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Industrial Engineering and Management
Business Analytics

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MONITORING SUPPLIER NETWORK'S QUALITY ASSURANCE – CASE: A HEAVY EQUIPMENT MANUFACTURING COMPANY

Master's Thesis

Examiners: 1st Supervisor: Post-Doctoral Researcher Jyrki Savolainen
2nd Supervisor: Professor Pasi Luukka

ABSTRACT

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Monitoring supplier network's quality assurance – case: a heavy equipment manufacturing company

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Keywords: supplier quality assurance, supplier monitoring, supplier data analysis, process mining

As manufacturing companies are focusing more on their key competencies and the importance of supplier networks is growing, the need for supplier data analysis has been acknowledged. The purpose of this thesis is to examine how a Finnish heavy equipment manufacturing company can design and implement a tool for analyzing supplier network's quality assurance.

First, this study discusses different methods and objectives for monitoring and evaluating the supplier network. Furthermore, the benefits and challenges of supplier analysis are observed from the literature. The concept of data analysis is studied to discover methods for analyzing and visualizing supplier data. In the practical part of this study, a tool for analyzing supplier quality assurance is designed for the case company using the discovered methods. The output of this thesis is a set of suggestions on how the case company could improve its ability to utilize supplier data.

This study is conducted as action research and the theoretical information for this thesis is collected by a literature review. The literature review revealed that there are no pre-defined principles or a universal solution for supplier data monitoring and evaluation. However, the literature does offer a variety of different methods and metrics for supplier analysis. This study discovered that supplier analytics has several benefits, such as financial advantages and enhanced quality. On the other hand, utilizing supplier analytics has its challenges, for example, choosing appropriate measures for the organization and developing towards a common goal in cooperation with the suppliers. This study discovered that designing and implementing a continuous process is necessary for succeeding in utilizing supplier analytics. The most significant finding of this thesis was four requirements for building an efficient supplier analysis tool: data quality, analysis tool usability, analysis tool adaptability, and understanding the processes behind the data.

TIIVISTELMÄ

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Toimittajaverkoston laaduntuottokyvyn mittarointi – tapaus: valmistavan raskaan teollisuuden yritys

Diplomityö
2021
112 sivua, 33 kuvaa, 14 taulukkoa ja 1 liite
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Hakusanat: toimittajien laaduntuottokyky, toimittajien monitorointi, toimittajadata-analyysi, prosessilouhinta

Toimittajadatan analysoinnin tarve on kasvanut valmistavan teollisuuden keskittyessä yhä enemmän ydinsosaamiseensa ja sen myötä toimittajien merkityksen kasvaessa. Tämän työn tarkoituksena on tutkia, kuinka raskaan teollisuuden valmistava yritys voi suunnitella ja toteuttaa analyysityökalun toimittajien laaduntuottokyvyn varmistamiseksi.

Työn alussa esitellään erilaisia menetelmiä ja tavoitteita toimittajaverkoston seurantaan ja arviointiin. Työssä tuodaan esiin kirjallisuudesta havaittuja toimittajien analysoinnin hyötyjä sekä haasteita. Empiriaosuudessa kohdeyritykselle suunnitellaan toimittajien laaduntuottokyvyn analysointiin sopiva työkalu, jossa hyödynnetään kirjallisuudesta löydettyjä mittareita ja menetelmiä. Työn lopputuloksena on esimerkkianalyysityökalun lisäksi ehdotuksia kohdeyrityksen toimittajien analysoinnin edellytyksien parantamiseksi.

Tämän tutkimuksen teoriaosuus on koostettu systemaattisen kirjallisuuskatsauksen perusteella. Kirjallisuuden perusteella paljastui, ettei valmiita periaatteita tai kaikille sopivaa ratkaisua toimittajien analysointiin ole ennalta määritetty. Sen sijaan kirjallisuudesta löytyi erilaisia menetelmiä sekä mittareita oman arviointityökalun koostamiseen. Toimittajien analysoinnilla havaittiin olevan erilaisia hyötyjä, kuten kustannushyödyt ja laadun paraneminen, mutta samalla vastaan voi tulla haasteita, kuten hyödyllisten mittareiden valitseminen sekä yhteystyön tekeminen toimittajien kanssa. Tutkimuksessa havaittiin, että jatkuvan prosessin luominen analytiikan hyödyntämiseksi toimittajaverkoston kehittämisessä on tärkeää. Tutkimuksen tärkein löytö on neljä osa-aluetta, jotka ovat ennakkoehtoja toimittaja-analytiikan onnistumiselle: datan laatu, analyysityökalun käytettävyys, analyysityökalun muokkautuvuus sekä datan taustalla olevien prosessien ymmärrys.

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I wish to express my deepest gratitude to my family and friends who have supported me throughout my studies and writing this thesis. Special thanks to my sister for our insightful discussions and moments of laughter. Finally, I must thank my partner for providing me unfailing support and believing in me.

On the 30th of May 2021 in Joensuu,
Maiju Kervinen

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LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
BSC	Balanced Scorecard
DEA	Data Envelopment Analysis
ETL	Extract, Load and Transform
ERP	Enterprise Resource Planning
ICT	Information and Communications Technology
GDPR	General Data Protection Regulation
KPI	Key Performance Indicator

MES	Manufacturing Execution System
MMS	Material Management System
PDM	Product Data management System
R&D	Research and Development
SPM	Supplier Performance Management
SQA	Supplier Quality Assurance
SQL	Structured Query Language
SCM	Supply Chain Management
WMS	Warehouse Management System

1 INTRODUCTION

This study examines how supplier data can be utilized for continuously improving the supplier network in a heavy equipment manufacturing company. This thesis strives to answer what to monitor and evaluate about the supplier network and how the supplier data can be processed into information supporting decision-making and continuous improvement. The objective is to examine the requirements for successfully implementing a supplier analysis tool by building one for the case company.

1.1 Background of the study

The importance of suppliers grows as companies become more focused on their core competencies to improve their performance. At the beginning of the 21st-century, purchasing costs formed on average half of the total costs of the whole industry sector in the US and Sweden. In 2010 the share of purchasing costs had grown to 70-80 percent of total expenses. (Gadde & Håkansson 2010, p. 4; Gadde et al. 2001, p. 5) Suppliers do not only affect the total cost of a product, but the quality and timeliness are also dependent on suppliers' performance (Reiss 2010). The toughening competition between companies is changing towards generating the best supply chain instead of competing head-to-head. The competition leads to the requirement to increase the competitiveness of supply chains (Antai 2011, pp. 162–163; Rosenberg 2020; Urbaniak 2015, p. 42).

One way to approach the competition is to analyze supplier data to understand the supplier network better and continuously improve it. The amount of existing data has grown, and digitalization has made it possible to utilize the data to supply chain development purposes (Mrozek et al. 2020, pp. 20 and 49). Exploiting supplier-related data allows the customer company to uncover hidden waste and cost drivers, increase performance visibility, mitigate risks and improve supplier performance (Gordon 2006, pp. 2–3). Managing information about suppliers and their performance also enables improving supplier relationships (Grimster 2020). Continuous improvement of supply chains leads to greater efficiency and profitability of the chains (Rosenberg 2020).

The challenge with utilizing supplier data analysis is creating a practical approach that will lead to receiving a return on investment in supplier evaluation (Gordon 2006, p. 3). The data might be available, but its utilization often requires organizational change, suitable tools, and enough analytical thinking competency. Involving employees from many organizational levels, good communications, and time are also commonly needed resources (Gordon 2008, p. 15). The benefits of supplier analysis can be broad if the process is given enough resources and planned carefully.

The literature about supplier analytics does not give a straight answer to what kind of supplier analysis solution would be the most beneficial. Instead, Mrozek et al. (2020, p. 74) and O'Brien (2014, p. 95) state that there are no universal solutions for analyzing suppliers. Literature reveals many different evaluation metrics, analysis tools, software, and visualization techniques available. Choosing the appropriate methods requires a company-specific approach to the challenge.

This master's thesis is conducted on behalf of a heavy equipment manufacturing company. The company has a broad supplier network and a lot of supplier data on hand. The case company wants to improve its supplier network by utilizing the data. A practical prototype tool for analyzing supplier quality assurance will be created for the case company during this study. Based on the observations made while implementing the tool, recommendations are made for the case company to improve its ability to utilize supplier analytics.

1.2 Research questions & limitations

As there are no universal solutions for supplier data analysis, this study goes through what kind of methods are presented in the literature to analyze and utilize supplier data. This study aims to comprehensively review the whole process of supplier data analysis, from choosing the metrics for monitoring suppliers to visualizing the supplier data. Supplier quality assurance has been selected as the perspective for supplier data analysis as it is an essential concept for the case company.

The first research question examines what kind of methods are defined in the literature to track and evaluate supplier performance. It also discovers how supplier quality assurance can be ensured using the tracking and evaluation results. The first research question and its sub-questions are defined as follows:

1. *How can supplier quality assurance be monitored and evaluated using supplier data based on the literature?*
    a. *What are the methods to track and evaluate supplier performance?*
    b. *How can the information gained from analyzing supplier performance be used for continuous improvement purposes?*
    c. *What benefits and challenges analyzing supplier quality assurance can have?*

The second research question assesses how the discovered methods can be utilized in a heavy equipment manufacturing company. The second research question is:

2. *How to design a management tool for supplier quality assurance for a heavy equipment manufacturing company, and which characteristics and functionalities should it include?*
    a. *What factors limit building the analysis tool?*
    b. *How should an ERP system be specified to support implementing the tool?*

The second research question examines what limits and challenges occur when designing an analysis tool for the case company. The current state of supplier analytics in the case company is assessed and a prototype analysis tool is designed and implemented to discover the limits and challenges. Building the demonstration tool allows inspecting what challenges occur while collecting the data, constructing the data model, and visualizing the data. As most of the supplier data comes from the case company's ERP system, specification requirements for how the ERP system should support supplier data analysis are presented based on the findings of this study. The final product of this thesis is a set of recommendations and guidelines for building an analysis tool for supplier quality assurance in the case company.

The first limitation of this study is to limit the analysis to focus only on supplier networks. As the case company intends to gain good insights on procurement analytics, the analysis of other company operations will be excluded from this study. Analyzing warranty claims will also be excluded from this thesis as the principles for handling warranty claims are not consistent in the case company. Therefore, the warranty process is difficult to analyze without a deep understanding of the warranty system. The second limitation of this study is to limit the evaluations to existing suppliers. New supplier selection will not be addressed. New supplier selection is an essential part of building an efficient network. Still, as the case company already has a broad supplier network, the main challenge is improving supplier performance and relationships within the existing suppliers. The third limitation is keeping the focus on descriptive analytics using historical data to describe what has happened and why. Analyzing supplier data is a relatively new concept for the case company, and according to the literature, it is in its infancy in other companies as well. Therefore, descriptive analytics is a reasonable way to start building an analysis system. After descriptive analytics is applied, focusing on predictive analytics can be considered.

1.3 Research methodology

In this study, a literature review is conducted to study supplier quality assurance, monitoring the supplier network, and utilizing supplier data. The literature findings are used as guidelines for designing a solution for the case company in the empirical part of this study. The methodology of this study is qualitative research with some features of quantitative analysis as some numerical supplier data is analyzed. This study is a case study executed as action research. This approach was chosen because the aim is to develop a company-specific solution for the case company. By using the action research method, supplier analysis is developed towards satisfaction during this study, and improvement recommendations are discovered for the case company.

1.4 Conceptual framework and structure of the study

The conceptual framework of this study (figure 1) is formed around the concept of supplier data analysis. The supplier data analysis is divided into four main ideas, supplier data, analyzing the supplier data, interpreting the analysis results, and using the outcomes to improve supplier quality assurance continuously. O'Brien (2014, p. 109) highlights the importance of considering monitoring suppliers as a process, and therefore the process-thinking has been included in the conceptual framework.

Figure 1 The conceptual framework of the study

The structure of this study is presented in figure 2. The theoretical part discusses the concepts of the supply chain, supply network, and supplier quality assurance. A variety of monitoring and evaluation methods for supplier quality assurance are discovered from the literature. In addition to the methods for assessing supplier quality assurance, the concept of supplier data analysis is examined in the theoretical part.

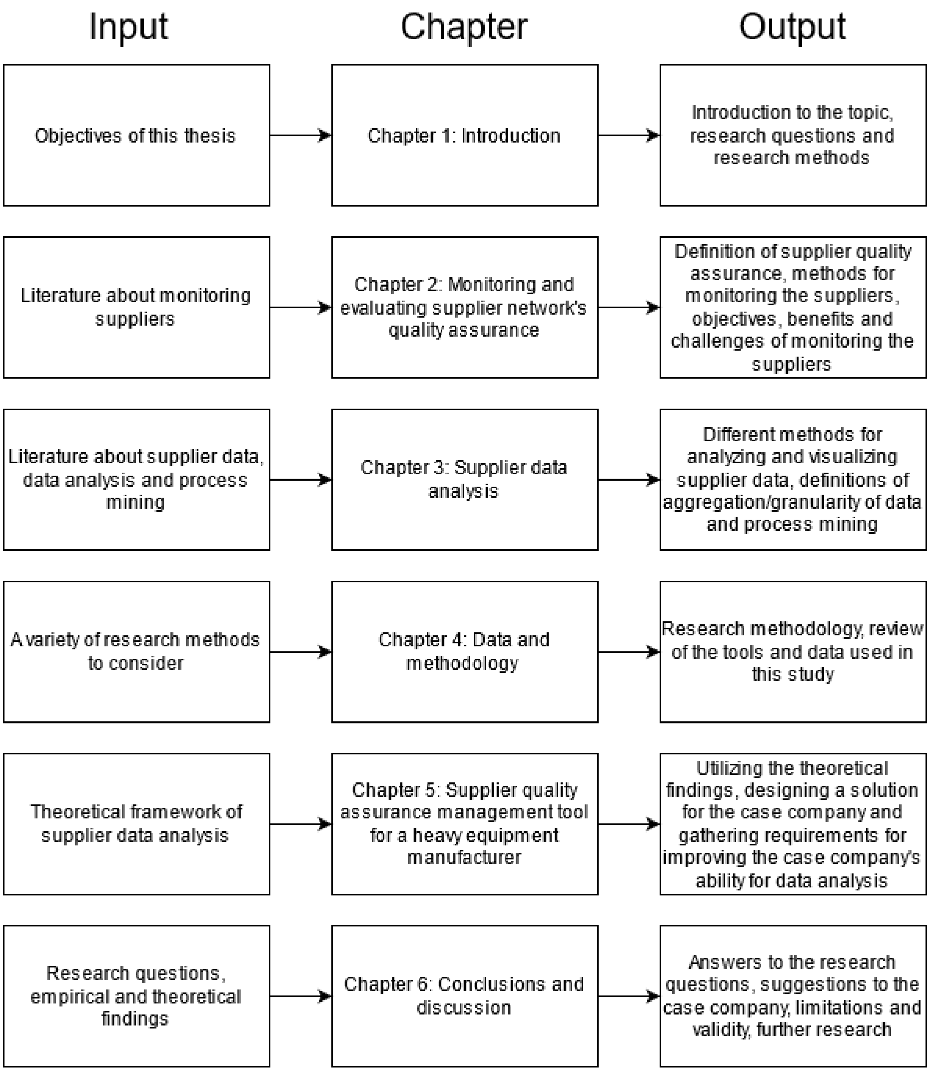


Figure 1 The structure of this study

The fourth chapter begins the empirical part of this study by discussing the data and methodology used. In chapter 5, the current state of monitoring the supplier network in the case company is examined, the analyzed purchasing and supplier quality processes modeled, and a management tool for supplier quality assurance designed for the case company. Based on the observations made while developing the tool, requirements for increasing the case company’s ability to efficient supplier data analysis are presented. In the last chapter, the results are revealed, and research questions are answered. The limitations and validity of this study are assessed, and further research is suggested.

2 MONITORING AND EVALUATING SUPPLIER NETWORK'S QUALITY ASSURANCE

"If you cannot measure it, you cannot manage it" is a common saying and also holds in supply chain management. Companies cannot improve the performance of processes that are not evaluated, and evaluations cannot be done without proper measurements (Csikai 2010, p. 30; Gunasekaran et al. 2004, p. 334). In this chapter, the concepts of supplier network and supplier network's quality assurance are examined. Then, measurements for supplier quality assurance and different methods for evaluating suppliers are discovered. Finally, the possible benefits and challenges of monitoring supplier network's quality assurance are researched.

2.1 Supply chain & supply network

Although the terms supply chain and supplier network are often used interchangeably, they have different meanings (Slack et al. 2009, p. 212). A supply chain is a network of resources involved in creating and delivering a good or service from raw materials and subcomponents to consumption (Prater and Whitehead 2012, p. 8-9). A supplier network consists of many supply chains. In a vast supply network, there might be plenty of supply chains linked when conducting a single operation (Slack et al. 2009, p. 212). According to Rezapour et al. (2018, pp. 2–5), a supply network involves all participants delivering a product or a service from a supplier to the end customer. Rezapour et al. describe that all participants add value to the product as it goes through the network. They also mention that a supplier network describes the material, information, and financial flows between the participants. Table 1 illustrates the differences between a supply chain and a supplier network. Braziotis et al. (2013, p. 649) have concluded that a supply chain is focused on products and services, whereas a supply network focuses on relationships. They consider a supply chain as a linear ongoing, relatively stable, simple system. A supply network instead is a highly complex non-linear dynamic system.

Table 1 Supply chain and supplier network based on (Braziotis et al. 2013, p. 649)

	Supply chain	**Supplier network**
Focus	Product/Service	Relationships
Design and configuration	Linear, relatively stable	Non-linear, dynamic
Complexity	Low	High

A supply network consists of a supply-side and a demand-side (figure 2). The supply side of the network provides the inputs directly or indirectly to the manufacturing organization. On the demand side, there are all of the supply chain participants involved in handling a manufactured product. (Kawa and Maryniak 2018, pp. 23–24)

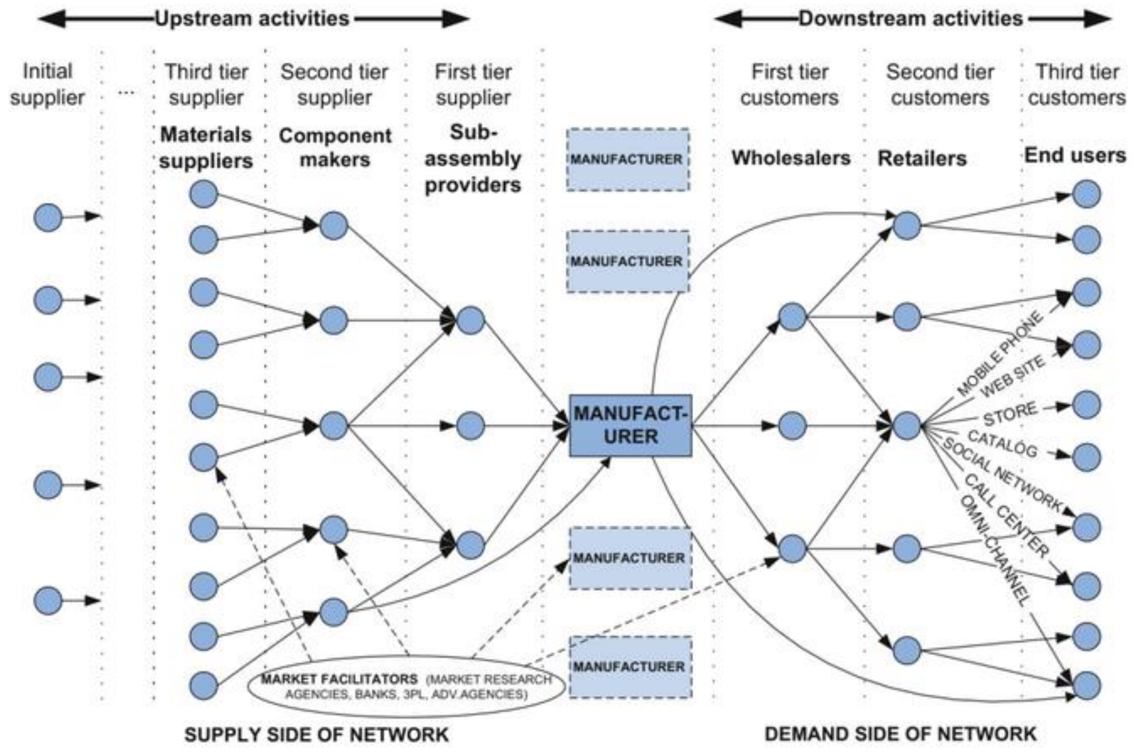


Figure 2 Supply-side and demand side of a supply network (Kawa and Maryniak 2018, p. 24)

Figure 2 gives an idea of how many participants a supplier network consists of, even if there are only ten suppliers and ten customers involved. As the supplier network is a broad concept, this study is limited to focus only on the supply side of the supplier network.

2.2 Supplier quality assurance

Purchasing functions in an organization can be divided into four categories – supplier sourcing, supplier integration, *supplier quality assurance*, and supplier development. The importance of each of these functions is compared in figure 4 below. Sourcing and implementing suppliers are the most essential and traditional functions. In contrast, supplier quality assurance and supplier development are more rarely conducted and require that the suppliers are already a part of the supplier network. (Marksberry 2012, p. 335)

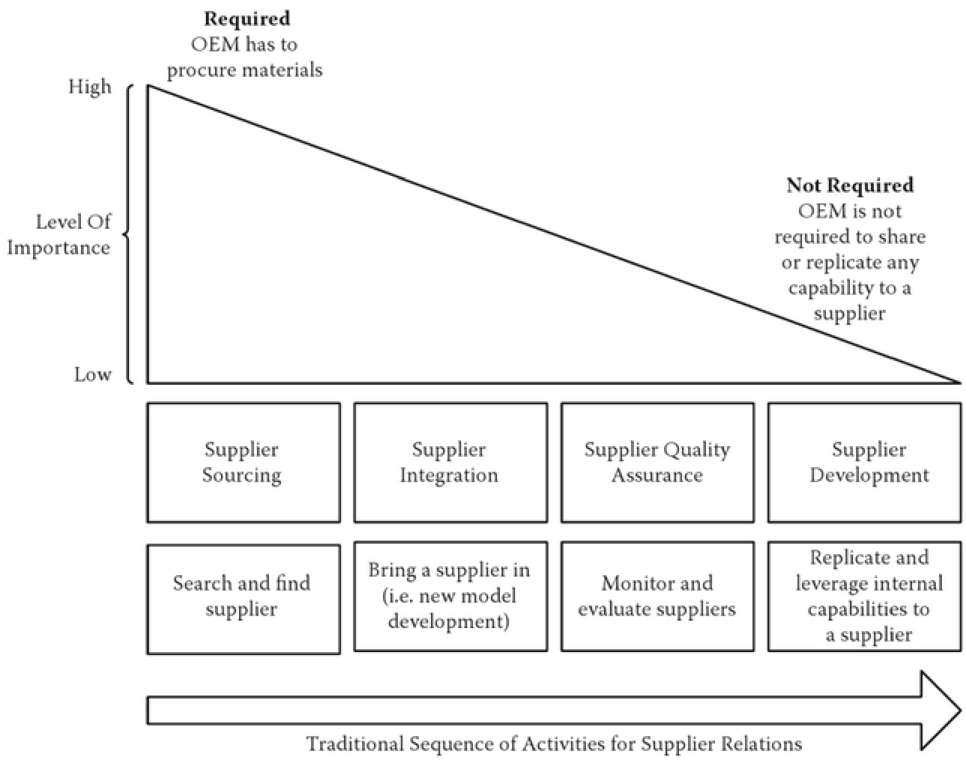


Figure 3 The importance and sequence of supplier relation activities (Marksberry 2012, p. 335)

Supplier quality assurance (SQA) represents a supplier's capability to deliver a good or a service that fills the requirements defined by the customer. Achieving quality assurance obliges suppliers to develop and manage a quality system that is effective and objectives attaining. (Karapetrovic and Willborn 1998, p. 116) Manufacturing companies' production output is highly dependent on how well suppliers perform (Slack et al. 2009, p. 210). A supplier might be unable to deliver products according to specifications at the expected time. In this case, the supplier might impact the manufactured product's market success and increases the manufacturer's on-costs (Csikai 2010, p. 29). Also, if one operation in the chain fails, the failure can be multiplied through the chain (Slack et al. 2009, p. 210). This underlines the importance of SQA and supplier development to optimize the possible failures.

