that ease efforts on routine. tasks	Expecting people to perform well without support.
On-the-job training	Learning from experiences and learning from working.	Basic training or no training at all.
Creating Shared Ownership	Ownership of actions and being tied to the focus area.	Change, vision and culture dictated by management.
Management by facts	Statistics and data that are based on facts.	Usage of subjective judgement of vague terms in management.
Simplification	Continuous efforts on providing people with system information.	Expecting people to monitor and understand by themselves.
Unification	Removing boundaries and creating empathy through information sharing.	"This is not my job" - behavior or fragmentation.

4.2 Choosing relevant visual representations

Despite the importance of visuals for managing projects, programs and portfolios, researchers and managers have paid only little attention to the subject. (Geraldi 2015: 7.)

"Visuals [i.e. visual representation] are an opportunity to think sharper, quicker and clearer" (Geraldi 2015: 7). It is essential for relevant information to be routed for the people in the organization. Routinely distributed relevant process information in a consistent and comprehensible format enables fast analysis of the information by the receiver and reduces equivocality. For example, alerts directed to the users of the information help to emphasize time criticality of the shared information. Dashboards, web-portals and mobile applications support distribution of the information. (Gaupner et al. 2015.) *"The point of enhancing visibility is to improve the relationship between systems and people"* (Veryard 1986).

The term *visual literacy* describes three interdependent areas of visual messages: the usage, the design and the user of the messages. Visual literacy aims to developing a critical and informed way of *"reading"* visual representations similarly as text. In order for visual representation to be an effective aid on communication and cognition between the three independent areas of visual literacy, it must be interactive, purposeful, truthful, efficient and aesthetic. (Geraldi & Alt 2015: 36-37.)

Table 8. The principles of designing visual representations (Geraldi & Alt 2015: 114).

Principle	Definition
Interactive	Data and parameters can be organized within established structure.
Purposeful	Addresses relevant perspectives of a problem.
Truthful	Data used is relevant and presented accurately.
Efficient	Mindful display of information that enables rapid and accurate interpretation.
Aesthetic	Harmonious, professional and beautiful representation of information.

4.3   Decision making and visual representation

Visual representation is often conducted with a two dimensional device, such as paper, wall or a computer screen. Despite the common usage of two dimensional devices, visuals

can represent the relationship between three dimensions, for example by animating the development of relevant information gathered. In verbal representation, the meaning is unfolded sequentially and linearly while visual representation can transmit the information instantly. Problem solving, decision making, memory and learning are all enhanced by visual representation. (Geraldi & Arlt 2015: 15, 17.) Relevant information for decision making is ideally visually represented according to the principles of visuals and functions of visual management.

Dashboards, web-portals and mobile applications support distribution of relevant information. (Gaupner et al. 2015.) *"The best information will be wasted if it is not routed to the people in the organization who need to perform their jobs"* (Gaupner et al. 2015). Decision making and recognition of trends can be aided by graphically representing relevant information with dashboards. Dashboards help decision makers to represent progress, compare alternative approaches, weigh risks and evaluate potential future outcomes. An example of effective use of dashboards is a visual depict of the level of readiness to exit a milestone or a gate where a decision must be made. Decision management process can be supported by establishing clear criterias for the arrival and exit in each decision gate or milestone. Visual representation of readiness provides decision makers with suggestions for decisions on whether to proceed with a program. The overall risk of moving forward to a next stage can be framed by using leading indicators when reviewing current situation. Therefore, relevant information for decision making combined with dashboards provide important leverage on risk assessment and cost confidence during the execution of a plan. (Orlowski et al. 2015.)

The following figure illustrates how decision making based on visual representations and visual management are a part of the basis of the conceptual framework presented earlier in this thesis. This visualization illustrates the importance of visual representation and visual management for delivering the relevant information to the users. It also clearly separates visibility as a concept from visual representation and visual management. Without focusing on the way relevant information is delivered for the users within the system to make decisions, the power of relevant information is not fully utilized.
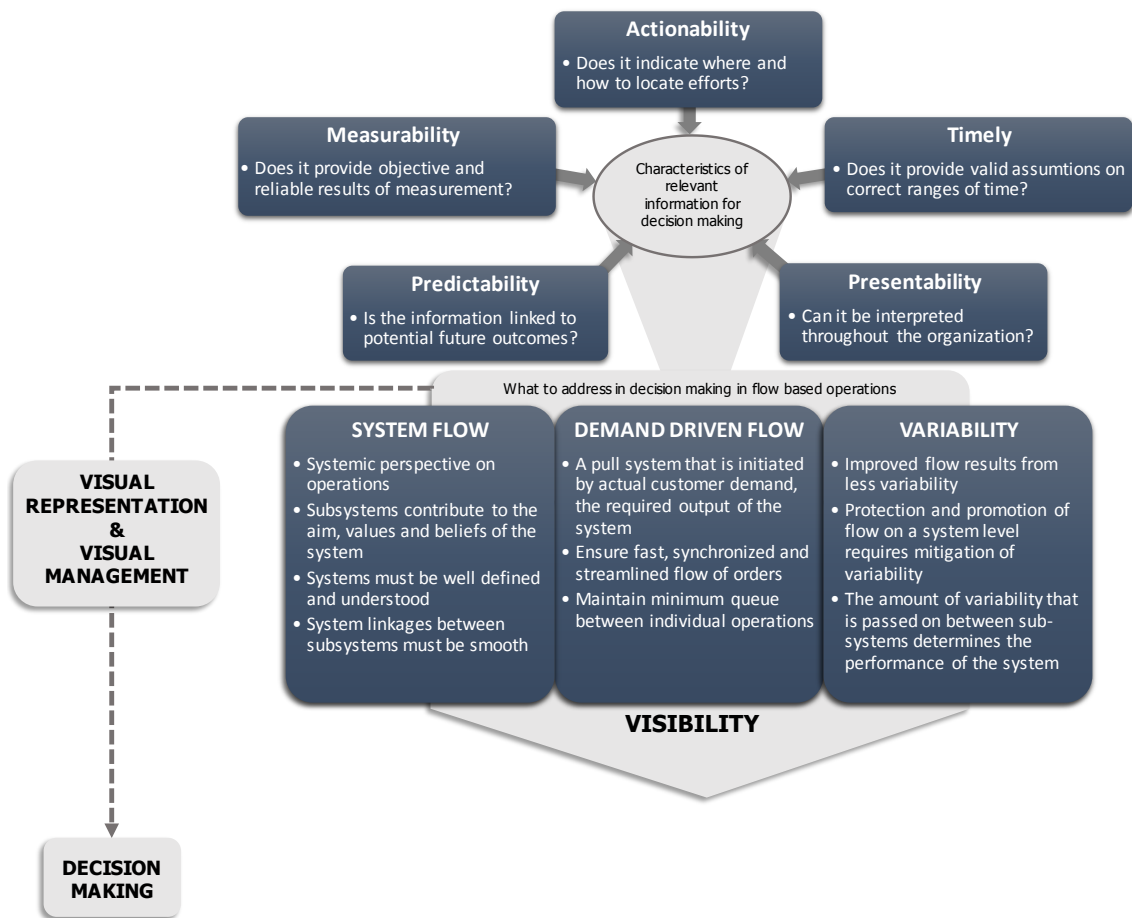
Figure 7. The framework for visual representation and relevant information for decision making.

4.4 Challenges in visibility and visual representation

According to Geraldi & Arlt (2015: 6-7) visual representation also poses a threat because it can bias decisions and encourage detrimental behaviours. It can also have a negative effect on communication and cognition through the following mistakes.

- Intensifying insignificant differences through inconsistent scales.
- Instilling false confidence by appearing professional.
- Encouraging unwarranted comparisons. (Geraldi & Arlt 2015: 6-7.)

"Visuals [visual representation] are enchantingly, and dangerously, convincing, and can yield legitimacy, professionalism, and exactness, which may not correspond to the nature of the data presented." (Geraldi & Arlt 2015: 9). Displaying abstract data, precise or not,

in an objective, concrete and precise way is persuasive and can blur the line between perception and reality. (Geraldi & Arlt 2015: 9).

According to Gamliel & Kreiner (2013), a picture is not always worth a thousand words. Some visual representations may be effective in attenuating the biases of the viewer while some visuals may be only as effective as a verbal presentation. The usefulness of a visual aid can depend on the words used in combination with the visuals as well as the on the tone that the subject is represented. Also, visual representation of only one side of a story (only the negative or the positive outcome of the same subject) may affect the effectiveness of the visual. (Gamliel & Kreiner 2013.)

Veryard (1986) describes the contradiction between visibility and concealment with an example of conjuror making something visible in order to make something else invisible. The phenomenon might occur always at some extent due to unconscious human control. Striving for as much visibility as possible somewhere might bring with it the loss of visibility elsewhere. Similarly to a photographer deciding on what is framed in a photo and what is left out, visual representation can distort reality by presenting only the favoured part of reality. Therefore, understanding the translation process of the objective represented is essential. Translation process describes how the objective of the visual representation was developed to an actual visual representation. (Geraldi & Arlt 2015: 15-16.)

Visibility alone is not enough because valuable information is hard to detect from the large amount of data managers face. According to Williams (et al. 2013), shortfalls in utilizing the visible information provided are the result of insufficient processing capability. These capabilities are the result of functional integration processes inside a company's organization. Barriers inside firms may arise when they are organized according to functions of the company, geographic locations or categories of products. These barriers restrain fast and effective information processing. Information sharing and collaboration between functions help overcoming these barriers. (Williams et al. 2013.)

In the context of supply chains, large amount of supply chain information is difficult to exploit within organizations. Information on supply chain operations is gathered among supply chain partners to manage the flows of information and materials across the businesses. These flows of information are shared through external linkages to reach relevant interconnected businesses. Several studies maintain that better access to information enables improvements in responsiveness, however the connection between the sharing of information and responsiveness is missing. Williams (et al 2013.) In these studies, researchers consider visibility as the *"visibility to greater access to high quality information describing various factors of demand and supply"* (Williams et al. 2013). In this context, visibility is seen as an outcome of the information sharing process between external integration partners within a supply chain. Therefore, studies on sharing of information and collaborative processes can be distinguished from studies of visibility. (Williams et al. 2013.)

5. VARIABILITY IN FLOW BASED OPERATING MODELS

This chapter investigates relevant literature on variability that is evident in the flow based operations of the case company. A formal definition for variability is *"the quality of non-uniformity of a class of entities"* (Hopp & Spearman 2011: 265). A simple and practical explanation of variability would be as follows: a group of individuals who have the same weight have no variability and a group of individuals of different weights is very variable. (Hopp & Spearman 2011: 265.)

Improved flow of relevant information and materials results from less variability (Ptak & Smith 2016: 17). Inversely, a change in ROI also follows the change in variation (Smith 2013). A change in variability is caused by a change in visibility. Variation experienced by an organization decreases when access to relevant information increases. Variation experienced by an organization increases when visibility is blocked or inhibited, or irrelevant information for decision making is generated. (Smith & Smith 2013c.) The following illustration represents the structure of this chapter.
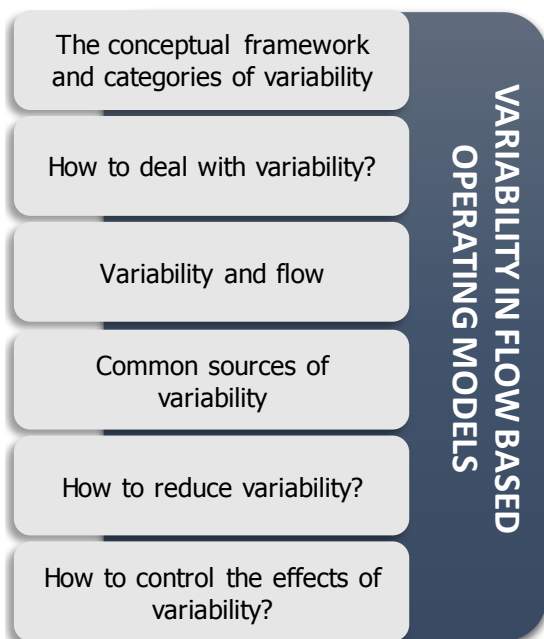
Figure 8. The structure of the literature review of variability.

5.1 The conceptual framework and categories of variability

Variation that occurs as a direct result of decisions is *controllable variation.* Differences in product descriptions and characteristics are examples of such variation. Batch processing also creates controllable variation in waiting times. This is because the first part of the batch that is finished will have to wait longer than the last part that finishes. Producing one at a time creates less variation by reducing the waiting times. Consequences of events not under immediate control create *random variation.* Unexpected contingencies such as customer demand or machine breakdowns are examples of random variation. (Hopp & Spearman 2011: 265.)

The roots of randomness can be divided into at least two types, which are true and apparent randomness. In apparent randomness, systems only seem to behave randomly *because of imperfect or incomplete information.* Improving information about the systems and processes will reduce randomness and variability. In true randomness, only statistical estimates of what will happen can be provided *because the universe actually behaves randomly.* Regardless of the type of the randomness, the effects are the same. The results of actions can never be guaranteed. (Hopp & Spearman 2011: 267.) This chapter further explains variability, its sources, how to deal with it and how to reduce it. The following figure illustrates the conceptual framework of this thesis. In addition to the characteristics of relevant information, focus areas of relevant information and visualization of relevant information, the categories of variation are added. Flow is also added to illustrate the importance of relevant information and variability to it. This conceptual framework illustrates the way that visibility (relevant information for decision making in flow based operating models) affects variability and flow. Working according to this framework will result in less controllable and random variation and therefore better flow and ultimately ROI.
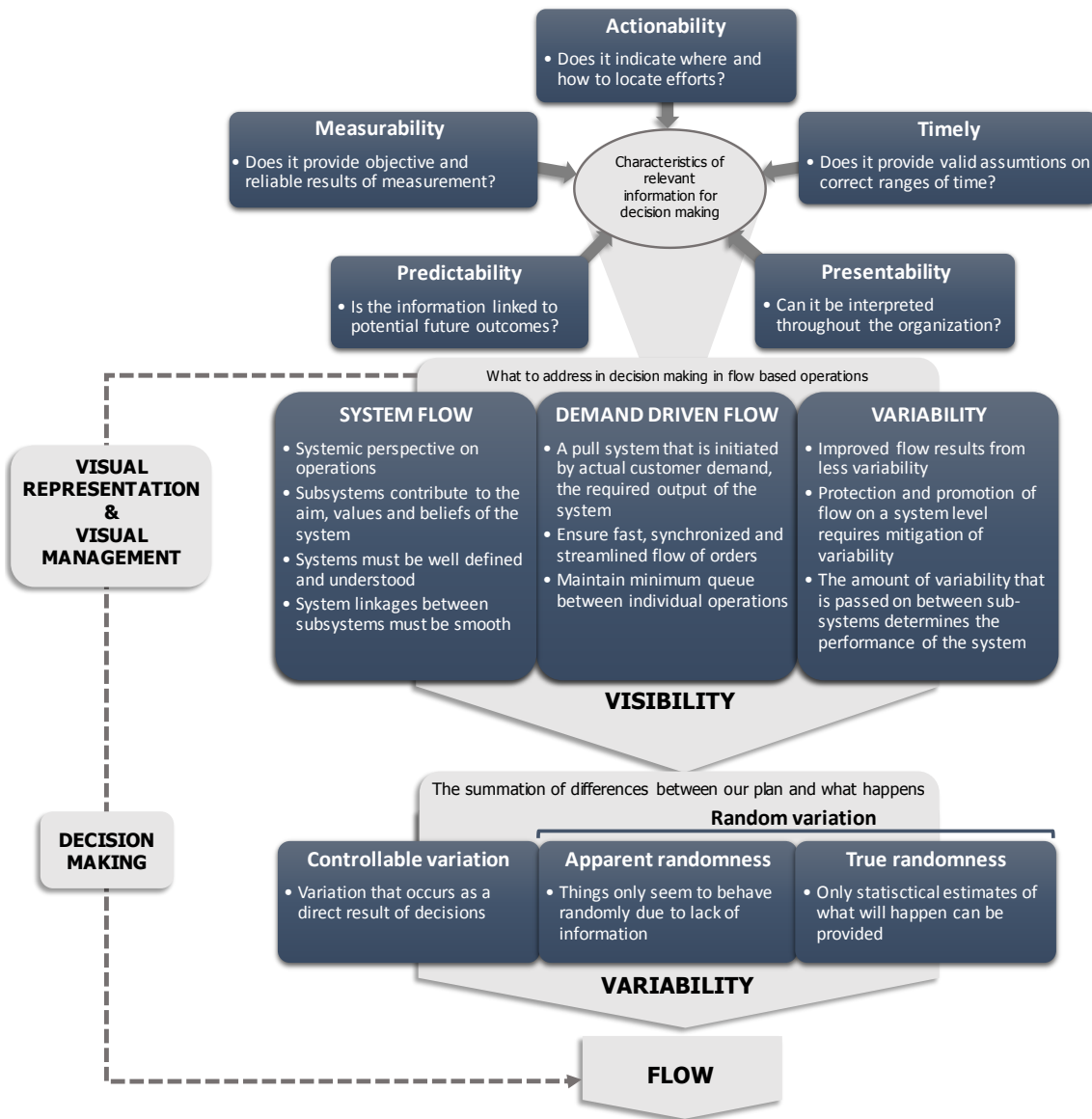
Figure 9. The conceptual framework of the thesis.

