VISUALIZING SUPPLIER QUALITY PERFORMANCE IN AN INTERACTIVE DASHBOARD

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Visualizing Supplier Quality Performance in an Interactive Dashboard

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Preface

This thesis “visualizing supplier quality performance in an interactive dashboard” is written to graduate from the Bachelor Industrial Engineering & Management at the University of Twente. The graduation assignment is carried out at VDL ETG Almelo with the purpose to improve long-term supplier quality performance with continuous improvement programs.

First of all I want to thank Joe Mullins, my supervisor at VDL ETG Almelo. I have enjoyed the weekly meetings where we discussed the progress with each other. I also want to thank Brian van der Gouw for given me the opportunity to carry out the assignment at VDL ETG Almelo.

Next to that, I want to thank my University of Twente supervisor Rogier Harmelink for guiding me in this graduation process and given me feedback on my work. I also want to thank Adina Aldea for willing to be my second examiner.

Timon Ambergen, 2021

Management Summary

VDL ETG Almelo is a Dutch company that creates system integrations of mechatronic systems and modules for OEMs (Original Equipment Manufacturing). The department where the thesis is carried out is focussed on the semiconductor industry.

The core problem solved in this thesis is: “no structural insight in supplier quality performance”. The goal of the thesis is to improve the long-term supplier quality performance based on data from incidents. A system to analyze supplier quality performance with backwards and forwards decision making capabilities needs to be built. The company should use the system to create continuous improvement plans with their suppliers.

In order to solve the core problem, a literature study is conducted. The literature study concluded that a performance measurement system is a great way in achieving continuous quality improvement and that a dashboard is the performance measurement system most applicable to this thesis. Further research is done to identify the KPIs used for measuring supplier quality performance, how data should be prepared and structured before creating a dashboard and how the KPIs can be visualized in the most effective way.

After the literature study, the processes within the company related to quality rejection are mapped in business process models. The KPIs currently used by the company to analyze supplier quality performance are documented and the requirements for the dashboard are discussed with the Supplier Quality Manager.

The final KPIs for the dashboard are selected out of the KPIs established in the literature review and the KPIs already used by the company. This selection is done with the multi-criteria decision making method Analytical Hierarchy Process (AHP). Business Intelligence software was not available at the company and therefore the decision is made to create the dashboard in Microsoft Excel. The data is gathered out of two different database and combined in Microsoft Excel. The data in Microsoft Excel is afterwards modelled with SQL queries and multidimensional data analysis is made possible with Online Analytical Processing (OLAP). The maintenance of the dashboards has been taken care of with a VBA program to manually add new purchasers or change the targets of KPIs.

The result is four operational dashboards and three analytical dashboards. The operational dashboards show the overall supplier quality performance on a seven day, six week, six month and three year level. Suppliers that stand out in this operational dashboard can be further analyzed in the analytical dashboards called supplier, purchaser and failure code dashboards. The end result is that the satisfaction of the Supplier Quality Manager with respect to the insight in supplier quality performance has increased from 2,5 (between unsatisfied and neutral) to 4,2 (satisfied) on a 1-5 scale.

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1 Problem Identification

Every year there are over 500 quality issues observed at VDL Enabling Technologies Group Almelo. Each quality issue leads to an investigation, machines might be down, production might stop, more inventory storage might be needed and suppliers should deliver new products. This thesis investigates the possibilities to decrease the amount of supplier quality issues on the long term. This chapter corresponds with the first step of the MPSM, problem identification, see section *1.3 Problem Solving Approach*. This means that in this chapter an introduction to VDL ETG Almelo is given, together with a problem cluster to identify the core problem and the core problem is expressed in variables to make it quantifiable.

1.1 Introduction to VDL Enabling Technologies Group Almelo

The Van Der Leegte family founded VDL Group in 1953. VDL Group is divided in 104 different companies, all companies operate in different disciplines, but closely work together. Because every company has its own specialism, risk is diversified. VDL Group has its headquarters in Eindhoven, and over 16.000 employees work for VDL Group divided over 20 countries (VDL Group, 2019). The products developed and created by VDL Group vary from solutions for the consumer market to the semiconductor sector to the automotive sector, see *Figure 13* in *Appendix A – Figures introduction VDL ETG Almelo*.

VDL Enabling Technologies Group Almelo is part of the subcontracting division of VDL Group. VDL ETG Almelo is focused on the mechatronic systems and metalworking sectors, VDL ETG Almelo create system integrations of mechatronic systems and modules for OEMs (Original Equipment Manufacturing). The department where the thesis is carried out is focussed on the semiconductor industry. VDL ETG Almelo describes their in-house facilities as “machining, high-speed milling, precision grinding, sheet metal work, laser cutting, mechanical and electrical (clean room) assembly, testing, product certification and onsite installation” (VDL Group Almelo).

1.2 Problem Description

The Purchasing department of VDL ETG Almelo wants to increase the quality of the products delivered by their suppliers. Data of supplier quality performance is already available, however using this raw data for making analysis and decisions is hard. VDL ETG Almelo wants to drive quality development based on data from incidents (failure codes), a system to manage this is not yet in place and needs to be built. The purpose of this system is to be a steering mechanism with backwards and forwards decision making capabilities based on quality performance. Next to this, the system should give VDL ETG Almelo the opportunity to communicate the supplier quality performance back to the suppliers and responsible purchasers.

1.2.1 Motivation for the Research

Yearly there are over 500 quality issues observed at VDL ETG Almelo. Every time a quality issue is observed, VDL ETG Almelo quality engineers have to investigate whether this quality issue can only be observed at this one product or at all products from the ordered batch. Production might be down for some time. If the issue is not easy to repair, the suppliers have to (manufacture and) send a new one, which will result in a delay of delivery. The consequence of quality issues slipped through the quality check by VDL ETG Almelo and detected when the product is already in use by the customer is even greater. In short, every quality issue costs a lot of money, the estimation of the Supplier Quality Manager is that every quality issue observed by VDL ETG Almelo will cost at least 2.000 euros. Therefore the main motivation for the research is to decrease the supplier quality issues, because this saves money, it allows the employees of VDL ETG Almelo to continue with their original work and it will result in higher quality standards.

1.2.2 Problem Cluster

To investigate the causal relations between problems, a problem cluster is made in *Figure 1*. A problem cluster serves to bring order to the problem context and to identify the core problem (Heerkens & Van Winden, 2017). The problem cluster shows that there are two action problems, namely low profits and dissatisfaction of the customer. Both action problems are caused by poor quality delivered products of the suppliers. To fix the problem of the poor quality delivered products, the suppliers of VDL ETG Almelo currently just replace the defect part with a new one. However, this replacement solution does not ensure that this defect will not happen in the future. Therefore, VDL ETG Almelo wants to create continuous improvement plans with their suppliers. To create these continuous improvement plans, VDL ETG Almelo needs to analyze data to get insight in the biggest underperformers and most occurring quality issues (failure codes). Due to the increase in demand of semiconductor products, the demand of VDL ETG Almelo has increased this year. This increase in demand leads to a work overload for the purchasers and quality engineers, which results in less time to focus on increasing long-term supplier quality. The continuous under performance of suppliers can also be caused by suppliers not being able to live up to the expectations of quality standards.

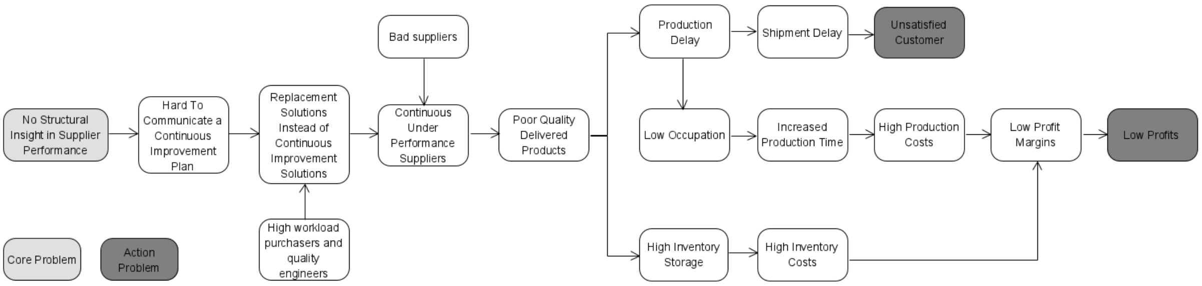


Figure 1. Problem cluster.

1.2.3 Core Problem

As concluded by the problem cluster, there are three main problems causing the action problems, namely no structural insight in supplier performance, high workload of the purchasers and quality engineers and bad suppliers. The high workload can be decreased by for instance optimizing purchasing processes in the company, bad suppliers can be replaced by better suppliers and structural insight can be created with a performance measurement tool. All problems are in the scope of an Industrial Engineering and Management thesis, together with the company the choice is made to define a solution for the core problem: “no structural insight in quality performance of suppliers”. Solving this core problem will also solve the other problems, meaning that giving insight in supplier performance gives the opportunity to communicate continuous improvement plans back to the suppliers, which will lead to better long-term supplier performance and therefore higher quality delivered products. The end result is that also the two action problems are solved to some extent, meaning that the customer satisfaction and the profit should grow.

1.2.4 Problem Quantification

Now that the core problem is established, it is time to set the discrepancy between the norm and reality of the problem. This will not only give the research goal, but it also makes it possible at the end to measure to what extent the core problem is solved. The core problem of this research is not directly measurable at the finish date of the thesis, therefore it should be divided into a variable and then indicators should be assigned to this variable. The core problem is defined as follows: “no structural insight in supplier quality performance”. The variable selected for this core problem is “insight”, this variable is not directly measurable, therefore this variable is concretized into six indicators. The indicators are created together with the Supplier Quality Manager and can be seen as requirements for the final solution. The indicators together with their argumentation can be found in *Table 1*.

Table 1. Indicators of the variable "insight"

Indicators	
Insight in overall Long-Term Quality Performance	VDL ETG Almelo first needs insight in the overall long-term quality performance. Having insight in this will show the most underperforming suppliers and therefore will show for which suppliers the most progress is still to gain.
Insight in Long-Term Quality Performance per Supplier	After knowing the suppliers that should improve, it should be possible to zoom in on this supplier and see if there is a trend.
Insight in overall failure codes	It is not only useful to check the performance from the suppliers perspective, but insight can also be gained by sorting on the different underperformance types.
Interpreting the data	How difficult or easy it is to interpret the data about quality performance. For instance analysing raw data in pivot tables is harder than analysing data visualized in graphs and charts. Another example, how hard is it to compare the data between suppliers.
Analyzing time	How long does it take to draw conclusions from the system.
Maintenance time	How long does it take to maintain the system. Is the data automatically or manually loaded and how long does this take.

The Supplier Quality Manager is asked to give a score between one and five to indicate the level of satisfaction on of all the indicators, the scale is visualized in *Table 2* in *Appendix B – Survey to determine the value of variable "insight"*. The average score of all the indicators is the score that will be assigned to the variable insight.

Table 2. Scale of satisfaction level

1	**2**	**3**	**4**	**5**
Very unsatisfied	Unsatisfied	Neutral	Satisfied	Very Satisfied

After the survey has been completed by the problem owner, see *Table 16* in *Appendix B – Survey to determine the value of variable "insight"*, the discrepancy between the norm and reality can be described as: The insight in the quality performance of suppliers should be increased from 2,5 to at least 4.

Another way to set the discrepancy between norm and reality is by measuring the difference in quality issues. In 2020 VDL ETG Almelo observed 500 quality issues, the goal of the research is to create a performance measurement tool which will be used to lower the amount of quality issues by creating continuous improvement plans. The discrepancy between norm and reality can also be described as: The percentage of quality issues (bought products versus products with quality issues) observed at VDL ETG Almelo should decrease with 2% from 5% per year to 3% per year (the numbers are not accurate, but serve as an example). There is however a problem with this way of quantifying the research problem. The problem is that this quantification cannot be measured at the end of the project, but after a year after completion of the project. Also a decrease in the percentage of quality issues can have multiple causes, so it cannot be ruled out that this decrease is per definition caused by the thesis.

1.3 Problem Solving Approach

The Managerial Problem Solving Method (MPSM) is used to solve managerial problems systematically (Heerkens & Van Winden, 2017). This thesis is solving a managerial problem by designing a performance measurement tool, therefore the decision is made to use the MPSM as problem solving approach.

The first step of the MPSM is problem identification, this corresponds with the first chapter of this thesis. In the problem identification a problem cluster is created to identify the core problem and the core problem is expressed in variables.

The second step of the MPSM is the solution planning, in this step a literature study is done to investigate various options to solve the core problem and all required information needed for this possible solution. The solution planning step corresponds with chapter *2 Theoretical Framework*.