Higher supplier quality results in fewer material defects and inspections (United States General Accounting Office 1996, p. 13). Monczka et al. (2020, pp. 306–307) define that zero defects can be understood as the only proper performance standard representing total quality. They also state that any deviation from the target is an opportunity lost because of scrap, rework, and possible customer dissatisfaction. Monczka et al. conclude that eliminating product and process variability is the key to producing high quality.

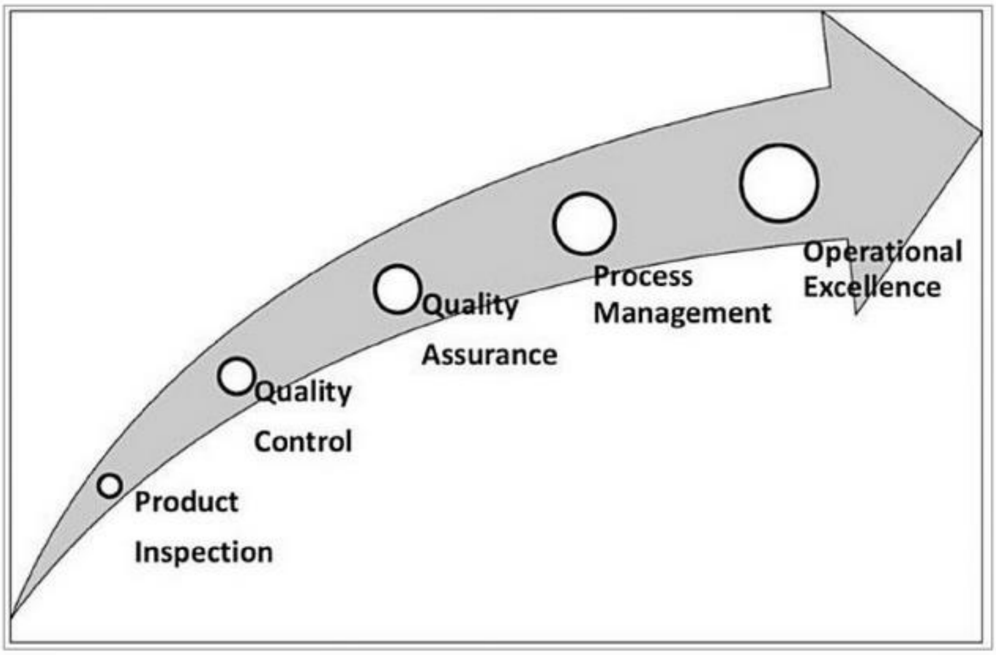


Figure 4 The states of managing supplier quality (Hutchins 2018)

Figure 4 above presents how quality assurance is linked to the overall evolution of quality in an organization. Quality assurance is in the middle of the path and necessary for process management and eventually achieving operational excellence. Achieving operational excellence requires an advanced level of quality management, such as analyzing suppliers, second-tier and lower suppliers, and direct suppliers. (Hutchins 2018)

2.2.1 The management process for supplier quality assurance

Supplier performance needs to be monitored and evaluated to improve supplier quality assurance (Marksberry 2012, p. 335). Therefore, a supplier performance management (SPM) process is introduced as a framework for continuously improving supplier quality assurance. According to Gordon (2008, p. 14), supplier performance management is approachable if a good management process is developed, implemented, and maintained. An efficient SPM system measures the right things and the right suppliers at the right time and usefully outputs the resulting information (O’Brien 2014, p. 108). Supplier management should be considered as a process instead of an event to manage suppliers effectively (Gordon 2008, p. 14).

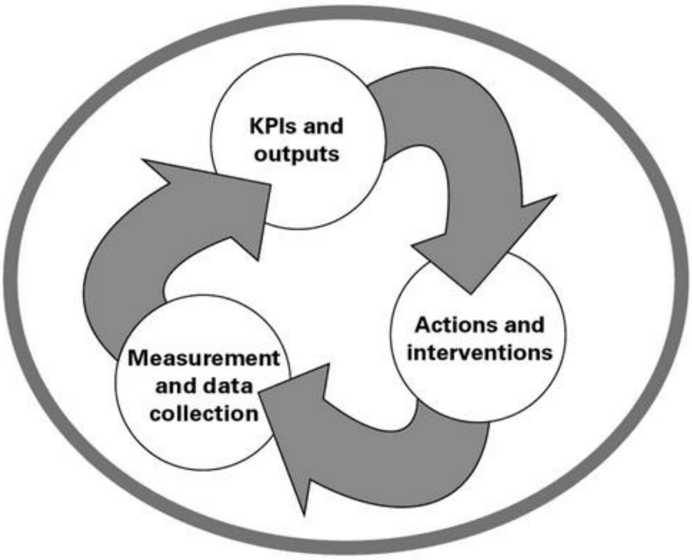


Figure 5 The process of supplier performance management (O’Brien 2014, p. 109)

One way to model the SPM process is shown in figure 5. The process incorporates three main components – analyzing the data, interpreting the results, and acting based on the analysis outputs. As the model suggests, an efficient approach to SPM is a closed-loop model where the process is continuously executed (O’Brien 2014, p. 109). Five following steps need to be concluded to build the process (O’Brien 2014, pp. 111–112):

1. Determining the overall goal for SPM
2. Determining requirements and targets to be satisfied and achieved
3. Determining KPIs indicating how the supplier is getting towards the set requirements and targets
4. Designing the measurement system to collect data and produce KPIs
5. Defining the output using the KPIs with supporting measures so that the output is visible to the right people in the process

This five-step implementation process indicates that proper planning is vital for SPM to succeed. Fernandez (1994, pp. 49–50) points out other important factors to consider when forming a process for managing supplier performance. According to Fernandez, establishing trusting customer-supplier relationships and integrating the suppliers into the system is important for success. Solid relationships with suppliers allow helping the suppliers to develop their operations. Gordon (2008, p. 14), O’Brien (2014, p. 109), and Fernandez (1994, pp. 49–50) have acknowledged the importance of continuous improvement during the process. Continuous improvement is the principle that when an unwanted occurrence happens, it should be reflected on and used as a driving force for change throughout the organization (Liker and Franz 2011, p. 2). Liker and Franz amplify that continuous improvement can be both minor changes and fundamental innovation. Continuous improvement of suppliers requires giving feedback to the suppliers about their performance (Fernandez 1994, pp. 49–50).

2.2.2 Indicators of supplier quality assurance

To be able to measure supplier quality assurance, monitored indicators need to be chosen. As Dey et al. (2015, pp. 4-5) state, there are multiple ways to categorize different supplier evaluation criteria. One way to measure SQA is by using traditional supplier performance indicators - cost, speed, flexibility, dependability, and quality. These indicators are important singularly but also dependent on one another (Prater and Whitehead 2012, p. 11; Slack et al. 2009, p. 217). All these criteria do not have to be used, but more criteria will give a broader perspective on supplier performance. For instance, Monczka et al. (2020, p. 329) have used three of the traditional measurement criteria: delivery performance, quality performance, and cost reduction.

A book by Hutchins (2018) defines that the aspects suppliers need to improve continuously are quality, cost, technology, and delivery process. Hutchins states that these four elements significantly impact industrial and commercial buy decisions. Technology is an aspect that the traditional indicators do not consider but could be helpful for companies to measure as the usage of technology can make operations more efficient. Technology might be more challenging to measure than the traditional measures and be more useful in supplier selection than measuring performance.

Dey et al. (2015, p 14) examine the following measurement criteria used in studies: quality performance, delivery performance, costing performance, organizational capability, environmental practices, social practices, and risk management practices. Dey et al. have taken the three most common of the traditional criteria, quality, delivery, and cost, and added some modern indicators to take environmental, social, and risk factors into account, as Kshetri (2018, p. 85) also suggest. Innovation, management, morale, and safety of suppliers can also be monitored (Imai 1997, p. 109).

Ho et al. (2010, p. 21) have studied the popularity of supplier evaluation and selection criteria. The study discovers that the most popular supplier evaluation and selection criteria are quality, delivery, price or cost, the capability of manufacturing, service, management technology, research and development, finance, flexibility, reputation, relationship, risk, safety, and environment in the order presented. Suraraksa and Shin (2019, p. 5) have used literature surveys and discussions with experts to define the criteria for evaluation. They found seven categories: cost, quality, capacity, service, finance, ICT, and sustainability. Also, Suraraksa and Shin (2019, pp. 12–13) have examined which supplier monitoring dimensions are the most important. The two most important aspects were found out to be quality and capacity. Service held third place and cost came fourth in the study.

In the literature, most of the studies about monitoring supplier data are done regarding supplier selection, whereas supplier monitoring is not a common topic. In addition to a study by Ho et al. (2010, p. 21), an article from Suraraksa and Shin (2019) describes criteria for both supplier selection and supplier monitoring separately. The report reveals that most of the supplier selection criteria can also be used for supplier monitoring. Still, there exist also measures that are suitable only for supplier selection or monitoring. For example, a supplier's sustainability and ICT systems are factors primarily used for supplier selection (Suraraksa and Shin 2019, p. 8).

Table 1 Supplier performance monitoring dimensions (three most common bolded and the authors in alphabetical order)

Supplier performance dimensions	**Author**
Quality, delivery, cost, organizational capability, environmental practices, social practices, risk management	(Dey et al. 2015, p. 14)
Safety, **quality, delivery, cost**	(Graban 2014)
Quality, cost, delivery, morale, safety	(Imai 1997, p. 109)
Cost, speed, dependability, risk reduction, sustainability, flexibility	(Kshetri 2018, p. 85)
Quality, cost, delivery	(Manalo and Manalo 2010, p. 869)
Quality, delivery, price, claims	(Pikousová and Průša 2013, p. 2)
Quality, cost, speed, flexibility, dependability	(Prater and Whitehead 2012, p. 11; Slack et al. 2009, p. 217)
Quality, cost, delivery, innovation, management	(SKF 2021)
Cost, quality, capacity, service, finance, ICT, sustainability	(Sullivan and Manoogian 2009, p. 15; Suraraksa and Shin 2019);
Quality, price, delivery, service	(Varley 2013, p. 83)

As concluded in table 1 above, quality, cost, and delivery are the most used supplier evaluation criteria. Shankar (2009, p. 17) states that monitoring and evaluating these three criteria can help recognize areas for continuous improvement. Supplier *delivery* performance indicates how well a supplier meets the required quantity and delivery due date (Monczka et al. 2020, p. 329). It is also a sign of the capability of the supply chain providing goods to the customer (Rao et al.

2011, p. 205). Examples for monitoring delivery performance are lead time (the time between order and delivery) or performance against agreed delivery times (CIPS 2021). Supplier *quality* performance can be evaluated in many ways, such as assessing suppliers' quality performance against previously defined objectives, tracking improvement rates and trends, or comparing similar suppliers together (Monczka et al. 2020, p. 329). Supplier quality measurements can be separated into four aspects: product quality, service quality, process quality, and organizational quality (Noshad and Awasthi 2015, p. 470). Suraraksa and Shin (2019, p. 8) divide the third monitored aspect, *cost*, into three categories: production, ordering, and logistics costs. Cost reduction is the main goal of monitoring costs and can be done by tracking supplier's actual costs or comparing suppliers from the same industry together (Monczka et al. 2020, p. 329).

One insightful measurement for both quality and cost is the cost of quality. The concept of cost of quality was developed in the 1950s but is still widely unused in process improvement. The real impact of quality costs might be difficult to notice as the quality costs are combined into different overhead expenses. Quality costs consist of costs of conformance and improving quality or avoiding poor quality costs. (Monczka et al. 2020, p. 307) In addition to the cost of quality, commonly used indicators for quality, cost, and delivery are presented in table 2.

Table 2 Indicators for quality, delivery, and cost

Criteria	**Indicators**
Quality	Acceptable parts per million (Noshad and Awasthi 2015, p. 470)
	Costs of quality (Noshad and Awasthi 2015, p. 470)
	Defect rate (Noshad and Awasthi 2015, p. 470)
	Mean Time Between Failure (CIPS 2021)
	No of supplier corrective action requests and the average corrective action request response time (Teli et al. 2012, p. 329)
	Order defect rate (Sullivan and Manoogian 2009, p. 15)
	Perfect rate (Noshad and Awasthi 2015, p. 470)
	Rejection from customers (Noshad and Awasthi 2015, p. 470)
	Rejection in incoming quality (Noshad and Awasthi 2015, p. 470)
	Reliability of quality (Noshad and Awasthi 2015, p. 470)
	Warranty claims (CIPS 2021)

Cost	Cost of poor quality (Noshad and Awasthi 2015, p. 468)
	Cost reduction (CIPS 2021)
	Logistics costs (Sullivan and Manoogian 2009, p. 15; Suraraksa and Shin 2019, p. 8)
	Ordering costs (Sullivan and Manoogian 2009, p. 15; Suraraksa and Shin 2019, p. 8)
	Production costs (Suraraksa and Shin 2019, p. 8)
	Total cost reduction year-over-year (Teli et al. 2012, p. 329)
Delivery	Information richness in carrying out delivery (Gunasekaran et al. 2004, p. 345)
	Lead time (the time between order and delivery) (Varley 2013, p. 84)
	Number of early deliveries (Teli et al. 2012, p. 329)
	Number of late deliveries (Teli et al. 2012, p. 329)
	Percentage of on-time deliveries (Teli et al. 2012, p. 329)
	Percentage of urgent deliveries (Gunasekaran et al. 2004, p. 345)

In addition to these example indicators, various metrics are provided in appendix 1.

2.3 Methods for evaluating a supplier network

Once the indicators for supplier performance are defined and implemented, evaluations can be concluded (Gordon 2005, p. 22). The first time supplier evaluation was considered in the literature was in the 1960s, and the importance of supplier evaluation has been acknowledged by several researchers (Narasimhan et al. 2001, p. 28-29). In the literature, there are various methods used for evaluating suppliers presented in table 3.

Table 3 Evaluation methods and frameworks for supplier evaluation

Supplier evaluation technique or framework	**Used for**	**Source**
ABC-analysis	Categorization, such as differentiating between suppliers	(Hofmann et al. 2012, p. 119; Kirst 2008, p. 33)

Analytic hierarchy process (AHP)	Finding the best solution from various dependable independent criteria	(Bogdanoff 2009; Ho et al. 2010, pp. 16–21; Willis et al. 1993, p. 2)
Analytic network process (ANP)	Finding the best solution from various possibly dependent criteria	(Ho et al. 2010, pp. 16–21)
Balanced scorecard	Performance monitoring system balanced between financial and non-financial measures	(Bhagwat and Sharma 2007, pp. 59–60)
Case-based reasoning	Reasoning based on previous experience; evaluating how well suppliers meet set specifications	(Ho et al. 2010, p. 18; Richter and Weber 2013, p. 18)
Categorical method	Rating suppliers with equally weighted attributes to compare them	(Willis et al. 1993, p. 1)
Cost Ratio Method	Rating suppliers based on cost analysis	(Willis et al. 1993, pp. 1–2)
CUSUM chart	Using previous samples for process control; detecting small changes	(Misra 2008, p. 192)
DEA-modeling	Measuring efficiency based on input and output values; rating and comparing suppliers	(Falagario et al. 2012, p. 525; Ho et al. 2010, pp. 16–21; Milan et al. 2009, p. 37)
Dimensional Analysis method	Combining criteria of different dimensions using relative positive or negative weights	(Loong 2018)
Design structure matrix (DSM)	Investigating relationships between components of a system, such as modeling cross-functional interactions of supply chain management	(Browning 2001, p. 292; Son et al. 2017, p. 232)
EFQM	A European framework for change leadership and performance improvement	(EFQM 2019)
ISO 9000	A standard for quality management	(Bedey et al. 2008, p. 126)
Linear programming	Evaluating suppliers based on targets and constraints, such as selecting suppliers by maximizing supplier score	(Ho et al. 2010, pp. 16–21)
Malcolm Baldrige Quality Award	A framework for quality management focused on continuous improvement	(Curkovic and Handfield 2006, p. 5)

Six Sigma	A group of tools and principles for process improvement; supplier performance evaluation	(Firat et al. 2017, p. 37; Tennant 2017)
SMART	Multi-attribute rating technique for improvement goals	(Conzemius and O'Neill 2009)
Supplier performance index (SPI)	Assessing total costs of supplier cooperation	(NC State University 2011)
Supply chain operations reference model (SCOR)	Analysing supply chains from four aspects: source, make, deliver and plan	(Huan et al. 2004, p. 24)
TOPSIS	Ranking alternatives by similarity to ideal solution	(Esfandiari and Rizvandi 2014, p. 1445)
Weighted-Point Method	Rating suppliers based on weighted performance attributes	(Willis et al. 1993, p. 1)

From these methods, seven are studied in more detail. ABC-analysis and balanced scorecard were chosen for further exploration because they are commonly known methods. The categorical, weighted point, and cost ratio methods will also be explored more, as they are relatively simple, informative techniques. In addition, analytic hierarchy process and data envelopment analysis are studied as they are common in literature and can be used for multi-criteria decision making, which is necessary for supplier performance management.

2.3.1 ABC-analysis

ABC-analysis (also known as Pareto analysis) can be used for identifying the critical and less essential suppliers as well as for supplier segmentation (Hofmann et al. 2012, p. 119; Kirst 2008, p. 33). When evaluating suppliers, this method can help decide which suppliers are the most important ones to monitor and which do not need as much attention. The technique allows to segment suppliers based on for example purchase volume.

The results are grouped into three categories, A, B, and C. Group A represents the smallest group, 10-20%, of suppliers that have the largest purchase volume and therefore, it is the most critical group. A group has 10-20 percent of the suppliers, B group has 30-50 percent, and C group 40-70 percent. Group A has the most significant purchase volume, and group C the lowest. (Moore et al. 2007, pp. 27–28) Figure 6 demonstrates the differences between these three groups.

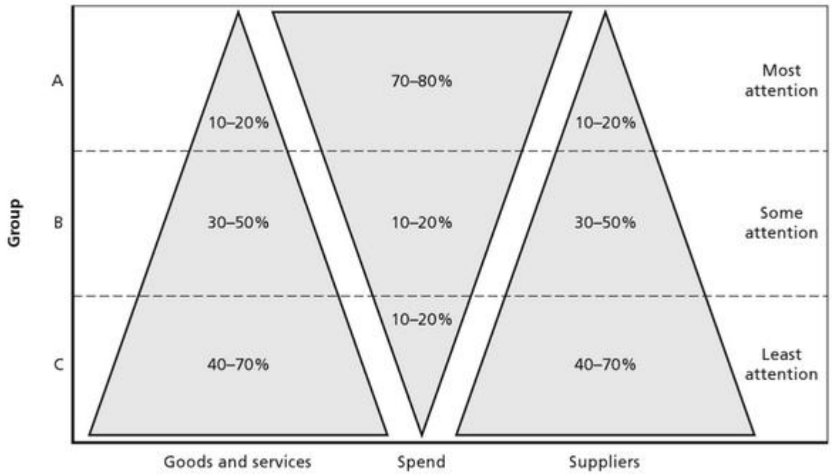


Figure 6 ABC-analysis groups (Moore et al. 2007, p. 28)

ABC analysis can also be done by using two categorizing criteria (Ølgod 2018), such as both purchase volume and delivery frequency. Using double ABC analysis allows taking both financial and non-financial aspects into account. If a supplier is categorized to group “A” for both purchase volume and delivery frequency, it belongs to group “AA” and so on (Ølgod 2018). The importance of the resulting categories is illustrated in figure 7.

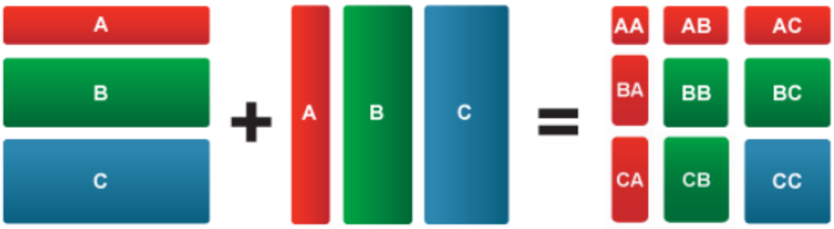


Figure 7 Double criteria ABC-analysis (Ølgod 2018)

Even though ABC analysis helps to pay attention to the most important suppliers, suppliers in the “B” and “C” categories should not be neglected either (Merrit 2019). All suppliers are essential to the operation of the whole supplier network. Nikolakopulos (2019) notes that ABC analysis can be resource-consuming as it needs to be conducted frequently. For that reason, in supplier analysis automating the ABC-analysis process could be beneficial.

2.3.2 Analytic hierarchy process

The analytic hierarchy process (AHP) is a decision-making method helping to find the best solution from various dependable criteria (Politis et al. 2010, p. 411). AHP helps to break down a complex multi-criteria challenge into levels of hierarchy (Loong 2018). The highest level represents the goal, the intermediate level consist of the criteria and sub-criteria, whereas the lowest level has all the alternatives (figure 8).

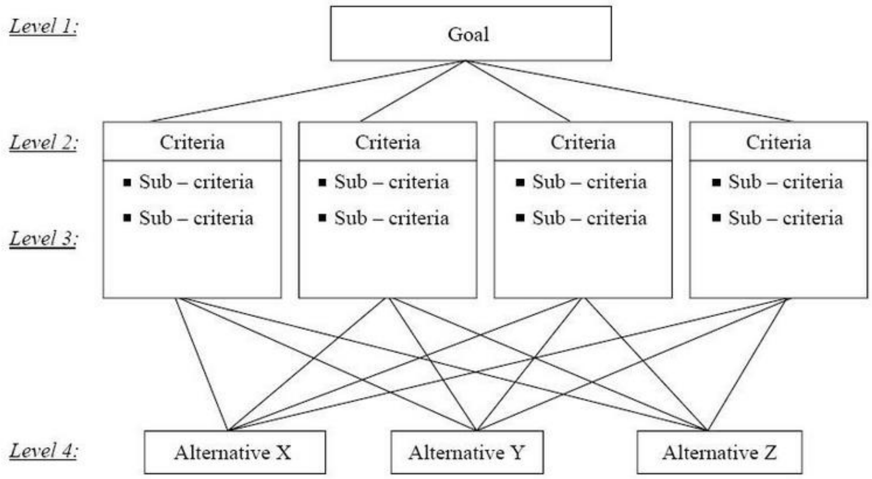


Figure 8 The structure of the analytical hierarchy process (Loong 2018)

When the goal, criteria, and alternatives have been defined, AHP is conducted by calculating the eigenvector for each supplier, and the results are normalized to make them comparable. After the calculations have been executed, the results indicate which alternative is the closest to achieving the goal. (Bogdanoff 2009, p. 106) The results need to be analyzed to discover why a specific supplier has a high or low resulting score.