5.2 How to deal with variability?

Inherent level of variability is present in any environment (Ptak & Smith 2016: 30). With variation, the results of actions can never be fully guaranteed. There are two different approaches for companies to use when dealing with variability, robust policies and optimal policies. Due to uncertainty, robust policies are the preferable option.

As stated earlier, with variability, the result of actions can never be guaranteed. To address this uncertainty, an organization must have *robust policies* that work well most of the time. (Hopp & Spearman 2011: 266).

> *"The lesson that Shewhart brought to manufacturing from Physics, and Deming made known worldwide, is that trying to be more accurate than the noise does not improve things but makes them worse – the result will most certainly not be an improvement but a deterioration in due-date performance"* (Goldratt 2008).

When referring to *the* noise, Goldratt (2008) means all the possible parameters that affect the system in place. It is impossible to generate an algorithm that would account for every change of parameter in an environment of high variability. (Goldratt 2008.)

Using *optimal policies*, companies will perform extremely well for a set of conditions that the optimal policy is designed for but perform poorly for other situations. Organizations today often seek to optimize processes that are inherently random. (Hopp & Spearman 2011: 266-267.) These tools frequently result in poor tangible results and bad schedules because the actual inputs to the processes are random. (Hopp & Spearman 2011: 267.) In addition to trying to use optimal policies and failing to address randomness, companies can further reduce effectiveness and increase variability by working around the systems in ad hoc spreadsheets to *"massage the output of the expensive software"* (Hopp & Spearman 2011: 267).

5.3 Variability and flow

The amount of variability that is passed on between discrete areas of the system determines the productivity of the system. (Smith & Smith 2013a.) *"Variability at a local [process] level in and of itself does not kill system flow. What kills system flow is the accumulation and amplification of variability"* (Smith & Smith 2013a). This accumulation and amplification occur due to the manner of interaction or failure of interaction between different processes of the system. Possibly the most commonly known effect of variability being passed on between individual processes is the bullwhip effect. (Smith & Smith 2013a.)

"A system is a series of functions or activities within an organization" (Latzko & Saunders 1995: 35). It includes components that are interdependent and necessary, but alone not sufficient, for accomplishing the goals of the system. In order for managers to profoundly understand the interaction of systems and subsystems, knowledge of variation is needed. According to Lazko & Saunders (1995: 35, 39), this knowledge includes the following elements.

- Importance of a stable system.
- Special and common cause variation.
- Variation always exists.
- Difference between stable and capable system.
- Uncertainty in statistical data.
- Understanding the mistakes of addressing common cause variation as a special cause variation and addressing special cause variation as common cause variation.
- Procedures aimed at these mistakes.

5.3.1   Variability and stability

A process that demonstrates a degree of statistical control is stable. The opposite of a stable process is an unstable process (Wheeler & Chambers 1992: 117).

> *"If a process is out of control, it has failed to display a reasonable degree of consistency in the past. Therefore, it is logical to expect that it will spontaneously begin to do so in the future"* (Wheeler & Chambers 1992: 130).

The outcome of a stable process can be, at some degree, predicted. The predictable nature of a stable process is the essence of statistical control. The ability to predict the conformity of a future product is significantly limited in an unstable process. (Wheeler & Chambers 1992: 117, 130.)

The capability of a process depends on the conformity of the product and the stability of the process. When a process is out of control and produces nonconforming products, it is in a *"state of chaos"* (Wheeler & Chambers 1992: 4). *The ideal state* of a process is stable and capable. It produces conforming products with a stable process. A process that is in

control but produces some nonconforming products is stable but not capable. A process that is stable but is not capable is in a *threshold state.* (Wheeler & Chambers 1992: 120.)

System stability means passing on as little variation as possible between processes (Smith 2016). A stable process also displays statistical control. In a stable system, inputs to the system must not be greater than or equivalent to its capacity in a long run. Capacity should be strictly greater than the rate of arrival to the system. If not, the levels of WIP will grow and never stabilize. Activities that increase capacity, such as subcontracting, extra shifts, overtime and rejection of new orders should be planned as a part of strategy rather than as a key to tackle turbulent environment, otherwise there is a risk of running the system in a constant *"fire-fighting"* mode. In order to achieve a stable system, the release rates should be planned to be reduced. Otherwise the rates need to be reduced anyway due to an unstable system. (Hopp & Spearman 2011: 315-317.)

5.3.2   Flow variability

Reducing variability is essential for improving production systems because variability is the source of various problems in manufacturing. Examples of what variability causes include losses in throughput, congestion, large amounts of work in progress (WIP) and extended lead times. Variability in manufacturing system is distinguishable from the way it propagates in an amplified manner downstream the system, eventually causing flow variability. (Deif 2012.) In flow variability, variability is being passed on between workstations and individual processes, affecting the behaviour of other stations by means of other types of variability. If the way of releasing work to the system or the way of moving work between subsystems is incorrect, flow variability is created. It is created due to the way work is released to the system or moved between stations. Variability in a system is therefore the combined result of the selection of processes, the design of the systems, the ways to control quality and the decisions of the management. (Hopp & Spearman 2011: 277-278, 301-302.)

5.3.3   The Bullwhip Effect

Despite the phenomenon known as the Bullwhip Effect has been throughoughly covered in literature, only very little part of that coverage focuses specifically on the objective of protecting and promoting the flow of relevant information and material. Bullwhip effect is the systematic breakdown of information and materials in a supply chain. In bullwhip effect, a minor change downstream the supply generates an extreme change in the supply upstream. Serially communicated information and materials orders combined with transportation delays in the supply chain cause backordered inventory to become an excess inventory. This is known as the oscillation effect. The wavy arrow on the top represents the way information becomes more disconnected from the origin of the signal the farther the chain goes. This amplification is created due to nervousness combined with batching practices. The wavy arrow at the bottom describes the way delays accumulate the relevant material flow distortions. The delays are caused by chronic shortages and late shipments. Synchronizing the supply chain can eliminate bullwhip effect. (Ptak & Smith 2016: 18-19.)
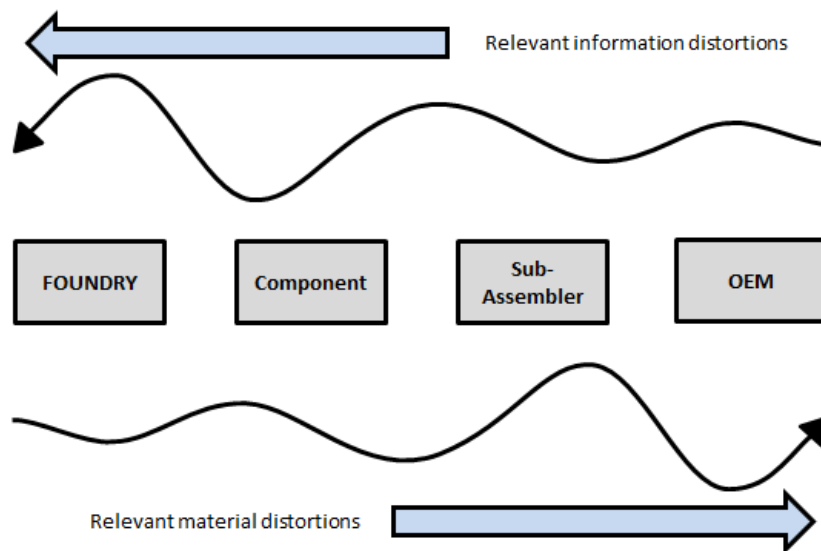
Figure 10. The Bullwhip Effect (Ptak & Smith 2016: 19).

5.4   Common sources of variability

In manufacturing environments, the most common sources of variability in local process level are:

- Natural variability
- Rework
- Random outages (Pre-emptive outage)
- Operator availability (Pre-emptive outage)
- Setups (Non-pre-emptive outage). (Hopp & Spearman 2011: 271, 277.)

Natural variability includes variability from sources that have not been predetermined such as different compositions of material that is being machined. Rework is a disruptive problem that means spending more time *getting the job right.* It has an erosive effect on capacity and it significantly effects the variability of process times. Rest of the sources of variability can be divided into pre-emptive outages and non-pre-emptive outages. Pre-emptive outages are breakdowns such as power outages, unavailable operators due to firefighting or emergencies, and running out of something to work on in the constraint. These force the progress of jobs or work to stop. Non-pre-emptive outages occur inevitably but they can be controlled to some extent. For example, when a tool starts to become dull or a machine is in the need of a replacement or a service, the current work can be finished without a forced stoppage. The most common cause for non-pre-emptive outages is machine setups. (Hopp & Spearman 2011: 271-277.) Despite the sources of variability in individual processes are addressed in this thesis, it should be taken into account that variability on systems level has the most erosive effect on the productivity of systems.

5.4.1   Batching and variability

Batch processing is often assumed as a normal business practice even though it is "*a particularly dramatic cause of variability*" (Hopp & Spearman 319). It results in long lead-times and piles of work moving downstream to next phases of the process. Reducing batch sizes enables work to flow with fewer interruptions. Despite there may be valid

reasons (root-causes) for batch processing, flow and reduced batch sizes focus a company's actions on better productivity, service and quality. Smaller batch sizes result in reduced lead-time and better flexibility. The appropriate batch size is developed according to the desired management time frame and necessary service levels. The smaller the size of the batch is, the better the lead-time and flexibility. (Keyte & Locher 2004: 73-74.) However, in practice, the trade-off of having small batch sizes is the increased amount of material handling. (Hopp & Spearman 319-320.)

Batch & Queue Processing

Process A		Process B		Process C
	1 day →		1 day →	

Lead time 2+ days

Flow Processing

Process A, B & C

Lead Time < 1 day
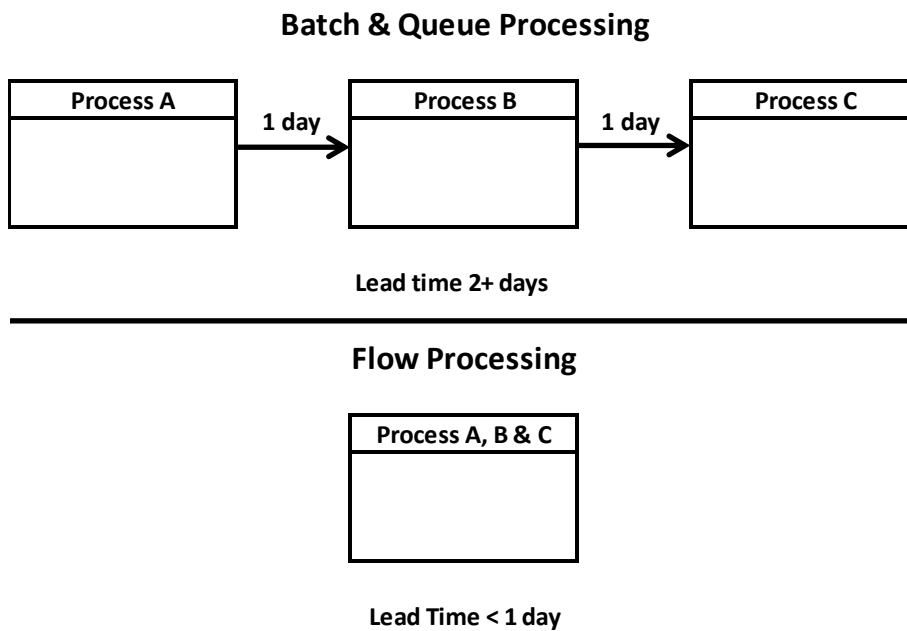
Figure 11. Batch- and Flow processing (Keyte & Locher 2004: 73.)

Traditional way of dealing with setup times is to increase batch sizes. The driver for bigger batch sizes is the increased amount of setup time when reducing batch sizes. When processing small batches, a work center is forced to repeatedly change the component it is working on. Each of these switches require a setup to be done. This may result in a situation where the actual time required for the setup is longer than the production time. To deal with this obstacle, techniques on reducing setups are required. Pioneered by Taiichi Ohno, the ideology on reducing batches has significantly affected the way Lean Manufacturing is strongly associated with small batch sizes and techniques on reducing setups. (Goldratt 2008.) Lean Manufacturing is commonly defined as *"a set a tools and techniques used for continuous improvement and seek the elimination of all types of waste in the production process"* (Cardon 2015).

By processing with batch sizes of one, the time required for a batch to form is as short as possible and no time is spent waiting for the queueing of large batches. In real world situations, striving for batch sizes of one is problematic because batch sizes affect capacity. Capacity can be increased and queueing reduced by increasing batch sizes. However, this increases also waiting times for starting and finishing batches. Small, efficient batch sizes can be achieved by focusing on reducing set-up times of sequential batching situations. The most efficient batch size of a simultaneous process depends on capacity and demand. It can be anything from one to the amount that can be fitted to the process. (Hopp & Spearman 320, 348.)