The third step of the MPSM is problem analysis, during the problem analysis a renewed and very close analysis of the selected core problem is done. The problem analysis is elaborated in chapter *3 Research in the Company*.

Solution generation is step four in the MPSM, in the solution generation formulates alternative solutions to solve the core problem. In this thesis it is important to choose as quickly as possible the solution, because the literature study in chapter *2 Theoretical Framework* and the research in the company in chapter *3 Research in the Company* are dependent on the chosen solution. Therefore the solution generation is part of the literature study and can be found in section *2.1 Supplier Quality Improvement* and *2.2 Performance Measurement Systems*. Other solutions that are not coming from the literature review are elaborated in chapter *4 Solution Generation*.

Step five of the MPSM is the solution choice, where all the choices before creating the final solution are elaborated. The solution choice is covered in chapter *5 Solution Choice*.

The sixth step in the MPSM is the implementation phase. In this step the final solution is created and as far as possible implemented in the company. The implementation is covered in chapter *6 Implementation of the Dashboards*.

The final step of the MPSM is evaluation, this step is covered in chapter *7 Evaluation* where again values will be assigned to the indicators to reveal to what extent the core problem is solved. The cycle of the MPSM can be seen in *Figure 15* in *Appendix C – MPSM*.

Table 3. Overlap MPSM and chapters in the thesis

Chapter	**Phase**
1 Problem Identification	Problem identification
2 Theoretical Framework	Solution planning
3 Research in the Company	Problem analysis
4 Solution generation	Solution generation
5 Solution choice	Solution choice
6 Implementation	Implementation
7 Evaluation	Evaluation
8 Conclusion, Limitation & Recommendations	

1.4 The Research Questions

In this section the research questions and corresponding sub questions are formulated. The first five research questions are researched with a literature study, research question six and seven are researched in the company or with the Supplier Quality Manager and Supplier Quality Engineer, the research in the company is based on the findings of the literature study.

1. **What are ways to continuously improve supplier quality performance?**

The purpose of thesis is to improve supplier quality performance. Therefore a literature study is conducted to investigate the various ways to improve quality performance.

2. **What are tools for performance measurement?**

Second, there are multiple performance measurement tools. A literature study is conducted to investigate these different tools and based on the findings in this research question, a choice can be made together with the company for a performance measurement tool.

3. **What KPIs related to quality performance are used in the literature?**
   a. Which KPIs exist that can express the quality performance of suppliers?
   b. How to select the final KPIs?

Third, the performance measurement tool should give insight into KPIs, which KPIs are the most convenient to use when measuring supplier quality performance will be investigated here.

4. **How to prepare, structure and model the required data?**

Fourth, it is also important to investigate how the data should be prepared and structured. How different data sources and consequent datasets are used in relation to each other is investigated here, but also how the data is shaped, stored, refreshed and used. A good understanding in structuring and preparing data stimulates to get the best performances for dashboards, but also for the consumption of the storage space, refresh power and maintenance time.

5. **How to visualize the KPIs in a performance measurement tool?**

Fifth, the best way to visualize the KPIs in the performance measurement tool should be investigated. What kind of graphs and charts are used to show what kind of KPIs. What is the best way to visualize those graphs and charts inside the performance measurement tool.

6. **What are the current processes in the company related to quality management?**
   a. What happens when quality issues are observed?
   b. How is the data of quality performance analyzed now?
   c. What KPIs are used to analyze the quality performance of suppliers now?

Sixth, the current way of working at VDL ETG Almelo should be investigated and mapped with business process models. Creating understanding in the way of working now will help in the process of solution generation. It investigates how performance is measurement now and if it is possible to build further on an already existing system. .

7. **What is the desired situation?**
   a. What are the main decisions to be taken based on the performance measurement tool?
   b. What are the main insights that the dashboard should give?
   c. What are the preferences for the visualization and the layout of the performance measurement tool?
   d. What is required to be delivered next to the performance measurement tool?

Last, how the performance measurement tool will be used by the management in the future should be discussed. This information can already simplify the decisions left in the solution generation. Also the requirements that the performance measurement tool must meet according to the management should be documented.

1.5 Research Design

In this section the goal of the research, the type of the research, the research subjects and the data gathering method is discussed.

1.5.1 Research goal

The goal of the research is to create a performance management tool which analyzes the quality performance of suppliers. The performance management tool should show which suppliers perform good on quality and which suppliers underperform on quality and in which area of quality performance. After those insights, the company can create a plan to improve the quality performance for the long run and the progress can be monitored with the performance management tool. To achieve this goal, research should be conducted on what the best performance measurement tool is for this thesis and how the tool can be created.

1.5.2 Type of Research

The research questions show that there are two types of research needed to answer all the research questions. For the first five research questions, the purpose is to gain understanding and providing insights in the process of creating a performance measurement tool. Therefore the type of research can be described as exploratory. It is not desired to collect directly original data (primary data), but analyzing data that someone else already collected is sufficient in this case (secondary data). The benefit of using secondary data relative to primary data is that is saves time and can expand the scope of the research, but is also means that there is less control over the reliability of the data. The objectives of the research involve describing subjective experiences, interpreting meanings, and understanding concepts instead of measuring variables and testing hypotheses, therefore the data needed in this research is qualitative data, not quantitative data.

The purpose of the last two research questions (questions six and seven) is to gain understanding in the VDL ETG Almelo working environment and the VDL ETG Almelo processes related to the quality checks and replacement of broken products. These research questions are answered by semi structured interviews with a Supplier Quality Manager and a Supplier Quality Engineer. This means that the type of research is exploratory with primary data, the data is collected directly by the researcher. The research is focused on words and meanings instead of numbers and statistics and the research does not control any variables, so the research is also qualitative and descriptive.

1.5.3 Research Subjects

The research subjects are related to databases. The main subjects are dashboards, KPI selection, KPI visualization, data preparation, data modelling and dashboard analysis.

1.5.4 Data Gathering Method

For the secondary research, where the first five research questions are answered, the data is gathered through the use of the databases Scopus (multidisciplinary) and Web of Science (multidisciplinary). These databases contain only peer reviewed articles, databases like Google Scholar do also contain non peer reviewed articles and the choice is made to use only databases with peer reviewed articles. This choice will probably result in higher quality articles and therefore a higher quality of the literature study.

For collecting primary data, semi structured interviews are conducted with the Supplier Quality Manager and a Supplier Quality Engineer. The total overview of the research questions with their corresponding type of research and data gathering method is given in *Table 4. Overview per Research Question.*

Table 4. Overview per Research Question.

Research Question	Type of Research	Data Gathering Method
1 What are ways to continuously improve supplier quality performance?	Exploratory, qualitative and secondary data	Scopus and Web of Science
2 What are tools for performance measurement?	Exploratory, qualitative and secondary data	Scopus and Web of Science
3 What KPIs related to quality performance are used in the literature?	Exploratory, qualitative and secondary data	Scopus and Web of Science
4 How to prepare, structure and model the required data?	Exploratory, qualitative and secondary data	Scopus and Web of Science
5 How to visualize the KPIs in a performance measurement tool?	Exploratory, qualitative and secondary data	Scopus and Web of Science
6 What are the current processes in the company related to quality management?	Exploratory, qualitative and primary data	Semi structured interviews with the Supplier Quality Manager and Supplier Quality Engineer
7 What is the desired situation?	Exploratory, qualitative and primary data	Semi structured interview with the Supplier Quality Manager

2 Theoretical Framework

The problem is identified in chapter *1 Problem Identification*, now it is time for the second step of the MPSM: solution planning. In this chapter a literature study is conducted to investigate the various options to solve the core problem and all required knowledge for possible solutions. The knowledge gained in this literature study is necessary in the discussion with the company where the final solution is chosen. This chapter answers the following research questions:

1. What are ways to continuously improve supplier quality performance?
2. What are tools and techniques for performance measurement?
3. What KPIs related to quality performance are used in the literature?
4. How to prepare, structure and model the required data in a data model?
5. How to visualize the KPIs in a performance measurement tool?

2.1 Supplier Quality Improvement

In this section the following research question will be answered: What are ways to continuously improve quality performance of supplier?

According to Monczka, the definition of supplier quality can be described as: “Supplier quality represents the ability to meet or exceed current and future customer (i.e., buyer and eventually end customer) expectations within critical performance areas on a consistent basis” (Monczka et al., 2016). Managing the supplier quality is a way to continuously improve a business. The quality levels of VDL ETG Almelo is of high importance because the high-technology and innovative industry VDL ETG Almelo is in, approach perfection and requires high precision.

Total Quality Management (TQM) is a widely accepted concept in quality management and it is focused on improving quality. According to Slack, TQM can be described as “an effective system for integrating the quality development, quality maintenance and quality improvement efforts of the various groups in an organization so as to enable production and service at the most economical levels which allow for full customer satisfaction” (Slack et al., 2016).

One of the elements of TQM is that decisions should be based on objective observations instead of subjective observations. This will allow Supplier Quality Managers to differentiate between the well-performing and underperforming suppliers, which can lead to the development of improvement programs and it allows the company to track the progress of suppliers after these improvement programs are implemented (Monczka et al., 2016).

The second important element of TQM is that there is always room for improvement and companies should aim for continuous improvement (also called “kaizen” in TQM). According to Monczka there are multiple approaches to continuous improve supplier quality. Two approaches are mentioned below:

- An effective way to show objective supplier quality performance is with a performance measurement system.
- Another approach is value analysis/value engineering (VA/VE). VA/VE investigates the costs of each element in a system, project, process or product and tries to minimize these costs without losing quality.

The outcome of the approaches can lead to various plans to improve. One plan is to switch from suppliers, however this is difficult for high-volume delivering suppliers and suppliers with long-term contracts. Another plan is to improve the underperforming suppliers, or reward well-performing suppliers. The underperforming suppliers can be identified based on the current quality levels, or on the ability of suppliers to positively influence the buyer’s total quality (Monczka et al., 2016).

What can be concluded from this research is that a performance measurement system plays a big role in continuous improvement of supplier quality. A performance measurement system is an excellent method to identify well-performing and underperforming suppliers and gives insight in possible corrective and preventive actions to improve supplier quality on the long-term. Therefore the remainder of the literature study dives deeper in the creation of performance measurement systems.

2.2 Performance Measurement Systems

In this section the following research question will be answered: What are tools for performance measurement?

There are two widely used performance measurement systems in businesses and organizations. The two are mentioned below:

- First there is a *dashboard*. According to Smith, the definition of a dashboard can be described as: "A dashboard includes a focused-selection of indicators to provide periodic snapshots of the organization's overall progress in relation to past results and future goals" (Smith, 2003).
- The second one is a *score card*. According to Wolk, the definition of a score card is: "A score card contains highlights from an organization's internal dashboards and facilitates sharing data externally with stakeholders" (Wolk et al., 2009).

The biggest difference between a dashboard and a scorecard is that a dashboard is a performance monitoring system, whereas a scorecard is a performance management system, see *Table 5*.

Table 5. Difference dashboard and scorecard.

Dashboard	**Scorecard**
A dashboard should be used for decision-making on the short term (tactical)	A scorecard should be used for decision-making on the long-term (strategic)
A dashboard should be used to show a snapshot of the current performance	A scorecard should be used to show trends over time
Dashboard are intended for individual managers	A scorecard is intended for monitor the management strategy
Dashboards show the performance (metric)	Scorecards show the progress (metrics as well as targets)
Data in a dashboard should be real time and can differ a lot from day to day	Data in a scorecard is based on a monthly level, data probably differs not that much from day to day

The performance measurement systems to gain structural insight in supplier quality performance and use this insight to create continuous improvement programs includes short-term or medium-term decision making, the dashboard should provide snapshots of business performance, an operationally focused individual manager (Supplier Quality Manager) should use the performance measurement tool and the performance measurement system should visualize the performance to understand the current state. These requirements are all characteristics of a dashboard, therefore a dashboard is the most desirable performance measurement system for VDL ETG Almelo and in the remainder of this chapter further research will be conducted on dashboards.

2.3 KPI selection

In order to analyze the quality performance of suppliers in a performance measurement system, it is crucial to establish the KPIs at first. VDL ETG Almelo will be questioned about their ideas and desires with respect to the KPI selection, but in this chapter the scientific literature will be analyzed to see what KPIs are recommend to measure quality performance of suppliers. The research question in this section is formulated as follows: What KPIs can be selected for analyzing quality performance of suppliers according to the literature? This research question is divided into two sub research questions:

a. Which KPIs exist that can express the quality performance of suppliers?
b. How to select the final KPIs?