AHP is often criticized over one issue – it does not handle uncertainty at all. When AHP is used, the qualitative criteria need to be precise. In some cases, describing criteria precisely in qualitative form can be challenging. This challenge can be solved with a modified fuzzy version of AHP. (Chan et al. 2008, pp. 3850–3851) Overall the AHP is usable for both – comparing suppliers together and evaluating certain suppliers in more detail. It requires more complex calculations than most of the discovered methods but gives beneficial results that can be analyzed in detail.

2.3.3 Balanced scorecard

A balanced scorecard (BSC) is a system to monitor performance that allows a company to access both financial measures reflecting the past and non-financial measures indicating the future (Kaplan and Norton 1996 pp. 8, 24–25). Niven (2002 p. 12) defines a balanced scorecard in three ways: a measurement system, a strategic management system, and a tool for communication. A balanced scorecard has four perspectives: financial, customer, internal business process, learning, and growth, and these aspects should be linked to company vision and strategy (Kaplan and Norton 1996). In the context of supplier analysis, supplier scorecards are a tool for ranking supplier's relative performance and tracking improvement in the quality of the suppliers (Noshad and Awasthi 2018, p. 2). BSC is recommended for operational daily performance monitoring (Bhagwat and Sharma 2007, p. 60). A simple example of a Balanced Scorecard is presented in table 4.

Table 4 An example of a Balanced Scorecard for supplier evaluation (adapted from Kwitko 2018)

Area	Key Performance Indicator	Measurement	Acceptable score	Score	Difference from acceptable score
Quality	KPI 1	How KPI 1 is measured	5	6	1
	KPI 2		5	4	-1
Cost	KPI 3		5	8	3
	KPI 4		5	10	5
Delivery	KPI 5		5	3	-2
	KPI 6		5	4	-1
		Overall	30	35	5

A beneficial scorecard requires defining a suitable mix of outcome measures and performance drivers that respect the company's strategy. Outcome indicators, such as market share and profitability, are necessary for measuring if the company's long-term strategic goals are achieved. Performance measures, such as cycle times or part-per-million defect rates, are used to monitor how the outcomes can be achieved. (Kaplan and Norton 1996)

The main challenge with balanced scorecards is balancing them. Often using a balanced scorecard is done by managing individual measures over short-term periods. The measures should be from a broad range and the inter-relationships considered. As Hill (2007) defines, a balanced scorecard should manage work and people instead of managing individual measures. Some practitioners of BSC assign weights to each measure to balance the scorecard. The weights are often based on expert judgment or Delphi technique, and therefore, the measures often reflect more the desired situation than the actual situation itself (Purwohedi and Ghozali 2006, p. 16). Also, if a small expert group defines the weights, they may not reflect the opinion of whole employees (Purwohedi and Ghozali 2006, p. 16). Another challenge has been noted by Bhagwat and Sharma (2007, pp. 59–60) when they have examined the usage of BSC for supply chain management. They noticed that some metrics compromise others. For example, increasing delivery reliability might compromise cost measures.

2.3.4 Categorical, weighted point, and cost ratio method

Willis et al. (1993, p. 1) have noticed that in literature, three primary methods for evaluating supplier performance are categorical, weighted point, and cost ratio methods. As these three methods are somewhat similar and straightforward, they are studied by comparing them together. The results of the comparison are shown in table 5.

The categorical method is simple; the purchaser assigns one of three values, either satisfactory (+), unsatisfactory (-), or neutral (0) for selected attributes for each supplier. The ratings are totaled for each supplier, and the total value is the supplier rating. (Willis et al. 1993, p. 1) The supplier with the highest ranking performs the best (Loong 2018). This method is intuitive and weights all the attributes equally, so the result does not reflect reality very well (Willis et al. 1993, p. 1).

From the three methods, the weighted point is highly likely the most used. In the weighted point method, weights are chosen by the relative importance of the examined performance factors. The factors are multiplied by their weights, and the products are totaled. Then the results of each supplier can be compared. (Willis et al., 1993, p. 1) In this method, the highest score indicates the best performance (Loong, 2018).

Table 5 Comparison of categorical, weighted point, and cost-ratio methods

Method	**Categorical method**	**Weighted point method**	**Cost-ratio method**
How the method is used	Setting a list of performance variables and assigning ratings to them.	Setting a list of performance attributes and weights regarding their importance level.	Calculating total company's purchasing price by using selling price and buyer's internal operating costs
Notes	Easy method, but does not represent reality well	Likely the most used, simple method, useful for comparing suppliers	Complexity and the need for a cost-accounting system limit usage

The cost-ratio method is the most complicated of these three. In the method, cost ratios for each supplier's material quality, delivery, and customer service are estimated. The costs associated with these categories are calculated and divided by the total purchasing cost. The gained percentage values are then totaled to get the overall cost ratio. (Willis et al. 1993, pp. 1–2) The best-performing supplier has the lowest net adjusted cost when using the cost-ratio method (Loong 2018). The complexity and the need for a comprehensive cost-accounting system limit the usage of the technique (Willis et al. 1993, pp. 1–2).

2.3.5 Data envelopment analysis

A literature review by Ho et al. (2010, p. 22) found data envelopment analysis (DEA) to be the most prevalent approach to supplier evaluation and selection. Data envelopment analysis compares weighted input and output measures for performance. The method is used mainly in supplier selection as it helps to compare suppliers. Input performance is the resources used by the supplier for the supply activity, such as the price of a purchase. Outputs in the model express how fair the provided service is. For instance, the outcome can be the quality of a product or delivery timeliness. (Falagario et al. 2012, p. 525)

When the input and output values and weights for each value have been defined, the calculation of efficiency value for each supplier is done by comparing the total output value with the total input value in the traditional DEA approach. If the relation between outputs and inputs is close to one, the supplier is efficient. If not, the supplier can be considered inefficient. (Falagario et al. 2012, p. 525) The formula for DEA is given by Falagario et al. (2012, p. 525):

$$\text{Efficiency} = \frac{\sum_{k=1}^{s} u_k * y_k}{\sum_{i=1}^{s} v_i * x_k}$$

In the formula, u values represent output values with y weight values. Similarly, v-values represent inputs, and x-values are the weights for the inputs. (Falagario et al. 2012, p. 525) As can be concluded from the formula, computationally DEA is simple to conduct. The challenge with this method is defining the input and output criteria and values properly. DEA is valuable when comparing suppliers, but it does not really allow to analyze single suppliers, and therefore, it might not be beneficial for managing supplier performance. However, the method could be used for deciding which suppliers need to be further analyzed.

2.4 Defining the objectives for supplier monitoring

As Pikousová and Průša (2013, p. 2) define, company strategy, philosophy and size affect what kind of supplier evaluation system is sophisticated. A common objective for evaluation is to ensure that set supplier performance criteria are met, reduce costs, mitigate risks, and identify room for improvement (CIPS 2013, p. 2; Nibusinessinfo 2021). The challenge with aiming at both low risks and low costs is that the goals are often conflicting (Yildiz et al. 2016, p. 662). The complexity of today’s supplier networks requires carefully balancing between these two goals.

Comparing the measurements with a set of chosen standards defines if the objectives are met. (Gunasekaran et al. 2004, p. 334). The standards should be both suitable for the business and respect generally accepted best practices (Gordon 2005, p. 23). There are different ways to set the standards for supplier monitoring (Gordon 2005, p. 23):

- Measuring performance against a third-party standard, for example, ISO 9001
- Using best practices such as the Malcolm Baldrige National Quality Award criteria

- Benchmarking industry leaders
- Using system data or internally collected customer feedback
- Generating a company-specific certification for evaluation

For supplier performance to be managed, the measured parameter values need to stay within chosen limit values defined by the set standards and remain comparatively constant. This way, a comparison between the planned and actual parameter values can be made and needed actions for improvements taken. (Gunasekaran et al. 2004, p. 334)

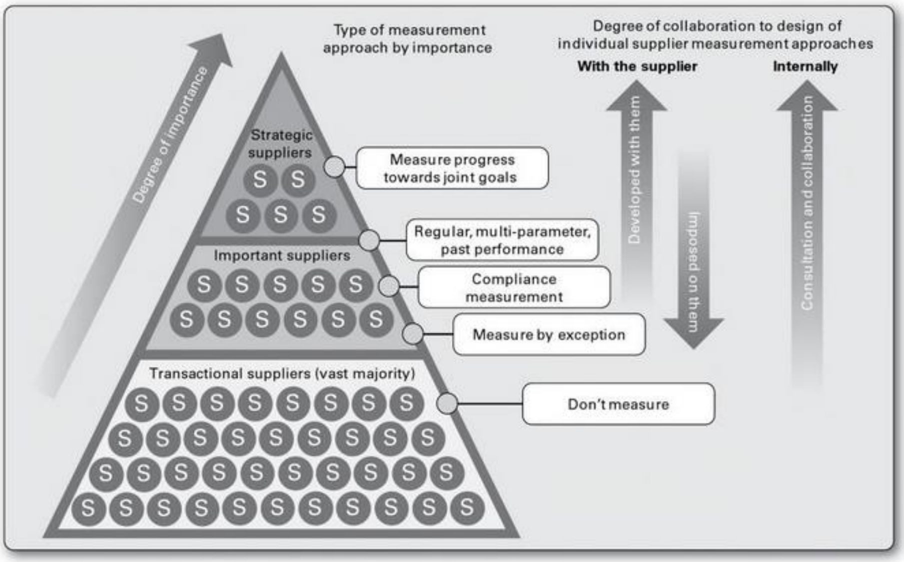


Figure 9 The difference between transactional, important, and strategic suppliers (O’Brien 2014, p. 96)

When setting the objectives, it should be noted that not all supplier network partners need to be similarly measured (Baudin 2005 p. 363; O’Brien 2014, p. 111). According to O’Brien (2014, p. 96), the suppliers can be divided into strategic, important, and transactional suppliers and evaluated differently, as figure 9 presents. O’Brien defines that transactional suppliers represent the vast majority and are not measured. Important suppliers are monitored by exception using past performance and compliance measures. Strategic suppliers are the most monitored using measures indicating how well the suppliers are moving towards joint goals.

2.5 Uses and benefits of supplier network monitoring and evaluation

Although monitoring and evaluating supplier networks can consume many resources, especially at the beginning of the process, the benefits of successful measuring are significant. Supplier performance management allows companies to improve value-adding activities instead of only reacting to problems relating to supplier performance (Gordon 2008, p. 4).

Pikousová and Průša (2013, p. 4) state that monitoring the suppliers allows to gain information about the status of the suppliers and understand how the relationship with them may affect successful business. They mention that cooperating closely with the suppliers, setting common targets, and implementing helpful measurement systems allow the relationships between customers and suppliers to grow stronger. Strong supplier relationships allow continuously improving the suppliers (Fernandez 1994, pp. 49–50). Implementing continuous improvement tools for supply chain management can enhance quality, increase effectiveness, and improve the communication and implementation of joint projects in the supply chain (Urbaniak 2015, p. 46). The main benefits of supplier measurement are illustrated in figure 10.

Figure 10 The benefits of measuring supplier performance

It is known that successful businesses such as Japanese automotive manufacturers are helping their suppliers to improve their operational processes. Assisting the suppliers to improve has a large scale of benefits from enhancing the service and possibly price, greater supplier loyalty, and commitment in the long term. (Slack et al. 2009, p. 228) According to Hartley and Choi (1996, p. 43), suppliers can often be caught up in daily activities, but the willingness to improve their processes does exist. Hartley and Choi propose that as a customer is looking at the supplier from an outside perspective, the customer may challenge the supplier organizations underlying assumptions and therefore drive improvement. Hartley and Choi also mention that supplier’s employees are found out to be more open to change when a customer is driving the improvement process. In addition to improving supplier performance and supplier relationships, measuring supplier networks also has financial benefits. In one literature review by Gunasekaran et al. (2004, pp. 345–346), 76 percent of the study participants had achieved an expected increase in return on investment by measuring supplier performance. The study also found out that systematic SCM can have an uplifting impact on market share.

2.6 Challenges of monitoring and evaluating a supplier network

The importance of supplier performance is widely understood, but many companies are unclear about what should be measured and how the results could be effectively used (Gordon 2008, p. 11). The usual challenges of monitoring suppliers are measuring the wrong things because it is easier, measuring too many things, not measuring enough, and measuring only what has happened, not what is happening (O’Brien 2014, p. 97). The chosen metrics should be aligned with the organization’s strategies and goals (Gordon 2008 pp. 14–15) to produce valuable results. The metrics meant for other companies’ purposes might not produce meaningful and actionable results, so it is often inefficient to take a template from another firm (Gordon 2008 pp. 14–15). Furthermore, the correct number of metrics is challenging to define. Often it is more valuable to use a few insightful metrics instead of a large variety of them (Bhagwat and Sharma 2007 p. 51; Gordon 2008 pp. 14–15). In addition, Bhagwat and Sharma (2007, p. 51) mention that balancing the metrics between financial and non-financial measures can also be a challenge for some companies, but it is necessary to do. Bhagwat and Sharma also recommend separating operational, tactical, and strategic level measurements to make the most appropriate decisions.

Lack of objectivity can also be a challenge when choosing the measures. Supplier evaluation techniques and metrics are often based on the subjective opinions of the purchasing department. In this experience-based method, the weights for different criteria are difficult to define objectively, and the final ranking is dependent on the selected weights. Also, if supplier evaluations are conducted in group settings, it might be challenging to reach a mutual understanding of the performance attributes. If the group changes, the decisions about the evaluations must be reconsidered. Combining managerial judgment with objective ranking methods can lead to more consistent decision-making. (Narasimhan et al. 2001, pp. 28–29)

The evaluation process might be based merely on supplier performance outcomes (for instance, cost, quality, and delivery). The issue is that the outcome itself does not describe the supplier's efficiency as the resources used by the supplier might be enormous. Having highly performing and highly efficient suppliers would be the ideal state. (Narasimhan et al. 2001, pp. 28–29) This idea is primarily understood in the automotive industry. For example, Toyota is continuously helping its suppliers to improve its system with small things that Toyota knows to be successful (Marksberry 2012, p. 353).

Another challenge is to deploy enough resources for the continuous improvement of the supply network. (Narasimhan et al. 2001, pp. 28–29) All supply chain participants need to be committed to common goals to improve supply chain performance (Gunasekaran et al. 2004 p. 346). Setting common coals can be challenging as all supply network partners might not have the same objectives (Wijnands and Ondersteijn 2006, p. 2). Gunasekaran et al. (2004 p. 346) define that the performance measurement program needs to consider all aspects of performance. They also state that the measures should be modified to match the varying needs of supply chain participants. According to Wijnands and Ondersteijn (2006, p. 2), sharing information between customers and suppliers can also challenge continuous improvement as the relevance of information can differ across different levels of the supply chain even though the information is highly relevant to the overall chain. Wijnands and Ondersteijn also define that information's strategic value often prevents freely exchanging it between supply chain participants.

The difficulty of selling the idea of utilizing supplier evaluation to senior management might prevent the implementation. Companies do not often know how to develop a good supplier performance management process that is measured and achieves return on investment. (Gordon, 2008 p. 11) As supplier evaluation requires changing business processes, employees from many levels, good communications, and time are needed for succeeding (Gordon 2008, p. 15). Implementing supplier evaluation might be entrusted to only one department, often either purchasing or quality, even though it may involve many stakeholders within the company and the supply chain (Gordon 2008, p. 14). Change management should be executed when successfully creating and implementing a process for evaluating and developing supplier performance (Gordon 2008, p. 15). Change management is a term for the tools and structures for keeping a change process under control (Kotter 2011). Implementing supplier analytics, or analytics in general, is likely to require change leadership in addition to change management. Change leadership is about the visions, processes, and forces that generate transformation (Kotter 2011).

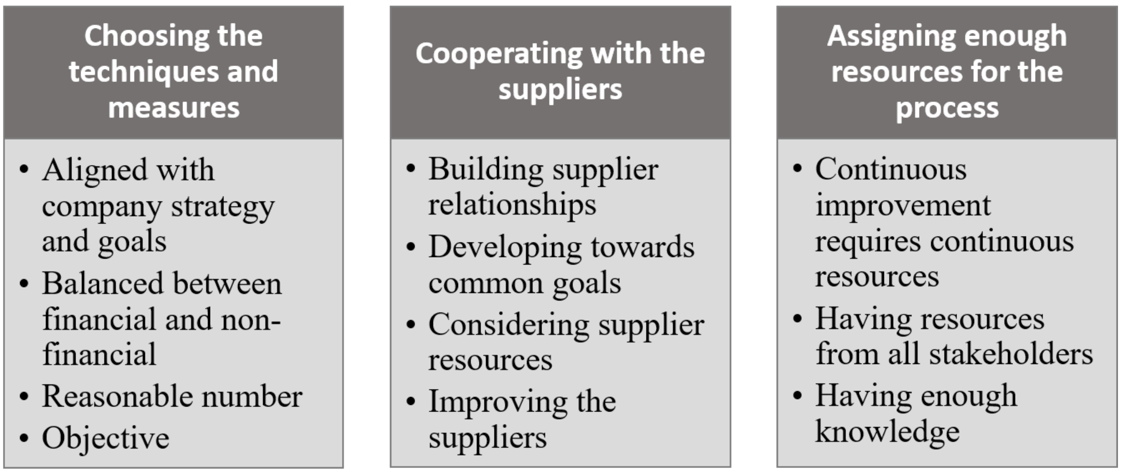


Figure 11 The challenges of monitoring suppliers

The challenges of monitoring suppliers have been concluded to figure 11 using three categories: choosing metrics, building supplier relationships, and assigning enough resources to the process. These challenges also work as a guideline for creating the supplier analysis process. Once the supplier monitoring and evaluation process has been defined – metrics and evaluation methods chosen, the objectives determined and possible challenges considered, designing the analysis tool for supplier data can begin. Therefore, the next chapter examines the concept of analyzing supplier data.

3 SUPPLIER DATA ANALYSIS

As Davenport and Harris (2017) define, data management aims to make sure that an organization has the right information and appropriately uses it. This goal can be pursued by following the five steps for data analysis presented in figure 13. In this thesis, the first two steps of the process have already been addressed in the previous chapter. This chapter examines the third and fourth steps in the process – collecting and analyzing the data. The fifth stage, interpreting the results, is also studied shortly by examining data visualization.

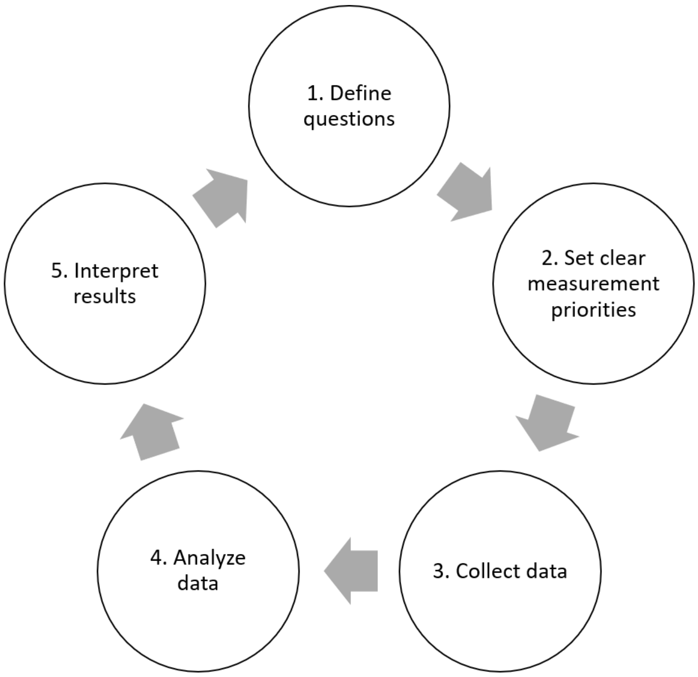


Figure 12 The data analysis process (Ewota 2020)

This chapter begins by defining the concept of supplier data. Next, four different levels of data analysis are examined to get an idea of what kind of questions supplier data analysis can answer. Three important topics related to supplier analytics, data aggregation, granularity, and visualization are reviewed. Finally, process mining is introduced as a method for analyzing supplier-related processes.

3.1 Supplier data

In 1996 Hartley and Choi (1996, pp. 38–41) recognized the importance of data-driven supplier development. Still, there are no pre-defined practices beneficial for all companies. Pearce (2019) reminds us that supply chain analytics is an evolving field of study. Pearce illustrates that just using different algorithms on data to see what happens is not the efficient way to do supplier analytics. Supplier analytics require *supplier data*, which describes all activities linked with the sourcing process (Biswas and Sen 2017, p. 6). As figure 13 shows, supplier data is one of the four aspects of data produced by a manufacturing company.

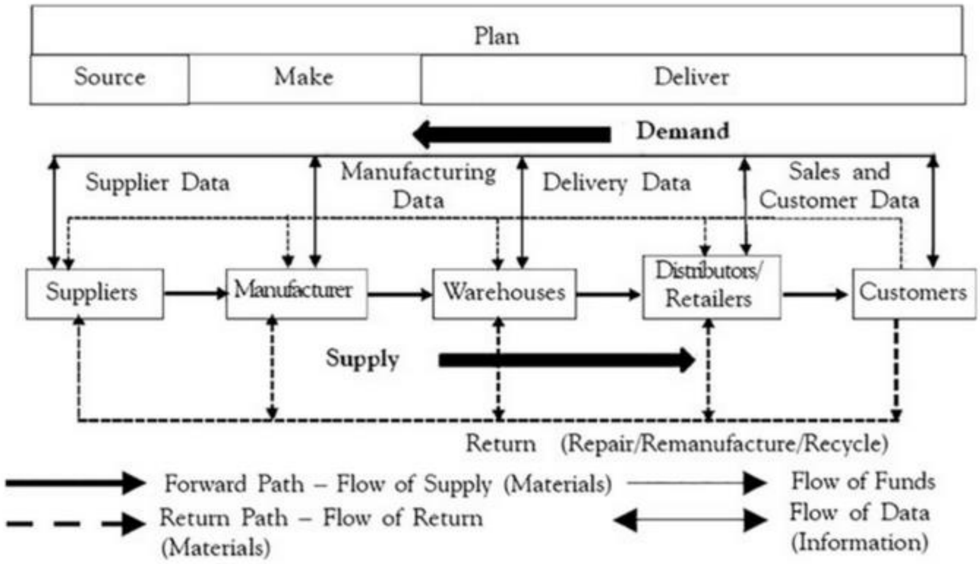


Figure 13 Data sources in a manufacturing company (Biswas and Sen 2016, p. 4)

Davenport and Harris (2017) have defined five aspects of data to regard when collecting the data for analysis: data relevance, data sourcing, data quantity, data quality, and data governance. These five points Davenport and Harris have considered can be studied with the following questions:

- What data is needed for the analysis? (Data relevance)
- Where can the required data be found? (Data sourcing)
- How much data is required? (Data quantity)

- How can the data be converted into a more accurate and valuable form for analysis? (Data quality)
- For managing the data, what rules and processes are required? (Data governance)

One web article by Greenstone (2014) states that an organization needs to decide what data about the supplier to collect, considering the industry, legislative requirements, and the chosen organizational strategy. Therefore, deciding what data to collect is an organization-specific question. Usually, the amount of collected data is large and requires appropriate handling tools (Greenstone 2014). Sievo (2021) explains that supplier data can be retrieved from internal and external data assets. According to Sievo, internal assets such as supplier-provided data and transaction data from ERP systems can be collected from inside the organization. Sievo describes external data assets to come from outside a company's databases, such as public information online. As the data can be scattered in different data sources, it should be united into one database. For example, Davenport and Harris (2017) describe how an American company GE had multiple overlapping supplier data sources. Different business units had their supplier databases across many transaction systems. The company decided to create an integrated database. That made it possible to press active suppliers for volume discounts. The company has estimated that the benefits from this project in the first year were 80 million dollars.