5.4.2   Variability and utilization

Utilization and variability are the two main drivers for queue time. *"If a station increases utilization without making any other changes, average WIP and cycle time will increase in a highly non-linear fashion"* (Hopp & Spearman 2011: 317). The effects of utilization to a system make it a challenging task to select a release date that is both efficient and enables short lead times. The amount that variability degrades performance depends on what is the source of the variability in the system. (Hopp & Spearman 2011: 317.) The efforts of reducing variability should be focused on the early phases of the line because *"variability early in a routing increases cycle time more than equivalent variability later in the routing"* (Hopp & Spearman 2011: 317). This applies especially to a system where the releases of work between subsystems are independent of completions, a push system. In a CONWIP (constant WIP) system, where completed work determines the release of work, the incentive of reducing variability as early as possible is of little significance. Variability at the fist station affects flow just as much as it does in the following stations. (Hopp & Spearman 2011: 317-318.)

The majority of total cycle time of an operation is spent waiting for resources. Actual process time often represents no more than fraction of the total cycle time of a plant. High utilization and high levels of variability contribute to long waiting times. Cycle times can be significantly reduced by increasing effective capacity (lowering the levels of

utilization) and reducing variability (congestion). Variability must be addressed when decreasing cycle times and WIP, otherwise throughput will decrease. Decreased throughput is the cost of reducing cycle times by limiting WIP if variability is not reduced. In other words, if WIP is decreased too much, there will not be anything to work on. Throughput can be ensured if variability reduced. Relevant information for decision making enables variability reductions through for example smoother production, layout improvements, control of flow, preventive ways of working and better quality. (Hopp & Spearman 2011: 282-283, 295,302.) In other words, *"we have to remove the rocks, not just lower the water"* (Hopp & Spearman 2011: 295).

5.5 How to reduce variability?

In operations management, variation reduction has been a central area for development through various different approached including for example lean (waste elimination), quality (continuous improvement) and scientific management (standardization). (Stratton 2008.)). Addressing and reducing variability is a key element of improving performance. In order to improve performance through variability reduction, the potential of reducing variability must be recognized and methods and tools must be developed. (Hopp & Spearman 2011: 309.) The following chapter represents common methods, tools and ways of working that could be considered to be implemented in the case company to reduce variability.

5.5.1 Common variability reduction methods

Cycle times can be reduced and throughput increased by adding capacity or reducing variability. Increasing capacity is easier to implement than variability reductions. However, variability reduction is the preferable option because it promotes an environment of continuous improvement mind-set, which in itself is a competitive advantage. Anyone can buy machinery but the ability of using it effectively cannot be bought. Also, the experiences of the variability reduction efforts can be utilized as a learning that is transferrable to other parts of the business as well. Variability reduction

requires that the sources of variability are identified and policies are modified and customized accordingly. (Hopp & Spearman 2011: 314.)

"Systems with good adaptive mechanisms continue to innovate. This is more a mechanism of exploration than exploitation" (Smith 2015). Fully optimizing a nonlinear system is impossible but it can be remodelled to continually learn and improve. To do so, occurrences should be captured and converted into a distribution or control charts with specified limits to recognize trends over time. The trends can be improved by converting opportunities into assigned actions and by tightening the specified limits of the model. (Smith 2015.)

A decrease in uniformity increases variability. For example, the more process times and inter arrival times are disparate, the more uniformity is decreased. Decrease in relevant information available causes randomness, which may be the reason for decreased uniformity. If the current variability is consistent with the variation expected or inherent to the system, the system is said to be in *control*. *Control charts* are commonly be used to follow up the range of fluctuations and controls by depicting target levels and control limits to measure the process and separate significant changes from natural variation. (Hopp & Spearman 2011: 308.) *"Control charts are the most common tools for determining whether a process is under statistical control" (*Madanhire & Mbohwa 2016). The following table represents other important Statistical Process Control (SPC) quality tools.

Table 9. Important SPC quality tools (Madanhire & Mbohwa 2016).

Tool	What it is used for
Check sheet	To count occurences or problems
Histogram	To identify tendencies and variations to one side or another
Pareto Chart	To identify the portions that yield issues
Cause and effect diagram	To identify assignable causes
Scatter diagram	To identify correlation and suggest causation
Graph	To visually display data

5.5.2   Statistical process control

"SPC (Statistical process control) is the application of statistical methods to monitoring and control of a process to ensure that it operates at its full potential to produce a conforming product" (Madanhire & Mbohwa 2016). SPC aids decision making by gathering and analysing data on processes. It adjusts the amount of relevant information required for making decisions by providing framework for visible involvement on business baselines and processes. SPC can be used for controlling inspections, testing, maintenance and improvement processes. Control charts, continuous improvement and design experiments are examples of essential tools for SPC. SPC enables detection and correction of variations that may affect the quality of products. When compared to quality inspection methods that focus on correcting problems after they occur, SPC has significant advantages. An out of control process generates an alarm directed to the owners of the process, thus enabling detection and elimination of the causes of the occurrence. A proactive approach such as this is effective for preventing the out of control variation of generating non-conformities in the items being produced. The following illustration presents required steps to generate a SPC implementation. (Madanhire & Mbohwa 2016.)
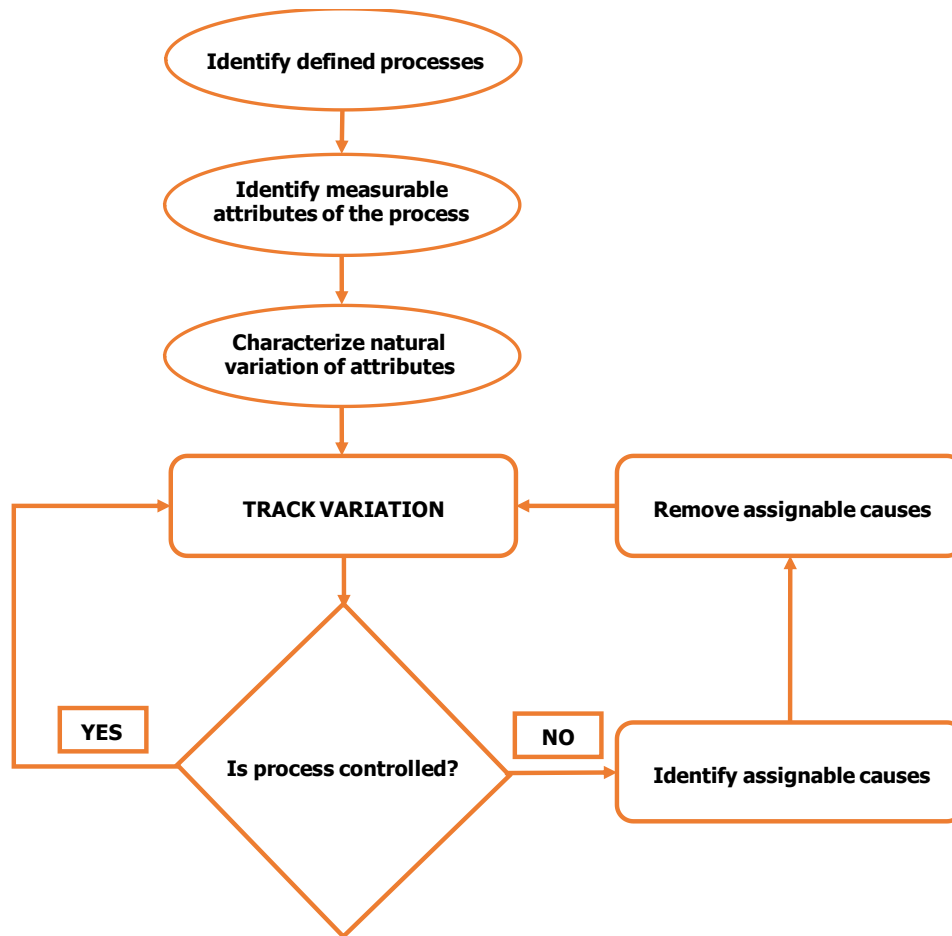
Figure 12. Steps to generate a SPC implementation (Madanhire & Mbohwa 2016).

An operating system can be analysed and plotted with a control chart called the Shewhart chart. A Shewhart chart can be used to illustrate whether a process is stable and under control. In this method, data is plotted with data points and upper and lower control limits (UCL & LCL) are computed to define the limits of common cause variation. Special or assignable cause variation is said to occur in the process when atleast one of the data is out of the control limits. When managing operations, it is essential to understand the difference between these two. Reaction to variation inside the control limits is *tampering*. Special cause variation must be investigated to find the source of the variation, take corrective actions and prevent it from happening again. Common cause variation is inherent in processes. It can be predicted and it will recur unless a fundamental change in the process is made. Addressing common cause variation as special cause variation only makes things worse. (Lazko & Saunders 1995: 39, 148, 151.)
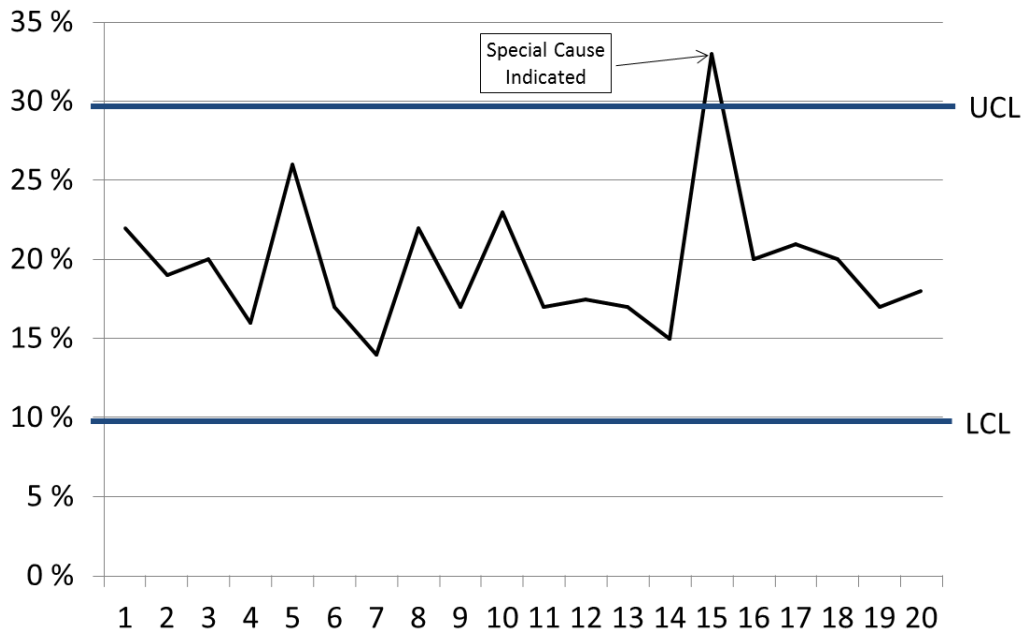
Figure 13. Shewhart Chart (Lazko & Saunders 1995: 39).

5.5.3   Value Stream Mapping

A powerful way of making systems, sub-systems and the inter-relationships between them visible is Value Stream Mapping. This is also evident in the case research of this thesis, as all of the three cases have, at some point of their journey, implemented VSM to better understand their operations and reduce waste. Value stream mapping is a practice used to eliminate waste and optimize end-to-end processes. In practice, a VSM is a visual representation of the end-to-end flow of activities from the initial customer contact to the delivery. It helps on identifying bottlenecks of a process that block flow by mainly focusing on time through the system, waste in the system and value generated in the system. It enables reductions in times through the system, set up times and inventory levels. VSM also generates a unified understanding and alignment of vocabulary among the organization. VSM is often considered as the basis of improvement actions. (Khurum, Petersen & Gorschek 2014.)

5.6 How to control the effects of variability?

The need for buffering has been shown to be driven by variation. Buffering choises then reflect on performance trade-offs. In short, increased variability drives the need for buffering and reduced variability enables smaller investment in buffers. (Stratton 2008.) This chapter explains some of the most common methods of dealing with the effects of variability. These tools, methods and ways of working are presented because they are also evident in the case study.

5.6.1 Variability buffering

"*Increasing variability always degrades the performance of a production system*" (Hopp & Spearman 2011: 309). Flexibility reduces the need for variability buffering. Variability buffers arise as a consequence of variability. (Hopp & Spearman 2011: 309, 313.) "*Variability of a production system will be buffered by some combination of:*

1. *Inventory*
2. *Capacity*
3. *Time*" (Hopp & Spearman 2011: 309).

This implies that there is a choice to be made on *how* variability degrades system performance. The strategies on how to cope with variability should depend on business environment. Failing to invest in reducing variability will generate losses in throughput, losses in capacity, larger inventories and inflated lead times as well as reduced customer service. (Hopp & Spearman 2011: 309, 311.)

In flow based operating models, relevant information for decision making is ideally provided by *visible and real-time inventory, capacity and time buffer status information.* These sources of information can align priorities and corrective actions towards protection and promotion of flow. Visual representation of these buffers also enables reporting and analysing of deviations from plan. Prioritization of resources and execution are based on the status of the buffers against schedule. (Smith & Smith 2013c.)

5.6.2   Decoupling

The transfer and amplification of variability in the form of distortions to relevant information and materials in systems level lead to flow variability and on supply chains level to the bullwhip effect. Stopping or mitigating this variability is not an option since variability always exists. The only way to tackle these problems is to stop variation from being passed between the parts of the system or the supply chain. A concept known as *decoupling* accomplishes this by creating independence between supply and material usage. In decoupling, inventory is denoted between operations to prevent production rate fluctuations from constraining the production in total and the next operation. (Ptak & Smith 2016: 35-37.)

Decoupling is used to isolate events that cause variability in one entity from impacting other entities of a system. Therefore, decoupling mitigates variability. The locations where strategic buffers/stocks are placed to create independence are called *decoupling points*. Decoupling points determine lead-times and inventory investment. In conventional MRP's, only a limited amount of decoupling can occur due to the way they are designed with the intention of tightly coupling everything. These shortcomings can be eliminated and variability reduced by placing decoupling points within the visibility horizon. System flow is secured and bullwhip effect mitigated by decoupling. (Ptak & Smith 41.)
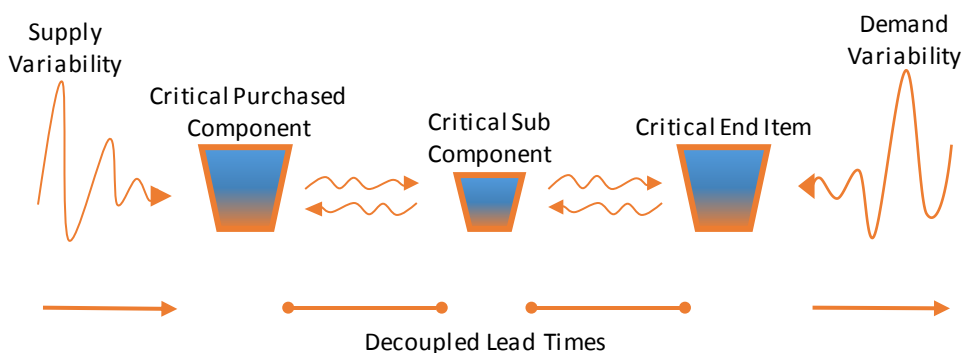
Figure 14. Illustration on decoupling points.