To answer this research question a selection of seven papers is made. The selection procedure of the literature is a systematic literature review and together with the final selected papers, can be found in *Appendix D – Systematic Literature Review*.

2.3.1 Quality KPIs in the Literature

This section answers the first sub research question: “Which KPIs exist that can express the quality performance of suppliers?”. There are five articles focused on quality related KPIs which will be evaluated in this chapter. The five articles are from Verhaelen, B., et al. (2021), Payaro, A., et al. (2016), Kang, N., et al. (2016), Cao, Y., et al. (2015), Jochem, R., et al. (2010). The KPIs mentioned in these articles are clustered in a Balanced Scorecard Framework. For the articles of Kang et al. (2016) and Jochem et al. (2010) only the KPIs related to quality are selected, otherwise the overview will be lost because of too much KPIs . For the other articles all KPIs are included in the BSC framework, the BSC framework is depicted in *Table 21* in *Appendix E – Tables of KPI selection*. Out of the BSC framework a list is made containing only KPIs related to quality. With quality the product quality is meant, so KPIs related to logistics are not taken into account. The KPIs related to product quality are elaborated in this section.

- Actual to planned scrap ratio (SQR): “The relationship between the actual and planned produced quantity that does not meet quality requirements and has to be scrapped or recycled” (Kang et al., 2016).
- Scrap ratio (SR): “The produced quantity that does not meet quality requirements and has to be scrapped or recycled, divided by the quantity that a work unit has processed (which may include the reworked ones and scraped ones)” (Kang et al., 2016).
- Rework ratio (RR): “The quantity that fails to meet the quality requirements, but these requirements can be met by reprocessing, divided by the quantity that a work unit has processed (which may include the reworked ones and scraped ones)” (Kang et al., 2016).
- First time quality (FTQ): “The percentage of good quality parts going through the manufacturing process in the first time” (Kang et al., 2016).
- Quality rate (QR): “The overall percentage of good quality parts after reworks” (Kang et al., 2016).
- Complaints rate (CR): “Number of complaints per unit of time or per units sold” (Verhaelen et al., 2021 ; Payaro et al., 2016).
- Non-conformity costs (NCC): “Costs of a deviation from a specification, a standard, or an expectation” (Verhaelen et al., 2021 ; Jochem et al., 2010).
- Major complaints rate (MCR): “Number of major complaints per unit of time or per units sold” (Cao et al., 2015).
- Process innovation projects (PIP): “Number of completed projects related to process innovation” (Cao et al., 2015).
- Technical improvement projects (TIP): “Number of completed projects related to technical improvement projects” (Cao et al., 2015).
- Accumulated failures trend (AFT): “Number of accumulated failures amongst projects, products or suppliers” (Jochem et al., 2010).
- Project amendments (PA): “Number of amendments per project or product” (Jochem et al., 2010).
- Outstanding corrective actions (OCA): “Number of observed complaints not yet solved” (Jochem et al., 2010).
- Inspection costs (IC): “Costs of quality inspection in valuta or hours” (Jochem et al., 2010).
- Supplier rating: “Weighted average of different KPIs, depends on the KPIs chosen for this rate and the weights assigned to each KPI and therefore differs per company” (Jochem et al., 2010).

2.3.2 KPI Selection Process

This section answers the second sub research question: "How to select the final KPIs"? In section *2.3.1 Quality KPIs in the Literature* a list quality KPIs has been drawn up and in section *3.1.3 KPIs related to Quality Management* the KPIs that the company already uses to analyze supplier quality performance is listed. This section will give an answer on how to select the right KPIs from both the literature and the company.

Choosing between KPIs in the selection process can be done on the basis of how well the KPIs meet various objectives or criteria. When multiple objectives are important to a decision maker, it may be difficult to choose between KPIs, this is where multi-criteria decision making (MCDA) comes into play. In the literature there are multiple MCDA methods for the selection of KPIs, for instance the AHP (Analytic Hierarchy Process) used by Podgórski (2015), KAM (KPI Assessment Methodology) used by Hester et al. (2017) and Collins et al. (2016).

In general, the MCDA methods mentioned above all determine first the criteria, second generate a weight to each criterion, third determine how well each KPI scores on every criteria and fourth based on the score and the weights determine the KPI with the highest overall score. The difference between the AHP and KAM is how the weights are determined for the criteria. The weights of the criteria in the AHP is determined by comparing the relative importance of the criteria with each other (De Montis et al., 2000). The KAM method ranks the criteria in descending order and the weights are determined based on those ranking (Hester et al., 2017 & Collins et al., 2016). The decision is made to use the AHP as MCDA method in this thesis. The advantage of pairwise comparison (AHP) over a numerically ranking in descending order (KAM) is that with the pairwise comparison it is possible to indicate how much more important one objective is over the other, while with the numerically ranking in descending order it is only possible to rank the objectives but it does not indicate how much more important one objective is over the other. In the remainder of this section the criteria for the KPIs and an explanation of how the AHP exactly works will be given.

KPIs must meet certain requirements, a lot of professionals use the SMART criteria to define KPIs (Podgórski, 2015). SMART stands for Specific, Measurable, Achievable, Relevant and Time-bound. Each KPI should meet these five criteria, therefore the definition of each SMART criterion are elaborated in *Table 6*.

Table 6. The meaning of SMART criteria. Source: (Podgórski, 2015).

Criterion	**Meaning**
Specific	The KPI should measure what you intent to measure.
Measurable	It should be possible to measure the KPI.
Achievable	The data for the KPI is achievable. This means the resources for the data and it should be possible in the timeframe of the project.
Relevant	The indication of the KPI aligns with the intention of the dashboard.
Time-bound	The KPI should be measurable throughout time.

The AHP works as follows. First, a 5x5 pairwise comparison matrix will be written down, there are five rows and columns because there are also five criteria. Then the relative importance of the criteria are given with numbers between 1 and 9, the meaning of each number is given in *Table 7*. The final weights are calculated with the following two steps:

1. Divide the entries of the columns by the sum of the column. This action will result in a new matrix.
2. For the new matrix, calculate the average for each row. The average of the row is the weight for the corresponding criterion.

Table 7. Rating scale for pairwise comparison of criteria in the AHP method. Source: (Winston & Goldberg, 2004).

Value	**Meaning**
1	Equal
2	Between equal and moderate
3	Moderate
4	Between moderate and strong
5	Strong
6	Between strong and very strong
7	Very strong
8	Between very strong and extreme
9	Extreme

How the consistency of rating the importance between criteria is can be calculated is further explained in *Appendix F – Consistency check in the AHP*.

2.4 Preparation, Structuring and Modelling of Data

In this section the following research question will be answered: How to prepare, structure and model the required data in a data model?

2.4.1 Business Intelligence Architecture

It is common that the data intended for BI comes from different sources. For instance, one operational database stores the orders of a purchasing department and another database stores the complaints of the orders. How an organization has organized the data sources is called the business intelligence architecture. Typically the raw data is created in data movement/streaming engines, these engines transfer the data to a relational database management system (RDBMS). This RDBMS allows the organization to execute SQL queries (Structured Query Language). The visualization of data is often showed in external front-end applications like Excel, Tableau or Power BI. A mid-tier server is software that makes it possible to transfer the data in the RDBMS to the front-end application (Chaudhuri et al., 2011). This whole business intelligence architecture is visualized in *Figure 2*.

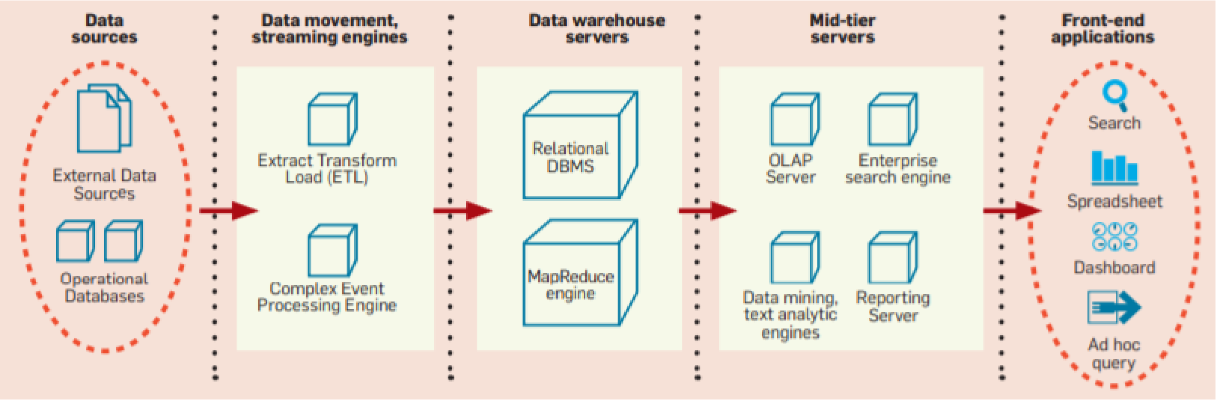


Figure 2. Business Intelligence Architecture. Source: Chaudhuri et al., 2011.

2.4.2 Data Quality

The data in the RDBMS should be accurate, complete and consistent. Data not meeting this requirement can lead to operational and financial problems for organizations, because decisions are not based on the actual performance of the organization, but a misrepresentation of the organization's performance. According to Gartner Inc. this happens in 25% of the Fortune 1000 companies. Data cleansing is an action to prevent poor data quality, it consists of detecting incorrect data and afterwards correcting this data (Laudon K. & Laudon J., 2014). A distinction can be made between two causes that lead to data quality issues:

1. Multiple RDBMS can have inconsistent ways of storing data. For example, at VDL ETG Almelo the quality database formats the name of purchaser as *Jansen, Peter* and the logistics database formats the purchaser as *Dhr. P. Jansen*.
2. Errors during data input can lead to inaccurate data. For example, at VDL ETG Almelo it occurs that the attribute *Date Finished* is blank and the attribute *Status* is labelled as *Finished* or vice versa.

2.5 Visualization of KPIs

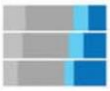
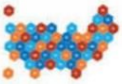
Dashboards are visual representations of data. This can be graphical visualizations as well as textual visualizations. Humans are better in interpreting graphical visualizations than textual (Few S., 2006). Therefore this chapter looks into the most efficient way to represent data visually. The following research question will be answered: How to visualize KPIs in a BI-dashboard? This section will answer this question for different chart types as well as the overall dashboard design.

2.5.1 Chart types

This section looks into how to restrict distortions and misrepresentations in the visualization of KPIs. The foundational research in this section comes from Cleveland and McGill (1984). Parts of this research have been replicated or clarified in later research, for instance the research of Evergreen (2019), which is also taken into consideration in this section.

Table 8. Chart types. Source: Evergreen (2019) & Cleveland & McGill (1984).

Chart type	**Icon**	**Explanation**
Only one number is of interest		
Big Number		If just one number is important, show this one number really big.
Icon Array		If a proportion of percentage is important, it can be shown with the Icon Array.
Pie/Donut		Donut charts are also used to visualize a percentage or proportion. However, the percentage should always be printed out next to the donut chart because humans are not that accurate in interpreting angles.
Bar/Column		To compare one number with other numbers, a bar chart with one highlighted bar can be useful.
Two numbers are of interest		
Side by Side		A side by side column or bar chart is a good way to compare two different number with each other. Stick to the comparison of only two number, otherwise it is hard to quickly interpret the data.

Slope graph		Humans are good in interpreting slopes, therefore the slope graph is useful to indicate that one category is outperforming other categories.
Back-to-Back		Humans like symmetry, therefore the back-to-back is convenient to the aesthetic appeal for humans. However, it is not that clear how much greater one value is in comparison with the other value, therefore this graph is not recommended.
Dot Plot		Humans are accurate in interpreting dots on a line, therefore the dot plot is a good alternative for the back-to-back graph.
Dumbbell Dot		If the gap between two values is of interest, the dumbbell dot plot is the best graph. The line between the two dots indicate the gap.
Small Multiples		Small multiples compare multi categories. For instance, the sales of three different products for four different states can be visualized with small multiples.
Compare against a target		
Benchmark Line		A simple thing as adding a target line to the graph gives more meaning to the figure.
Combo		Combo is where the target depends on other values and therefore can change over time.
Bullet Chart		The bar in the bullet chart is the actual value of the KPI. The three different colors represent a range like poor/satisfactory/good and the red line represents the target.
Indicator Dots		Indicator dots show whether or not a target has been met.
Percentage are of interest		
Stacked Bar		The proportion of values of a whole can be visualized with the stacked bar. However, it is hard to see that the stacked bar shows percentages instead of raw numbers.
Histogram		For binned quantitative values the histogram is the way to go.
Tree Map		Treemaps represents parts of a whole. They are popular because they also visualize a hierarchy. This graph is famous for showing the size of companies in the S&P500.
Bing Map		Bing maps are points on a world map. They are good ways to visualize demographic data.
Change over time is of interest		
Line		Change overtime is almost always expressed as a line, humans are so used to this and therefore the advice is to use the line for showing change over time.
Stacked Column		Tiny trends can be visualized with the stacked column chart .
Deviation Bar		When sometimes the outcome is negative and sometimes the outcome is positive, the deviation bar is often used. A famous example is the turnover of companies.