When collecting data, data security needs to be considered. The book of Franks (2020, p.194) defines three understandable ethical rules for implementing analytics in supply chains. The first rule is about autonomy, as people need to be able to make autonomous decisions about the use of their data. The second rule says "do no harm" while maximizing benefits. The third guideline highlights empathy and transparency. How the data analysis has lead to an action should be explainable to the supplier. In addition to these three rules, Agrawal (2021) notes that General Data Protection Regulation (GDPR) should also be followed as large volumes of data are exchanged. GDPR is a legal framework protecting personally identifiable information. Agrawal explains that the GDPR and laws define what information should be retained, deleted, or encrypted. The data privacy for supplier data is a complex topic to study and therefore is not addressed further in this thesis.

Data security is a part of a larger concept mentioned by Davenport and Harris (2017), data governance. Ladley (2019, p. 17) defines the concept of data governance to be a business capability (figure 15) that allows organizations to gain value from their data. Ladley (2019 p. 23) states that this business capability involves, for example, properly handling the data by defining and verifying data handling policies, rules, and standards.

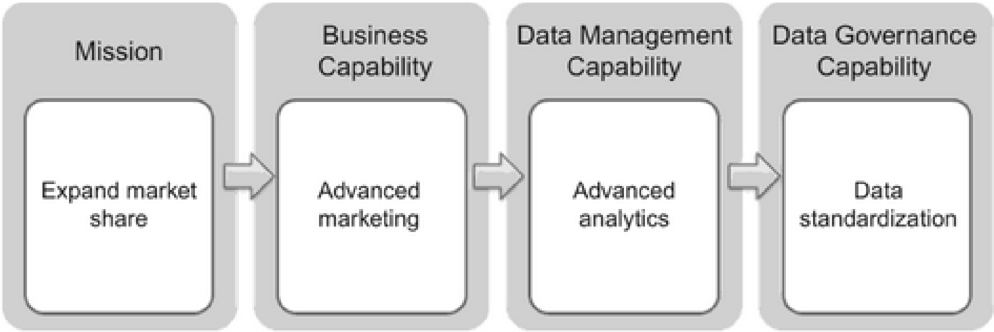


Figure 14 Data governance as a capability (Ladley 2019, p. 19)

Considering these various aspects of handling data is necessary for gaining value from the supplier data. Assuring data relevance, data sourcing, and ensuring data quantity are organization-specific tasks. Instead, data quality and data governance can be ensured using similar principles across organizations (Ladley 2019, pp. 24–25).

3.2 Different types of data analysis: descriptive, predictive, prescriptive, and autonomous

Supplier data analysis can be done on different levels. One common way to divide data analysis is descriptive, predictive, prescriptive, and autonomous (Davenport and Harris 2017). As figure 15 indicates, the more sophisticated the level of data analysis is, the more competitive advantage can be gained.

Descriptive analytics means describing what has happened in the past. This analysis level gives insights into what kind of changes have occurred previously. Descriptive analysis is the most used way of analysis in organizations, even though implementing other levels could bring more value to the organization. (Ramanathan et al. 2017, p. 68) According to Mrozek et al. (2020, p.

48), predictive analytics, in turn, tries to identify trends and patterns in the data. Mrozek et al. have concluded that various recognitions and analyzing methods can be used to conduct predictive analysis. They say that the goal is to make short-time predictions and generate knowledge relevant to the business. Predictive analytics can, for example, forecast the demand of a product (Ramanathan et al. 2017, p. 68). Prescriptive analytics is a system that establishes automated recommendations for future actions (Mrozek et al. 2020, pp. 48–49). It gives the optimal solution to a problem or offers the best of several alternatives (Ramanathan et al. 2017, p. 68). Therefore, prescriptive analytics is a decision-making tool that can take a large scale of factors into account. Prescriptive analytics can interact with decision-makers or make automatic decisions (Mrozek et al. 2020, pp. 48–49).

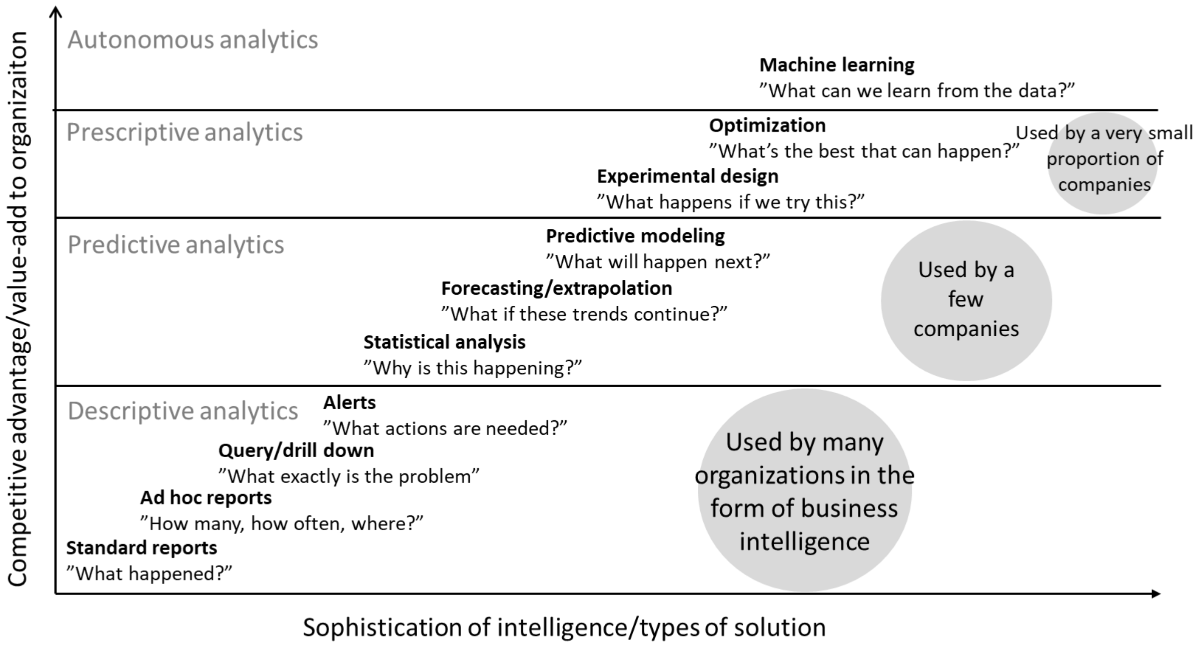


Figure 15 The different perspectives of data analytics (Davenport and Harris, 2017; Ramanathan et al. 2017, p. 68)

Autonomous analytics is the most advanced level of data analysis. For example, a book by Ramanathan et al. 2017, p. 68) does not recognize this fourth stage as an aspect of data analysis. On autonomous analytics level, machine learning algorithms are used to learn from the data (Davenport and Harris 2017). Balaganur (2020) states that an autonomous machine learning system learns from the data and gets better as the volume of data grows. Balaganur also mentions that autonomous analytics systems discover, what has happened, why it happened, and what will happen next.

The levels of data analysis, what business questions the levels answer, and how common they are among organizations are illustrated in figure 15. When implementing data analysis practices in an organization, a reasonable way to start is by using descriptive analytics. Once describing the past is under control, an organization can start making predictions and move towards the predictive and prescriptive levels. Autonomous analytics is likely the way organizations operate in the future, but rare organizations can use machine learning algorithms today.

3.3 Supplier data aggregation and granularity

Whereas in the past, supplier data was in the form of aggregate level KPIs with a low level of detail, today, granular real-time data is also available, and performance management has turned from a regular, often monthly process to an operational one (McKinsey & Company 2016). Therefore, it is beneficial to understand supplier data aggregation and granularity concepts when conducting supplier data analysis.

Supplier data aggregation

To conclude supplier data analysis, the data needs to be collected and summarized into analyzable form. This process of preparing a suitable amount of high-quality data for analysis is called data aggregation. (Import.io 2019) As supplier data commonly comes from different data sources and the amount is large, data aggregation is necessary for feasible use of the data (Cai et al. 2019, p. 1398). Even though the topic of supplier data aggregation seems obligatory for efficient analysis, in the literature, there are not many studies about the concept of data aggregation, especially from a supplier data point of view. One survey by (Pereyrol et al. 2009, p. 1) has studied how aggregation can be used to assess complex supply chains.

Data aggregation can be done in multiple ways. For example, aggregating data across products, locations, or time is possible (Jin 2013, p. 20). According to Ritou et al. (2019, p. 475), for instance information about multiple suppliers can be gathered into singular KPIs, and the information could be collected on a daily, weekly, or monthly basis, which means aggregating it across time. Ritou et al. state that data aggregation makes it possible to obtain a smaller volume of more meaningful data. Aggregation can lower the number of queried rows for calculations and reduce the time for refreshing dashboards (ZE Media 2018). Also, data aggregation can be used to combine unreliable data measurements to more accurate and meaningful data (Xiao 2007, pp. 133–134). The basic idea of data aggregation is presented in figure 16. Although the picture represents data aggregation in sensor networks, the same idea goes for supplier data analysis.

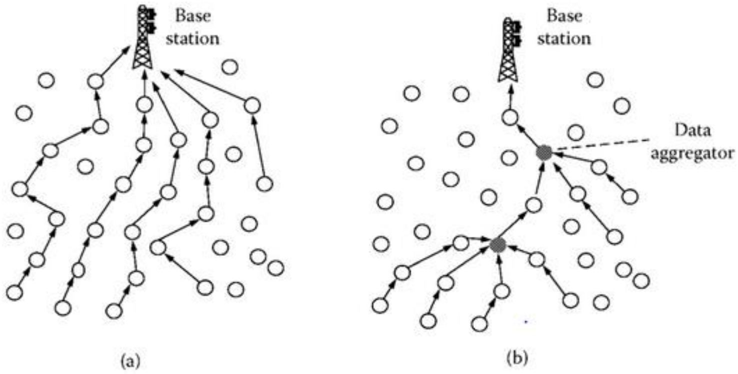


Figure 16 Data aggregation. (Xiao 2007, p. 134)

There are multiple techniques for data aggregation (Dumka et al. 2019). Krunal (2020) defines that data aggregation as either a manual process, particularly if the organization is on the early levels of data analysis, or an automated one. According to Krunal, automatic aggregation is done by using software to conduct the aggregation from different sources. As Mullins (2021) mentions, a simple example of data aggregation is using measurements such as sum, average, or counting to summarize the data. Mullins particularizes that it can be more valuable to investigate the average ages of customers instead of identifying each customer. The benefits of data aggregation are discovering patterns and inferring information from the data, saving storage space, and reducing bandwidth and energy costs (Cai et al. 2019, p. 1398).

Supplier data aggregation has two crucial risks. The first one is that it may affect the statistical properties of a data series (Amemiya and Wu 1972, p. 628) and therefore affect supply chain decision-making if the decisions rely on statistical results (Jin 2013, pp. 20–21). The second risk is that aggregation can cause a masking effect on variance visibility (Chen and Lee 2012,

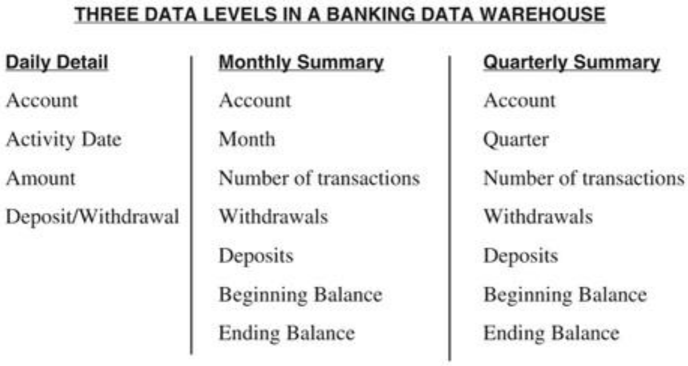
p. 18). As variance in logistics factors, for instance, lead time and demand, affect inventory policies, such as safety stock, the masking effect on variability can cause unpleasant effects (Jin 2013, pp. 20–21).

Supplier data granularity

To put it simply, granulation and aggregation are opposite operations (Gminski 2020). Whereas data aggregation lowers the level of detail, granularity increases it. The data in a model, decision-making process or analysis report can be presented in a deep level of detail, in which case data granularity is high (Ponniah 2011, p. 28; Westmeyer 2018). Increasing data granularity helps organizations gain actionable insights from the data (Westmeyer 2018). Figure 17 illustrates how data can be observed on different granularity levels by observing different length periods.

Figure 17 Different levels of granularity (the since start level represents the most aggregate data and the shortest time frame, last seven days, also shows the most negligible oscillations in the data) (Gordon 2008, p. 14)

Using a high level of granularity data is beneficial when the aim is to make exploratory data analysis (Iliinsky and Steele 2021), which aims at understanding the data and explaining the patterns and connections in it (Nussbaumer Knaflic 2015, p. 33). The challenge with a high level of granularity is that a high level of detail requires storing more data (Ponniah 2011, p. 28). Iliinsky and Steele (2021) explain that a lower level of granularity is more beneficial when sharing insights with the audience. They also state that every bit of information cannot be presented, and the decision about what information is the most relevant to represent needs to be made. Figure 18 illustrates how banking data can be shown in a detailed daily collected form or summarized form.



THREE DATA LEVELS IN A BANKING DATA WAREHOUSE

Daily Detail	Monthly Summary	Quarterly Summary
Account	Account	Account
Activity Date	Month	Quarter
Amount	Number of transactions	Number of transactions
Deposit/Withdrawal	Withdrawals	Withdrawals
	Deposits	Deposits
	Beginning Balance	Beginning Balance
	Ending Balance	Ending Balance

Figure 18 The levels of data granularity in banking data

Aggregation and granularity from a visualization perspective are defined as the level of allowed manipulation of the data and the visualizations. Fine granularity provides access to single data values such as an individual number in a table cell. Aggregate level tools present sets of values at an attribute or attribute group level. (Méndez et al. 2018, p. 9)

Table 6 Data aggregation and granularity

	High aggregation	**High granularity**
Level of detail	Low	High
Used for	Presenting insights to the audience; detecting patterns and trends	Explaining the origin of the trends and patterns in the data; drilling into a specific phenomenon at a detailed level
Benefits	Overview on the data based on the aggregations; storing less data	Detailed view on the data
Examples of use	Using functions as sum or average to summarize the data	Accessing a single number in a table cell in a visualization
Risks	Statistical properties of the data may change; masking the effect on variance visibility	Needing to store and handle a large amount of data; inability to arrive at insights due to random variations

Table 6 compares these two discussed situations, having highly aggregated or highly granular data. As data aggregation and granularity are closely linked to visualizing the data and presenting it to an audience, supplier data visualization is examined next shortly.

3.4 Data visualization

Visualizing the data plays an essential role in data analysis. Visualization helps to see the meaningful patterns and connections in the data (TED-Ed, 2012). As the name of Knaflic's (2015) book "Storytelling with data" indicates, visualization can be used to tell memorable stories to the audience. Visualization is a tool for conducting the fifth part of the data analysis process – interpreting the analysis results.

There are two ways of data visualization. The first one, presentation graphics, does not show how a result was concluded but offers convincing evidence about its conclusion. The second type, exploratory graphics, is used for seeking new insights from the data, such as patterns or outliers. Presentation graphics are aggregate visualizations for the audience to see, whereas exploratory graphics are more detailed and operational. (Chen et al. 2007, p. 5) The possible risks of data visualization are making unintentional errors leading to misinformation or purposefully manipulating the data by visualization and therefore affecting the story told to the audience (Evergreen 2019). These issues can, for example, harm supplier relationships if the suppliers are given inaccurate information.

When visualizing data, the following factors should be considered:

- What information to present (Walsh 2020)
- The usage of different graphs (Knaflic 2015, pp. 43–44)
- The level of granularity/aggregation (Méndez et al. 2018, p. 9)
- The use of colors and shapes (Knaflic 2015, p. 110)

Choosing the data to be visualized depends on the case, but generally, the data must be clean. Common faults in data are data duplication, not noticed NA values, and missing data. Bad quality data leads to bad visualizations. (Ayalasomayajula 2021) A handful of different visualizations will be enough to visualize data efficiently. Knaflic defines in his book (2015 pp. 43–69) that in addition to simple text and tables, a few chart types are the most commonly used in his work, such as scatterplots, line- and bar charts. Knaflic states that for sharing one or two numbers, simple text is usable. He also mentions that tables should be used when multiple values of specific measures need to be presented or the audience needs to be able to examine the rows and columns of interest. Knaflic advises that different graphs are suitable for different purposes, and therefore they should be used advisedly.

It is beneficial to consider what colors and shapes are used when visualizing data, as differentiating colors and shapes attract the audience's attention (TED-Ed 2012). Colors can be used in a large variety of ways. For example, Rost (2018) has defined a list of simple rules to follow when using colors, such as using the same color for the same variable and explaining the used color encodings to the audience. Similarly, there are many rules for using shapes. For instance, similar, connected, or closely placed objects are distinguished as a group (Knaflic 2015, pp. 181–184). Getting familiar with these principles can enhance the quality of created visualizations.

3.5 Process mining for supplier data

Process mining is an integral part of supplier data analysis as procurement involves several different processes. Process mining links data science and process management together (Van Der Aalst et al. 2012, p. 15; Van Der Aalst 2016, p. 15). The relevance of process mining has grown as the amount of available event data has increased (Van Der Aalst 2016, p. 15). Process mining can be used to discover processes, analyze if a process is performed as specified, and analyze performance and look for improvement possibilities (Van Der Aalst 2003). The data used for process mining is event log data. The event log data must at least have a case ID, activity, and timestamp information for each event (Er et al. 2017, p. 220). Process mining turns the event log data into actionable insights (Van Der Aalst 2013, p. 3). Figure 19 illustrates how data science and process management are linked together and what insights process mining can give.

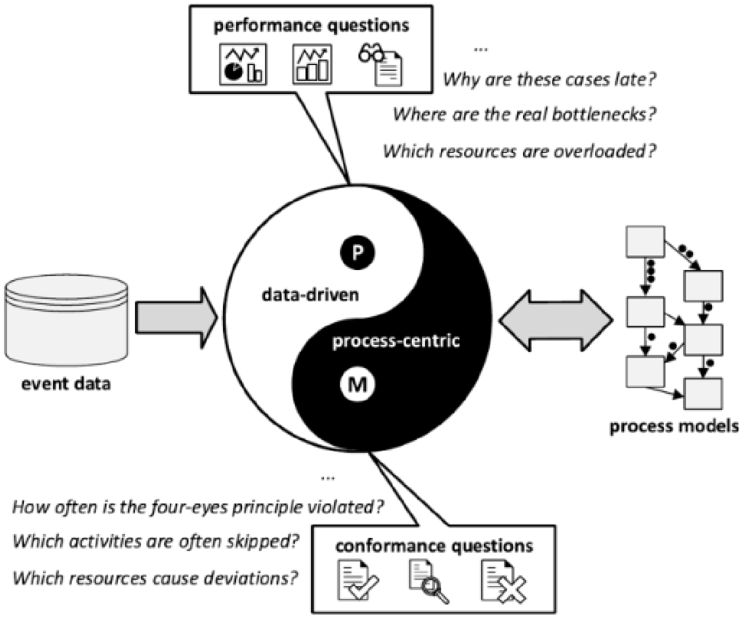


Figure 19 Process mining as a link between data science and process science (Van Der Aalst 2016, p. 26)

Three typical process mining types are process discovery (Aalst et al. 2004, pp. 3–4), conformance checking (Van Der Aalst 2016, p. 244), and process enhancement (Van Der Aalst 2016, p. 276). The purposes and example techniques for these three are presented in table 7.

Table 7 Process mining approaches

Process mining technique	**Purpose**	**Example techniques**
Discovery	Transforming an event log into a process model (Aalst et al. 2004, pp. 3–4)	Petri nets, Workflow nets (Aalst et al. 2004, p. 7); Process tree (Leemans et al. 2014, p. 3)
Conformance checking	Comparing the behavior observed from the event log data with modeled behavior (Carmona et al. 2018, p. 6; Van Der Aalst 2016, p. 244)	Business alignment (Aalst 2005, p. 198); trace alignment (Hutchison et al. 2010, p. 227); replay (Rozinat and Aalst 2008, p. 10);
Enhancement	To improve the existing process based on information gained from event log data (Van Der Aalst 2016, p. 276); configuring information systems (Aalst et al. 2004, pp. 4–5)	Model repair, model extension (Yasmin et al. 2018, p. 67)

Different techniques can be combined depending on the type of the analyzed process. The methods that generate the most benefit depend on the kind of process investigated. Well-structured and straightforward processes do not benefit that much from process discovery. Instead, conformance checking and process enhancement can give valuable results about simple processes. Also, using prediction techniques is possible for straightforward processes. In turn, complex, not structured processes require process discovery to understand them, and for example, prediction might not be beneficial. (Van Der Aalst 2016, p. 22)

Process mining can be conducted from many perspectives such as control-flow, organizational, case, or time perspective (Van Der Aalst 2016, p. 34). The results of process mining can be used for instance for improving business processes or configuring process-based business information systems such as Enterprise Resource Planning (ERP) systems. (Aalst et al. 2004, pp. 4–5). As Aalst (2016, p. 34) describes, process mining is a broad concept with many use cases and benefits.

3.6 Summary of the theoretical phase

The literature review shows that monitoring supplier quality assurance has been recognized to have a variety of benefits and challenges. The benefits, such as financial benefits and improving supplier relationships, can be achieved if the process for managing SQA is well established and organization-specific factors considered when designing the analysis system.

There are different indicators and evaluation methods to support the supplier analysis. Many of the evaluation methods and indicators were proposed for supplier selection purposes, indicating that supplier selection may be considered more important than monitoring and developing the suppliers. However, many of the methods are usable for both supplier selection and performance evaluation. The seven evaluation methods examined in detail in this thesis help categorize suppliers and calculate overall performance scores for them. For monitoring the suppliers, three categories of indicators were found out to be the most used in literature: cost, quality, and delivery. These categories create a reasonable basis for an analysis system, but other categories can be used as well if the aim is to analyze supplier quality assurance more broadly. The indicators should be balanced and represent the overall situation of the suppliers.