5.6.3   Control points

There might be circumstances where additional scheduling capabilities are needed. According to Ptak & Smith (2015: 247) these circumstances include the following.

- When shorter lead times, better variability control and smaller inventory at the stock position can be achieved with scheduling.
- When the usage of various resources that are shared among many items takes away the ability to decouple. In these situations, commitments to customer are more likely to get fulfilled with detailed scheduling.
- When capacity requirements are spread among different operations and detailed scheduling is needed to arrange the capacity between mixed operations.

The situations require scheduling that is based on *control points.* (Ptak & Smith 2015: 247). *"Control points do not decouple"* (Ptak & Smith 2015: 247). Control points are used to transfer and amplify control within a given area. Within that area, the amplification and transference of variability can be minimized. Control points are used to simplify the planning, scheduling and control functions through strategic positioning. There are various different kinds of control points, including operations with progress gates, decision points, different kinds of constraints and points of shipment. At these points, the planning and implementation of detailed schedules is monitored. (Ptak & Smith 2015: 247.)

5.6.4   Variability and flexibility

As described earlier, dealing with variability requires buffers of some kind. The effects of variability can also be mitigated to some extent with flexibility. *"Flexibility reduces the amount of variability buffering required in a production system"* (Hopp & Spearman 2011: 313). A buffer that is flexible is more likely to be available and can be used in more ways than a non-flexible buffer. An example of a flexible solution is cross-trained workforce or generic WIP (work in progress) held in systems with late product customization. Systems can be built with flexibility in mind by focusing on the design of products and facilities, equiptment, policies or management of vendors. Flexible models

are key for making diverse, customized products at mass-production costs. (Hopp & Spearman 2011: 313-314.)

5.6.5 Theory of Constraints

"TOC is a management philosophy which is focused on the weakest ring(s) in the chain to improve the performance of systems" (Simsit, Gunay & Vayvay 2014). TOC is used as a problem structuring and solving method to better understand the structure of the processes. TOC is put forth by E. Goldratt in his novel *The Goal* from 1984. In order for companies to make more money, the throughput of a system should be increased, while simultaneously minimizing the expenses and inventories. According to TOC, performance is determined by the throughput of the weakest link at the chain, called the constraint. The identification of the system and its weakest link, the constraint, and elimination of it is the idea behind TOC. The essence of TOC is to focus on continuously improving the system by identification and elimination of constraints. (Simsit et al. 2014.)

6. EMPIRICAL WORK

The following chapter highlights the research approach, research methodology, research process, case company business units, and results of the research. A conceptual framework was generated based on the review of relevant literature on the subject of visibility and variability in flow based operating models. The chapters 1-5 of this thesis addressed the first research question: *"how visibility and variability in flow based operations are understood in the relevant literature?"* Based on the findings of the literature review, a conceptual framework was generated. Figure 15 illustrates the structure and the process of the research.

6.1 Research approach & method selection

In this research, data is collected, analyzed and interpreted in order to understand a phenomenon in the case company. In the research process, objectives, data management and communication of findings are systematically defined in an accordance to established frameworks and guidelines. There are three common approached to conducting a research, qualitative research, quantitative research and mixed methods. Quantitative research is often conducted to answer research questions requiring numerical data. Qualitative research is commonly used to answer questions that require structural data. Mixed methods is the combination of quantitative and qualitative, it is used to answer research questions that require both numerical and structural data. (Williams 2007.)

This research is conducted as a qualitative research. *"Qualitative research is a holistic approach that involves discovery"* (Williams 2007). Qualitative research method was selected because it allows the researcher to be involved in the experiences of the interviewees. Also, qualitative research occurs in a natural setting, thus enabling high level of detail. When compared to quantitative research, qualitative research has stronger correlation between the observer and the data. (Williams 2007.) *"Qualitative method allows the researcher to explore and better understand the complexity of a phenomenon"* (Williams 2007). The research is carried out as a constructivist grounded theory. In

constructivism based theory, *"the researcher constructs theory as an outcome of their interpretation of the participants stories"* (Mills, Bonner & Francis 2006). This allows the research to realistically contribute to the existing relevant literature and the conceptual framework.

In the qualitative research of this thesis, interviews were used to collect data and to uncover the participant's experiences on the subject. *"An interview is a method of collecting data in which quantitative or qualitative questions can be asked"* (Doody & Noonan 2013). Unlike quantitative questions, qualitative questions are open-ended, giving the participants the option of responding in the way they see the best with their own words. (Doody & Noonan 2013).

The research interviews followed a semi-structured agenda in order to gather information on the research topic and further explore findings. In qualitative research, semi structured interviews are commonly used. The conceptual framework provided the structure and topics for the interviews. The flexible nature of semi-structured interviews encourage depth and vitality and allow exploration of issues that arise during the interviews. This was clearly favourable for the interviews of this research. This allowed the direction and atmosphere of the interview to determine the order and wording of the questions. (Doody & Noonan 2013.)

6.2   Data collection and research process

As stated earlier, the data of this research was gathered with a constructivists approach. The conceptual framework provided the guideline for the data collection. There were three techniques to acquire the data of the research. Firstly, the research involved the investigation of the characteristics of the relevant information in each embedded case unit. Secondly, the features (system flow, demand driven flow and variability) of relevant information in flow based operations in each embedded case unit was investigated. The investigation on visual management and visual representation was conducted by investigating the way relevant information was provided for the people in each

organization. Thirdly, the investigation on visual management and visual representation was conducted by investigating the way relevant information was provided for the people in each organization. The research on these distinct areas provided an overview of visibility in the case company, how it affects variability and how it could be further developed.
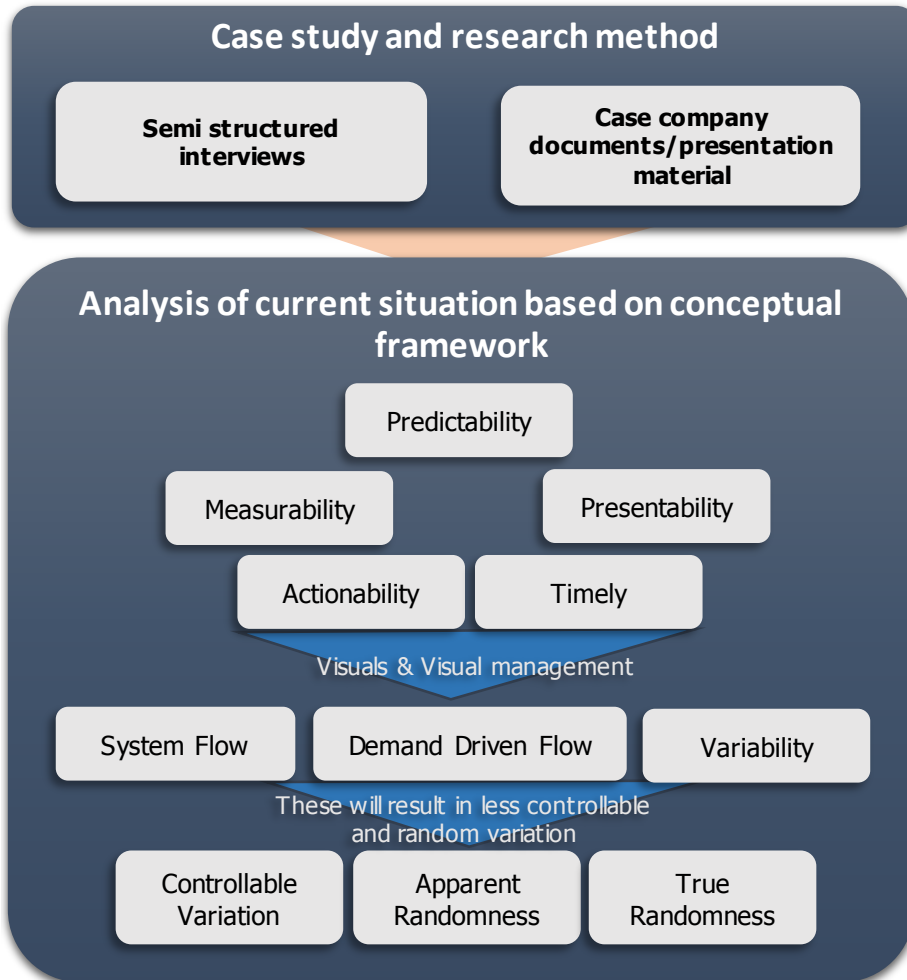
Figure 15. The research process.

6.2.1 Conducted interviews

The table below represents the roles of the interviewees of the cases. The interviews were started with an introduction to the subject. The interviews followed a semi-structured agenda, with the conceptual framework and scope of this thesis providing a guideline for the subjects. Interviewees were asked to introduce themselves and their role in the organization. The duration of the interviews varied from 20 to 45 minutes. The interviews

were recorded and an exact transcript was made of each interview. The framework figure represents the topics that were covered in the interviews. In the following chapters, the research of each case unit is presented and explained based on the findings of the interviews.

Table 10. Conducted interviews.

Case Unit	Role	Method
Case One	Managing Director	Virtual meeting
	General Manager, Production	Virtual meeting
Case Two	Value Stream Manager, BWMS & Compressors	Virtual meeting
	Buyer, BWMS & Compressors	Virtual meeting
Case Three	Director, Project Management	Face to face
	Director, Delivery Centre	Face to face

6.2.2 Other material used

In addition to the conducted interviews, some case company archived documents were used to support the empirical study as background information on the situation in each case. The documents have been originally used as presentation material by the business owners to report on their concerned initiatives. The documents used are from 2016 and 2017.

Table 11. Documents used.

Document name	Case unit	Date	Type of document
Production presentation	Case One	02/2016	Presentation
DDMRP overview	Case Two	01/2017	Presentation
Overview of improvement actions	Case Three	11/2016	Presentation
Performance management structure	Case Three	11/2016	Presentation

6.3   Research case introduction

The objective of the research is to conduct a descriptive single case study (with three embedded units) on the effects of visibility to variability in the flow based operating models of an industrial organization. *"A descriptive case study is used to describe an intervention or phenomenon and the real-life context in which it occurred"* (Baxter & Jack 2008). Single case study with embedded business units enables the comparison of the embedded units with each other and the larger system. In this method *"data can be analysed within the subunits separately (within case analysis), between the different subunits (between case analysis), or across all of the subunits (cross-case analysis)"* (Baxter & Jack 2008). Finally, the analysis is returned to address the initial, global issue. (Baxter & Jack 2008.)

The case company provides solutions for customers in marine, oil and gas industries. The case company's embedded business units that were a part of this research provide installations for customers in a variety of businesses, including cruise ships, ferries, fishing vessels, merchant, navy, offshore, ship design, special vessels and yachts. The strategy of the case company is to be a leader in efficiency, gas and dual fuel solutions and environmental solutions through offering:
- lifecycle solutions for ship owners and operators
- integrated solutions for the shipbuilding industry, owners and operators
- the best customer value and customer experience in marine industry.

6.3.1   Case selection

As stated in the motivation for the research of this thesis, the importance of flow was initially addressed during improvement activities in the business units of the case company. The case selection was done according to what business units had recently undergone flow improvement activities in their operations. These cases were most likely to have clear similarities and practical examples that can be reflected in the existing relevant literature on visibility and variability. This approach therefore provides relevant content for the conceptual framework also. This method of case selection is also

beneficial for the efficiency and effectiveness of the qualitative research because majority of the vocabulary used is already familiar for the people that were interviewed.

6.3.2   Case One introduction

The first case to be studied of the three embedded units of the company manufactures pumps mainly for marine industry. This embedded unit is responsible for end-to-end operations from research and development to aftersales and consists of the following independent sub-business lines: pumps, valves and gas solutions. These sub-business lines provide equipment and services to the marine, oil and gas and industrial markets. In the production facilities, there is a foundry, machine shop and an assembly line. The research of this thesis in the first case focuses on performance indication and visual management practices in pumps production, where flow is achieved by working according to the actual demand pull.

Case One
- Relevant information for decision making in production
- Flow of orders through production according to actual customer demand pull
- Visual and performance management practices
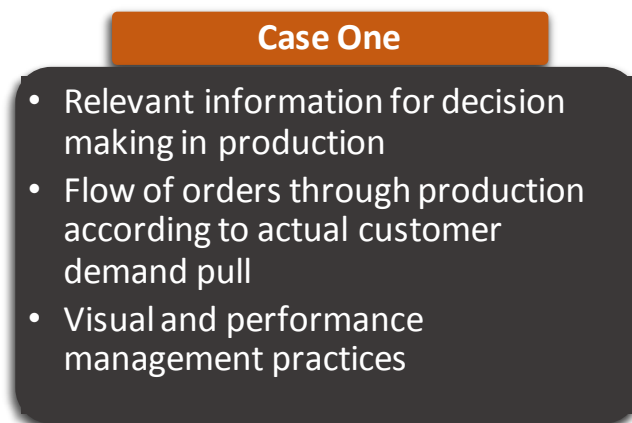
Figure 16. Research focus areas in Case One.

6.3.3 Case Two introduction

The second case to be studied of the three embedded units of the company manufactures ballast water management systems and compressors. Ballast water management systems (BWMS) are used in vessels that have a varying cargo situation from destination to destination. Ballast water is used to stabilize a partly empty ship and retain similar operating characteristics regardless of cargo situation. The company has currently two products for ballast water treatment. The research of this thesis focuses on the purchasing activities of the ballast water management systems and compressors. In the purchasing operations of Case Two, a demand driven material requirements planning software, referred to as Software One, is used. The software is used to achieve better flow of materials by making inventory buffers clearly visible for buyers.

Case Two

- Relevant information for decision making in purchasing activities
- Flow of materials in production according to actual demand pull
- Demand driven material requirements planning tool that has visually represented inventory buffers
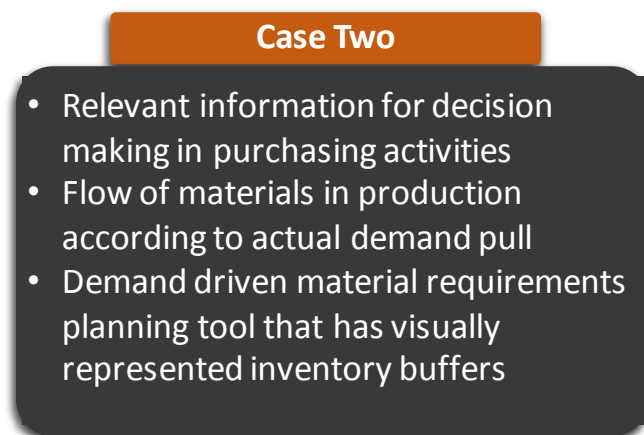
Figure 17. Research focus areas in Case Two.

6.3.4 Case Three introduction

The last case to be studied of the three embedded units of the company manufactures, develops, delivers and maintains engine products of the case company. The factory of this embedded unit manufactures engine products for all the business solutions of the case company. The research of this thesis in this embedded unit focuses on how stability and system flow is enabled by aligning relevant information for decision making of each subsystem with each other through visual management and performance indication practices.