Slope graph		Humans are good in interpreting slopes, therefore the slope graph is useful to indicate that one category is outperforming other categories.
Sankey		The flow between different objects can be visualized with the Sankey. The width represents the corresponding quantity.

2.5.2 Design and Layout

An important aspect in dashboard design is the aesthetic appeal. Therefore this section looks into key elements that contribute to a well-designed dashboard.

- Overuse and misuse for the user panel, buttons, borders and background within the dashboard can distract the user in case of over- and misuse. This distracts from the key messages, there calm colors like light blue, light grey, or light beige are recommended (Bera P., 2016 & Malik S., 2005).
- KPIs in the dashboard should differentiate from the background by means of an own color scheme (Malik S., 2005).
- An overload of information in a single dashboard can be overwhelming. Therefore the content should be limited between four and six windows (Malik S., 2005).
- The windows should be symmetrically aligned for an effective visual representation (Malik S., 2005).
- Drill down allows the user of the dashboard to go from a general view to a more specific view. Drill down offers interaction with the user and is therefore a great tool to use in dashboards (Malik S., 2005).
- Drill through is a BI capability that allows the user to see the information in the dashboard from multiple perspectives. Also drill through offers user interaction and is therefore a powerful tool to use (Malik S., 2005).
- Humans are used to read from left to right and from top to bottom, therefore the upper-left corner is the most important place in the dashboard and the most important KPI should be placed here (Nadelhoffer E., 2016).
- It is already mentioned that user interaction is important for side-by-side analysis. User interaction can also be stimulate by means of filter options like multi-select boxes, single select radio buttons, drop-down lists and search boxes (Nadelhoffer E., 2016).
- The information in the dashboard should be on one screen, the user should see the information at a glance (Few S., 2006).

3 Research in the Company

Until now the problem is identified in chapter *1 Problem Identification* and the literature review is given in chapter *2 Theoretical Framework*. In this chapter the third step of the MPSM is done (problem analysis). This means that in this chapter a renewed and very close analysis of the selected core problem is done. Actions included in this chapter is mapping the current processes related to quality rejection, reviewing the KPIs currently used by the company to analyze supplier quality performance and outlining the desired situation in the eyes of the company. The knowledge gained in chapter *2 Theoretical Framework*, is taken into account in the discussion with the company. The research questions answered in this chapter are:

6. What are the current processes in the company related to quality management?
7. What is the desired situation?

3.1 Current Situation

This paragraph formulates an answer to the research question: "What are the current processes in the company related to quality management?". This research question is divided into the following sub research questions:

1. What happens when quality issues are observed?
2. How is the data of quality performance analyzed now?
3. What KPIs are used to analyze the quality performance of suppliers now?

3.1.1 Business Processes Related to Quality Management

It is important to map the business processes related to quality management in order to develop the dashboard. The data collected in these business processes should be visualized in the dashboard. Therefore it is important to know what data is actually collected in the business processes, where the data is stored, what the purpose of the stored data is and how the data is accessible.

Intended manufacturing process without quality complaints

The intended process of manufacturing products will proceed according to the following steps: first a product will be shipped by the supplier, at arrival there is a first article inspection to check the quality of the product, then the product will go in production, the product will finish in production, the final product will be shipped to the customer and the customer will receive the product. This process is visualized in *Figure 16* in *Appendix G – BPM intended manufacturing process without quality issues*.

The rejection process

However, this intended process can be disturbed by quality complaints, there are three points in time where quality complaints can be observed: (1) first article inspection at arrival, (2) during production or (3) at the customer. Either way, the products with quality issues will be brought to the Quality Engineer who investigates the origin of the issue: where did the quality issue arise, at the supplier or at VDL ETG Almelo. The Quality Engineer decides whether the products can be used in production anyway with a deviation note or whether the supplier should solve the problem, this can be done by sending new products or repair the broken products. In the latter case, the Quality Engineer indicates the complaints in REM.net and the Quality Engineer should create a 4D or a 8D-report. A 4D-report is created for incidents and a 8D-reports is created for quality problems with a big impact, what a 4D and 8D report exactly is will be explained later in this section. In case of 4D-report, the Quality Engineer will solve the problem with the supplier and in case of a 8D-report the corresponding purchaser will solve the problem with the supplier. The business process of rejecting products and solving quality issues with suppliers is visualized in *Figure 3*, to simplify reading the business process model the steps already explained in *Figure 16. Business Process Model for the intended manufacturing process without quality* *issues* are made white, for instance “product shipment”. *Table 9. Legend of the Business Process Model* explains the objects showed in the Business Process Model of *Figure 3*.

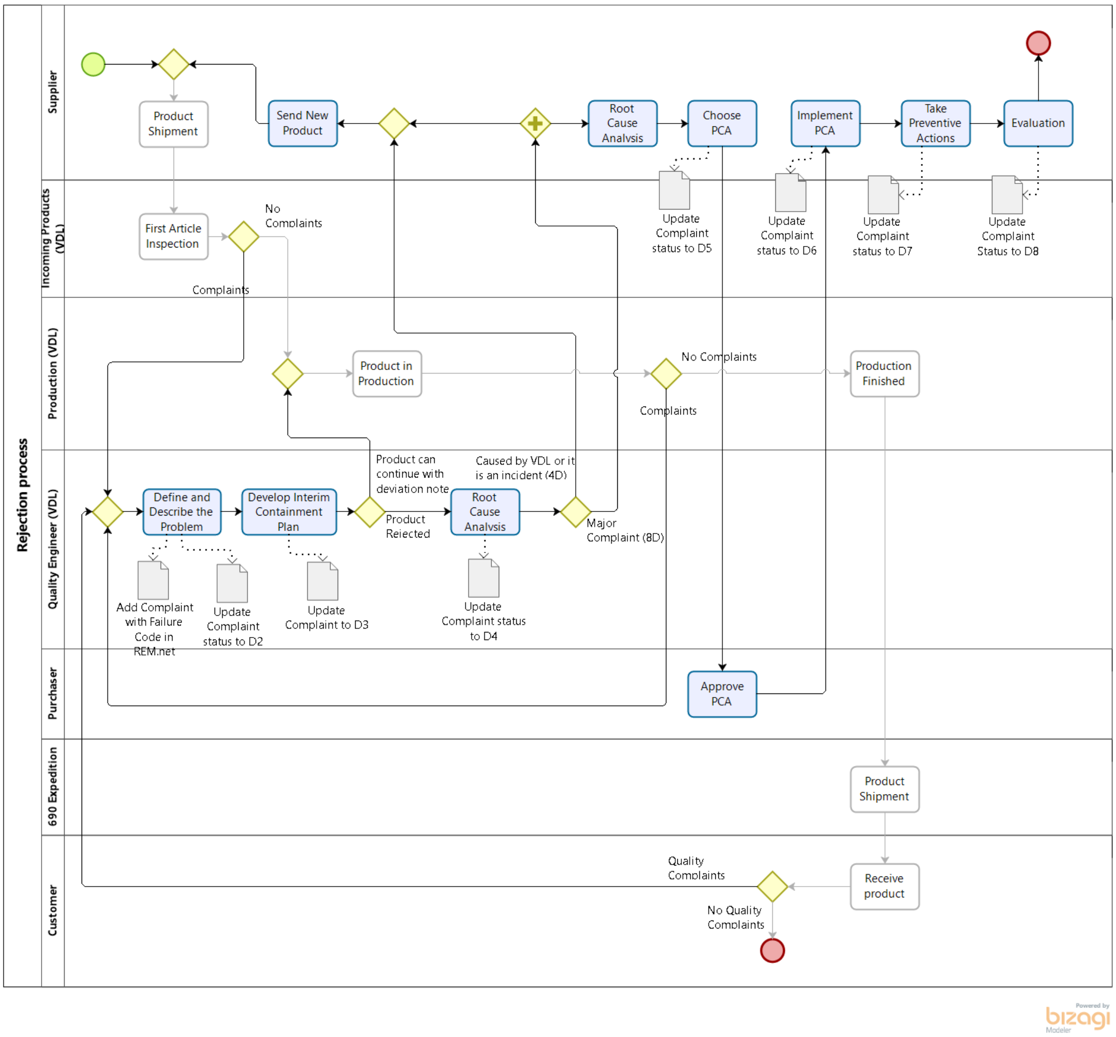


Figure 3. Business Process Model of the Rejection Process

Table 9. Legend of the Business Process Model

Icon	**Name**	**Explanation**
🟢	Start-event	The process starts with the start-event.
🔴	End-event	The process ends with the end-event.
🟦	Activity	Tasks in a process are represented by an activity. The blue activities in *Figure 3. Business Process Model of the Rejection Process* show the activities only executed when there is a quality complaint.
▭	Activity	Tasks in a process are represented by an activity. The white activities in *Figure 3. Business Process Model of the Rejection Process* represent the activities without quality complaints. So when there are no quality complaints, only the white activities are executed.
◇	Exclusive Gateways	Exclusive gateways (decisions) locate where the process can diverge in multiple directions. Only one of the possible directions will be followed in the process. The exclusive gateway also indicate where multiple flows in a process can converge to one flow again.
◈	Parallel Gateways	Parallel gateways are the same as exclusive gateways except for the fact that the multiple paths followed after a parallel gateway will be executed all and simultaneously. So in *Figure 3. Business Process Model of the Rejection Process* the parallel gateway indicates that after a 8D the supplier will simultaneously send a new product and will start the investigation to the root cause.
🗎	Data object	Data objects indicate where in the process documents and data will be created or updated. Data objects can be electronic but also tangible.

The 8D report

The 8D-report is used at VDL ETG Almelo for the documentation of complaints and as communication tool between VDL ETG Almelo and their suppliers to solve quality complaints. The 8D-reports consists of eight steps: "Define a team (D1), Define and Describe the Problem (D2), Develop Interim Containment Plan and Implement and Verify Interim Actions (D3), Determine, Identify, and Verify Root Causes and Escape Points (D4), Choose and Verify Permanent Corrections for Problem/Non Conformity (D5), Implement and Validate Corrective Actions (D6), Take Preventive Measures (D7), and Evaluation (D8)" (CAQ, 2020). How the D8 steps are followed at VDL ETG Almelo will be discussed quickly below.

D1 Team
The Quality Engineer and responsible purchaser are always part of the 8D team, also employees of the supplier are part of the 8D team.

D2 Define and Describe the Problem
First, VDL ETG Almelo will give a problem description, the following questions should be answered in this problem description: what is exactly the problem, use photos, sketches or technical specifications to detail the problem? Is the problem caused by the suppliers or by VDL ETG Almelo itself?

D3 Develop Interim Containment Plan and Implement and Verify Interim Actions

Interim Containment Actions are:

1. Avoiding further escalations.
2. Avoiding reoccurrence of this complaint.
3. Repairing the broken products to prevent distortion of the production process or delivery to the customer.
4. Create a process to detect quality issues early.

D4 Determine, Identify, and Verify Root Causes and Escape Points

To find the root cause, VDL ETG Almelo uses three different approaches:

- The Ishikawa diagram, this is a fishbone diagram to get to the root cause of a problem by modelling the interdependencies (CAQ, 2020).
- The 5-why method, asks five times the question “why?” to come to the root cause (CAQ, 2020).
- The “is – is not” method. In this method there are eight questions for which the answers for the “is” and “is not” should be given. The eight questions are: Who? What? When? Where? Why? How? How many? How often?

D5 Choose and Verify Permanent Corrections for Problem/Non Conformity

This step is executed by the supplier. What the supplier is permanently going to do to prevent the same quality complaint from happening is worked out in this step. The permanent corrective actions (PCA) must be approved by VDL ETG Almelo.

D6 Implement and Validate Corrective Actions

In this step the supplier will eventually implement the PCA and the supplier should provide proof to VDL ETG Almelo that the PCA is implemented, this can be done by showing photos or a copy of a certificate of employee training for example.

D7 Take Preventive Measures

After a while, VDL ETG Almelo will measure if the PCA has worked. If so, the company can use this PCA for other suppliers having comparable quality complaints to improve the whole supply chain.

D8 Evaluation

The last step is the evaluation of the 8D process together with the supplier.