The literature revealed that there are multiple aspects to consider when analyzing supplier data, from collecting the appropriate data to presenting it to the audience in an understandable way. Descriptive analytics was found out to be the most popular way of analytics in organizations. On the more advanced levels, predictions and automated decisions are made. Data granularity and aggregation concepts have not been discussed much in literature from supplier data analysis point of view. Still, the common principles are also applicable for presenting supplier data on different levels of detail. Another aspect of analyzing supplier data, process mining, links data analysis with the procurement processes and allows inspection and enhancement of operations.

4 DATA AND METHODOLOGY

The case firm is a Finnish heavy equipment manufacturer focused on one industry sector. The company produces high technology machinery for its customers worldwide. The case company has an extensive supplier network. Purchased components and materials represent almost half of the firm's turnover, and therefore, there is potential to gain advantages by analyzing and developing the supplier network. The case company has already expanded its operations towards Lean principles to increase productivity as the production volumes have increased over the years. This study is one part of increasing productivity and therefore in line with the strategy of the case firm.

This study is mainly conducted as qualitative research, although some features of quantitative research are involved as numerical data is analyzed. Qualitative research aims to understand the studied phenomena using qualitative data (Lapan et al. 2011). There are a variety of methods to conduct qualitative research (Ramos 2020, p. 631). From the methods, case study was chosen for this study as it allows to study a complex phenomenon and collect data from multiple sources (Koskinen et al. 2005, p. 156; Lapan et al. 2011; Morgan et al. 2017, p. 1060). As there are no pre-defined ways for building an analysis system for analyzing supplier performance, the research design is based on trial and error ideology. Therefore, the methodology used is action research. McNiff (2013, p. 23) defines that the practitioner checks if the practice is satisfactory or not in the action research method. McNiff advises that acceptable practices should be justified using authentical evidence, and unsatisfactory practices should be acted on. Thereby, the researched system develops towards satisfaction.

4.1 Data collection methods

As the methodology in this study is action research, the empirical part is conducted by observing the organization and participating in the organization's development activities by building the analysis tool based on the observations. Table 8 shows what is examined in the empirical phase of this study, how the data for each topic is collected, and what is the aim of the examination.

Table 8 The framework for data collection

What to examine	How to collect the data	The aim of the analysis
The current state of monitoring the supplier network	Analyzing the existing monitoring system, interviewing people, interviewing other manufacturing companies	Enabling the organization to understand the need for development and gaining background information for the proposed solution
Performance indicators, review practice, and target setting for SQA	Interviewing people, observing the current analysis tool	Understanding what features the new analysis tool should have and what targets could be set
The purchasing, claim handling, and reclamation process	Analyzing process graphs, process mining, interviewing people	Gaining background information for building the analysis tool
Available data and it's quality	Analyzing the available data, interviewing people responsible for handling the data	Understanding the possibilities and restrictions the data has, recognizing needs for collecting specific data
Different levels of data granularity and aggregation	Analyzing the available data, interviewing people	Understanding on what level of detail the data can/should be analyzed
How other Finnish manufacturing companies conduct supplier analysis	Informal discussions with other companies	To gain an overview of how the case company is developing compared to other companies

As table 8 shows, the data is collected in many ways – by observing the current system and interviewing people from the case company and other manufacturing companies. This way, an overall picture of the organization's current state is formed, and ideas for development gathered. After the data has been collected, the analysis tool is built.

4.2 SIPOC charts for presenting the monitored processes

In this study, high-level process diagrams, called SIPOC charts, are used to model the processes to be monitored. SIPOC is an abbreviation for supplier, input, process, output, and customer. Figure 20 illustrates the parties of the SIPOC diagram.

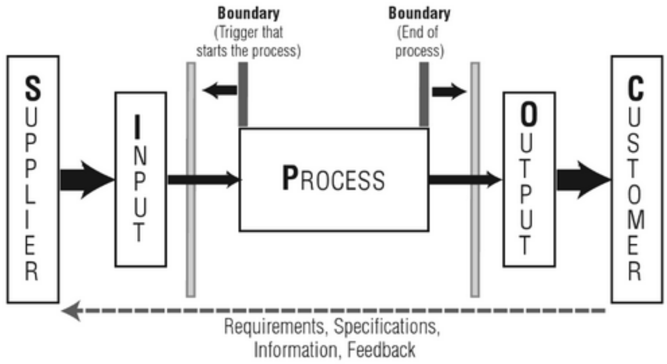


Figure 20 The SIPOC diagram (George 2010, p. 68)

For example, a SIPOC chart could be used to represent a case of a defective product or a service. In the diagram, the supplier is a party, who provides the faulty product or service. The customer is an internal or external party unsatisfied with the product or service. In addition, the inputs and outputs of the process are defined. (Pakdil 2020 pp. 3–4; Shankar 2009, pp. 3–5) The process in the graph explains how the process is performed and what subprocesses there are (Pakdil 2020, p. 3).

4.3 ProM for process mining

As the monitored processes in the case company are complex, a process mining tool ProM is used to describe the processes and identify possible pitfalls in them. ProM is an open-source program with a pluggable architecture, which means that new process mining techniques can be added to the software by adding plug-ins. Weijters et al. (2007, p. 1) describe ProM as a practical and versatile tool for discovering different process perspectives. Weijters et al. demonstrate that ProM supports control-flow mining, resource and performance analysis, and conformance checking. Even though the case company has not previously used proM, the software was chosen for this study because it is practical and offers many features for monitoring processes efficiently.

The data is transformed into a process model by converting the log data CSV files into XES files. The XES files are used for modeling the processes using ProM's Inductive Visual Miner. The process mining results are presented as process trees to get models that are easy to interpret. The resulting process trees give information about how the process flows, how common specific actions are, and how long the sojourn times between activities are. (Aalst 2020, p. 8) reminds us that Directly-Follows Graphs involving process trees need to be carefully interpreted to avoid misleading conclusions. Aalst also states that simplifying the models can lead to bottleneck information being deceiving. ProM's Alpha Miner was also tested for discovering the models. As real-life data tends to be complex and Alpha Miner does not filter out noise, the resulting Petri Nets were not understandable.

4.4 Power BI as a data analysis tool

The case company has already started using Microsoft Power BI for reporting purposes, and therefore, it is also used in this study. Power BI is a cloud-based collection of tools published by Microsoft in 2015 for organizations to collate, manage and analyze data. The software can be connected to various data sources from Excel spreadsheets to databases to process significant quantities of data. Power BI's user interface is user-friendly and straightforward to use. It has machine learning capabilities for spotting patterns in data and making predictions. (Wright 2021; Zakaria 2020) According to Microsoft (2019), Power BI has a Data Analysis Expression (DAX) feature, which allows the user to make calculations using a collection of functions, constants, and operators. Microsoft highlights that simple reports can be created even without this DAX feature, but the feature enables more complex analyses to solve business challenges.

4.5 The data used for monitoring and evaluating suppliers

As the case company is a large heavy equipment manufacturer, the company produces a significant amount of data every day. For this study, the data is collected from the case company's information systems as CSV files. This way, the data is limited to an amount easy to handle and produce example solutions. The time frame is limited to one month for some of the data to reduce the data amount. The data is imported into Power BI as CSV files, and all necessary changes to the data are made in the software.

Table 9 represents one data table used in this study. Some of the values in the table are hidden, but the table gives an idea about what kind of information the case company has available for analysis. The table has information about claim handling: what items have been defective, when, and why.

Table 9 An example of a data table used

Supplier	Claim ID	Description	Item	Status	Type	Reason	Reson description	Creation date	No of defective pcs	Cost of the claim
xxx	xxxxxx	xxx	xxx	Finished	Casting	Surface quality	Manufacturing defect	dd.mm.yyyy	xx	xxx
xxx	xxxxxx	xxx	xxx	Read	Assembly	Defective part	Not working properly	dd.mm.yyyy	xx	xxx
xxx	xxxxxx	xxx	xxx	Read	Assembly	Defective part	Leakage	dd.mm.yyyy	xx	xxx
xxx	xxxxxx	xxx	xxx	New	Casting	Surface quality	Dimensions and geometry	dd.mm.yyyy	xx	xxx
xxx	xxxxxx	xxx	xxx	Answered	Electric	Unworkability	Not connecting	dd.mm.yyyy	xx	xxx

Exporting the data as CSV files from the information systems manually is not a permanent solution for supplier analysis. There is a possibility to automatize the process of collecting the CSV files and analyzing them, but it will not be conducted in this study as the aim is to create a demo version of the analysis system. Instead, building a data platform for handling supplier data is discussed in this study.

5 SUPPLIER QUALITY ASSURANCE MANAGEMENT TOOL FOR A HEAVY EQUIPMENT MANUFACTURER

This chapter aims to demonstrate implementing a supplier analysis tool in the case company and discover what challenges and limitations occur. The supplier analysis tool is designed for assessing the supplier quality assurance of the supply side of the supplier network. Firstly, the current state of monitoring and evaluating the supplier network in the case company is considered. Objectives for the demonstration analysis tool are discussed and the monitored processes modeled using SIPOC charts and a process mining tool, ProM. Next, the supplier data analysis tool is designed using PowerBI. Based on the discoveries made while implementing the demonstration analysis tool, suggestions are made for the case company for improving its ability to utilize supplier analytics.

5.1 The process for building an analysis tool

The literature emphasizes the importance of creating a continuous process for supplier management. In addition to developing and implementing the process, it needs to be maintained. Since process thinking is an essential factor for succeeding in supplier data analysis, the process implemented in this thesis is described in table 10 below. The last two steps of the process are not conducted in this thesis. Still, they are presented in the table to ensure the continuity of the process. The process in table 10 can be followed for creating analysis tools for other company operations as well.

Table 10 The phases of building the analysis tool

Phase	**Results**	**Challenges**
Getting an overview of the case company's current situation	Understanding the challenges and whishes the case company has for the tool	Having a variety of different views and opinions on the topic
Choosing the metrics, evaluation methods and targets	A documented plan of the chosen metrics and methods and targets	Deciding the limit values and calculation methods for the metrics
Process modeling	Understanding the processes in detail, finding pitfalls in them	Using only a limited amount of data, preprocessing the data into analyzable form
Gathering the data for the analysis	A relational data model of pre-processed data	Finding many identifying ID numbers for the suppliers, lack of data availability
Building the analysis tool	An analysis tool built based on the case company' needs and practices discovered from the literature	Presenting only useful information, building a tool that meets everyone's needs and the limitations of the data
Test use of the analysis tool	An idea of what needs to be developed further in the analysis tool and what is working well	Small test group, getting constructive feedback
Using the analysis tool for continuous improvement	*Data-based business decisions*	*Reliability and interpretation of the analysis results*
Updating and improving the analysis tool	*The analysis tool is up to date and corresponding to the case company's objectives*	*Getting constructive feedback and developing ideas, having the resources for development*

The first four steps of the process form the planning phase. The planning phase aims to ensure that the tool meets the needs of the case company. Building the relational model for the data and deciding the measures, methods, and presentation ways took the most time when implementing the analysis tool in this study. Every phase of the process has some challenges examined in more detail in the next sub-chapters.

5.2 A current state analysis of monitoring the supplier network

From the four purchasing functions presented in chapter 2, the case company has already created principles for supplier sourcing and integration. The supplier network is relatively stable, and the focus is currently on improving the network's quality assurance. The company does product inspections and has quality control principles. The target is to improve quality assurance and process management principles to develop towards operational excellence, as presented in the literature review. The case company has recognized the need for monitoring and evaluating suppliers and generated a descriptive analysis system for monitoring using a few indicators. The tool is somewhat limited, and the aim is to change the tracking from just doing it for the joy of measuring into a pre-defined well-managed process.

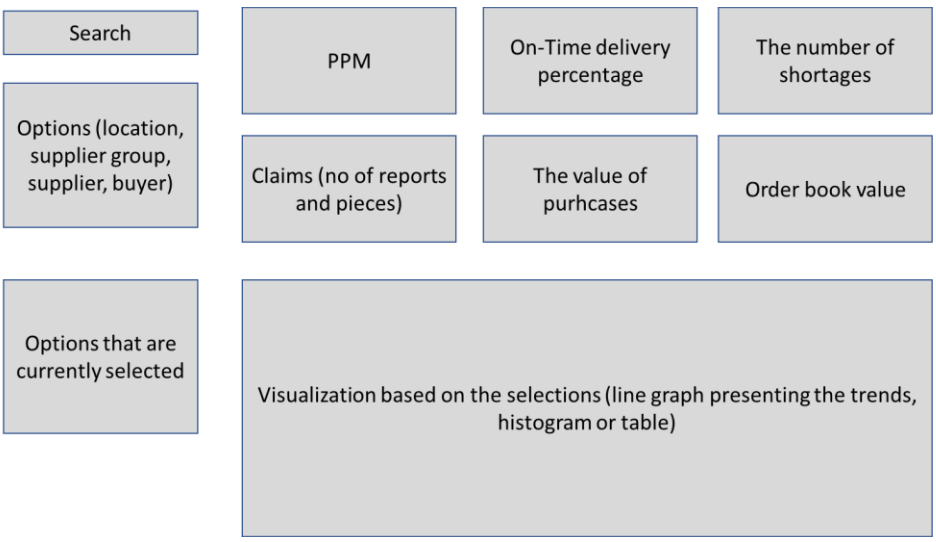


Figure 21 The current supplier analysis dashboard

Figure 21 represents the current analysis dashboard for supplier analysis. The dashboard has six aggregate KPI values and a graph illustrating the PPM value trend. The data can be filtered by location, purchasing group, supplier, buyer, or item using drop-down menus. Visualization of the current system is based on the case company's brand colors and one highlight color, light green. This study revealed that the case company has an even older, more straightforward supplier analysis system that reviews the KPI values on a more detailed level. For example, the old version allows inspecting delivery reliability on order level. It shows if the delivery has been either early or late, which is impossible in the current system. Finding the second supplier analysis system advocates the idea that the case company needs one more comprehensive supplier analysis tool as currently, purchasers are using two similar systems parallelly.

Interviewing people in the case company and assessing the current dashboards revealed several challenges in the current system. The first challenge, data accuracy, prevents the case company from using the monitoring results for making decisions. An example issue is that some suppliers might have more accurate information about their performance that differs from the case company's monitored KPI's. Therefore, the case company's information is not valuable for improving supplier performance. The case company does have a lot of supplier data available, and by ensuring its accuracy, the data allows to analyze the suppliers.

The second discovered challenge, traceability, also relates to the measurements not being reliable. As the data comes from different sources and the traceability is low, it is difficult to determine what factors affect specific measurements. The comparability of the measures is also a challenge. For example, the differing supply volumes are not considered when calculating some of the measures, which reduces the comparability of the measures. It would be beneficial to be able to compare the measurements of suppliers, items, or procurement groups together. All in all, the measures might not reflect the actual real-life situation well, and using them as a basis for decision-making is risky. These issues are approached in this thesis by assessing the processes with the process mining tool to define how different process features affect monitoring them. Mining the processes helps to understand the data, and therefore producing accurate data for a specific measure is easier. Measurement traceability must also be ensured by clearly documenting how the measurements are calculated and what data is used.

The case company hopes that the developed tool monitors the supplier network so that the results are meaningful and can be converted into actions for improvement. This challenge of being able to gain benefits from using the data is also noted to be common in the theory. The reports should be visually apparent and understandable so that all stakeholders can benefit from them. In the case company’s current system, some of the visualizations have so much information that understanding them is challenging. The aim is to be able to present some of the visualizations directly to the suppliers. Clear visualizations could improve using the data as a basis for decision-making.

When comparing these discovered challenges with those found in the literature, the case company’s main challenges are data-related instead of those represented in the theoretical part. The case company already uses a selection of valuable measures suggested in the literature. Supplier relationships are strong, so building the relationships is more a part of daily operations than a challenge. Instead, improving the suppliers is not systematically done. Change leadership challenges might occur from both the case company’s and the suppliers’ side when improving the supplier based on the data continuously. Involving enough resources and knowledge for enhancing SQA needs to be considered, as it was defined as a challenge for many organizations in the literature.

5.3 Objectives for the analysis tool

Even though the analysis tool is a demonstration version, objectives for it are clearly defined to work as a guideline for building a functional analysis tool. Currently, in the case firm, the supplier performance management process is more event-based than process-like. A lot of data is collected, but the KPIs and outputs are not all reliable. Actions and interventions are taken but not necessarily based on the analysis results because of the unreliability. Transforming the supplier analysis into a continuous process instead of singular events would require for the analysis tool to be understandable and accurate and the usage managed so that the tool is utilized in daily operations. The objectives are presented in figure 22 based on the previously discovered challenges.

	Challenges	Objectives
Data accuracy	• Inaccurate data leads to inaccurate KPI values • Suppliers may have more accurate information	• Understanding the processes • Detecting possible issues in the data
Traceability	• Data comes from several sources • Measurement accuracy difficult to define	• Clear documentation • Ability to inspect certain measures in more detail
Comparability	• Different scales for the same indicator • Not taking all affecting factors into account	• Putting all measures on the same scale • Generating functions to the analysis tool that allow comparison
Result usability	• Not measuring usable things • Results not used for imrovement	• Defining what the objectives for the tool are • Systematically using the monitoring results for improvement
Visualization	• Unclear reports with too much information • Ease of use of the reports	• Presenting a suitable amount of easy-to-understand data • Making the reports easy to use

Figure 22 The objectives for the analysis tool based on the discovered challenges

Although there are various challenges with monitoring suppliers in the case company, the framework for data analysis already exists in the case firm. Analysis software is available, and the company has noticed some of the possible benefits of monitoring. Analyzing company operations is a part of daily operations, and for example, production is tracked continuously, and improvements are made based on the case company’s data. Overall, interviewing the case company’s employees revealed that the case company has two primary goals for a supplier data analysis tool: gaining actionable results and assessing the effectiveness of the taken actions.

Collecting and analyzing data without understanding the context does not produce accurate results. Therefore, the processes behind the data are modeled to increase understanding of what the collected data represents. Data accuracy is ensured by detecting possible issues in the data. The analysis tool structure is documented to ensure traceability. Therefore it is possible to discover what data is used, how it has been pre-processed, and how the analysis is conducted. The documentation of the analysis tool is done mainly in the software itself. PowerBI offers the possibility to write descriptions for all tables and columns. In addition, simple explanations of the used measures are written down as a separate document to see how the measures are calculated.

The analysis tool is constructed so that all the measures are on the same scale if possible. The data limitations might restrict using the same scales for all of the measures. But otherwise, the measures are made comparable, and the comparison is allowed from many perspectives. The analysis tool is made to benefit the purchasing and quality functions of the case firm. Visualization is used to make the reports simple and easy to use. Instead of the intense company colors, more appealing colors are used, and the visualizations are made with a decent amount of information. Even though the tool is not used for an actual use case, feedback is gathered from the case company's employees to discover possible issues in the analysis tool.

5.4 Description of the processes to be monitored

As the theory revealed, supplier networks are non-linear and complex systems. The same complexity can be notified from the case company's processes as well. The processes linked to supplier quality assurance, order-to-delivery, claim handling, and reclamation handling was chosen to be examined in more detail. There is event log data available for these processes, and the processes are key functions in daily operations between the case company and the suppliers. These processes were modeled to understand how the processes flow and which stakeholders, items, documents, and case company operations are involved. For this study, two aspects, resources, and controls, have been added to the SIPOC chart to be able to understand what resources, especially systems generating data, are linked to the process and what controls are necessary for monitoring the processes.

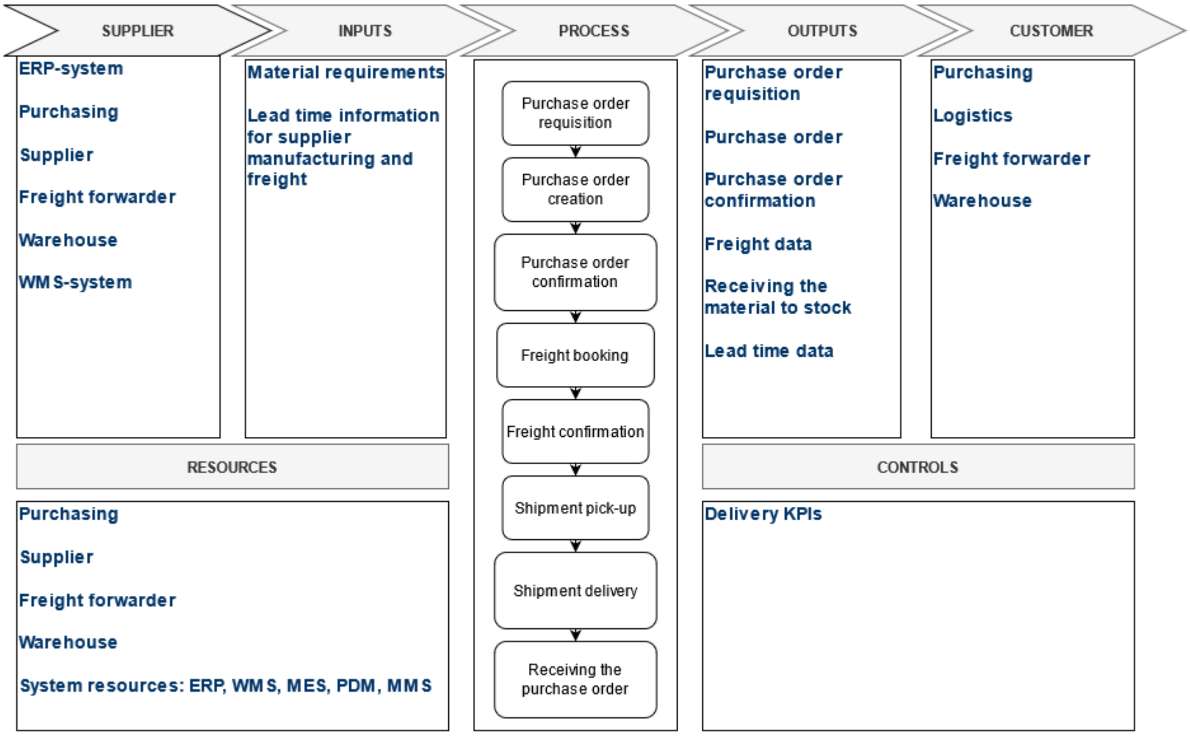


Figure 23 A SIPOC chart of the order-to-delivery process

The first chart (figure 23) represents the order-to-delivery process in the case company. The process is modeled as a linear set of actions involving the case company, a supplier, and a freight forwarder. The chart reveals that the process produces data from different aspects: order handling, freight, and receiving goods. The process is handled with delivery performance KPIs. One crucial factor to note from figure 23 is that the case company has five different systems generating data: an ERP-system, warehouse management system (WMS), manufacturing execution system (MES), product data management system (PDM) as well as a material management system (MMS). This may be why the current system is slow to use as the data is collected from various sources. The data from different sources could be stored in a common database. The data could then be accessed with SQL commands from one source to make using business intelligence tools such as PowerBI faster.