Case Three

- Alignment of relevant information for decision making in subsystems according to system flow
- Stability by focusing on flow varibility
- Stability of system flow according to actual demand pull
- Visual and performance management practices
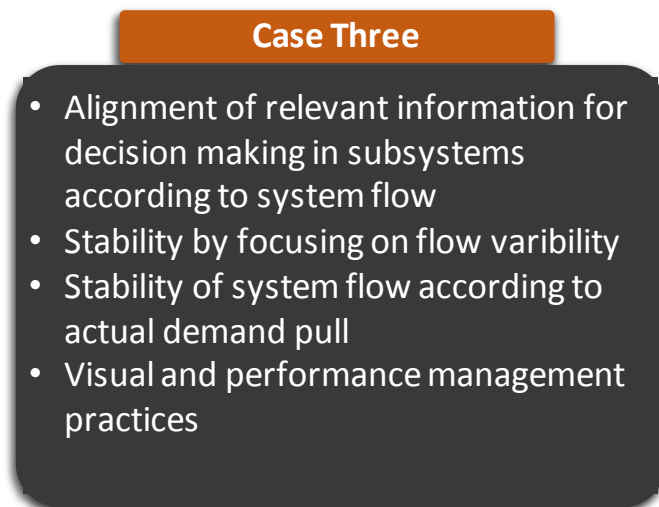
Figure 18. Research focus areas in Case Three.

6.4 Results of current situation analysis of Case One

In Case One, relevant information for decision making (visibility) is understood and implemented as simplicity in theories, tools and approaches in order to develop a understanding of the operations. Visibility is aimed at simplifying the communication within the organization through understanding of the operations and opportunities that can be exploited. It also works as an incentive of interaction by helping people to understand where a change is needed, if it is needed, and how it should be addressed.

6.4.1 Overview of tools, methods and measurements used

Prior to the implementation of the tools and methods presented in this research, the habit of striving for high utilization in all subsystems of Case One caused overproduction, resulting in high WIP and long lead times throughout the system. As stated in Little's Law (Throuhput = WIP / Cycle Time), the same throughput can be achieved with long cycle times and large WIP or with short cycle times and small WIP, but the difference in these ways of achieving throughput is caused variability (Hopp & Spearman 2011: 264). The system with short cycle times, small WIP and less variability is the preferable option. The following tools, methods, and ways of working are implemented to provide relevant

information for decision making, to manage variability and to improve flow and reduce lead times.

- Value Stream Mapping (conducted prior to implementation of other tools and methods).
- Implementation of Theory of Constraints (TOC).
- Implementation of Demand Driven/pull operations (Kanban/CONWIP pull method).
- On Time Delivery measurements (OTD) to customer delivery date.
- Inventory availability measurements.
- Lead time measurements.
- Kanban board (daily delivery follow up).
- Regular Kaizen events.

The analysis of relevant information for decision making in Case one is conducted based on the effects of the implemented tools, methods and ways of working.

Measurements used for decision making in tactical relevant range

- TOC, CONWIP and Kanban
- Lead time measurements
- OTD Measurement

Variability and Flow

- Less WIP
- Shorter lead times
- Better throughput
- Better flow of orders
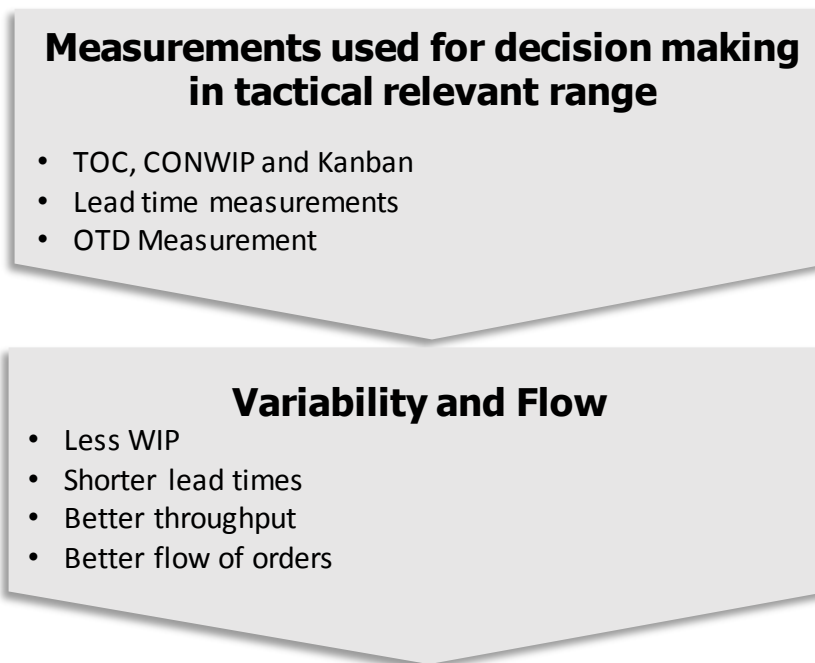
Figure 19. Methods used in Case One and effects to variability and flow.

6.4.2   Visibility in Case One

The amount of WIP is controlled with simple CONWIP cards that are physically visible for every production order on the shop floor. The use of the CONWIP cards is based on a Kanban system. *"The Kanban system is a pull system approach that gives authorization to produce at a required rate and specific time in order to replenish part that already consumed by the customer"* (Adnan, Jaffar, Yusoff & Halim 2013). *"CONWIP is a generalized form of Kanban. Like Kanban, it relies on signals"* (Spearman, Woodruff & Hopp 1990). A combination of Kanban and CONWIP systems is a hybrid system. A hybrid system *"consists of a CONWIP system with capacity restrictions in the intermediate buffers by means of a Kanban system"* (Bertolini, Bevilacqua & Grassi 2005). By switching from working with push-methods to working according to the actual market demand pull, WIP and lead time were reduced significantly. The WIP is prioritized based on buffer penetration at the constraint of the end-to-end process. The constraint is currently in the end phases of the end-to-end process, where buffering is based on capacity to align it according to the variance in demand. Each phase of the process has a visually represented listing of production orders that are prioritized based on the throughput of the constraint.
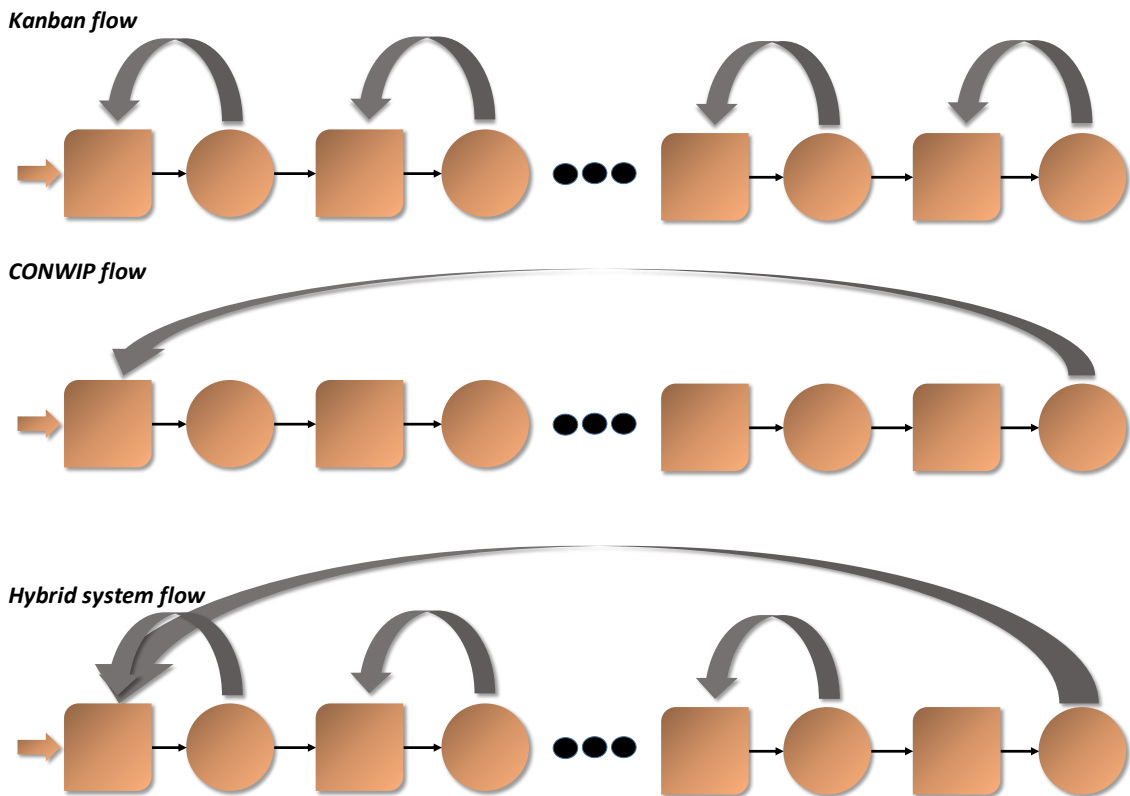
Figure 20. Kanban, CONWIP and hybrid system flow (Bertolini et al. 2005).

To assure OTD performance, to avoid sub-optimization and to generate systemic thinking in production, a visual board is used for daily and weekly meetings on current topics of the end-to-end delivery process. The visual board focuses mainly on the status customer deliveries and communication of measurements on current OTD and WIP levels. Value Stream Mapping was also conducted to reduce waste, to locate the constraints and to create systemic thinking. VSM also enabled dramatic reduction of lead times. There is also a KPI for the number of Kaizen events conducted, with a requirement for at least two Kaizen events in a month. Kaizen in Japanese means improvement, and the idea of it is based on *"the participation of the workforce in process improvement and refinement"* (Brunet & New 2003). These events encourage the people in the organization to take part in improving operations, with the results being visually represented for all to see. Overall, based on the case the experiences of the participants in the interviews, the enablers for good performance in Case One have been the visualization of relevant information and the simplicity and effectivity of the methods and tools implemented that generate relevant information for decision making.

In the overview figures of the characteristics and focus areas of relevant information for decision making in the cases, simple + and − illustrations are used. Plus sign refers to something that is seen as a strength in the corresponding area. Minus sign refers to something that is a challenge or could be considered as a potential area of development for the corresponding area. These + and − illustrations are used similarly in each of the case units to secure similar evaluation and comparison between the cases.
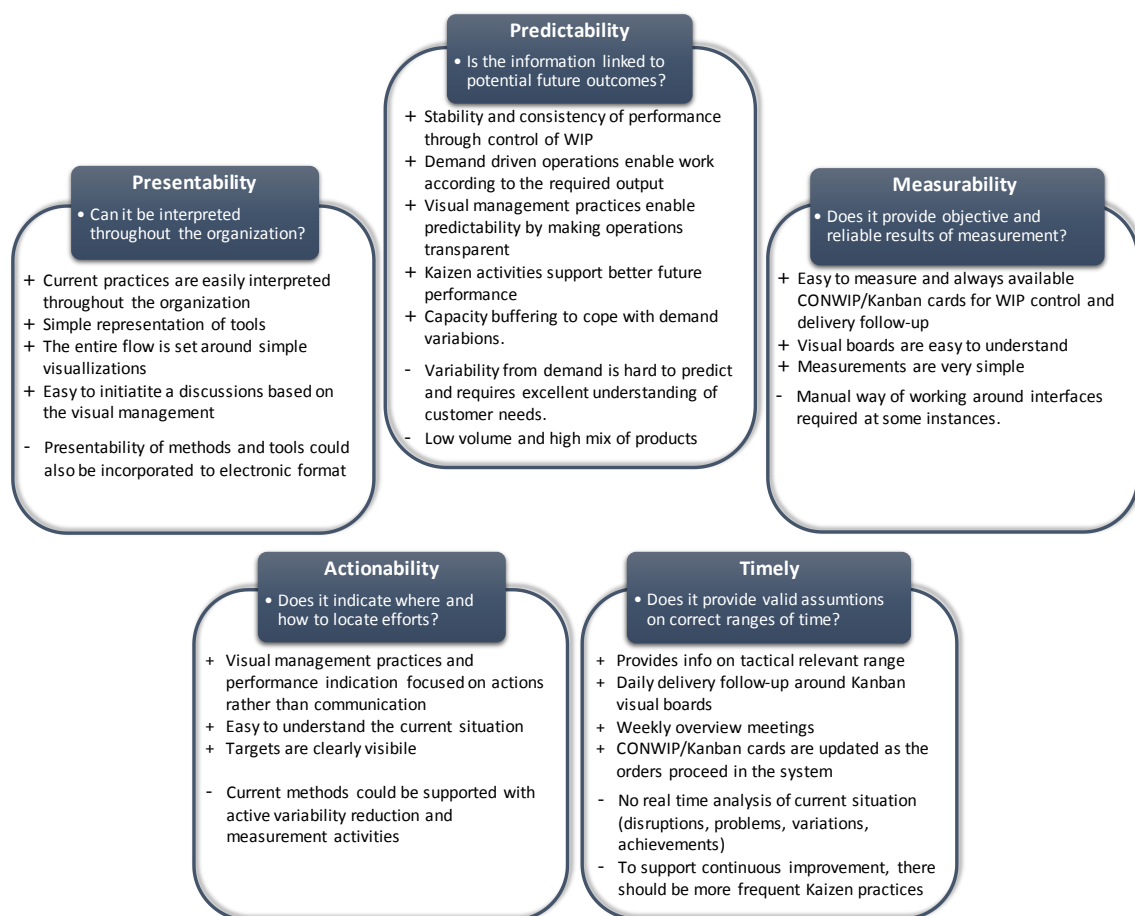
Figure 21. Overview of characteristics of relevant information in Case One.

6.4.3 Variability in Case One

In Case One, there are both make-to-stock and make-to-order products. In make-to-order products the variability comes mainly from the varying demand of the market. In make-to-stock products the variability occurs due to low volume and high mix of products. High

mix of products is a direct result of decision, and therefore controllable variation. Information on customer preferences and needs would possibly enable the streamlining of offering and therefore variability reduction. Striving for optimal policies to address the random variation in the process is not an option. Random variation occurs due to the nature of the business and inability to generate perfect schedules that are based on forecasts. The systems are not only seem to behave randomly, but the variation is inherently random. Therefore, robust policies are used to tackle these challenges related to variation. TOC implementation is used to address problems related to scheduling and Kanban/CONWIP methods to address demand variability. Kaizen events would ideally support the development of these tools and methods even further. OTD measurements are lagging metrics of the ability to carry out the end-to-end process in a consistent and stabile way, but a leading metric for customer satisfaction, and is therefore a valid measurement in flow based operating model, where benefits are related to the speed of flow of relevant information and materials.

SYSTEM FLOW	DEMAND DRIVEN FLOW	VARIABILITY
+ TOC enables systemic perspective by requiring focus on all of the subsystems + Subsystems contribute to the system by active follow-up practices and the methods and tools implemented + Clear definitions of each phase of work - Very production focused implementation of methods and tools, other phases of work and other systems (ie. suppliers) could also be more clearly incorporated to current methods and visual management practices	+ Production flow according to the principles of demand driven operations and TOC + A production order and the contstraint of the system determine how orders proceed within the system + WIP is prevented from accumulating with simple visual tools, methods and follow up practices - The amount of orders/work/tasks as a WIP in each system could also be clearly represented to rapidly determine current lead time capability - Incorporation to real time electronic format	+ Variability is controlled with simple methods and tools + Protection of flow enabled by TOC + WIP limitation and TOC allows variability to occur at other stages of production as long as it does not disrupt the constraint + Internal flexibility of personnel enabling rotation of capacity within the flow - Variability control but not reduction, ie. does not directly address the sources of variation which cause the need for buffering - More frequent continuous improvement activities required to limit variability

Figure 22. The focus areas of relevant information in flow based operations of Case One.