Failure codes

Every quality issue that is registered in REM.net will also receive a failure code. Failure codes are the types of quality complaints. This information is important in the final dashboard, because a supplier with quality complaints of the same type over and over again is likely to improve long-term quality when solving the origin of this problem with permanent corrective actions. The failure codes used are given in *Table 23* in *Appendix H – Table with failure codes*.

3.1.2 Analysis of Quality Performance

As mentioned in the business process of rejected products, the software program REM.net from software provider CAQ is used to document supplier and quality complaints. All supplier and quality complaints are filled in REM.net and REM.net moves the data to the Quality Database. To analyze the stored data in REM.net, the business intelligence tool iQBS is used. This tool allows to load the stored data from REM.net into Excel.

The data of the orders are generated by the purchasers in the ERP system Baan. The Quality Engineers are not using Baan in the rejection process, only the purchasers use Baan. Baan moves the data to the Logistics Database. Thereafter, the business intelligence tool iQBS is once again used to load the data of the Logistics database in Excel. An overview of the business intelligence architecture of VDL ETG Almelo is given in *Figure 4. Business Intelligence Architecture of the purchasing department of VDL ETG Almelo*. The typical business intelligence architecture according to Chaudhuri et al., 2011 elaborated in the literature study in *2.4.1 Business Intelligence Architecture* is used to create *Figure 4*.

Currently pivot tables are created from the data loaded in Excel. These pivot tables are used to analyze the quality performance of suppliers. There are multiple Excel files with different quality, the goal is to have all data combined in one Excel file. Also because of using pivot tables there is lack of visualization of the quality performance, the goal is to create a dashboard visualizing the KPIs related to quality performance to analyze possible long-term improvement. The KPIs currently used by VDL ETG Almelo are elaborated in the next section.

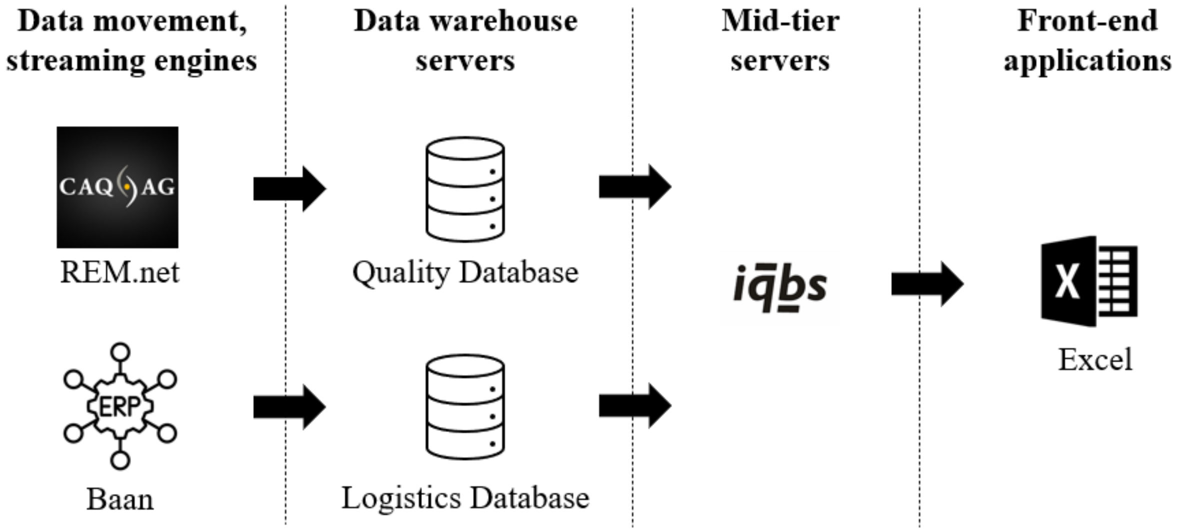


Figure 4. Business Intelligence Architecture of the purchasing department of VDL ETG Almelo

3.1.3 KPIs related to Quality Management

The main KPIs used by VDL ETG Almelo to analyze the quality performance of suppliers are: number of complaints (parts per million), SRS (supplier rating system) and MQP score (Manufacturing Quality Performance).

<u>Number of complaints</u>
The number of complaints are analyzed in three different ways at VDL ETG Almelo. The first way is just by counting the amount of complaints. Complaints are counted per delivered order line. Multiple errors on one order line are calculated as one complaint. Multiple errors in one batch, delivered over multiple order lines can be calculated several times. The number of complaints cannot be compared

between suppliers because some suppliers deliver more products than others. Therefore the second way, is by calculating the percentage of complaints by dividing the number of complaints by the total order lines. There is also a third way, which is PPM (parts per million). Many businesses use PPM to measure their quality performance, PPMs means one defect in a million or 1/1.000.000. At VDL ETG Almelo, suppliers with a complaints rate less than 1.000 PPM or 1% are considered as quality suppliers.

SRS (supplier rating system)

A Supplier Rating System (SRS) is a system that enable companies to make informed supplier decisions. The system highlights each supplier’s strengths and weaknesses across multiple areas. The Supplier Rating System at VDL ETG Almelo is focused on the logistical performance of suppliers and the quality performance of suppliers, the KPIs used are visualized in *Table 10.*

Table 10. Overview KPIs in the Supplier Rating System.

KPI		**Definition**
		▨ **Quality related KPIs**
		Logistic related KPIs
ECLIP	Early Confirmed Line Item Performance	Order lines delivered on, or before, the first confirmed delivery date as a percentage of all confirmed order lines for this particular month. Score = 1, if delivery date is max 4 working days before, or on the confirmed delivery date, else the score = 0.
CLIP	Confirmed Line Item Performance	Order lines delivered on or max 4 working days before the first confirmed delivery date, as a percentage of all confirmed orderliness for this particular month. Score = 1, if delivery date is max 4 working days before, or on the confirmed delivery date, else the score = 0.
ERLIP	Early Requested Line Item Performance	Order lines delivered on, or before, the first requested delivery date as a percentage of all requested order lines for this particular month. Score = 1, if delivery date is before, or on the requested delivery date, else, the score = 0.
RLIP	Requested Line Item Performance	Order lines delivered on or max 4 working days before the first requested delivery date, as a percentage of all requested orderliness for this particular month. Score = 1, if delivery date is max 4 working days before, or on the requested delivery date, else the score = 0.
ILP	Inventory Level Performance (VMI)	Total number of working days between minimum and maximum stock-level boundaries as percentage of the total number of working days for this particular month.
Order Confirmation		Order lines confirmed within 3 working days as a percentage of order lines placed in the month.
Rejected Parts		Total of rejected parts.
Rejected Parts %		Number of rejects parts / delivered parts.
Order lines		Number of order lines actually delivered in the month. Included order lines without order number.
Complaints		Complaints are counted per delivered order line. Multiple errors on one order line are calculated as one complaint. Multiple errors in one batch, delivered over multiple order lines can be calculated several times.
Complaints %		Number of complaints / order lines.

Reported CoPQ	Reported Cost of Poor Quality	All reported Cost of Poor Quality, related to purchased parts and to the cost of rebuilding / reinstallation of the purchased parts.

MQP score

MQP score stands for Manufacturing Quality Performance. It is the percentage of rejected parts, so it is calculated by dividing the amount of rejected parts by the amount of delivered parts. Suppliers with a MQP score less than 500 PPM or 0,05% are considered as quality suppliers.

3.2 Desired Situation

This paragraph formulates an answer to the research question: “What is the desired situation?”. This research question is divided into the following sub research questions:

1. What are the main decisions taken based on the dashboard?
2. What are the main insights that the dashboard should give?
3. What are the preferences for the visualization and the layout of the dashboard?
4. What is required to be delivered next to the dashboard?

The research questions are answered with requirements engineering. Requirements engineering is about defining, documenting and maintaining requirements throughout the life cycle of an information system’s development. Requirements engineering is an iterative process. First, the business requirements must be developed and established, then the business requirements form input for developing requirements at user level. It may be necessary to supplement and/or further refine the business requirements throughout the process. The business requirements are developed together with the Supplier Quality Manager in the form of a semi-structured interview.

3.2.1 Main Decisions

- The purpose of the dashboard is to be a steering mechanism with backwards and forwards decision making capabilities based on quality performance.
- The dashboard should give insight in the quality performance of suppliers and should be used as a tool to spot potential suppliers where improvement programs can improve quality in the future.
- The dashboard should give insight in the lead time of managing complaints (the time between the Quality Engineer confirmed that there is a complaint and when the complaint is solved), Insight in the lead time is important because it allows the Supplier Quality Manager to make decisions like adding more purchasers to a specific complaint.
- The dashboard should also give insight per commodity group (mechanical, electrical and OEM purchasers/suppliers), which lead to insights with respect to resource capacity and decisions as adding more purchasers to a specific commodity group.

3.2.2 Main Insights

To solve the core problem, structural insight in supplier quality performance should be given to the Supplier Quality Manager. To quantify this core problem, six indicators are assigned to the variable ‘insight’. These indicators are already requirements, improving those indicators will improve the overall insight in supplier quality performance. The indicators are created together with the Supplier Quality Manager and can be found in *Table 1. Indicators of the variable "insight"*. In this section the indicators are listed as concretize requirements for the dashboard. The main insights can be divided into the cross-sections that the dashboard should be able to show and the information that the dashboard should show for all the cross-sections.

Cross-sections

- The dashboard should give insight in 4D, 8D as well as both complaints.

- The dashboard should look back 7 days in time to give an overview of the current situation.
- The dashboard should look back 6 weeks in time.
- The dashboard should look back 6 months in time.
- The dashboard should look back 3 years in time.
- The dashboard should give insight in the quality performance per supplier.
- The dashboard should give insight in the quality performance per purchaser.
- The dashboard should give insight in the failure codes of the quality complaints.
- The dashboard should give insight per commodity group (mechanical, electrical and OEM purchasers).

Information in the cross-sections

- The amount of open complaints should be showed in the dashboard.
- The amount of new and finished complaints should be showed in the dashboard.
- The lead time of managing complaints should be showed in the dashboard.
- The most occurring failure codes should be showed in the dashboard.
- Because supplier complaints can also be observed at the customer, the amount of customer complaints should also be showed in the dashboard.
- Also the most underperforming suppliers should be visible in the dashboard.

3.2.3 Layout and Design

- The data in the dashboard should be easy to read.
- The KPIs in the dashboard should be easy to interpret.
- The dashboard should have a clear story line.
- The student is free in the layout and design of the dashboard. Because the development of a dashboard is a continuing iterative process, feedback on the layout and design will be giving throughout the project.

3.2.4 Deliverables

The company requires two different written reports next to the dashboard.

- The first written report is a report with recommendations to improve the dashboard in the future. Everything that is not included in the dashboard caused by time restrictions or other limitations should be included in this report. This written report corresponds with chapter *8 Conclusion, Limitations and Recommendations*.
- The second written report should be a manual how to maintain and work with the dashboard. This report describes how to interpret the KPIs on the dashboard, the intentional users of the dashboard, what decisions should be taken based on the dashboards, the actions needed to be taken when new purchasers should be added to the dashboard and the limitations of the dashboard. This written report is delivered to the company and is not part of this thesis.

4 Solution Generation

The first three steps of the MPSM are elaborated in chapter *1 Problem Identification*, chapter *2 Theoretical Framework* and chapter *3 Research in the Company*. This chapter elaborates the fourth step of the MPSM: solution generation. This is the step where all the possible solutions to solve the core problem are elaborated and an advice for one specific solution is given.