The second and third processes, claim and reclamation handling are the same process from two aspects. The claim handling process describes how claims are handled in the case company. Reclamation handling shows how the claims are handled at the supplier’s end. Handling claims and reclamations are currently difficult to follow up in the case company. However, the ERP system has some data for analyzing them already available, and therefore the possibility to improve the processes does exist.

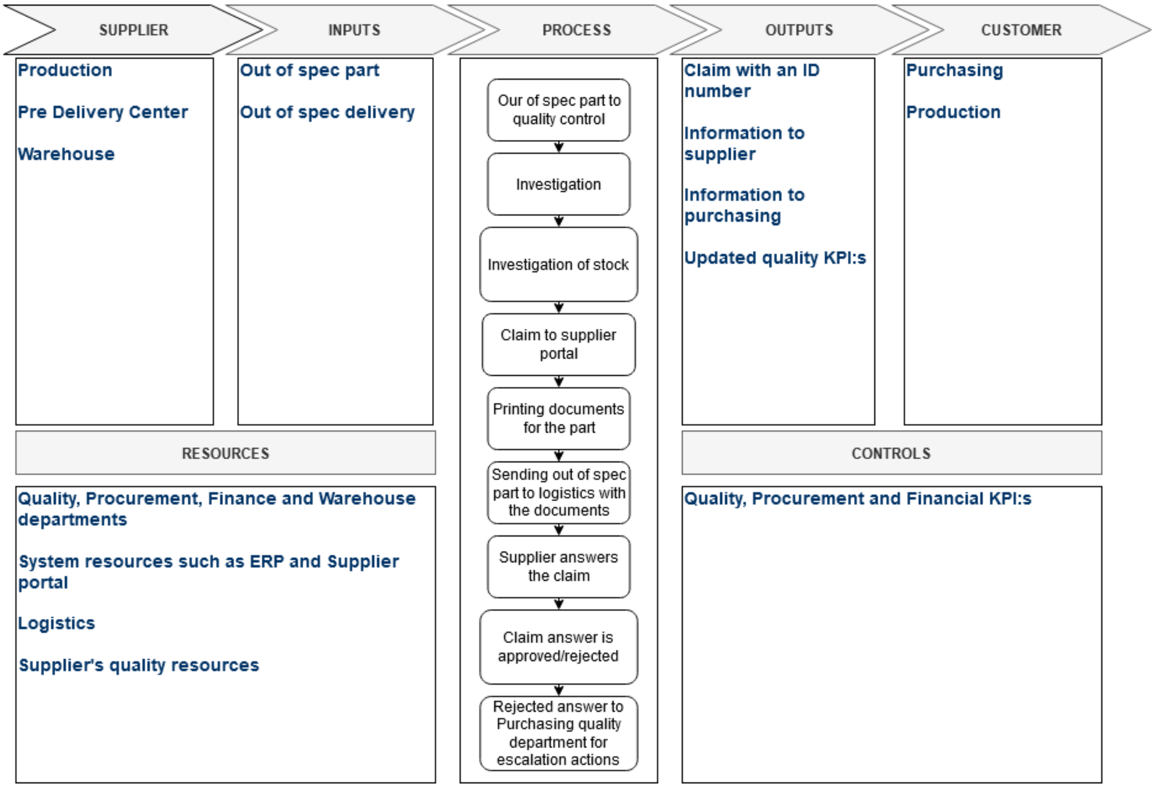


Figure 24 Claim handling SIPOC chart

Figure 24 above represents the case company's view on the claim handling process. The claims are made from defective parts and deliveries by the production, warehouse, or pre-delivery center of the case company. Yet one more data system is included – the supplier portal. The portal is the channel for communicating information between the case company and its suppliers. The supplier portal does not currently have any kind of analysis available for the suppliers to investigate. Therefore, a dashboard for the suppliers is created.

As the claim handling process involves several of the case company's departments, it would be necessary to be able to follow who has the responsibility to react to a specific claim and how the claim handling is proceeding. The claim handling process involves escalation actions that have not been defined in more detail. The case company has built strong relationships with its suppliers and does not use "punishments" as escalation actions. Despite that, it would be beneficial for the case company to define a straightforward escalation process to follow and possibly consider if using a penalty is necessary.

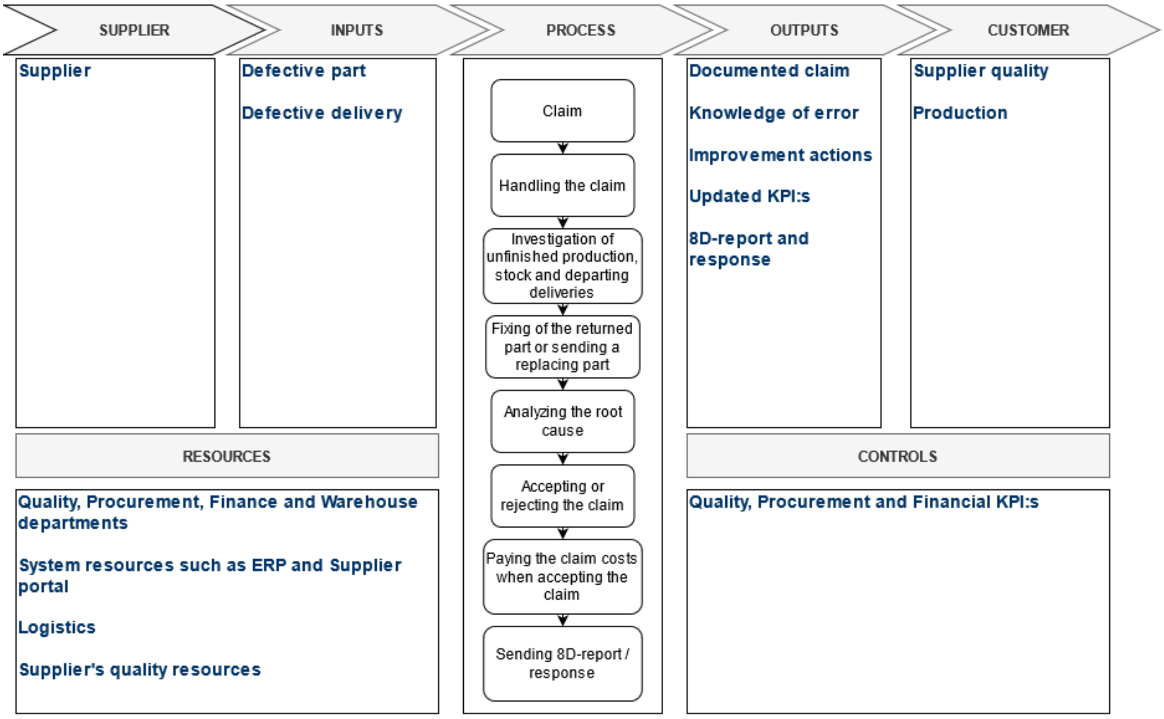


Figure 25 Reclamation handling SIPOC chart

The reclamation process (Figure 25) is the process suppliers need to go through once the case company makes a claim. This process requires the supplier to discover possible errors and make improvement actions based on them. The supplier needs to report the improvement actions, but the effectiveness of the actions is not currently assessed. Also, the case company has data about some old claims that the suppliers have not responded to in the first place. Setting a reminder for the supplier to answer a claim could benefit.

The process charts confirm that it is essential to make sure that the controls are carefully chosen KPIs from different perspectives as there are many participants and steps in the processes. The data is stored in multiple stores in various forms, and it needs to be gathered into one data model and pre-processed for analyzing it. These three processes cover only a part of the whole purchasing and quality functions, and for example, the logistics process and supplier relationship management could also be modeled and analyzed.

5.5 Process mining

As the SIPOC charts model how the ideal process flow, a process mining tool is required for getting a more detailed view of the reality. The order-to-delivery process is inspected using order processing event log data from the moment a purchase request is created to the moment the parts are received to the case company's stock. The claim handling and reclamation processes are examined as one process using data from when a claim is created to the moment the claim handling has been finished. The process mining techniques used to study these processes are *discovery* and *conformance checking*. After the real-life process models have been created, they are compared to the SIPOC charts and the case company's understanding of the processes to define how the actual process differs from the ideal model. The quantity of data used for process mining is small in this thesis, as the data is collected and integrated by hand. The amount of the data might affect the results so that all possible actions and paths in the process are not discovered. A more significant amount of data should be collected, integrated, and processed to get more reliable results.

The order-to-delivery process

The event log dataset contains data about the purchase orders and deliveries gathered from the ERP system and the supplier portal about the order-to-delivery process. The first modeled dataset has four cases of one domestic supplier because precise delivery data is currently available for that one supplier only. As the first dataset has only four instances, another dataset with ten cases from domestic and foreign suppliers is also modeled.

Figure 26 The order to delivery process for one domestic supplier

The order-to-delivery process modeled as a process tree with ProM for one domestic supplier is relatively linear. The process variations occur between repairing a defective part at the case company or ordering replacing parts. Also, for one of the ten cases, a supplier response has not been received.

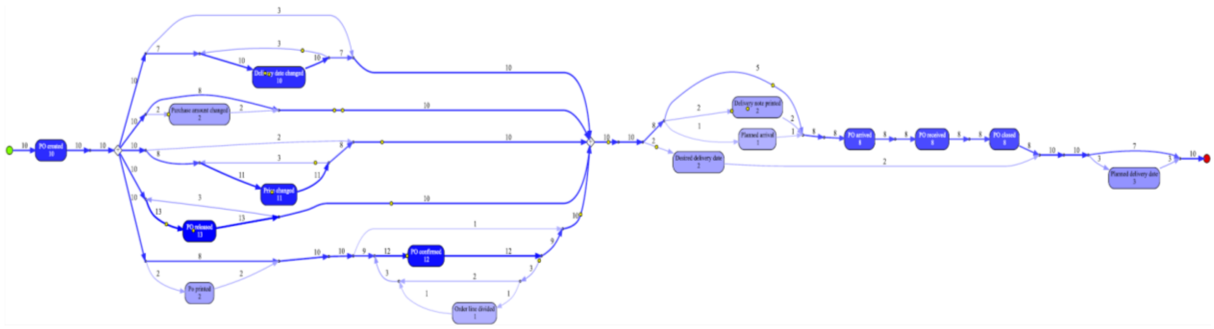


Figure 27 The order to delivery process for three domestic and seven foreign suppliers

When comparing figures 26 and 27, it can be noted that the process with ten suppliers has a lot more variability than the process for one supplier only. Figure 27 is more complex because for some orders, purchase prices, amounts, and delivery dates have been changed after the order has been released. Also, two of the orders have been printed and sent to the supplier by email. The majority of the orders have been handled via the supplier portal. For one order, an order line has been divided into two as the supplier has not been able to deliver the whole line at once. Some of the orders have been confirmed for later, even though their original guaranteed delivery dates have already passed. The conformance checking discoveries from the processes are listed in table 11. If a feature of the process is included in the model, it is marked with “x” in the table. The excluded features of the process have been discovered from the case company’s employees.

Table 11 Conformance checking for the order-delivery-process

Action	SIPOC chart	ProM process model	Excluded
Purchase request	x	x	
Creating a purchase order	x	x	
Releasing the purchase order		x	
Confirming the purchase order	x	x	
Printing the purchase order		x	
Changing the delivery date		x	
Purchaser’s actions to prepone or postpone the order			x
Booking the freight	x	x	
Freight confirmation	x		
Printing a delivery note		x	
Shipment pick-up	x	x	
Freight arrival time changes			x
Shipment delivery	x	x	
Receiving the goods	x	x	
Sending the goods to quality inspection			x
Informing the supplier that goods have arrived if they have been ordered without an order number			x
Closing the purchase order in the warehouse		x	
Storing the goods in the warehouse or shipping them to other operations			x
Closing the purchase order by a purchaser instead of the warehouse			x
Sending an invoice			x
Paying the invoice			x
Receiving, accepting, and paying freight invoice			x
Receiving the goods to the wrong location			x

Modeling the order-to-delivery process revealed that currently, logistics are difficult to measure as there is no data available. Data about the orders instead is available on order and order line level. Inspecting this process further with the case company’s employees revealed that all actions could not be measured from the data collected from the ERP system. The modeled process does not involve invoicing information or cases where the goods are received by a purchaser instead of the warehouse or delivered to quality inspection. Sometimes goods are also delivered to the wrong site. Also, purchasers might do certain actions to prepone or postpone an order. In addition to the unmeasurable actions, the small size of the datasets might lead to the process seeming more linear than it is.

The claim handling process

The event log data was collected from the ERP system and the supplier portal for the claim handling process. The first event log dataset includes log data about one domestic supplier to discover the main route the process takes and what kind of deviations there are. The second dataset has twelve cases from three both domestic and foreign suppliers to get an overview of how the process differs between the suppliers.

Figure 28 The claim handling process of one domestic supplier with eleven cases

Figures 28 and 29 indicate that analyzing more suppliers equals having more variability in the process. For one supplier, the claim handling process is relatively linear. The decision between repairing a defective part and ordering a replacement part changes the process flow. Also, some claims have not been answered by the supplier. The process in figure 29 involves more communication between the supplier and the case company, and the process can take a variety of different paths and repeat the same actions multiple times.

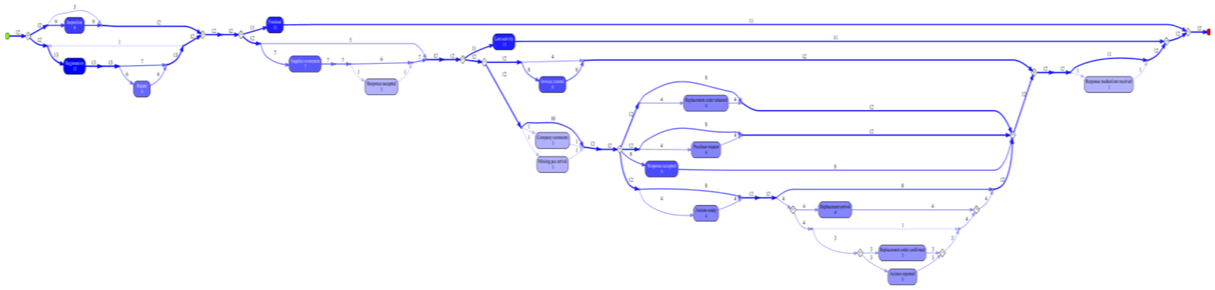


Figure 29 The claim handling process of three suppliers with twelve cases

For conformance checking, the ProM models were compared to the SIPOC chart of the process. As table 12 shows, more steps can be inspected from the data than the SIPOC chart indicates. Currently, log data related to the parts returned to their suppliers as defective is not available. Also, handling credit notes causes manual work for the case company, and the data of the credit notes is not unambiguous.

Table 12 Conformance checking for the claim handling process

Action	SIPOC chart	ProM process model	Excluded
Arrival to quality control/registration	x	x	
Investigation	x	x	
Repair		x	
Registration	x	x	
Printing documents	x		
Sending the part to logistics	x		
Supplier answers the claim	x	x	
Claim answer approval	x	x	
Escalation actions	x		
Finishing the claim handling		x	
Case company commenting the claim		x	
Supplier commenting the claim		x	
Last handling activity		x	
Creating an invoice		x	
Purchase request		x	
Replacement order handling		x	
Reporting corrective actions		x	
The arrival of missing parts		x	
The arrival of replacing parts		x	
Transactions about returned parts between the dispatch department and the delivery center			x
The pickup date of a defective part to the supplier			x
Returned part arriving at the supplier			x
Receiving a credit note			x

The process mining revealed that the data in the ERP system is not complete as some actions do not produce data. When pre-processing the data it was noticed that the ERP system has three differently named columns with the same timestamp information at least for the inspected cases. These three actions were combined into one. The timestamp information was in different formats, and the timestamps were changed to the same format before process mining. When mining the processes, it was noted that the involved suppliers have differing principles for handling the orders and the claims. For example, one supplier used a corrective action report that was sent to the supplier portal after handling a claim. The differences in the principles between the suppliers challenge creating common measurements and comparing the supplier together.

In addition to possible data improvements, ProM revealed some possible features to measure from the order-to-delivery and claim processes. For example, the number of late and early deliveries could be measured. Also, analyzing the logistics can improve the order-to-delivery process if data can be made available. For claim handling, inspection and repair were involved in almost every case, and therefore measuring the times and possible costs for inspection and repair might be beneficial. In addition, the rates for received supplier responses and accepted supplier responses could be measured to see how systematically the claims are handled. To inspect that further, it is possible to discover how fast the suppliers answer the claims and how quickly replacing parts are shipped. On the other hand, the data does not precisely represent how the claim is handled internally in the case company, and collecting more detailed internal event log data could be informative. When making the specification requirements for the ERP system, it is necessary to discuss how precisely and in detail the processes need to be monitored.

5.6 The data for supplier quality assurance analysis

Before building an analysis tool it is necessary to find out what data is available and how it can be processed into analyzable form. In chapter 4 the supplier data used for this study was briefly introduced. This sub-chapter examines what supplier data the case company’s information systems produce and how the data is pre-processed for the analysis tool. The data was gathered based on the plan of what the analysis tool is going to measure. The data is collected from the ERP system, the PDM system, and the material management system considering the five aspects of data: data relevance, data sourcing, data quantity, data quality, and data governance. The data is cleaned before analyzing it by removing excess columns from the data tables that are not necessary for the analysis to ensure data quality. The data rows involving errors were deleted as there were only four errors in the data. The timestamps are separated into two columns, date and time, to be able to filter the data based on both values.

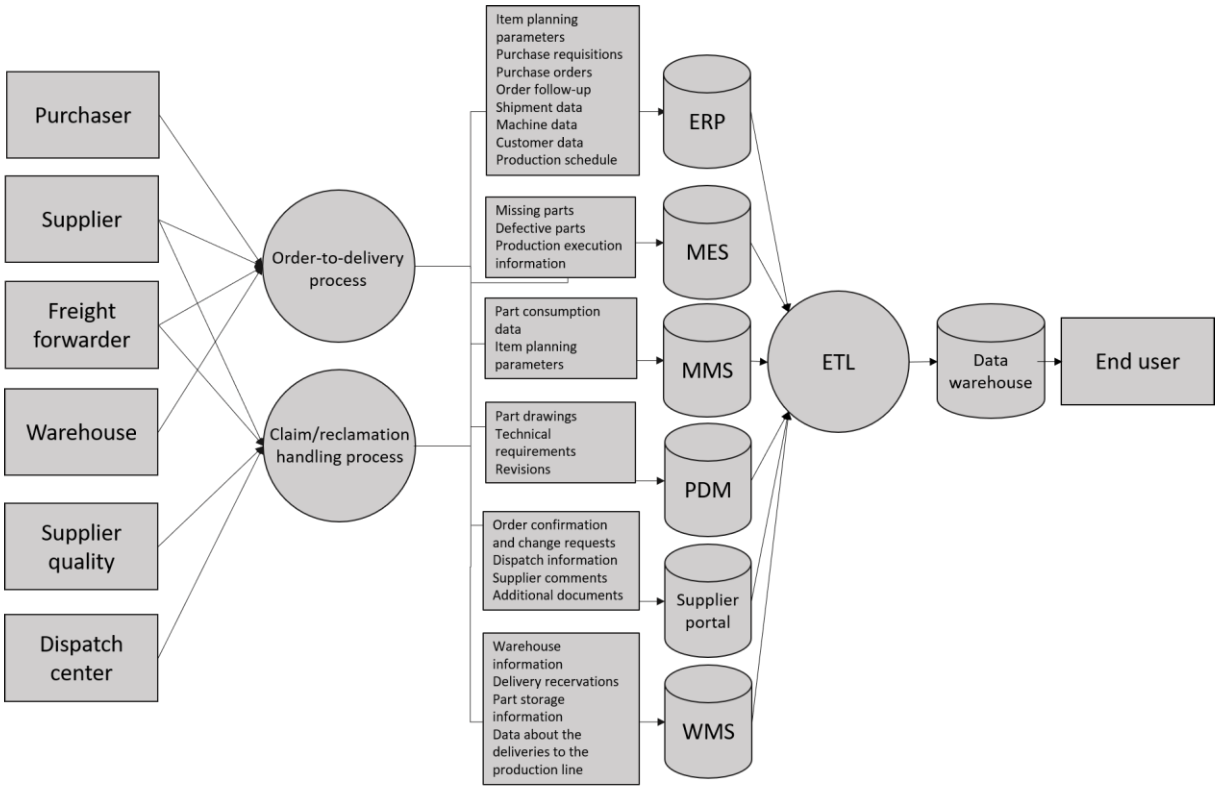


Figure 30 Supplier data flow

Figure 30 shows on a high level how the supplier data flows from the parties involved to the end-user. The ETL process in the figure stands for data extraction, transformation, and loading, which can be done using different tools. The data is stored in a data warehouse to be available for analysis. In this thesis, the ETL process is manually executed, and the data is loaded directly to the analysis software. The data handling process needs to be well defined to ensure data governance. In chapter 5, recommendations are made for improving this data handling process.

The data model is formed as a star schema. Star schema is a simple denormalized data model with fact and dimension tables representing the data (Sanchez-Ayala, 2020). The resulting star schema consists of 36 data tables, seven of which are dimension tables and 29 fact tables. The amount of data tables is significant due to collecting the data from various systems and aspects. The relations between the data tables are constructed manually in PowerBI so that all dimension tables are linked to corresponding fact tables.

5.7 The metrics and methods for monitoring SQA

The literature considers choosing the right metrics to be a difficult task. This task is approached in this study by first forming a broad list of metrics (appendix 1) and choosing the most appropriate ones from the list (table 13). The list involves proposed indicators for quality, cost, delivery, capacity and relationships, including other factors that have been reviewed from literature or found out when investigating how the case company operates. For instance, research & development (R&D) was chosen to be one criterion, as the case company could benefit from finding out how R&D functions and the supplier network are related.

The KPIs chosen for this demonstration analysis tool are based on the idea of the balanced scorecard. Both financial and non-financial metrics are used. First, one metric was chosen from each of the three most common categories discovered from the literature: cost, quality, and delivery. The selected metrics are the cost of poor quality, defective parts per million, and delivery reliability. The tool is built so that these three KPIs can be inspected from several perspectives. In addition to these three measures, other measures were chosen to understand what factors affect the three most important KPIs. The analysis tool ended up having 19 measures which are presented in table 13. Limit values were defined only for the three main KPIs as they are used to get a quick overview of the supplier network. In this study, the limit values are defined to be the same for all suppliers to simplify the analysis. It might be beneficial to define supplier-specific limit values, especially for the strategic suppliers, to gain the most profit.