6.5 Results of current situation analysis of Case Two

In Case Two, this research focuses on the purchasing activities that are conducted in accordance to Demand Driven Material Requirements Planning (DDMRP) model in the production of Ballast Water Management Systems and Compressors. Relevant

information for decision making is provided to the buyers through a purchasing software that works according to the principles of DDMRP (referred to as Software One). The software is installed as an additional software next to a more traditional material requirements planning software (referred to as Software Two). Software One recognizes the parts that need to be purchased based on material inventory buffer levels. It provides relevant information for decision making in the form of visual representation of the inventory buffer levels combined with dynamic representation of re-order points.

6.5.1   Overview of Software One

Material Requirements Planning is *"a set of techniques that uses (1) bill of material data, (2) inventory data, and (3) the master production schedule to calculate requirements for materials"* (Ptak & Smith 2016: 3). The material requirements planning and manufacturing resource planning tools are associated with a push system. (Prakash & Feng 2011.) MRP systems generate time-phased recommendations to release replenishment orders for material. (Ptak & Smith 2016: 3) (APICS 2013: 103). MRP systems manage material and components flow on the floor of the factory. The purpose is to optimize inventories by aligning the supply of materials and schedules of all products and parts with demand. *"* (Dinesh, Arun & Pranaw 2014.) MRP systems attempt to keep *"adequate inventory levels to assure that required materials are available when needed"* (Dinesh, Arun & Pranaw 2014).

Software One is a Demand Driven Material Requirements Planning (DDMRP) purchasing tool based on the principles of Demand Driven Operation Model (DDOM). DDOM is a model that utilizes actual demand in combination with strategic decoupling points and stock, time and capacity buffers to create supply orders, operational scheduling, and execution (Ptak & Smith 329). It aims on generating a *"predictable and agile system that promotes and protects flow of relevant information and materials within the tactical operational range (hourly, daily, weekly)* (Ptak & Smith 2015: 329). DDMRP is used to protect and promote flow of relevant information and materials through modelling, planning and managing supply chains according to the principles of DDOM (Ptak & Smith 2015: 328).

The implementation of DDMRP way-of-working in Case Two is conducted in three phases.

1. Replenishment of purchased parts, spares and subcontracted machined parts with Software One.
2. Replenishment of strategic intermediate components with Software One
   a. Strategic bill of materials de-coupling
   b. Compression of top level Software One lead times to meet shorter market lead times.
   c. Decoupling of production planning at strategic, replenished components.
3. Finite production capacity planning and shop floor buffer management (Drum Buffer Rope software referred to as Planning Software)

In this thesis, the focus is on the usage of Software One in the purchasing operations and how it delivers relevant information for decision making for the purchasers. Phase three, the implementation and usage of Planning Software, will not be studied.

6.5.2   Using Software One

Software One helps the buyers to see what to order on a day-to-day basis by better visibility and prioritization information when compared to conventional MRP systems, such as Software Two. The time consuming generation of uncertain forecasts is not necessary when using inventory buffering. The buyer can easily see how to prioritize purchasing by looking at the buffer profiles and the front screen dashboard of the system. It therefore enables making decisions on priority and on timing of the order. Software One provides predictability on the readiness for starting production through inventory buffering. The items to be purchased can be easily predicted with clearly indicated buffer levels on each item. The clear representation of what to buy also predictability of the quantity of orders eventually coming in. Software One also enables right order volumes due to clear indication of what is needed for the buffers to remain on ideal level. If applied correctly, the buffering enables the needed stock to be available already when a customer places an order, while preventing the inventories to grow out of control. Software One

also generates daily reports that help tracking the current situation. The reports include information on how things are ordered and how many things should have been ordered.

The buyer does purchasing activities based on buffer levels presented by Software One. There are three buffer zones, red, yellow and green. The number on the right side of the coloured bar indicates planning priorities, which is the number of parts in the category, including both buffered and non-buffered. All the parts within the system have a grouping that is based on part attributes: the type of part (made, bought or distributed), lead time category (long, medium, short) and variability category (high, medium, low). Each of the buffer zones (red, yellow and green) has a group of settings applied that are similar to the attributes of the parts.

Figure 23. A screenshot of Software One buyers screen.

- Red zone: the protection zone
  - o The red zone is divided to *Critical, High and High (Non-buffered)* part categories that prioritize what needs to be bought.
- Yellow zone: the reorder zone
  - o This area generates an alert, which is a trigger for re-ordering.
  - o In the Yellow zone, parts are prioritized as *Medium.*

- Green zone: the order quantity zone
    - o In the Green zone, parts are prioritized as *Low*.
- Over Top of Green
    - o This is category would ideally consist of nothing. It indicates how many parts there are as excess inventory based on the buffering attributes.

Based on the amounts in the right hand side of the buffers, the buyer knows that there are in total 498 (2+10+35+35+416) units buffered. If the OToG amount is included, the amount of inventory is currently over 80 percent ((498+407) / 498 = 1,82) more than necessary.

Measurements used for decision making in tactical relevant range

- Real time inventory buffer levels
    - All the parts within the system have a grouping that is based on part attributes: the type of part (made, bought or distributed), lead time category (long, medium, short) and variability category (high, medium, low)
    - Priority: Critical, high, high (non-buffered), medium, low and over the top of green (too much)

Variability and Flow

- Better material availability
- Shorter lead times
- Better flow of information (between buyers)
- Better flow of materials

Figure 24. Methods used in Case Two and effects to variability and flow.

Predictability

• Is the information linked to future outcomes?

+ Inventory buffering provides predictability on readiness for starting production.
+ Day-to-day predictability on what to buy.
+ Easy to predict the quantity of orders and parts coming in.
- Does not directly address the sources of variability
- Software One is used for variability control, not variability reduction
- Software One does not take into account what to buy the next day

Presentability

• Can it be interpreted throughout the organization?

+ Easily interpreted throughout the users of Software One.
+ The idea is easy to understand among users and non-users.
+ Buffering is simply presented with decent additional information.

- No visualization of buffer levels in other subsystems (production, manufacturing etc.)

Measurability

• Does it provide objective and reliable results of measurement?

+ Software One does the measuring of adequate buffer levels for the buyers based on historical data of the type of part, lead time and variability.
+ No need to generate detailed forecasts.
+ Daily report shows quantity and volume of orders.
- High reliance on Software Two masterdata.
- Requires working around two softwares in some items that are not in the scope of buffering (indirect purchasing and subcontracting activities)

Actionability

• Does it indicate where and how to locate efforts?

+ Clear priority list on what to buy based on buffer levels.
+ Easy to take actions on what to buy just by looking at the buffer levels.
+ Allows some decisions on when to order.
+ Target levels are clearly visibile.

- Manual way of working around two systems required at some instances to take action
- Current methods could be supported with active variability reduction and measurement activities

Timely

• Does it provide valid assumtions on correct ranges of time?

+ Provides information on tactical relevant range.
+ The buffer levels are updated daily.
+ Real time visibility of buffer levels.
+ With the daily report, the orders can be trended for decision making in strategic relevant range.
- Changes in Software Two masterdata are updated to Software One with one day of latency
- Provides information for decision making only for the current day.

Figure 25. The characteristics of relevant information in Case Two.

6.5.3   Challenges with Software One

Software One is still in the implementation phase and the problems related to working with it are currently being addressed. Inaccurate or incomplete Software One master data, which is located in Software Two, causes the challenges. The most important information for purchasing in Case Two are supplier and contract information, quantity and requirement date, of which only the quantity is currently utilized in Software One. These and other technical implementation problems and software related problems will not be further reviewed in this thesis.

However, the challenge of using inventory buffering tool such as Software One lies within the elimination of the sources of variability. Software One controls variability through inventory buffering. Variability reduction requires activities focused at variability

reduction, for example active supplier development and follow up, to ensure that the buffer levels are as low as possible. This has been taken into account by initiating a variability reduction related training to the personnel in the production and support operations. Despite carrying out a training to address variability, a software that encourages buffering can cause myopia within materials management to use buffering instead of focus on active variability reduction activities.

SYSTEM FLOW	DEMAND DRIVEN FLOW	VARIABILITY
+ When working ideally, Software one ensures materials availability and fast flow in production + No sub-optimization between buyers when using Software One - Does not take into account pre-purchasing phases in the system - Does not include supplier inventories - Requires management of two interfaces (Software One and Software Two)	+ Works according to the principles of demand driven operations + Materials are only consumed and ordered when actual demand pull has occurred + When working ideally, Software One aligns the purchasing of material to the required output of the system - The amount of orders/work/tasks as a WIP in each system could also be clearly represented to rapidly determine current lead time capability - Incorporation to real time electronic format	+ Enables better flow by mitigating the effects of demand variations + Protects flow with inventory buffers against variability + Improves flow in production by working according to actual demand rather than uncertain forecasts and schedules - Variability control but not reduction, ie. does not directly address the sources of variation which cause the need for buffering - Management of two interfaces (Software One and Two) can cause variability

Figure 26. The focus areas of relevant information in flow based operations of Case Two.

6.6 Results of current situation analysis of Case Three

In Case Three this thesis focuses on their methods, tools and ways of working that are implemented to generate systems thinking and visibility, stability and demand driven operations. Case Three initiated improvement activities in the third quarter of 2015, with focus on better performance through improved visibility and synchronization of different functions, performance management, material and information availability and significant lead time reductions. The visualization of relevant information for decision making has been implemented for a longer period of time but with less structural approach.

6.6.1   Overview of tools, methods and measurements used in Case Three

In Case Three, the following leading metrics and methods are used as relevant information for decision making. These are also incorporated as a part of their daily and weekly practices to assure same priorities and information throughout the subsystems. In addition to these, there are also other KPI's but these are the most essential for decision making within the system on a tactical relevant range.

Measurements used for decision making in tactical relevant range
- Measurement of the number of incomplete inputs to other subsystems
- Measurement of incomplete information and changes within freeze period
- Measurement of the amount of missing material when releasing order to assembly
- Lead time in assembly
- On-time testing

Variability and Flow
- More information that is right the first time
- Less suboptimization
- Less changes that occur late in the process
- Less material shortages in assembly
- Better flow of information and materials
- Deviations and rootcauses of issues are easier to identify
- On-time delivery is secured and predictable

Figure 27. Methods used as and effects to variability in Case Three.

6.6.2   Visibility in Case Three

This thesis focuses primarily on the way the end-to-end (customer order to customer delivery) operations are managed by generating visibility and systemic understanding in all of the sub-systems of the organization. In Case Three, each sub-system is aligned with the aim, values and beliefs of the entire system by active follow up, performance indication and performance management practices that are linked with each other. Visibility is understood as relevant information that is available and communicated without requiring significant amounts of effort while enabling better understanding throughout the system. Visibility is also seen as a supporting factor for the reasoning behind actions taken.

The following listing includes subsystems that are incorporated to the systemic end-to-end practices. Each of the subsystem (sales, project management, engineering, supply management, delivery centre, quality and finance and controlling) has clearly defined and actively implemented indicators that the subsystem measures to assure alignment with the aim, values and beliefs of the entire system. The subsystems have their relevant information for decision making visually represented with visual management practices that are incorporated as standard way of working as weekly or biweekly follow-up practices in each organization. Timely follow-up in each system is essential for the whole system to function according to plan. Without the follow-up practices, the lack of knowledge on the performance of a single subsystem can detoriate the performance of the whole system.
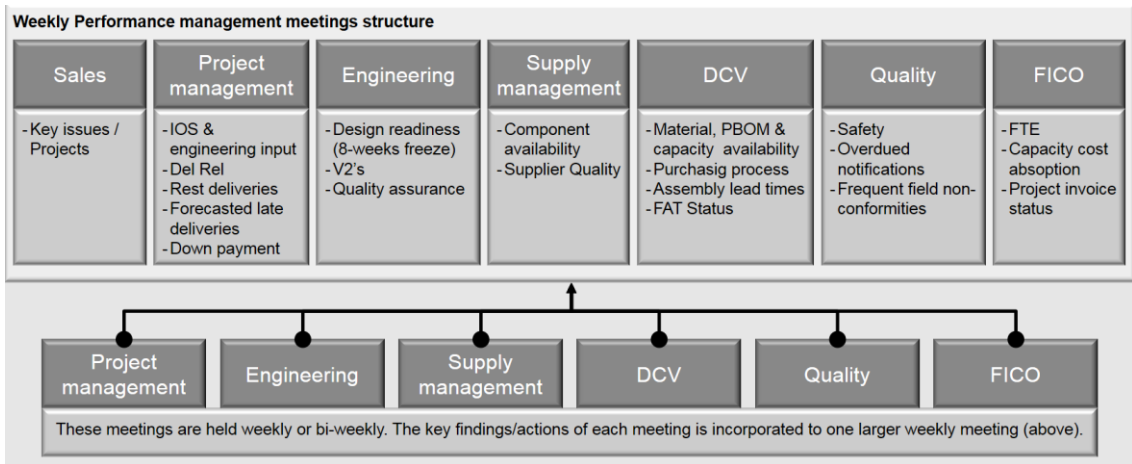
Figure 28. Case Three weekly meeting structure.

Even after the implementation of these unified performance management and indication practices that generate visibility on a systemic level, there are various silos of information in the mailboxes, folders and other personal databases of the people within the entire system. This is problematic because some of the information withing these silos would be useful in generating fact based decision making. However, utilizing all information is not seen as only a positive thing, because too much data might not be particularly useful due to the risk of losing the main message of the information, which is the relevant information for decision making. The implementation of performance indication and performance management practices in each subsystem is seen as only the start of the journey on generating better system flow, demand driven operations, variability control and variability reduction.

SYSTEM FLOW	DEMAND DRIVEN FLOW	VARIABILITY
+ The way of working is designed to gain systemic understanding and avoid suboptimization + Subsystems contribute to the system by aligned aims, values and beliefs + Measures and practices are aligned within subsystems + Clear definitions responsibilities of each subsystem and linkages are smooth with measurements that aim for system flow - The way of working is still a work in progress and practices could be even more action orientated	+ Flow according to actual pull from the customer + Flow of orders is based on the system readiness of carrying out the order in a synchronized way while maintaining minimum queues between subsystems + The accumulation of WIP is recognized in each subsystem and is prevented from having an effect to other subsystems by correct and aligned measurements - The amount of orders/work/tasks as a WIP in each system could also be clearly represented to rapidly determine current lead time capability - Incorporation to real time electronic format	+ Flow variability is prevented from occurring to some extent with relevant leading metrics + Protection of flow with freeze concept, which visualizes the time buffer until freeze point + Variability might occur at some subsystems but it does not disrupt the entire process - Current measurements must be supported by the identification sources of variation which cause the need for variability control - Continuous improvement activities required to limit variability

Figure 29. The focus areas of relevant information in flow based operations of Case Three.