4.1 The Possible Solutions

The literature study in section *2.1 Supplier Quality Improvement* concluded that a performance measurement system plays a big role in continuous improvement of supplier quality (Monczka et al., 2016). Other possible solutions to increase the insight in supplier quality performance and result in the ability to generate continuous improvement programs is a search algorithm or an one-time-only supplier quality analysis like value analysis/value engineering. With a search algorithm is meant that the computer will analyze the supplier quality data and based on certain thresholds generate a ranked list with suppliers that can improve the most on quality. By an one-time-only supplier quality analysis is meant that the student will conduct an analysis of the current supplier quality performance and will generate multiple continuous improvement programs. An overview of the solutions is given in *Figure 5. Overview solution choices.*

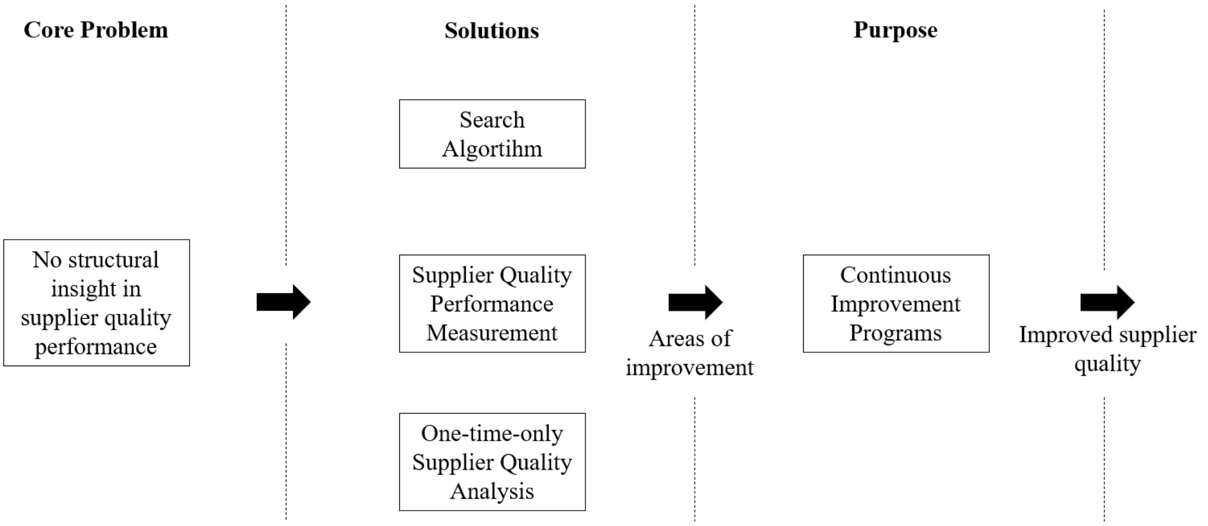


Figure 5. Overview solution choices.

The advantage of a search algorithm and performance measurement system is that this system can be used over and over again by the company to analyze the areas of improvement. Whereas the one-time-only analysis is an one-time report with recommendations and cannot be used to analyze supplier quality performance in the future again. The disadvantage of the search algorithm is that it is based on programming code, which is hard to implement. The performance measurement system is on the other hand easier to implement and easier for the company to understand and read. Therefore the advice is given in section *2.1 Supplier Quality Improvement* to create a performance measurement system. All the advantages and disadvantages of the solutions are given in *Table 11. Advantages and Disadvantages of the Solutions.*

Table 11. Advantages and Disadvantages of the Solutions.

Solution	**Advantages**	**Disadvantages**
Search Algorithm	Can be used over and over again.	Does not show why certain suppliers are chosen. Hard to implement. No human interaction.
Supplier Quality Performance Measurement System	Can be used over and over again. Easy to understand for the company. Easy to maintain for the company. Human interaction is possible.	Company should use it to analyze supplier quality after the thesis.
One-time-only Supplier Quality Analysis.	Supplier quality can directly be influenced by the student. Easy to create.	It creates insight, but to solve the core problem it should create structural insight.

5 Solution Choice

The first four steps of the MPSM are elaborated in chapter *1 Problem Identification*, chapter *2 Theoretical Framework*, chapter *3 Research in the Company* and chapter *4 Solution Generation*. This chapter elaborates the fifth step of the MPSM: solution choice. This is the step where the final solution to solve the core problem is chosen. Next to that, the design choices for the solution, KPI selection and Tool selection are elaborated in this chapter.

5.1 Dashboard as a Solution

The Supplier Quality Manager agreed on the advice that a performance measurement system is the best solution for the core problem. Section *2.2 Performance Measurement Systems* concluded that a dashboard is the most feasible performance measurement system for this thesis. Another performance measurement system is a Balance Scorecard. However, the Balance Scorecard is more suitable for long-term strategic planning, representing trends in business activity over time supported by a clearly defined management strategy. Whereas the dashboard is more focused on short-term/medium-term tactical planning, operationally focused and support by individual managers, which visualizes the performance to understand the current state. Therefore the decision is made to create a dashboard to visualize supplier quality performance.

5.2 KPI Selection

A dashboard provides a graphical representation of Key Performance Indicators, Metrics and Measures to monitor performance. Measures are raw numbers. Metrics are summarized measures which have a meaning and KPIs are those metrics which express the performance of a company or project either ongoing or completed. In this section the KPIs for the dashboard will be selected. The KPIs will be derived from the already used KPIs by VDL ETG Almelo and the literature study on quality related KPIs. The final selection of KPIs is made with the AHP method, which is a MCDA method. The KPI selection process will be elaborated in this section and at the end a short explanation of each KPI is given.

The weights for the SMART criteria are given in *Table 12*. For the calculation of the weights and the consistency check, see *Appendix I – Calculation of the weights for the KPI selection*.

Table 12. Weights for the SMART criteria.

Criterion	**Weight**
Specific	5,11%
Measurable	27,69%
Achievable	12,42%
Relevant	47,91%
Time-bound	6,88%

For each KPI found in the literature review and used by the company a score is given to every SMART criterion. The scale of the scores given to the criteria can be found in *Table 13*.

Table 13. Scale of the scores given to each criterion.

1	**2**	**3**	**4**	**5**
Poor	Insufficient	Neutral	Sufficient	Good

In *Table 14* the KPIs are scored against the SMART criteria. KPIs with a total score of 4 and higher are selected for the dashboards. Scoring the KPIs against the SMART criteria is done together with the Supplier Quality Manager. The reason why the first four KPIs in *Table 14* are given a score of 1 on all criteria is that all KPIs are focused on the quality added by the manufacturing process, whereas the dashboard is focused on supplier quality performance.

Table 14. Final KPI selection

Literature KPIs	**S**	**M**	**A**	**R**	**T**	**TOTAL**
Actual to planned scrap ratio	1	1	1	1	1	1,00
Scrap ratio	1	1	1	1	1	1,00
Rework ratio	1	1	1	1	1	1,00
First time quality	1	1	1	1	1	1,00
Quality rate	5	5	4	5	5	4,88
Complaints rate	5	5	5	5	5	5,00
Non-conformity costs	4	5	3	3	5	3,74
Major complaints rate	4	5	5	5	5	4,95
Process innovation projects	4	5	5	5	5	4,95
Technical improvement projects	3	3	2	3	3	2,88
Accumulated failures trend	5	3	3	5	4	4,13
Project amendments	3	2	2	1	2	1,57
Outstanding corrective actions	5	5	5	5	5	5,00
Inspection costs	3	1	1	2	1	1,58
Supplier Rating	1	5	5	3	3	3,70
Company KPIs						
Number of complaints	4	5	5	4	5	4,47
%Complaints (or PPM)	5	5	5	5	5	5,00
Rejected parts	3	5	5	3	5	3,94
%Rejected parts (MQP)	5	5	4	5	5	4,88
Cost of Poor Quality	4	5	3	3	5	3,74

Next to the KPIs selected above, there are two KPIs added to the final selection. The Top10 Underperforming suppliers and the lead time of finished complaints are added because in section *3.2.2 Main Insights*, the Supplier Quality Manager indicated that this information is important for the insights in supplier quality performance. Below the final KPIs and what those KPIs measure in the context of VDL ETG Almelo is explained.

Total Open Complaints

This is a measure showing the number of observed complaints not yet solved. This measure is also known as Outstanding Corrective Actions (OCA) as mentioned by (Jochem et al., 2010). The total open complaints should be given for supplier complaints and customer complaints. For supplier complaints the open complaints should be showed for 4D's (incidents) as well as 8D's (major complaints rate (Cao et al., 2015)) as well as both. In addition, the total open complaints should also be given for every supplier, purchaser and failure code.

Average Lead Time Finished Complaints

The average lead time is a metric which shows the average time a supplier needed to solve a supplier complaint and VDL ETG Almelo needed to solve a customer complaint. This KPI is calculated in days and for supplier complaints it should show the average for 4D's (incidents) as well as 8D's major complaints rate (Cao et al., 2015)) as well as both. The average lead time should be given for open complaints, complaints last 6 weeks, last 6 months, last 12 months, per supplier, per purchaser and per failure code.

Supplier MQP score last 12 months (%)

The total rejected parts in the last twelve months divided by the total delivered quantity in the last twelve months of the supplier. The target for the MQP score is 500 PPM or 0,05%. The overall percentage of good quality parts is called the Quality Rate (QR) by (Kang et al., 2016).

Supplier %Complaints last 12 months

The total number of complaints in the last twelve months divided by the total number of order lines in the last twelve months of the supplier. The target for the %complaints is 1000 PPM or 1%. The number of complaints per unit of time or per units sold is called the complaints rate (CR) by (Verhaelen et al., 2021 ; Payaro et al., 2016).

New Complaints over Time

The number of new supplier complaints and the number of new customer complaints per month. For supplier complaints this KPI should show 4D's (incidents) as well as 8D's (major complaints rate (Cao et al., 2015)) as well as both. For supplier complaints this KPI should also show the number for mechanical buyers, electrical buyers and OEM buyers. The time horizon should show the last 7 days, last 6 weeks, last 6 months and last 12 months. The new complaints should also be shown per supplier, purchaser and failure code.

Finished Complaints over Time

The number of finished complaints for suppliers and the number of finished complaints for customers per month. For supplier complaints this KPI should show 4D's (incidents) as well as 8D's (major complaints rate (Cao et al., 2015)) as well as both. For supplier complaints this KPI should also show the number for mechanical buyers, electrical buyers and OEM buyers. 8D's are not only major complaints, a major complaint always comes with a plan to improve the process at the supplier, therefore the number of finished 8D's can also be seen as the KPI Process Innovation Projects (PIP) as described by (Cao et al., 2015), the number of finished innovation projects. The time horizon for this complaint should show the last 7 days, last 6 weeks and last 6 months, last 12 months. The finished complaints should also be shown per supplier, purchaser and failure code.

Open Complaints over Time

The number of supplier and customer complaints not yet solved per month. For supplier complaints this KPI should show 4D's (incidents) as well as 8D's (major complaints rate (Cao et al., 2015)) as well as both. The time horizon for this complaint should show the last 7 days, last 6 weeks and last 6 months, last 12 months. The open complaints should also be shown per supplier, purchaser and failure code.

Supplier MQP Score over Time (%)

The total rejected parts divided by the total delivered parts of a supplier per month, visualized over the last twelve months. The target for the MQP is 500 PPM or 0,05%. The MQP score should also be shown per supplier, purchaser and failure code.

Supplier %Complaints over Time

The total number of complaints divided by the total number of order lines of a supplier per month, visualized over the last twelve months. The target for the %complaints is 1000 PPM or 1%. The %Complaints should also be shown per supplier, purchaser and failure code.

Lead Time Finished Complaints over Time

The number of observed finished supplier complaints and the number of observed finished customer complaints within bins of ten days will be visualized. For supplier complaints this KPI should show 4D's (incidents) as well as 8D's (major complaints rate (Cao et al., 2015)) as well as both. The time horizon for this complaint should show the last 6 months and last 12 months. The lead time should also be shown per supplier, purchaser and failure code.

Top10 Underperforming Suppliers
This KPI shows the suppliers with the most supplier complaints per 4D's (incidents) and 8D's (major complaints rate (Cao et al., 2015)) and both. This KPI should also show the top underperforming suppliers for mechanical buyers, electrical buyers, OEM buyers, suppliers, purchasers and failure codes. The time horizon for this KPI is the last 6 months and last 12 months.

Top10 Failure Codes
This KPI shows the most occurred failure codes of supplier complaints per 4D's (incidents) and 8D's (major complaints rate (Cao et al., 2015)) and both. The most occurring failure codes should also be shown per supplier and purchaser on the time horizon of last 6 months and last 12 months. This KPI is comparable to the accumulated failures trend mentioned by (Jochem et al., 2010).

5.3 Tool Selection

In this section the business intelligence software is chosen. A limited number of KPIs can be visualized in a simple dashboard software tool. Whereas lots of data integrations, thousands of metrics feeding the KPIs with hundreds of users, a more advanced BI solution would be more suitable. The final dashboard software tool is selected based on an evaluation of the three most used BI software tools. The evaluation weights the pros and cons of each tool and the final tool is selected based on the needs of the company.

There are three dominant market leaders in field of BI applications: Power BI (Microsoft), Tableau and Qlik (Sense and View), see *Figure 6* for the Magic Quadrant (leaders, visionaries, Niche Players and Challengers) of the total market as of February 2021 according to Gartner Inc.

Figure 6. Business Intelligence applications ordered in the Magic Quadrant. Source: Gartner Inc.

All three parties score well on ease of use, data visualization, mobile BI, cloud and enterprise vision. Qlik scores well overall, but lags behind on data discovery. Qlik's price is also a disadvantage. Tableau's weaknesses are data integration, collaboration or sharing of data and also the price. Where Power BI lags behind in dashboarding and on-premise, it excels in price, ease of use and data sharing (HSO, 2021).