Table 13 The measures used in the analysis tool

Measure	Explanation	Limit values
Cost of poor quality	The cost of poor quality measured in checking and repairing costs.	5 percent out of total purchases
Defective parts per million	The number of defective parts per million delivered parts. Defective means either the delivery being inaccurate or the item being defective.	Maximum 500 defective parts per million

Delivery reliability	The timeline for reliable deliveries is at most two days before or two days after the confirmed delivery date.	Minimum 95% correct deliveries
Inventory value	The value of the purchased goods currently in the inventory	Not defined
Late order lines	The number of order lines that should have already arrived the day before	Not defined
Forthcoming order lines	The number of order lines arriving in the future based on real orders	Not defined
No of claims	The number of claims	Not defined
Inspection hours for claims	The hours spent inspecting a defective delivery	Not defined
Repairing hours for claims	The hours spent repairing a defective delivery	Not defined
Inspection and repair costs accepted by the supplier	The inspection or repair costs for a defective delivery the supplier has accepted	Not defined
Unfinished claims	The number of unfinished claims	Not defined
Not invoiced inspection and repair costs	The costs that have not been invoiced measured in euros	Not defined
Not invoiceable costs	Not invoiceable costs measured in euros	Not defined
Claim handling time	Minimum, maximum, and average handling time for claims	Not defined
Claims without supplier response	The number of claims without a response from the supplier	Not defined
Claims without acceptance of the supplier response	The number of claims whose supplier response has not been accepted by the case company	Not defined
Consumption data about the parts	No of used, purchased and claimed parts	Not defined
Revision information about the parts	The dates when the specs of a part have changed	Not defined
Zero lines	The number of unavailable parts in the spare part inventory	Not defined

When choosing the metrics, it was discovered that all the measures in the literature cannot be used currently in the case company, as the available data does not allow to calculate them. The measures used in the demonstration tool were chosen so that they can be calculated for this thesis using the available data. When calculating the cost of poor quality for example the costs from delayed production are not included as they are challenging to discover from the data. Another example is that the delivery reliability timeline used in this study is rather long for a just-in-time production ideology. Deciding how the measures are calculated and what data needs to be collected for the measurements was found out to be essential for building an efficient analysis tool.

The evaluation methods used in this thesis were chosen based on how applicable the methods are in PowerBI and how beneficial the methods are for achieving the set objectives. ABC analysis is used in this thesis for categorizing the suppliers for the analysis. A balanced scorecard ideology is used for creating the layout for the analysis tool. As the cost data about supplier quality assurance in the case company is limited, cost-ratio-method’s usability was assessed to be low. As the aim is not to calculate an overall score for the suppliers, categorical and weighted point methods are not used. The AHP and DEA methods were excluded from the analysis tool because they require more mathematical understanding than the other methods.

5.8 Building a demonstration tool for monitoring and evaluating supplier quality assurance

As the processes have been modeled and the metrics together with the evaluation methods chosen, building the analysis tool can begin. The case company is at the beginning of its journey on the data analytics path and therefore the analysis tool is based on descriptive analytics. The aim is to investigate, what has happened in the supplier network, what issues there are, and what kind of actions need to be taken by the purchasers and the supplier quality department.

5.8.1 ABC-analysis as a method for supplier categorization

ABC-analysis is used for segmenting the suppliers into strategic (A-group), important (B-group), and transactional (C-group) suppliers. The method allows the use of both financial and non-financial metrics. Therefore, two measures were chosen, total purchases to represent the financial aspect and total order rows to represent the non-financial aspect. The cumulative values and cumulative percentage values were calculated, and the ABC-class was defined based on the cumulative percentage value. As the case company has a few extensive suppliers that form a large part of total purchases and order lines, the limits were set so that A was assigned to 90 percent of the total purchases and order lines. Seven percent of the total sales and rows are assigned to class B, and the last three percent to class C. The ABC analysis resulted in 54 suppliers in class A, 261 suppliers in class B, and 502 in class C. For these classes, three different analysis reports were created so that A-class has the most detailed analysis report and C-class the most aggregate and simple report to test how different levels of aggregation can be represented in the analysis tool.

5.8.2 The structure of the analysis tool

The analysis tool is built by creating separate report sheets for different analysis areas. Table 14 presents the contents of the report sheets in the analysis tool. Each report sheet is based on either the order-to-delivery, claim handling, or reclamation handling process.

Table 14 The dashboards of the analysis tool

Name of the sheet	Process	Contents
A-class	Order-to-delivery	5 KPIs: delivery reliability, cost of poor quality, late order lines, PPM and inventory value; early, late and on-time deliveries; oncoming order load; all late order lines in a table
B-class	Order-to-delivery	4 KPIs and their trend graphs: delivery reliability, PPM, cost of poor quality, and inventory value
C-class	Order-to-delivery	3 KPIs: delivery reliability, PPM, and the cost of poor quality
Claim handling	Claim handling	No of claims based on claim type; no of defective pcs; cost of poor quality; and the no of suppliers that have claims
Inspection and repair	Claim handling	Inspection and repairing hours; percentage of accepted inspection and repairing costs; no of claims per location; all claims in a table
Claim handling time and invoicing	Claim handling	The no of unfinished claims; no of claims in different handling states; the amount of not invoiced costs; claim handling times; not invoiceable costs
Claim responses	Reclamation handling	No of claims without a response; no of claims without response approval; the claim lines that require further processing
Parts	Order-to-delivery	No of used, purchased, and claimed parts; poor quality costs; revision information; all claims in a table
Zero lines	Order-to-delivery	Total no of zero lines; the trend line for all zero lines summarized and the zero lines per supplier; all zero-lines in a table
Supplier view	Order-to-delivery, reclamation handling	3 KPIs with trend lines and limit values: delivery reliability, PPM and costs of poor quality; a radar chart representing the overall situation of a supplier

The varying dashboards for the A, B, and C supplier categories are based on O'Brien's (2014, p. 96) recommendations. A-class suppliers are the most important group and therefore measured in the most detail to define how well the A-class suppliers are progressing towards joint goals (O'Brien 2014 p. 96). Accordingly, the A-class sheet has the most detailed supplier analysis report that can be used for continuously improving the strategic suppliers. The case company requested a graph visualizing the upcoming orders to be able to even out the demand load. This way, delivery peaks in the warehouse and abnormal demand spikes for the suppliers can be reduced.

The B-class, important suppliers, are regularly measured with the main goal of compliance (O’Brien 2014 p. 96). The important suppliers are not developed as much as the strategic, but some of the suppliers can be taken into more precise inspection if compliance goals are not met. The B-class dashboard presents three KPI values and a trend graph of the KPI values for inspecting how the suppliers have been developing. For the C-category, O’Brien (2014, p 96) suggested not measuring the suppliers at all. Still, as the aim is to get a good overview of the supplier network’s total situation, the transactional suppliers have a dashboard sheet. However, the report is simple and in aggregate form with only three numerical KPIs for getting a quick overview.

In addition to measuring the order-to-delivery process, the analysis focuses on the claim handling process. The goal is to prevent claims from occurring and, if a claim is made, to improve handling the claims. The analysis tool can be used to lower the number of claims by inspecting which suppliers tend to deliver defective goods and improving them towards better quality. A lower rate of claims will also lead to a lower rate of inspection time, repair time and costs. It is possible to ensure that all necessary actions are taken and claim handling is not left unfinished by inspecting how the claim handling is proceeding.

For part-specific information, there are two analysis sheets. The first one is for investigating part consumption data. Changes in the consumption and the number of defective parts can be compared to when part drawings have been changed. This is to answer whether a difference in the drawings has increased or lowered the number of defective pieces. The second part-specific dashboard is for zero-lines, which represent the spare parts currently not available on stock. The last analysis sheet is the supplier view, which could be linked to the supplier portal for the suppliers to inspect.

The analysis tool has been built based on the balanced scorecard ideology. Even though the tool does not yet involve all the BSC areas (financial, customer, internal business process and learning and growth), both financial and non-financial aspects have been considered. Also, the main KPIs are valued as equally important without sub-optimizing any of them. An overall score for the suppliers is not calculated in this tool, as definitions of each KPI’s importance have not been made. It could be beneficial to define an overall score for the suppliers to see which supplier is performing the best. The challenge is that so-called soft measurements based on a purchaser's opinion are not included. Therefore, calculating an overall score for the suppliers might not describe the overall situation well enough.

5.8.3 Supplier data visualization

When creating the visualizations, the four factors discovered from the literature were used as a guideline – choosing the appropriate information to present, using suitable graphs, deciding the level of aggregation or granularity, and considering what kind of shapes and colors to use. When examining the literature, two ways for data visualization were discovered. The first one, presentation graphics, is used in the analysis tool for presenting information in an aggregate form for the audience. For example, the supplier view sheet consists of presentation graphics. The second type of visualization, exploratory graphics, is used to make the analysis tool appropriate for operational daily use, such as presenting the late order lines on order line level.

The adaptability of the analysis tool was discovered to be essential for utilizing the tool in daily operations. Several filters were added to make the tool adaptable. The filters allow the user to analyze the data in more specified ways regarding the user's needs. Using the filters affects the granularity of the report, as for example, different timelines for analysis change how precisely the data is presented. A longer timeline in a graph makes the visualizations more aggregate and vice versa. An example of the filters used is illustrated in figure 31.

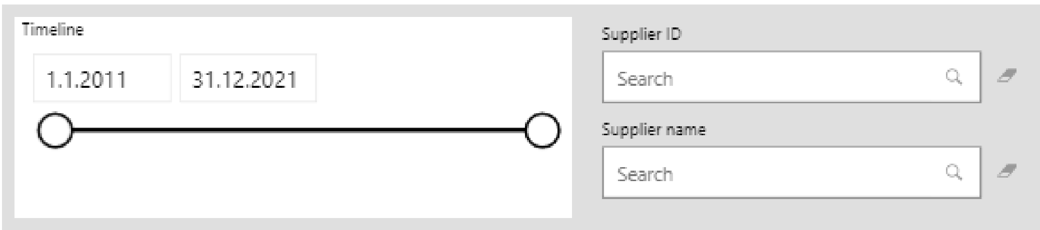


Figure 31 The date and supplier filters in the analysis tool

The limited quality and amount of the data does affect the quality of the visualizations in the analysis tool, as (Ayalasomayajula 2021) mentions to happen. Some of the visualizations lack data from specific periods or other features, and therefore the visualizations are informative only with certain filters. The amount of information presented in one graph and one report sheet was kept reasonable throughout all of the analysis sheets to intelligible the visualizations. The most complex graph in the analysis tool (figure 32) combines three claim handling attributes. Even though the chart presents a lot of data at once, readability is not compromised.

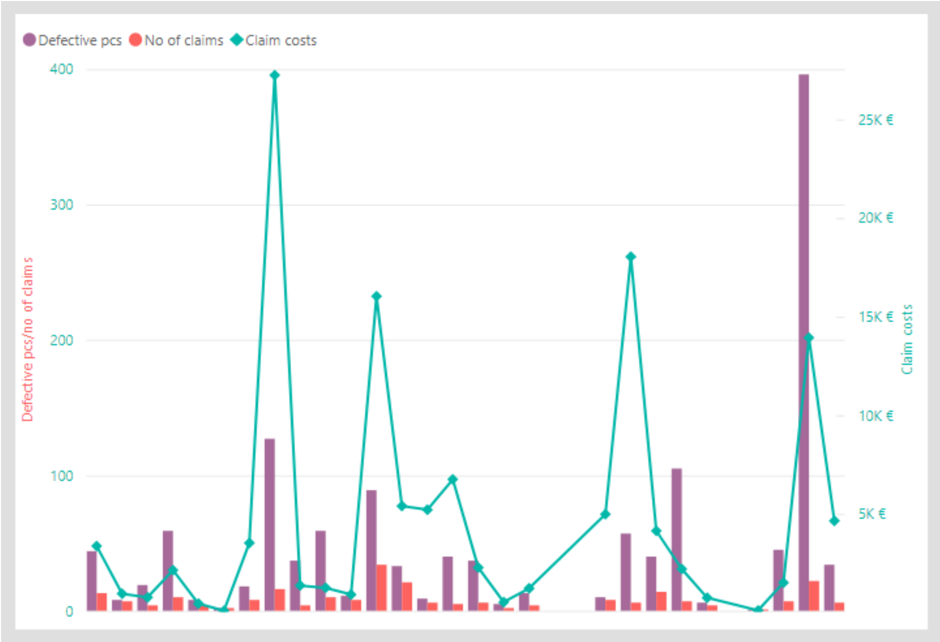


Figure 32 The claim handling data graph

Many of the visualizations are simply in aggregate number form, as in figure 33 below. In addition, line and bar charts are used for their simplicity. A Box and Whisker chart represents the claim handling times, and a radar chart is used to present suppliers their overall situation. Some tables were also used for expressing detailed data. The intense brand colors from the previous analysis tool were replaced with clear and neutral colors to make the tool more readable. To indicate if a KPI is on the good or the wrong side of the limit value, green and red highlight colors were used. Figure 33 represents the colors used in the analysis tool.

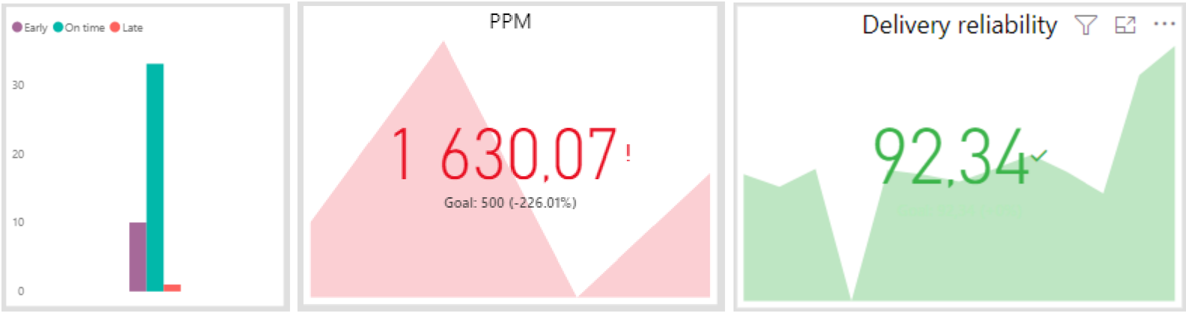


Figure 33 The colors used for the visualizations

In the literature, supplier data aggregation was noticed to have two critical risks - changing the statistical properties of a data series and a masking effect. Both risks are realized on a small scale in the analysis tool. Some of the KPI values are based on aggregate monthly data, such as the PPM value, and therefore, for instance, the range of a KPI value can differ from the actual situation. The masking effect can also occur in the analysis tool. One example is that when inspecting one defective part takes a lot of time, the average value of inspection hours might increase. The average value can seem high even though most of the claims are inspected in a shorter time. This can lead to the conclusion that the inspection period has lengthened, although the change is caused by only one case, which is an occurrence of the masking effect. To lower this risk, both mean and median values for the inspection and repair hours have been calculated in the analysis tool. These challenges confirm that when the analysis tool is built, an understanding of statistics is necessary.

The detailed tables in the tool allow purchasers to see, what order lines are late, which claims are not yet finished, and what items are missing from the spare part stock. As the tables show all individual occurrences, they are easy to act on and inspecting what factors affect the aggregate visualizations is possible. As the amount of data was limited in this thesis, the issue of needing to store and handle large amounts of data did not realize. The challenge could arise when the analysis tool is used with a complete dataset. It might be necessary to set more filters for the tables so that the amount of information in one table stays reasonable.

5.9 Resulting requirements for building a supplier analysis tool

The demonstration analysis tool was built to discover what aspects the case company needs to consider when designing analysis tools. The requirements for building an analysis tool are divided into four categories: data requirements, analysis tool design requirements, process understanding, and managerial requirements.

5.9.1 Data requirements

It was discovered that the data accuracy and availability limited the process of building the analysis tool the most. Low data availability limited creating the visualizations for the tool and low data reliability made the created visualizations inaccurate. Thereby ensuring having the right data available is a crucial factor for the analysis tool to work correctly. The data not being reliable was the most common reason for a purchaser not to use analysis reports to support procurement. For supplier quality, the availability of data limited the usage. The data was either scattered to several locations or not collected in the first place. If the data's accuracy and availability are ensured, the possibility to build a tool that meets the users' needs becomes enabled. When the tool corresponds well to the users' requirements and the set goals, the tool will be reasonable and motivational to use.

Specification requirements for the ERP system are suggested, and a data platform for collecting and processing the supplier data is presented in this sub-chapter. Updating the ERP system allows the case company to produce more valuable data to be utilized. By designing a data platform, the data is made available for the end-users in usable form.

ERP-system specifications

This study revealed that most of the supplier data is stored in the case company's ERP system. Therefore, the case company's ERP system should better support data analysis by collecting more easily analyzable data. This same challenge was also noticed by another Finnish heavy equipment manufacturer informally interviewed during this study.

Two main issues limited building the relational data model for the analysis tool. First, the data does have unique identifying values for each record, but there can be multiple identifying values for the same supplier or customer. Analyzing the suppliers and customers requires that one supplier or customer has only one unique identifying value. Secondly, the same attributes are named differently between the data tables. Using the same names for the same attributes in all data tables facilitates understanding the relations between the data tables.

The ERP system should have all the data in the same format to ease pre-processing the data. For example, the timestamps are in three different forms and need to be transformed to a similar format before the analysis. Also, recording more precise data could improve the quality of the analysis results. For the order data, recording the original confirmed delivery dates was requested by the purchasers of the case company. Currently, the delivery reliability values are not correct because of the imprecise order data. Also, information about the orders made with too short delivery time could be stored. This way, it could be analyzed how many rushed orders the case company makes. In addition, collecting more precise data about claim handling, logistics and the case company's internal processes could produce insightful results.

Data platform

Ekola (2020) describes a data platform as a data logistics network and an infrastructure for analyzing large amounts of data. The supplier data is distributed to several information systems, and a data platform could be designed to process and combine the pre-processed data into one data warehouse. Hence, the data would be available for analysis in easily analyzable form. The more automated this process can be designed, the more efficiently the data is available for analysis. The slowness of the case company's current analysis tool has been one reason for not using the supplier analysis tool continuously. A well-designed data platform can enable faster analysis by reducing data processing delays. To minimize the querying time, it is also possible to consider storing the data in aggregate form. As the literature showed, storing aggregate data means storing less data as different functions are used for data summarization. For some visualizations, granular data is required, and the balance between aggregate and granular data depends on what kind of information the case company wants to extract from the data.

The data platform should be designed so that the case company's data governance principles are followed. Even though data governance is only one of the five aspects of data mentioned by Davenport and Harris (2017), a data governance framework can help achieve the other four aspects of data, such as data quality. In addition to data governance, scalability can also become an essential feature of a data platform when the amount of data grows. The case company is currently focusing on descriptive analytics when analyzing supplier data. In the future, applying predictive, prescriptive, or even autonomous analytics is easier if the data platform is self-scalable and data governance principles are defined for expanding the use of analytics.

One of the challenges when building the demonstration tool was discovering the relations between the data tables. Column names in the data tables did not match even though the columns represented the same attribute. The PowerBI data model is based on relations between data tables. Therefore storing both the data tables and their relations to a data warehouse could be beneficial. When the relations are automatically stored, it will not be necessary to discover the relations by hand. The data platform should collect the data from all the information systems that produce supplier data discovered in subchapter 5.5.

For the demonstration tool, the data was collected from a certain point of time. The time aspect needs to be considered when building a data platform. Does the data need to be gathered for processing in real-time, or is batch processing at one time of the day enough? Combining real-time and batch-processed data is a possible option as well. For supplier data, collecting the data in batches is likely to be enough. During this study, the data structure was discovered to differ between the data sources. Not all supplier data is in a structured table form. For example, the case company's comments on a supplier's response to a claim are in a freely written form. The same goes for the supplier comments in the supplier portal. Transforming this kind of unstructured data into a structured form might be needed to consider when building the data platform. If text documents are collected, text mining could give additional insights into the data.

5.9.2 Analysis tool design requirements

The second most common reason for not using analysis tools in the case company was poor usability. The previous analysis tool was slow to use and did not have many modifying options for getting insights from different perspectives. The literature revealed that it is necessary to involve employees from different levels and operations to succeed in utilizing supplier analytics. With a flexible analysis tool, all users can inspect the supplier network from their point of view. The demonstration analysis tool was made flexible with a variety of filters. Also, both aggregate visualizations and data in a table form were included. Therefore, the users can use the aggregate visualizations to inspect the supplier network's overall situation and the detailed data for operational use cases. Also, the reports for three supplier categories enable analyzing suppliers differently based on the importance of a supplier, as was requested in the literature. The adaptability of an analysis tool was discovered to be a similar issue to choosing the number of metrics for the analysis. Too many editing possibilities make the use complicated, and too few opportunities to edit the visualizations limit the usage too much. With a broad range of filters, the users can modify the report, and the visualizations automatically adapt to the filtering. The dashboard formatting was kept unchangeable so that the user will not have too many modification options.

The visualizations changed a lot compared to the previous tool. Colors were used considering the principles defined in the literature. The colors were set to be calmer, and therefore the highlight colors stand out better. The graphs were chosen mostly from the set of basic diagrams recommended in the literature – bar charts, line charts, and tables. The information presented by these three types of graphs is easy to internalize, and misinterpretations' probability is low. The literature also revealed that using simple numeric visualizations is very informative. Numeric visualizations were utilized across the built analysis tool, and they are quick to interpret.

When building the analysis tool, communication between the builder of the analysis tool and the users is necessary. Communication allows combining features the users see necessary and the builder's analytics knowledge. Developing the tool based on the user's insights the tool is more likely to match the needs, and the users are more involved in the process from the beginning. One example of a user-based request is that the purchasers would benefit more from the tool if the reports were linked to the ERP system. For instance, there could be a link from the PowerBI straight to the ERP system. Hence, the users could take action in the ERP system based on the analysis report.

The literature revealed that it is necessary to give the suppliers feedback about their performance for improving them. In addition, the literature warned that sharing information between the supply network participants is often challenging. If the appearance of the tool is pleasant and measures accurate, it is possible to use the tool for providing feedback to the suppliers in the form of performance KPIs. Linking the analysis tool to the supplier portal would enable the suppliers to inspect their performance. Making the visualizations available to the suppliers would automatize sharing the data analysis results between the customer and the suppliers and reduce the risk of not sharing enough information.

Even though the demand side of the supplier network was left out from this study, it would be important to include it in the analysis tool. The analysis does not represent the whole life cycle of an item because the events after a machine leaves the factory are excluded. Yet another thing to consider is creating various filter combinations for different use cases for the analysis tool. Therefore, for example, reporting the results to the senior management is faster, as the correct filters can be applied by pressing one button.

5.9.3 Process understanding requirements

The literature recommends process mining for inspecting and improving business processes. The case company has modeled its processes previously on a high level. Process mining was discovered to give a deeper understanding of the processes. As the literature suggests, process mining can be used for inspecting data flows as well as examining business processes in the case company. The process mining done for the two processes in this thesis revealed more actions than the high-level process models indicate. Understanding the processes well is necessary for analyzing them, and therefore, process mining is a practical step before building an analysis tool. The case company could use process mining also for improving processes as it reveals possible pitfalls in them.

In this thesis, the amount of data used for process mining does not reflect reality very well. Therefore it would be essential to do process mining with larger datasets that involve data about all the case company's suppliers. ProM is a viable option for the case company as a process mining tool. The tool was recommended in the literature because it is an open-source program with many techniques for process mining. The challenges in the case company might be that the software requires pre-processing the data and some process mining knowledge is necessary.

5.9.4 Managerial requirements

From a management perspective, an efficient analysis tool requires as little managerial involvement as possible. The literature revealed that change management and change leadership might be necessary for implementing supplier analytics. Still, the motivation for further use should raise from the benefits the tool gives by facilitating procurement and quality assurance work. The tool should be built so that the purchasing and supplier quality experts can modify the reports in the analysis tool without assistance from other specialists. This allows the usage of the tool to be a continuous process, which is recommended in the literature.