6.6.3 Variability in Case Three

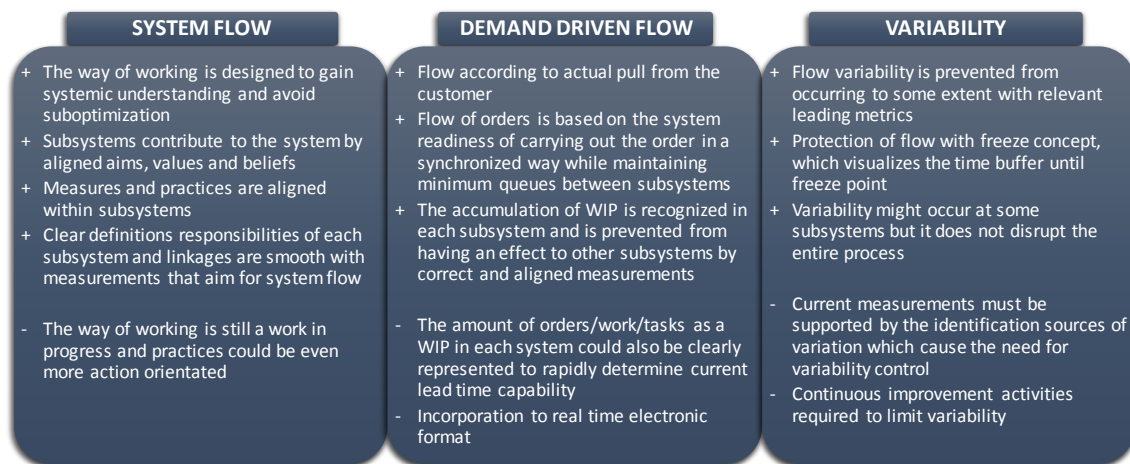There are many deviations from plan that occur due to changes in the scope of delivery coming from the customer or due to technical challenges in orders that were not realized prior to selling a project. The actual changes in the process are not measured if they come from the customer. Only the end result, which is on-time-delivery or delivery accuracy, is measured. This is because the changes from the customer often have a price and they are often perceived as *positive risks,* that might enable for example more net sales or better customer satisfaction.

One of the most important things for system flow and stability in Case Three (the amount of variability that is passed on) is a method known as *the freeze point concept.* It is a method that uses control points to ensure plan stability and to visualize the amount of work to be done on a weekly basis. The freezing point illustrates a point in time when the plan should be *frozen,* a control point after which changes and requirements to the plan are no longer accepted. This method has been implemented for the early phases of the process to ensure smooth flow when proceeding. Prior to the implementation of freeze point concept, there were many plans with incomplete information during a period of time when all the information should have been in place. Making the level of readiness visible aligned the way of working to prevent changes from plan occurring. The concept also provided clear targets for the needs of the system.
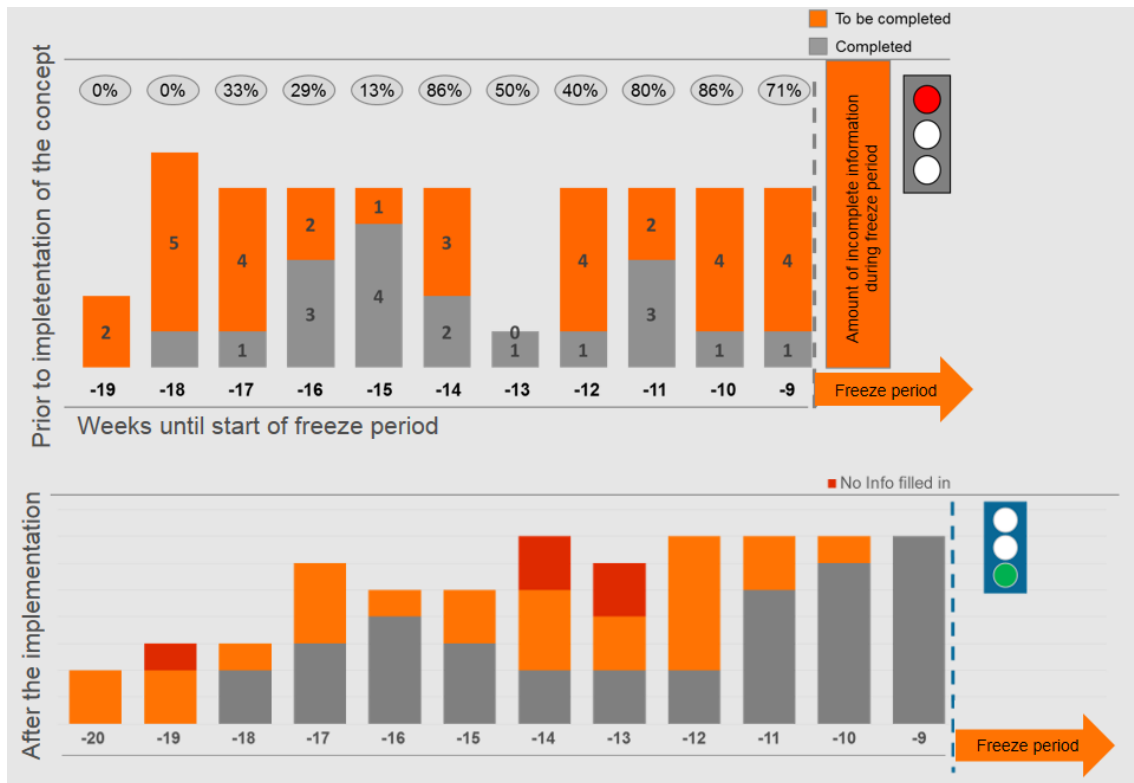
Figure 30. Example of freeze point concept implementation in Case Three.

Most of the variation comes from the customer and is therefore uncontrollable and inherently random. Customers are communicated about the freeze period, which prevents some changes from occurring. Securing the customer with what is going to be delivered, in other words ensuring what the customer really wants, also prevents some random variation from occurring. Therefore, the amount of true randomness can be quite small if cooperation with the customer is very active and the customer needs are well understood. Regardless of the variation, an excellent understanding of customer needs and

requirements is required for the measurements, methods and ways of working to be effective.

Predictability

• Is the information linked to potential future outcomes?

+ Predictability between subsystems through alingned aim, values, measures and beliefs
+ Potential future targets are enabled through methods aiming for stability
+ Visual and performance management practices enable predictability by making operations transparent

- Variability from demand and from customer is hard to predict and requires excellent understanding of customer needs
- Sales and customer interaction could be incorporated more clearly to the systemic follow up practices

Presentability

• Can it be interpreted throughout the organization?

+ Practices are based on the ability to be interpreted throughout the organization
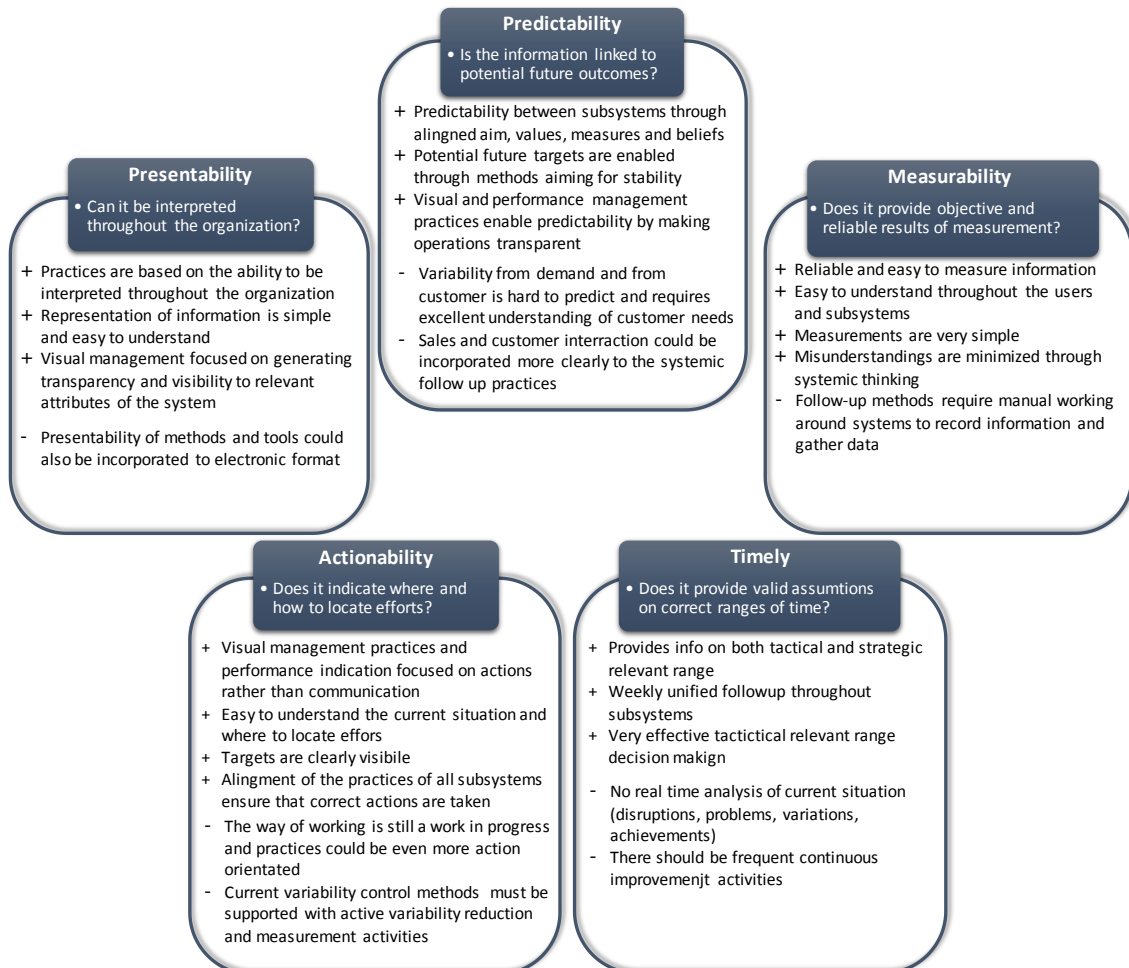+ Representation of information is simple and easy to understand
+ Visual management focused on generating transparency and visibility to relevant attributes of the system

- Presentability of methods and tools could also be incorporated to electronic format

Measurability

• Does it provide objective and reliable results of measurement?

+ Reliable and easy to measure information
+ Easy to understand throughout the users and subsystems
+ Measurements are very simple
+ Misunderstandings are minimized through systemic thinking
- Follow-up methods require manual working around systems to record information and gather data

Actionability

• Does it indicate where and how to locate efforts?

+ Visual management practices and performance indication focused on actions rather than communication
+ Easy to understand the current situation and where to locate effors
+ Targets are clearly visibile
+ Alingment of the practices of all subsystems ensure that correct actions are taken
- The way of working is still a work in progress and practices could be even more action orientated
- Current variability control methods must be supported with active variability reduction and measurement activities

Timely

• Does it provide valid assumptions on correct ranges of time?

+ Provides info on both tactical and strategic relevant range
+ Weekly unified followup throughout subsystems
+ Very effective tactictical relevant range decision makign
- No real time analysis of current situation (disruptions, problems, variations, achievements)
- There should be frequent continuous improvemenjt activities

Figure 31. Overview of the characteristics of relevant information in Case Three.

6.7 Summary of characteristics of relevant information

The characterstics of relevant information for decision making should be the starting point when improving visibility. Either objective, data based metrics or subjective judgement can be used to demonstrate changes in performance and help to locate efforts to improve performance, while data based metrics are the preferable option. Analytical tools that require time-consuming analysis are not useful for operational purposes where decisions must be made fast. Data used must be set in the context of the process to transform it into

meaningful process information, such as KPI's (key performance indicators) that provide direct decision making support.

The key characterstics of relevant information for decision making are derived from the review of relevant literature. These characteristics should be taken into account as thoroughly as possible when developing relevant information for decision making. They include the following:

- Predictability - linkage to potential future outcomes.
- Measurability - objective and reliable results of measurements.
- Timely - valid assumptions on correct ranges of time.
- Actionability - indication on where to locate efforts.
- Presentability - interpretation throughout the organization.

The following table includes features of the characteristics of relevant information for decision making in the embedded units of the case company. This table summarises the answer to the second research question from the perspective of characteristics of relevant information in the case company.

Table 12. Overview of the characteristics of relevant information in each case unit.

		Case One	Case Two	Case Three
Predictability	Strengths	Stability and consistency through pull methods, WIP control and capacity buffering.	Inventory buffering provides readiness for creating flow and starting production.	Systemic alignement of aim, values, measures and beliefs create consistency and stability to achieve future targets.
	Challenges	Variability from demand is hard to predict and high mix of products create further variation.	Software One is a tool for variability control, variability reduction requires separate activities.	Variability from demand is hard to predict.
Measurability	Strengths	Easy to measure and understand methods that provide reliable results of measurements and are available for all.	Software One measures adequate buffer levels for the buyers and takes away the need to generate detailed forecasts.	Simple, reliable and easy to measure and understand performance indicators that are utilized throughout the system.
	Challenges	Manual way of working around interfaces required at some instances to record and gather data.	High reliance of Software Two masterdata that requires working around two softwares.	Manual way of working around interfaces required at some instances to record and gather data.
Timeliness	Strengths	Active (daily and weekly) visual management to assure valid assumptions on tactical relevant range.	Real time visibility to inventory buffers enables buyers to do valid assumptions on tactical relevant range.	Valid assumptions can be made on both tactical and strategic relevant range with systemic incorporation of data.
	Challenges	Analysis of changes from plan could be incorporated as a daily method.	Provides visibility only for what to buy on the current day.	Analysis of changes from plan could be incorporated as a real time follow up.
Actionability	Strengths	Simple and action oriented way of working with clear targets on how to locate efforts.	Clear visualization of buffer levels clearly indicates buyers on where to locate efforts.	Action oriented and aligned way of working with clear targets and focus areas throughout the system.
	Challenges	Incorporation of more variability reduction and measurement activities to visual management practices.	Incorporation of variability reduction and measurement activities. Working around softwares at some instances.	More action oriented meeting practices. Incorporation of more variability reduction and measurement activities.
Presentability	Strengths	Simple and easy to interpret practices that are focused on visualization of flow.	The principles of the software are easy to understand and interpret throughout the organization.	Practices are built based on the ability to be interpreted throughout the organization to achieve system flow.
	Challenges	Current methods could also interpreted to electoric format to ensure understanding in all subsystems.	Buffer levels could also be somehow visualized in other subsystems.	Current methods could also interpreted to electoric format.

6.8 Summary of focus areas of relevant information

The characteristics of relevant information addressed in the table above (table 12) apply generally to organizations that strive for better visibility. To make the conceptual framework specific for flow based operations, a more detailed description on what to address with relevant information was needed. These focus areas of flow based operations were defined based on what are the key contributors in achieving flow. The distinction of these focus areas was built around the amended version of Georg Plossl's first law of manufacturing: *"all benefits will be directly related to the speed of flow of relevant information and materials"* (Ptak, Smith 2016: 18). As stated in the literature review and conceptual framework earlier in the thesis, relevant information for decision making must address the following focus areas:

- System flow.
- Demand driven flow.
- Variability.