The price is an important criteria. Power BI, Tableau and Qlik all have a basic version which is free to use, however the free version of Tableau and Qlik have very limited features. To upgrade Tableau to the advanced version it will cost $100 per user, to upgrade Qlik to the advanced version it will cost $30 per user per month. The free version of Power BI has more features than the free versions of Tableau and Qlik. However, the biggest difference between the free and advanced version over Power BI is that with advanced it is possible to share data, reports, and dashboards with other users who also have the advanced version. Therefore, to work with Power BI within VDL ETG Almelo the advanced version is required, and it will cost the company $10 per user per month (WallStreetMojo, 2020).

VDL ETG Almelo uses iQBS for collecting company data and the implementation of dashboards. iQBS offers two BI applications for the creation of dashboards: Power BI and SAP. The dashboards at VDL ETG Almelo are currently built in Excel, however they are aiming for a BI application to build their dashboards in the future. Based on the fact that iQBS offers Power BI as an application, Power BI is the market leader Power BI scores high at sharing dashboards and Power BI is cheaper than the competitors, the recommendation is to use Power BI in the future. However, the dashboards on supplier quality performance should be in place shortly. Because it is not possible to share dashboards with other users on the free version of Power BI and the fact that VDL ETG Almelo is not sure about the BI application used in the future the choice is made to use Excel as the tool for building the dashboards. Other dashboards at VDL ETG Almelo are also built in Excel, which ensures that employees are capable of working and maintaining the dashboards.

5.4 Dashboard Design

There are two options with respect to showing the time dimensions of the KPIs: make one dashboard where the KPIs can be changed at the push of a button or make different dashboards for each time dimension. The choice is made to make different dashboards for each time dimension, because the risk is there that because not all graphs will change, the overview of the dashboard will be lost as a consequence. Another argument for making different dashboards per time dimension is to make the maintainability of the dashboard more understandable for the employees. One dashboard with all the different time dimensions as buttons, requires one pivot table for each KPI which changes the dimension scope of this pivot table, more code is required to obtain the required result, which makes it more complex to maintain the dashboard.

For visualization of KPIs in graphs and charts the guidelines from Cleveland and McGill (1984) and Evergreen (2019) are considered. For important single measures like the number of open complaints, average lead time, MQP score and %Complaints the number is printed big at the top of the dashboard. Side by Side column charts are used to show how two numbers compare, like the new and finished complaints. Change over time like the amount of open complaint over time is visualized with lines. For the MQP score and %Complaints over time, a column chart with a benchmark line is used. The lead time is visualized using binned quantitative values and is therefore visualized with a histogram. For the Top10 underperformers, failure codes and item groups the choice could have been made to visualize it with a pie chart or treemap. However, because humans are not great in judging areas and slopes, just a list is shown. The list also give the opportunity to drill down to the origin of the data when observing something striking, which is also a key characteristic of great dashboards according to (Malik S., 2005).

The interactive dashboard buttons are programmed using Visual Basic (VBA). The code will select the required data structure and afterwards it will deselect the old data structure. For the supplier, purchaser and failure code dashboard, a drop down menu is created. When selecting the required supplier, purchaser or failure code, clicking on the GO button will change the underlying pivot tables.

The most important KPI (new, finished and open complaints) is placed at the top left of the dashboard as recommended by (Nadelhoffer E., 2016). In the month and year dashboard the aspect of symmetry is well applied, in other dashboards it was hard to apply the theory of symmetry because of the size difference of the KPI visualizations (supplier and failure code dashboard) or because of too few KPIs per dashboard (day and month dashboard).

For the background colors of the dashboard dark blue is chosen. This color is chosen because the company colors of VDL ETG Almelo are also dark blue. The color of the user panel is light blue because light blue and dark blue combine well together, also a light blue user panel is recommended by (Malik S., 2005). The charts have a different color scheme than the background to differentiate from the background, which is also recommended by (Malik S., 2005).

6 Implementation of the Dashboards

The first five steps of the MPSM are elaborated in chapter *1 Problem Identification*, chapter *2 Theoretical Framework*, chapter *3 Research in the Company*, chapter *4 Solution Generation* and *5 Solution Choice*. This chapter elaborates the sixth step of the MPSM: solution implementation. The solution implementation is the step of the MPSM where the solution is worked out, in this thesis it is the step where the dashboard is created. In this section the core problem is solved by combining the knowledge gained in the literature review (chapter *2 Theoretical Framework*) and the research in the company (chapter *3 Research in the Company*).

6.1 Systematic Dashboard Building Approach

One of the key aspects of a thesis is that is must meet the criteria that it is reproducible. Therefore, a systematic approach is created to ensure that different people will come to the same result when hypothetically repeating this thesis at VDL ETG Almelo. The systematic approach of building the dashboard is visualized in *Figure 7*. This systematic approach of dashboard building can also be used in other VDL ETG Almelo departments (like the sales, finance and other purchasing departments like the parts or projects purchasing department) or VDL locations. In this section all the steps in the systematic approach are explained, in the other sections of this chapter the implementation of these steps at VDL ETG Almelo are discussed.

The systematic approach consist of four steps:

1. The data needed for the KPIs will be gathered
2. The data will be prepared, structured and cleansed so it can be used in the dashboard
3. The dashboard will be built from modelled data
4. A policy to easily maintain the dashboard will be created

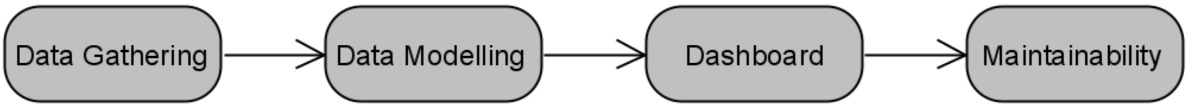


Figure 7. Systematic Dashboard Building Approach.

Step1: Data Gathering
First the data to calculate the KPIs should be gathered. The data can be gathered from multiple databases.

Step 2: Data Modelling
The gathered data should be cleaned, prepared and modelled before it can be used to create the dashboard. Data from different datasets should be combined to one dataset, taking the data quality into account. Data cleansing is also part of this step: incorrect, incomplete, improperly formatted or redundant data should be deleted of dataset to ensure data quality. In this step the KPIs are also calculated using SQL and multi-dimensional views are created with pivoting which is a popular OLAP method.

Step 3: Dashboard Design
The KPIs calculated in the data modelling step, will be visualized in graphs and charts in this step. The visualized KPIs will also be made interactive by creating buttons next to the graphs and charts.

Step 4: Maintainability
The purpose of the dashboard is that it can be used by the company after thesis. This means that the dashboard should be maintainable and can be used by the employees. A policy for changing events like hiring a new purchaser should be created if this data is not dynamically added to the dataset.

6.2 Data Gathering

The data needed to calculate and show the KPIs in the dashboards is retrieved from the Quality Database. To calculate the MQP score the total delivered parts are needed and to calculate the %Complaints the order lines are needed. However, the delivered parts and order lines are stored in the Logistics Database, therefore this database is also required. For the business intelligence architecture of the purchasing department of VDL ETG Almelo, see *Figure 4. Business Intelligence Architecture of the purchasing department of VDL ETG Almelo*. To show which data structures are stored in which database, Entity-Relationship Diagrams are constructed for both databases, see *Figure 8* and *Figure 9*. It is immediately noticeable, that not the same database set-up is used. For instance, in the Quality Database the purchaser is not a separate entity, but the purchaser is a data structure in the entity *order* under the name of *responsible*. In the Logistics Database the purchaser is a separate entity called *Buyer* and the purchaser has an one-to-many relationship with the entity *order*. The gathered data can be loaded into Excel using iQBS. The connection between Excel and iQBS makes it possible that the data can be refreshed when opening the excel file, therefore the data will always be up-to-date. It is important to notice that the data refreshes once in 24 hours at midnight, therefore the complaints created today will not be visible in the data, it will be visible tomorrow.

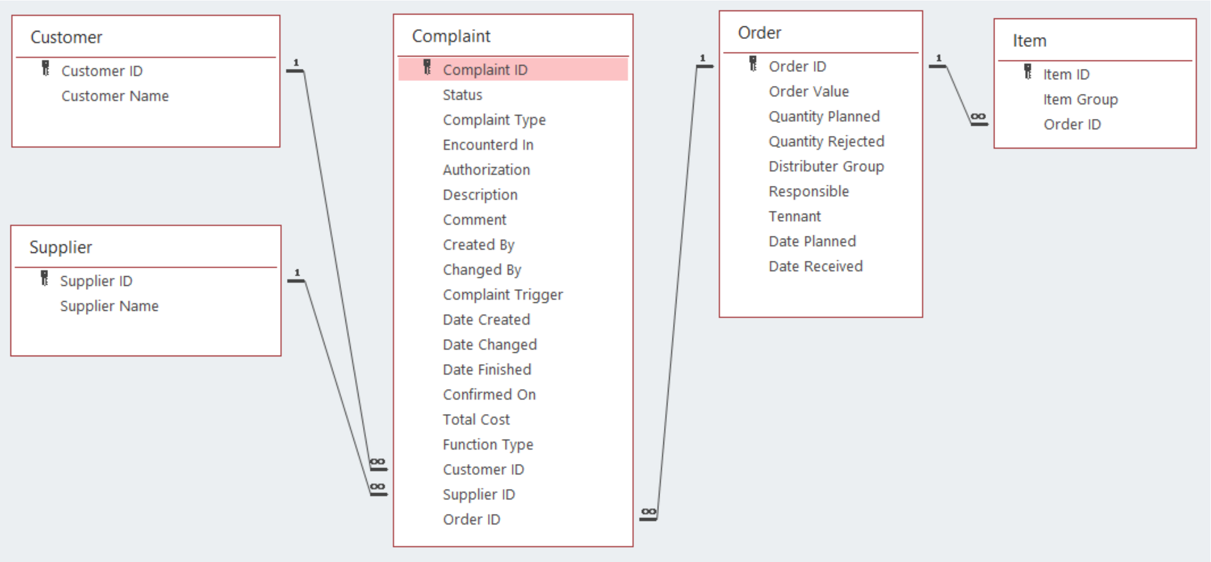


Figure 8. Entity-Relationship Diagram for the Quality Database

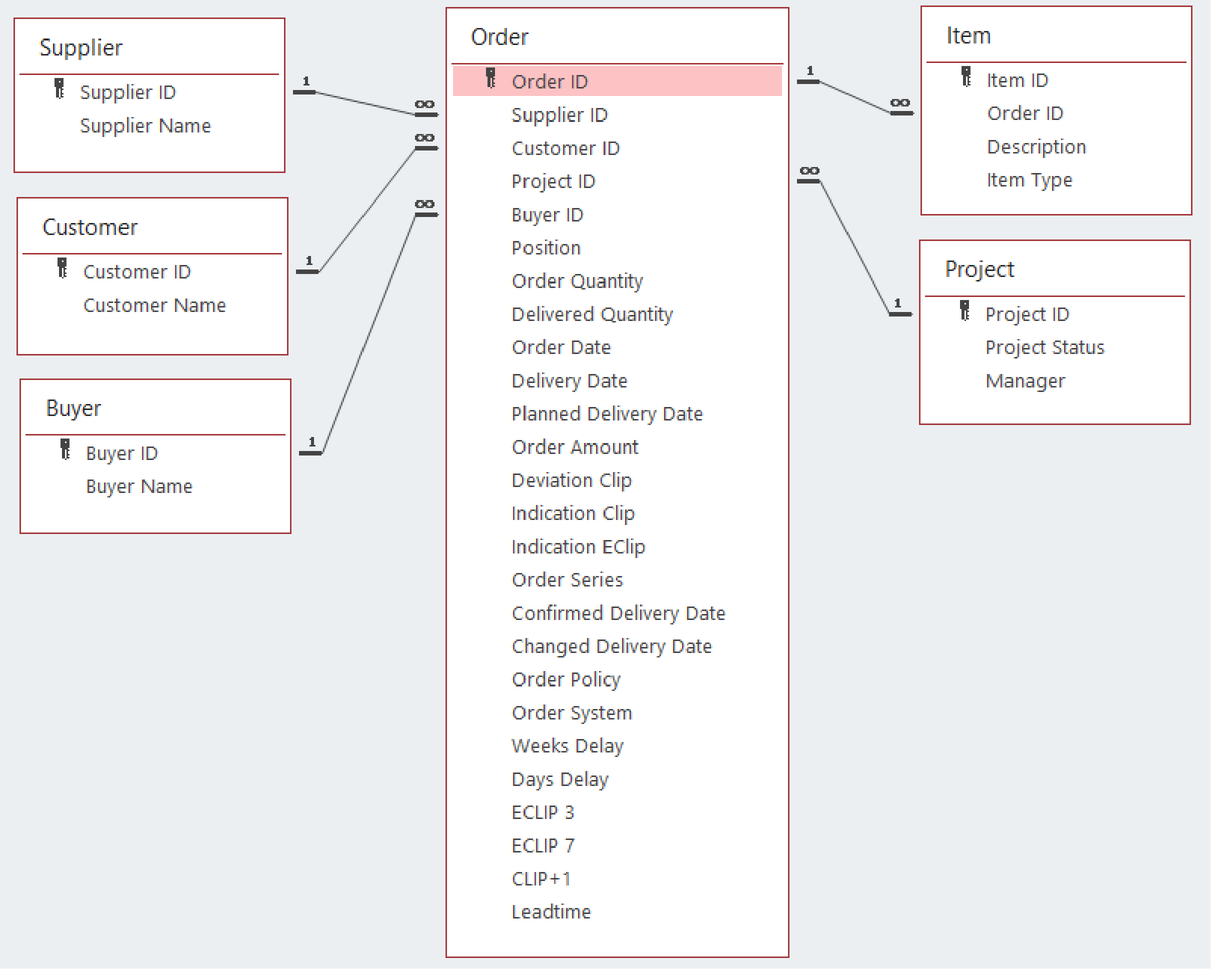


Figure 9. Entity-Relationship Diagram for the Logistics Database

6.3 Data Modelling

Now that the data is gathered and loaded into Excel, the data should be prepared, structured and cleansed. The purpose of data modelling is to calculate the required data for the KPIs, to query different time dimensions and that all while ensuring high data quality.