As the literature revealed and the whole process of building the demonstration analysis tool showed, carefully choosing the goals, metrics, and methods for the tool is a prerequisite for building a tool that supports the case company's strategy. In the literature, there are various ways to choose the goals for analyzing supplier quality assurance. In this case, forming company-specific evaluation criteria and choosing limit values based on previous experience was a suitable method to begin supplier analysis. Following certain best practices or standards requires a deep understanding of them, and benchmarking other manufacturers did not produce many new insights in this study. Therefore, following a standard, best practices, or an industry leader was not considered a feasible solution for the demonstration analysis tool even though the literature considered them possible options.

The most important selection criteria for choosing the metrics and methods for supplier data analysis are organization specificity and understandability based on the empirical findings of this study. The literature review showed that optimization between financial and non-financial metrics is necessary. As the case company aims for both, cost reductions and quality improvements, the optimal state between better quality and lower costs should be considered. The case company also needs to consider the calculation methods for the KPIs as the calculation methods affect the results. For example, considering hidden costs when calculating the cost measures would make the analysis more reality-representing.

From the evaluation methods, only ABC-analysis and the balanced scorecard ideology were used in the analysis tool. They were already familiar for the case company, and the results were easy to interpret. The evaluation methods presented in the literature are applicable if the case company decides to for example calculate overall scores for the suppliers, rate suppliers based on cost factors, or measure supplier efficiency based on input and output values.

5.9.5 Prioritizing the requirements

As achieving all the requirements discovered when building a demonstration tool might be challenging, the requirements are prioritized based on a decision-making criteria prioritization matrix by (Heikinheimo 2021, p. 117). In the model, four requirements are prioritized so that one requirement is set as the most important, two as the next important, and for the fourth one, the situation is accepted.

Table 15 A decision-making prioritization matrix for building an analysis tool

		Data quality	**Analysis tool usability**	**Analysis tool adaptability**	**Process mining**
1	Define the most important criterion (1 pc)	x			
2	Define the next important criteria (2 pcs)		x	x	
3	Accept the situation for the last criteria (1 pc)				x

Data quality was chosen to be the most important factor to ensure when building an analysis tool. Analysis tool usability and adaptability are crucial for designing an analysis tool that experts are willing to use in their work. Ensuring usability and adaptability also could reduce the amount of managerial support required. Process mining was ranked as the least important factor in the design process. Process mining can produce valuable insights but does not benefit if data reliability, analysis tool usability, and adaptability are not secured.

6 CONCLUSIONS AND DISCUSSION

The topic for this thesis arose from a heavy equipment manufacturing company willing to improve its supplier network's quality assurance by data analysis. The case company had noticed the importance of data analysis for monitoring its supplier network and therefore already started its analysis journey. However, the case company had issues regarding what to measure and how to do it efficiently. The available analysis tool was not used for continuously improving the supplier network because it was considered unreliable.

This thesis studied how supplier data analysis can be conducted based on a systematic literature review to assist the case company. The literature review revealed that designing a continuous process for analyzing suppliers is necessary to succeed. Also, the literature had to offer a variety of measurements and methods to use for monitoring the suppliers. Different aspects of data analysis were discovered to work as a guideline for building an analysis tool for the case company.

The methodology for the empirical part was an action study. The current state of analyzing the supplier network in the case company was analyzed. Based on the challenges discovered from the analysis, objectives for a new analysis tool were discussed. Three processes, order-to-delivery, claim handling, and reclamation handling, were surveyed with a process mining tool to discover, how the processes flow and what could be monitored about the processes. A demonstration supplier analysis tool was built for the case company using the findings from the literature and from examining the case company's features and challenges. For the tool, supplier data was collected from the case company's information systems and metrics and methods chosen based on those presented in the literature. As a result of designing the demonstration analysis tool for supplier quality assurance, requirements for building and using an efficient and beneficial supplier analysis tool were discovered.

It was found that the data used for the analysis affects the results a lot. Low data availability and reliability can prevent experts from using analysis tools in their work or lead to wrong decisions. The design of the analysis tool also affects how efficient the analysis tool is. An analysis tool that allows the users to modify the analysis features for example by using filters, makes the tool more usable. Process mining was discovered to benefit when building an analysis tool as the data is produced by different business processes. Understanding the processes helped to assess how well the data used for the analysis represents reality.

6.1 Answering the research questions

The main research issues of this study were investigating how supplier quality assurance can be monitored and evaluated and how a supplier quality assurance analysis tool can be built for a heavy equipment manufacturing company. This study also examined the benefits and challenges analyzing SQA might involve and how the analysis results can be used for continuous improvement. Moreover, this study aimed to gain a broad understanding of building a supplier analysis tool and therefore produce guidelines for the case company to support future activities. The two research questions are answered based on the literature review and the empirical findings of this study. The first question was divided into three sub-questions to get a deeper look at analyzing supplier quality assurance.

1. *How can supplier quality assurance be monitored and evaluated using supplier data based on the literature?*

Supplier quality assurance was found out to be the third important factor in supplier management after supplier sourcing and supplier integration. Quality assurance is a step on the road towards operational excellence and analyzing SQA can help develop the supplier network processes towards reducing waste and adding more value to the processes. From the reviewed literature, books by (Fernandez, 1994, pp. 49–50), (Gordon, 2008, p. 14) and (O’Brien, 2014, p. 109) stated that designing a management process is a prerequisite for successfully managing supplier performance. The process involves four aspects, goal setting, data collection, data analysis and interpreting the results for continuous improvement. In addition, data quality and organization-specific methods and metrics were found out to be essential for analyzing supplier quality assurance efficiently. The first research question was divided into three sub-questions to get a deeper view of monitoring and evaluating SQA.

a. *What are the methods to track and evaluate supplier performance?*

A variety of methods for monitoring supplier performance were discovered from the literature. The literature indicated that it is essential to choose a few basic methods and monitored KPIs for efficient analysis. The literature review and a discussion with another heavy equipment manufacturer company confirmed that using a few representative metrics is more beneficial than measuring a large variety of different features. By reviewing the literature, three categories of metrics were found out to be the most used: cost, delivery and quality. These three categories can be measured in different ways, and some metrics were collected for each category.

For evaluating supplier performance, the discovered methods were mostly used for supplier selection in the literature. Some of the methods are suitable for evaluating supplier performance as well. In this study, a variety of methods was collected from the literature and seven of them investigated in more detail: ABC-analysis, analytical hierarchy process, balanced scorecard, categorical, weighted point and cost ratio methods, as well as data envelopment analysis. These methods have varying applications, such as categorizing the suppliers and calculating overall performance scores for them.

b. *How can the information gained from analyzing supplier performance be used for continuous improvement purposes?*

Analyzing supplier data itself produces valuable results only if the discoveries are used for improvement actions. The literature review revealed that supplier data analysis needs to be a continuous process, not a single event. As well as choosing the metrics, building the process also needs to be done on an organization-specific level. In addition to designing the process, selecting the goals for supplier analysis is crucial for succeeding. The goals can be controversial, and optimization between the targets is necessary. For example, lowering costs and improving quality might not be possible at the same time.

For the information produced by the analysis to be useful for improvement actions, it needs to be easily available, understandable, and reliable. The analysis results can be used for helping suppliers to improve their processes as well as for the case company to improve. When the information is reliable and simply presented, it can be used as a communication tool between the company and its suppliers. Setting limit values and targets for the supplier makes it possible to follow how the supplier is making progress. Also, when the suppliers are constantly monitored, setting penalties or rewards for encouraging the suppliers to improve is possible. When actions are taken, the analysis results can be used to define how effective the actions are.

c. *What benefits and challenges analyzing supplier quality assurance can have?*

The literature showed that analyzing supplier quality has a large range of benefits and challenges. The more the analysis results are used for improvement, the more benefits can be gained. Probably the most significant benefit is obtaining more competitive advantage by reducing waste in the processes, improving quality, and reducing costs. The literature revealed that many organizations already use descriptive analytics, and in the future, using analytics might be necessary for staying in the market. Data analysis allows to make data-based decisions and to follow how well the decisions are affecting the performance.

Whereas the benefits can be precious for companies, the list of possible challenges is rather long. Three main challenges were discovered from the literature: choosing the techniques and methods for SQA analysis, cooperation with the suppliers, and assigning enough resources for the process. The empirical part also revealed other challenges, such as low data accuracy and unclear visualizations. Comparing the case company’s challenges with the literature recommendations and the challenges other interviewed manufacturing companies had revealed that many companies are battling with similar issues. The complexity of the supplier network can also limit the analysis. In this thesis, the focus was set on the demand side of the network to simplify the analysis. Therefore, the analysis does not represent the whole lifecycle of the purchased goods.

2. *How to build a supplier quality assurance management tool for a heavy equipment manufacturing company, and which characteristics and functionalities should it include?*

As the case company wanted to improve monitoring its suppliers, a demonstration analysis tool was built based on the literature findings and the case company's challenges and desires. As company-specificity was one of the requirements for succeeding, the focus was set on three processes, order-to-delivery, claim handling, and reclamation handling process because they take a lot of the case company's resources. The analysis tool was designed by first inspecting the case company's current situation. From the current situation, challenges were discovered. Based on the existing analysis tool and the literature review, objectives were set for a new analysis tool. The processes to be analyzed were familiarized with a process mining tool to decide what to measure and to discover what data is available about the processes. After modeling the processes, the measures and methods were chosen based on the suggestions gained from the literature considering the case company's features.

When the groundwork for building the analysis tool was done, the analysis tool was implemented by first collecting the data and forming a relational model of it to the analysis program PowerBI. Separate dashboard sheets for each measured area were created so that every sheet has a reasonable amount of data visualizations. The literature revealed how data analysis can be done on different levels of detail. The analysis tool was built to have the possibility for both, aggregate KPI inspections as well as examining the data in a granular form from tables. The previous tool did not meet all users' needs very well, and therefore, the demonstration tool was made editable for every user's needs with a variety of different filters. Different visualization principles discovered from the literature were considered to make the tool understandable and pleasant to inspect. The analysis tool was documented to ease the use.

a. *What factors limit implementing the analysis tool?*

Building the demonstration analysis tool revealed that poor quality and low availability of data are the main limiting factors in building an analysis tool. Poor quality data was noticed to result in poor quality visualizations, as can be expected. Also, assessing the quality of the data can be challenging. In this study, a process mining tool was used to understand how the processes behind the data flow to know how well the data represents reality. Data pre-processing is necessary for ensuring the quality of the data. As most of the supplier data is collected to the case company's ERP system, the system's specifications define what data is available. The ERP system was discovered to have some limitations, which are considered in the next sub-question in more detail. In addition to enhancing the ERP system, the case company was suggested building an automatic data platform for collecting, processing, and storing the supplier data.

Setting the goals and limit values for the analysis tool was identified as a challenge in this thesis. Should there be separate goals for each supplier? How to balance the goals between financial and non-financial? Answering these questions requires proper planning before building an analysis tool. If there are no set targets, following the progress of the supplier network is difficult.

Low usability can also limit using the tool. It was discovered that the analysis tool should meet the needs of all users. The user needs were considered by selecting different visualizations, some aggregate and some detailed, and by adding a variety of filters to the tool so that the tool is adaptable. A reasonable amount of metrics and visualization were selected for the tool to make the dashboards easy to interpret. Using highlight colors for monitoring the limit values of KPIs help to get a quick overview of a supplier and the supplier network's situation. The usability of the demonstration tool was not assessed in an actual use case. The usability can be properly assessed once the tool has been tested in developing the suppliers. Nevertheless, it was noticed that users' feedback and continuously improving the analysis tool is necessary for making the tool match the users' needs. The case company's previous analysis tools were left in low usage if the users' needs were not adequately met. Users are often experts in their field and can tell what features an analysis tool should have.

It can be concluded that building and implementing a supplier analysis tool is a multi-step process that requires commitment from all, the builder of the tool, the users, and the management. It would be recommended to get started in analyzing supplier performance by monitoring just a few metrics but doing that well and utilizing the results for continuous improvement. Setting too high objectives at once might make the project seem too large to implement. After the analysis process with a few informative metrics has been observed to work well, the analysis tool could be expanded to have more metrics and information available for decision-making.

b. How an ERP-system should be specified to support implementing the tool?

The case company's ERP system does produce a lot of supplier data which enabled building the analysis tool in the first place. Data is available about many aspects, such as the orders, claims, suppliers, and customers. The challenges are the quality of the data and the requirement for more detailed information for more accurate visualizations. Inspecting the order-to-delivery, claim handling, and reclamation handling processes revealed that some of the process steps are not saved to the ERP system. Also, the ERP system produced additional steps that were not taken in reality when handling a purchase order.

When an ERP system reflects reality well and stores data from many aspects the visualizations can be made accurate and reality-reflecting. For example, detailed log data with the information about who is behind the action and cost data about quality-related action could be stored in the ERP system. Also, information about the shipments could be collected to analyze how much the freight affects the supplier metrics.

In addition to improving what data is collected, it is also valuable to consider how the data is collected. The case company's ERP system had duplicate values, differing forms of presenting information, and differing column names for the same attributes. These seem like tiny details but affect the pre-processing of the data a lot. When the data is systematically stored in the same format, all columns named by the same principles, and unnecessary values removed from the ERP system, the data is easier to transform to an analyzable format.

6.2 Suggestions for the case company

Davenport and Harris (2014, p. 68) state that the most advanced organizations monitor their suppliers and their suppliers' suppliers. As the literature reveals, a high level of analysis is still practiced only by a few companies. The case company belongs to this vast majority of organizations using descriptive analytics to study what has happened and what actions need to be taken. As the case company is dependent on its suppliers, it can gain value from analyzing the supplier network. Currently, it would be beneficial for the case company to start to utilize descriptive analytics as a part of business operations more. Although predicting the future would benefit the case firm, it is valuable to use descriptive analytics first with a reasonable amount of measures. Once the first level of analysis is well in hands, predictive and prescriptive analytics can be considered for gaining more benefits.

This study has given a guideline to the case company to develop its descriptive supplier analysis system towards actionable results and using them in daily operations. In this study, it was discovered that the same metrics and methods for analysis do not work for every organization, and therefore, the case company would benefit from focusing on what it needs more than on what the literature has revealed about monitoring suppliers or what other Finnish manufacturers are monitoring. The analysis process should be well defined, enough resources assigned to the process, and the process should be continuously improved to minimize the challenges linked to analyzing the suppliers.

During the study, it was revealed that the challenges the case company has regarding supplier analytics are mostly data-related. Therefore, focusing on improving the amount and quality of available data would be useful. This study gives suggestions on defining the specifications for an updated ERP system, which can be utilized when the case company is updating its ERP system. Also, designing a data platform for supplier data analysis can assist the case company in producing analyzable data. When the data and the measures are reliable, the tool can be taken into action. Once the tool is applicable for supplier improvement, generating a clear supplier escalation process for the situations when a supplier is not performing on the agreed level is necessary. Also, rewarding the suppliers more might benefit by encouraging the suppliers to a higher-level of quality assurance.

A reliable analysis tool can offer a helping hand in managing suppliers, and therefore investing in it is reasonable. On the other hand, improving the supplier network should not be only based on data. Good supplier relationships still require good communication. Purchasers and supplier quality experts can make decisions with the assistance of an analysis tool, but the need for decision-making capacity does not vanish by using descriptive analytics. Also, everything cannot be measured, at least not yet.

6.3 Limitations and validity

The findings of this study offer new insights into the topic of supplier data analysis for continuous improvement purposes. Both topics, improving suppliers and data analysis have been previously studied, but combining them is has not been studied much. Regarding the literature, not many organizations efficiently use data analysis for improving suppliers even though there is a variety of possible benefits. Studies for using analytics for supplier selection were more common than using the results for improving already existing suppliers. This study focused on improving the suppliers and took process mining into account, which was not common in studies related to supplier analytics.

This thesis was done as an action study for a heavy equipment manufacturing company by considering the company's challenges and requests. Therefore, the results might not apply to other organizations. Also, this study was done using limited example data, which might have biased the results. Only the supply side of the supplier network was considered as the warranty system would have been too large an aspect to consider for the scope of this study. Involving also the demand side could have given more comprehensive information about analyzing the whole supplier network.

The case company's procurement, supplier quality department, and IT department were involved in this study. Even though continuously improving the supplier network using the analysis tool requires contribution from the suppliers, the suppliers' point of view was not incorporated into this research. Due to the scope of this study, the analysis tool was built as a demonstration to discover the challenges faced during the process. The results of the study could have been more reliable if the tool was tested in action as a part of managing supplier relationships.

6.4 Future research

Using supplier data analysis as part of improving the supplier network has many benefits. Therefore, this topic could be studied further in other organizations and industries. Further research could inspect how supplier data analysis tools are utilized in decision making and how suppliers can be committed to using data for developing the business actions as this thesis was focused on building an analysis tool. Also, studying supplier analysis from a predictive and prescriptive point of view could produce valuable information about the topic of supplier analysis. The biases linked to supplier data analysis would require further studying as well to avoid possibly producing misleading information.

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Appendix 1 A list of metrics for monitoring suppliers

Quality	**Cost**	**Delivery**	**Service**	**Capacity**	**ICT**	**Claims**
Acceptable parts per million (Noshad and Awasthi 2015 p. 470)	Production costs (Suraraksa and Shin 2019 p. 8)	Lead time (the time between order and delivery) (Varley 2013 p. 84)	Accuracy of product and quality delivered (Sullivan and Manoogian 2009 p. 15)(Suraraksa and Shin 2019 p. 8)	Time to recovery (TTR) (Sullivan and Manoogian 2009 p. 15; Suraraksa and Shin 2019 p. 8)	Production and scheduling system (Sullivan and Manoogian 2009 p. 15)	Claim costs
Defect rate (Noshad and Awasthi 2015 p. 470)	Ordering costs (Sullivan and Manoogian 2009 p. 15; Suraraksa and Shin 2019 p. 8)	Response time (to notices of defects etc) (Desai 2019)	Reliability of delivery service (Sullivan and Manoogian 2009 p. 15; Suraraksa and Shin 2019 p. 8)	Shortages of raw matrials (Sullivan and Manoogian 2009 p. 15)	Purchase order and payment system (Suraraksa and Shin 2019 p. 8)	Sojourn times of the claim process
Perfect rate (Noshad and Awasthi 2015 p. 470)	Logistics costs (Sullivan and Manoogian 2009 p. 15; Suraraksa and Shin 2019 p. 8)	Performance against agreed delivery times (CIPS 2021)	Speed and timeliness of communication (Sullivan and Manoogian 2009 p. 15; Suraraksa and Shin 2019 p. 8)	Manufacturing capacity (Sullivan and Manoogian 2009 p. 15)	Production and scheduling system (Suraraksa and Shin 2019 p. 8)	Acceptance and payment of compensation costs
Rejection in incoming quality (Noshad and Awasthi 2015 p. 470)	Cost reduction (CIPS 2021)	Delivery reliability	Sharing of information (Suraraksa and Shin 2019 p. 8)	Flexibility in productinon (Sullivan and Manoogian 2009 p. 15)	Inventory management system (Suraraksa and Shin 2019 p. 8)	Inspection and repair hours
Rejection from customers (Noshad and Awasthi 2015 p. 470)	Cost of poor quality (Noshad and Awasthi 2015 p. 468)	The timeliness of delivery (Varley 2013 p. 84)	Returns (Suraraksa and Shin 2019 p. 8)	Mean Time Between Failure (MTBF) (CIPS 2021)	Usage of data analysis	No of finished/unfinished claims
Cost of quality (Noshad and Awasthi 2015 p. 470)	Percentage of urgent deliveries (Gunasekaran et al. 2004 p. 345)	Customer service response time (CIPS 2021)		Usage of performance indicators	Claim categories	Downside SC adaptability (Bauer & Göbl 2017, p. 10)
Reliability of quality (Noshad and Awasthi 2015 p. 470)	Information richness in carrying out delivery (Gunasekaran et al. 2004 p. 345)				The conformance of the claim handling process	
Warranty claims (CIPS 2021)	Number of early deliveries (Teli et al. 2012 p. 329)					
Order defect rate (Sullivan and Manoogian 2009 p.	Number of late deliveries (Teli et al. 2012 p. 329)					
MRB inventory levels, no of SCARs, avg. SCAR response time, past due SCARs, no of RMAs processed last qtr (Teli et al. 2012 p. 329)	Percentage of on-time deliveries (Teli et al. 2012 p. 329)					
The condition of arriving goods	Delivery reliability to the production line					
Quality level (Suraraksa and Shin	Accuracy of the shipping documents					
Responsibility for product quality (Suraraksa and Shin 2019 p. 8)	Delivery performance during emergency (Dey et al. 2015, p. 197)					
Responsiveness for product quality (Suraraksa and Shin 2019 p. 8)	Probability of a perfect order					
Orders defect rate (Suraraksa and Shin 2019 p. 8)	Delivery location accuracy (Taghizadeh & Hafezi 2012, p. 4)					
Total cost reduction year-over-year (Teli et al. 2012 p. 329)						
Open book costing (costing transparency) (Dey et al. 2015, p. 197)						

Appendix 1 A list of metrics for monitoring suppliers

Felixibility	Dependability/reliabil	Finance	Sustainability	Forecasts	Case company purch	Case company R&D
Total coverage time (Bauer & Göbl 2017, p. 10)	How well contact attempts are noted by suppliers	Fixed assets (Suraraksa and Shin 2019 p. 8)	Work safety and labor health (Sullivan and Manoogian 2009 p. 15; Suraraksa and Shin 2019 p. 8)	The accuracy of the forecasts	Order accuracy	Work hours per case
Perfect order fulfilment (Bauer & Göbl 2017, p. 10)	Compliance with agreed contracts	Comparative balance sheet (Suraraksa and Shin 2019 p. 8)	Employment practices (Suraraksa and Shin 2019 p. 8)	Forecasts' affect on delivery reliability	Rate of emergency purhcases (Hovius 2016)	Product configuration changes
Order fulfilment cycle time (Bauer & Göbl 2017, p. 10)	Perfect order fulfillment (Taghizadeh & Hafezi 2012, p. 3)	Debt or credit rating (Suraraksa and Shin 2019 p. 8)	Contractual stakeholders influence (Suraraksa and Shin 2019 p. 8)	Forecasts' affect on inventory levels	Costs of the purchasing function (Pohl and Förstl 2011, p. 237)	Accuracy of product configurations
Upside SC flexibility (Bauer & Göbl 2017, p. 10)	Risk assessment	Financial capability (Suraraksa and Shin 2019 p. 8)		Production disturbance rate (Pohl and Förstl 2011, p. 237)	Continuous learning of the purchasing functon (Pohl and Förstl 2011, p. 237)	New product development performance
Upside SC adaptability (Bauer & Göbl 2017, p. 10)		Financial stability (Suraraksa and Shin 2019 p. 8)		Purchasing volume development (Pohl and Förstl 2011, p. 237)	Supplier satisfaction (Pohl and Förstl 2011, p. 237)	The conformance of the research and development process
				Quality assurance, controlling and supplier development (Pohl and Förstl 2011, p. 237)		
				Average time fo processing a purchasing request (Pohl and Förstl 2011, p. 237)		