The following table represents the relevant information for decision making in flow based operations of the embedded units of the case company. This table summarises the answer to the second research question from the perspective of focus areas of relevant information in flow based operations of the case company.

Table 13. Overview of the focus areas of relevant information in each case unit.

		Case One	Case Two	Case Three
System Flow	Strengths	System flow addressed with methods that align the operations of the subsystems to the system goals.	Software One ensures material availability and fast flow in production and prevents suboptimization between buyers.	Systemic alignement of aim, values, measures and beliefs throughout subsystems to achieve system flow.
	Challenges	Incorporation of all subsystems (ie. suppliers and others who are not part of them currently) to current practices.	Does not adress pre-purhcasing activities or supplier inventories in the system and requires work around two interfaces.	The way of working could be even more action oriented to ensure system performance.
Demand Driven Flow	Strengths	Current way of working, tools and methods are based on demand driven principles and actual market demand pull.	Software One is based on demand driven principles and aligns work according to the required output of the system.	Flow is aligned with the actual demand pull and is based on the system readiness of carrying out work with minumum queue.
	Challenges	Implementation of real time follow up of current status as the amount of orders/work/tasks in each subsystem.	Implementation of real time follow up of current status as the amount of orders/work/tasks in each subsystem.	Implementation of real time follow up of current status as the amount of orders/work/tasks in each subsystem.
Variability	Strengths	Variability control through simple methods and tools that focus on WIP limitation and stability of flow.	Protects flow in production by stock buffering, thus mitigating the some of the effects of demand variations in materials management.	Protection of flow by time buffers, by focusing on stability and by methods that adress potential sources of variability.
	Challenges	Implementation of more variability reduction activities that support continuous improvement mindset.	Does not adress the sources of variation which cause the need for buffering. Working with two interfaces can also cause variability.	Implementation of more variability reduction activities that support continuous improvement mindset.

6.9   Potential areas of development

This chapter provides an answer to the third research question. The answer is provided by comparing the conceptual framework with the case company research data. The answer is based on the challenges and potential development areas of the characteristics and focus areas of relevant information for decision making in flow based operations of the case company.

6.9.1 Development in characteristics of relevant information

In the case study, the features of the characteristics are divided to *strengths and challenges*, to distinguish possible future development areas. The characteristics were identified from the perspective of flow based operating models, which is reflected especially in the challenges of the characteristics. There were challenges in relevant information for decision making in all of the characteristics with clear resemblance in some areas. The most common challenges or potential development areas that were evident in all embedded units are presented in the table below.

Table 14. Development areas of characteristics of relevant information.

Characterstic	Potential development area
Predictability • Is the information linked to future outcomes?	Variations in demand.
Measurability • Does it provide objective and reliable results of measurement?	Information is located in different interfaces.
Timely • Does it provide valid assumtions on correct ranges of time?	Real time analysis of changes from plan.
Actionability • Does it indicate where and how to locate efforts?	Lack of variability measurment and reduction related information.
Presentability • Can it be interpreted throughout the organization?	Incorporation to (electronic) format that is intereted thoruhout the system.

6.9.2   Development in focus areas of relevant information

Similarly as with the characteristics of relevant information reviewed earlier, the focus areas are divided into *strengths and challenges* in each embedded case unit to distinguish possible future development areas. There were challenges in relevant information for decision making in all of the features of relevant information with clear resemblance in some areas. The most common challenges and potential development areas are separated in a table below.

Table 15. Development areas of the focus areas of relevant information.

Focus area	Potential development area
System flow	Incorporation of all subsystems to current practices.
Demand driven flow	Real time follow up of current status as amount of orders/work/tasks in each subsystem.
Variability	Variability measurement and reduction activities and the identification of the sources of variability.

6.9.3   Variability measurement and reduction

Variability measurement and reduction was the most evident potential development area when reflecting the conceptual framework to the case research. However, it was also evident throughout the case study that variability is addressed in each of the cases. The method of controlling variability varied between cases: Case One mainly uses WIP control methods, Case Two uses inventory buffering software and Case Three utilizes systems thinking, control points and time buffers. In the case study, variability reduction was not as evident as variability control. The only variability reduction related features were the regular Kaizen events of Case One and the variability reduction related training that was planned to be provided for some of the personnel of Case Two.

Variability measurement and reduction should be implemented more clearly to the relevant information for decision making of each case. Variability reduction could be implemented as statistical process control methods, which would aid decision making by gathering and analysing data on processes. SPC would enable detection and correction of variations that affect the quality of the operations and drive the need for current variability control methods. *"SPC is the application of statistical methods to monitoring and control of a process to ensure that it operates at its full potential to produce a conforming product"* (Madanhire & Mbohwa 2016). When working ideally, with the help of SPC, the causes of variations could be eliminated. SPC would enable a proactive approach to variability and therefore prevent out of control deviations or non-conformities from occurring in the system. The most commonly used SPC tools are control charts, continuous improvement and design experiments.

A system that effectively generates and utilizes relevant information for decision making secures system flow by breaking variation and damping its effects. (Smith & Smith 2013c.) Working according to required output of the system (the actual market demand pull) with good system flow will enable better performance throughout the system. The protection and promotion of system flow according to actual market demand requires management of variability on a system level. Variability that occurs at a local process level does not in itself corrupt system flow. The amplification and accumulation of variability that is passed on between subsystems has the most erosive effect for flow. Variability at a local process level should still be managed and reduced. Active variability reduction is essential for maintaining performance and it requires identification of the sources of variability, thus enabling better understanding of the operations. Variability reduction is in itself a source of competitive advantage because it promotes an environment of continuous improvement mindset.

6.9.4   Other areas of development

During the review of the characteristics of relevant information for decision making, the before mentioned potential focus area of variability reduction and measurement was very

evident throughout the embedded case units. In addition to variability reduction, the following potential development areas also resembled in the cases:
- Predictability: variations in demand.
- Measurability: information is located in different interfaces.
- Presentability: incorporation to a (electronic) format that is interpreted throughout the system.
- System flow: incorporation of all subsystems to current practices.
- Demand driven flow: real time follow up of current status as amount of order/work/tasks in each subsystem.

Variations in demand occur to some extent as an outcome of true randomness, in which only statistical estimates of what will happen can be provided. More relevant information on the customer and overall market situation would probably account for some amount of apparent randomness but the majority of the variability still occurs truly randomly. To generate as much relevant information on demand as possible and to generate valid statistical estimates on demand variations, a significant amount of time should be spent with the customer. This is beneficial for the company regardless of trying to reduce variability or not. For example, relevant information for decision making can be generated from the amount and the quality of time spent with customer, because it reflects to how random the demand variations appear.

Information that is located in different interfaces can cause problems if the integration of the interfaces is not seamless. This is similar to the potential development area of system flow, where some of the subsystems are not aligned or incorporated to the current practices and are therefore generating variability and limited visibility for the rest of the system. The implementation of software such as Software One in Case Two requires excellent front end work to ensure that the information that is utilized in the new software is correct. Only through solid and correct masterdata can the implementation be carried out seamlessly without causing problems later on. Unclear or incomplete master data can cause significant amounts of work and trouble later on when the software is supposed to be used for decision making.

The development area of presentability, incorporation to a format that is interpreted throughout the system, can be useful for the generation of better system flow and also for the generation of better demand driven flow. For example, the WIP control methods of Case Two might not be useful for people outside the workshop because it is only visible in the actual workshop. Generating digital follow up procedures could enable better system flow by providing better interpretation of the relevant information in subsystems that previously did not have the information available. This would also enable real time follow up of current status in each subsystem. The digitalization of simple and effective methods for achieving flow provides system flow, demand driven flow and variability a significant improvement opportunity. However, as with all improvement actions, a holistic understanding of the current situation is required before the implementation of new ways of working.

6.10 Discussion

The level of maturity in generating and using relevant information for decision making varies a lot depending on the focus area of relevant information (system flow, demand driven flow or variability) between the case units. The following list summarises the findings.

- The systems thinking approach of Case Three should be implemented in both Case One and Case Two.
- The DDMRP purchasing software (Software One) in Case Two could be implemented to both Case One and Case Three.
- The WIP control methods of Case One could also be implemented in Case Two.
- Regular Kaizen activities of Case One should be implemented in both Case Two and Case Three.

When it comes to system flow, the most advanced level of maturity is in Case Three. Case Three has gone through improvement actions for over a year to generate their systems thinking to a level where it is now. They have successfully aligned the way of working in subsystems to the goals of the entire system. This way of working should be

implemented also in Case One and Case Two, to achieve the benefits of system flow and to prevent variability from being passed on between subsystems.

Demand driven flow is most clearly evident in Case Two, where the entire materials management relies on a software that works according to DDMRP principles. The implementation of Software One should be considered in both Case One and Case Three. This would further amplify the benefits of demand driven flow and make it easier to manage the effects of variability by utilizing inventory buffering.

Case One uses more traditional approach to align their working according to the actual demand pull by utilizing TOC, Kanban and CONWIP methods to control WIP throughout the production. The methods used to align the work to actual demand pull by controlling WIP could be utilized also in the production of Case Two. In Case Three, the production activities are embedded within their system follow up and are not studied in this thesis. In addition to WIP control, Case One also uses regular Kaizen events to support continuous improvement. This way of working should be implemented in both of the other cases also.

The ability to generate and use relevant information for decision making is essential for organizations regardless of their size and industry. Today there are techniques and technologies available for the capture and usage of relevant information faster, more efficiently and more precisely than ever before. However, it is the easy to understand methods, tools and ways of working that seem to prevail and maintain their ground for the development of supply chains and operations in general. The usage of modern technologies that are combined with easy to understand methods, tools and ways of working that are proven effective, is the ideal approach for the development of operations in the future.

7. CONCLUSION

The results of the empirical work emphasize the importance of a structured and holistic approach in generating and using visibility (relevant information for decision making) for the purposes of maintaining and improving operational performance in complex supply-demand networks. The effectiveness of operations and improvement actions can be only achieved when considering all the prerequisites for achieving flow. The characteristics of relevant information are generic and widely applicable for businesses trying to generate relevant information for decision making. When critically considering all of the characteristics, potential development areas in the current way of working will most likely occur and operations will be improved. This was also evident in the empirical work of this thesis, since the review of the characteristics of relevant information in the case company managed to point out potential development areas.

As described, the characteristics of relevant information can be useful for the purposes of improving operations. However, they will not generate specific suggestions for the purposes of improving visibility in the context of supply chain management, operations management and flow based operating models. To address this issue, the literature review of this thesis aimed to identify the most important focus areas of relevant information for decision making in flow based operating models. In this context, flow is articulated by George Plossl in the first law of manufacturing: *"all benefits are directly related to the speed of flow of information and materials"* (Ptak & Smith 2016: 15). The focus areas that arised during the review of relevant literature were *system flow, demand driven flow and variability.*

System flow, demand driven flow and variability are not new concepts in the context of operations- and supply chain management. The characteristics of relevant information were also chosen based on existing knowledge on information that is usable for decision making. To combine these existing concepts and characteristics, a conceptual framework was generated. With the framework, the information that already exists in the relevant literature was connected. The conceptual framework provides a supporting structure for building visibility in order to achieve flow. The goal of this thesis was to create a new

picture of the existing information and meanings of visibility by demonstrating how the characteristics and focus areas of visibility work together in a real world example. The results of the empirical work clearly link to the conceptual framework by providing an understanding of the current situation and a course for the future with potential areas of development.

7.1   Overview of research questions

The purpose of this thesis was to study how visibility is understood and implemented in the operations of the case company and in relevant literature. The conceptual framework was used to evaluate the current state of visibility in the embedded units of the case company and find suggestions on how to further improve visibility in the operations of the case company. The purpose of this thesis was reflected in the research questions. The findings of the case research contribute to the existing knowledge on how relevant information should be generated and used for decision making in order to control and reduce variability in flow based operations.

Question 1. *How visibility and variability in flow based operations are understood in the relevant literature?*

This was answered by conducting a literature review on the concepts of this thesis and by developing a conceptual framework. The conceptual framework summarises the answer to this research question. The distinctive areas studied in this thesis with the framework were the characteristics of relevant information, focus areas of relevant information, variability, visual representation and visual management. Tables 1 and 2 further elaborate the literature explanations of the characteristics and focus areas of relevant information for decision making, which were used as a basis for the evaluation of how visibility is currently understood and implemented in the case company.

Question 2. *How visibility is currently understood and implemented in the case company business operations?*

The empirical work provides an answer to this question. A case study was conducted, where the embedded units (Case One, Case Two and Case Three) of the case company were analyzed around the conceptual framework. The tables 12 & 13 provide an overview of the characteristics and focus areas of relevant information for decision making in the operations of the case company.

Question 3. *How visibility can be further improved in the case company based on conceptual framework?*

This was answered by comparing the conceptual framework from the literature with case company data. The anwer to this research question is provided in the chapter 6.9. Tables 14 and 15 provide an overview of the potential development areas. The prioritization and level of distinction between the potential development areas was determined based on how evident the observations were in the cases.

7.2   Future research

With digitalization of current ways of working reshaping the industry, it is of significant importance to study on where, how and when to locate these digitalization efforts. The prerequisite for digitalization and new technologies in general to reach their full potential as a part of the operating systems of organizations today is to understand what is relevant information for decision making, how it is generated and how it is used. Only through this knowledge can the drivers of variability, flow and ultimately ROI be understood.

In addition to addressing the before mentioned potential future research area, more research with practical examples of the importance of flow would be beneficial for the acknowledgement of the importance of flow. The cost efficiency driven way of working that encourages suboptimization and high utilization everywhere requires more research that builds awareness of the effects of failing to focus on flow. Despite the fact that existing literature on flow based operations agrees on the benefits of striving for flow

instead of unit cost efficiency, the prevailing mindset of reducing unit costs, focusing on suboptimized measures or striving for high utilization everywhere as the main strategy for decision making still encourages the wrong behaviours.

7.3   Research limitations and exclusions

The relationship between flow and ROI (return on investment) is not studied in this thesis. The relationship between flow and ROI is already articulated in the first law of manufacturing by George Plossl in Orlicky's Material Requirements Planning: *"all benefits are directly related to the speed of flow of information and materials"* (Ptak & Smith 2016: 15). In addition on how flow affects ROI, the relationship between variability and flow has also not been thoroughly studied in this thesis because *"the one thing most process improvement philosophies agree on is that the No. 1 enemy of flow is variability"* (Smith & Smith 2013b).

The initial start of the generation of the conceptual framework was a challenging task. This was especially evident because the literature on the subject of the framework is very variable and the case company has not undergone similar researches before. Due to these challenges, the specified identification of the research scope was essential. As expected, the limitation of scope was challenging because of the broad and multidimensional nature of the concept of visibility. However, this task was also rewarding, because the definition of visibility in flow based operations can be beneficial for the reader.

The research does not go further into detail on variability reduction and control techniques because that would have expanded the scope excessively. Therefore, the variability reduction basics that are relevant for the case company are briefly introduced to initiate further discussions and research on how to generate relevant information for decision making on variability reduction of flow based operations.

Overall, the potential development areas are specific for the operations of the case company business units but generalizable for potential future development in other organizations and studies.

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