6.3.1 Preparation and Structuring of Data

This section goes through all the steps performed in preparing and structuring of the data.

Step 1: Deleting unnecessary data
The data is first loaded with iQBS into Excel in the form of pivot tables. In the pivot tables it is possible to use SQL to deselect specific data structures. This is done for empty data structures and data structures not really needed to analyze complaints to improve loading times. For the Quality Database these are the data structures of the entity *order*: *order value*, *quantity planned*, *date planned* and *date received*. For the Logistics Database these are the almost all the data structures except from *delivered quantity* and *CLIP + 1* because with *CLIP + 1* the order lines can be extracted. The size of the Excel file is decreased from 10MB to 2MB and the time to open the file decreased from 1 minute to 10 seconds.

Step 2: Filter data on time
There are a couple of time dimensions needed for the dashboards: last 7 days for the day dashboard, last 6 weeks for the week dashboard, last 6 months and last 12 months for the month dashboard and last 12

months and last 36 months for the year dashboard. The data is filtered on these time dimension by using SQL.

Step 3: Filter the data on data structures
To ensure that each pivot table shows the data for the correct purchasing department, some filters are added. The pivot tables are filtered on authorization (complaints should be justified by the supplier), complaint types (only 4D's and 8D's are of interest), distributor group (ALM systems is selected) and responsible (the quality engineers are filtered out and the purchasers are selected).

Step 4: Calculate new data structures
Some KPIs are not already available in the databases and should therefore be calculated using SQL again.

- The lead time of complaints is not directly available and is therefore calculated using SQL. The lead time is the time between a *Confirmed on* and *Date Finished*. The lead time is always calculated from the *Confirmed on* date and not from the *Date Created* because the *Date Created* is date where the complaint is observed and the *Confirmed on* date is the date where the Quality Engineer has confirmed that the observed complaint is indeed a complaint caused by the supplier. In case that the complaint is not finished yet, the lead time is calculated as the time between *Confirmed on* and today.
- The days, weeks, months and years are also calculated with SQL. For days the format is just dd-mm-yyyy, for weeks the format is yyyyww, for months the format is yyyymm and for years the format is just yyyy.
- The MQP score is calculated by dividing the *Rejected Parts* by the *Delivered Parts*. However, the *Rejected Parts* is stored in the Quality Database and *the Delivered* Parts is stored in the Logistics Database, therefore it was not possible to calculate this score with SQL. The MQP score is calculated with Excel functions instead, after both a pivot table with the Quality data and a pivot table with the Logistics data was created.
- The %Complaints is the same story as the MQP score, the *Complaints* are extracted from the Quality Database and the *Order Lines* are extracted from the Logistics Database.

6.3.2 Data Quality

In this section the data is analyzed to spot two different types of data quality problems: one caused by redundant and inconsistent data produced by multiple systems feeding a data warehouse and one caused by errors during data input.

A different database design is used for the Quality Database and the Logistics Database. This does not have to lead to data quality problems, but it should be taken into account when constructing the dashboard. For instance, in the Quality Database the purchaser is referred to as *Responsible* where in the Logistics Database the same purchaser is referred to as *Buyer Name*. The data input for the *responsible* is formatted as *Jansen, Peter* and the data input for *Buyer Name* is formatted as *260439 – Dhr. P. Jansen*. In the Purchaser Dashboard this will cause an error if all pivot tables will be filtered on *Jansen, Peter*. The best way to solve this is by selecting all pivot tables on the *Buyer ID* which is 260439 in this example, however in the Quality Database the purchaser is not a separate entity, and therefore the purchaser ID number is not present, so this option expires. Another possible solution is to extract the surnames of both databases and compare then look up the corresponding full name in the other database, however this option is error prone because two purchaser can have the same surname. The decision is made to look up all the purchasers once and add both the name format of the Quality Database and the Logistics Database in an Excel sheet, whereafter the dashboard will select each pivot table to their corresponding purchaser format. The disadvantage of this solution is that it makes the dashboard maintenance-sensitive. A new purchaser should manually added to this list in both the Quality and Logistics Database format.

Another observed data quality issue is that in some care cases the supplier is stored under a different name between the two database. For instance, a German supplier with an umlaut in the supplier name is stored without the umlaut in the Quality Database and with the umlaut in the Logistics Database. As showed in the database design, the supplier is a separate entity for both the Quality and Logistics Database, therefore this problem can be solved by looking up the corresponding *Supplier ID* and filter all the pivot tables based on the *supplier ID*.

Another observed data quality issue is caused by errors during data input, namely in some rare cases the *Confirmed on* is earlier than the *Date Created*. This will lead to a negative lead time, which will lead to a lower average lead time. The recommendation for the company is to create a data input manual which ensures that errors during data input will be minimized, but for now the negative lead times are filtered out the calculation for the average lead time.

It also occurs that the attribute *Date Finished* is blank while the attribute *Status* is labelled as Finished or vice versa. This error is caused by the Quality Engineer not filling in the *Status* as Finished before closing the complaint. This means that the *Date Finished* is leading and therefore the dashboard will rely on the *Date Finished* rather on the *Status*.

6.4 The Dashboards

The final dashboards are created in two Excel files. One file contains the operational dashboards, giving insight in the overall supplier quality performance. If anything stands out in these dashboards, the analytical dashboards (supplier, purchaser or failure code dashboards) in the other file can be used to drill down and come closer to the bottle neck. All dashboards are described extensively in *Appendix K – Dashboard Demonstration*, but in this section the one operational and the one analytical dashboard covering the most important data for this thesis are showed.

The month dashboard is the operational dashboard giving the most important information. It shows the new, finished and open complaints and the lead time for supplier quality complaints as well as customer quality complaints. Furthermore the MQP score and the %Complaints per month are given for the supplier quality complaints and the most underperforming suppliers and most occurring items and failure codes are showed.

Top10 Underperformers ALL (last 6 months)		4D	8D	Total
1	[redacted]	4	7	11
2	[redacted]	10	1	11
3	[redacted]	5	5	10
4	[redacted]	9	1	10
5	[redacted]	10	0	10
6	[redacted]	7	2	9
7	[redacted]	6	3	9
8	[redacted]	8	0	8
9	[redacted]	0	8	8
10	[redacted]	7	1	8

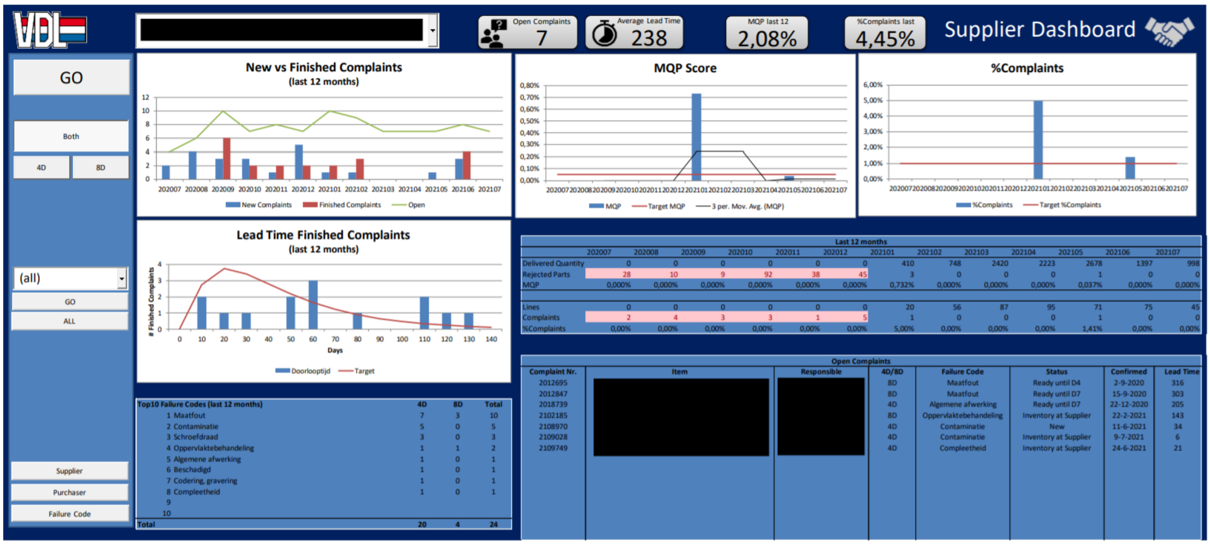
Top10 Items ALL (last 6 months)		4D	8D	Total
1	[redacted]	6	0	6
2	[redacted]	4	1	5
3	[redacted]	3	0	3
4	[redacted]	3	0	3
5	[redacted]	0	3	3
6	[redacted]	3	0	3
7	[redacted]	0	3	3
8	[redacted]	2	1	3
9	[redacted]	1	2	3
10	[redacted]	1	2	3

Top10 Failure Codes ALL (last 6 months)		4D	8D	Total
1	Maatfout	40	9	49
2	Compleetheid	33	5	38
3	Functioneel	19	16	35
4	Beschadigd	18	5	23
5	Algemene afwerking	18	3	21
6	Codering, gravering	12	3	15
7	Schroefdraad	9	5	14
8	Contaminatie	11	2	13
9	Oppervlaktebehandeling	8	2	10
10	Lucht- en vloeistofverbinding	5	3	8

Figure 10. Month dashboard.

When for instance a supplier stands out in the operational dashboard, the analytical dashboard called "supplier dashboard" can be used to give an overview of that specific supplier. This dashboard shows the amount of new, finished and open complaints. Furthermore the lead time, MQP score and

%Complaints per month are showed in graphs. The exact numbers of rejected parts and delivered parts (needed for the MQP score) and the complaints and order lines (needed for the %Complaints) are again showed in a table. A list with all the open complaints for the selected supplier are given and the most occurring failure codes are given. It is even possible to zoom in on one specific failure code for the selected supplier. At the user panel one can select a failure code and the dashboard will adjust with information of that one specific failure code.



[redacted]

Open Complaints 7

Average Lead Time 238

MQP last 12 2,08%

%Complaints last 4,45%

Last 12 months	202007	202008	202009	202010	202011	202012	202101	202102	202103	202104	202105	202106	202107
Delivered Quantity	0	0	0	0	0	0	410	748	2420	2223	2678	1397	998
Rejected Parts	28	10	9	92	38	45	3	0	0	0	1	0	0
MQP	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,732%	0,000%	0,000%	0,000%	0,037%	0,000%	0,000%
Lines	0	0	0	0	0	0	20	56	87	95	71	75	45
Complaints	2	4	3	3	1	5	1	0	0	0	1	0	0
%Complaints	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	5,00%	0,00%	0,00%	0,00%	1,41%	0,00%	0,00%

Top10 Failure Codes (last 12 months)	4D	8D	Total
1 Maatfout	7	3	10
2 Contaminatie	5	0	5
3 Schroefdraad	3	0	3
4 Oppervlaktebehandeling	1	1	2
5 Algemene afwerking	1	0	1
6 Beschadigd	1	0	1
7 Codering, gravering	1	0	1
8 Compleetheid	1	0	1
9			
10			
Total	20	4	24

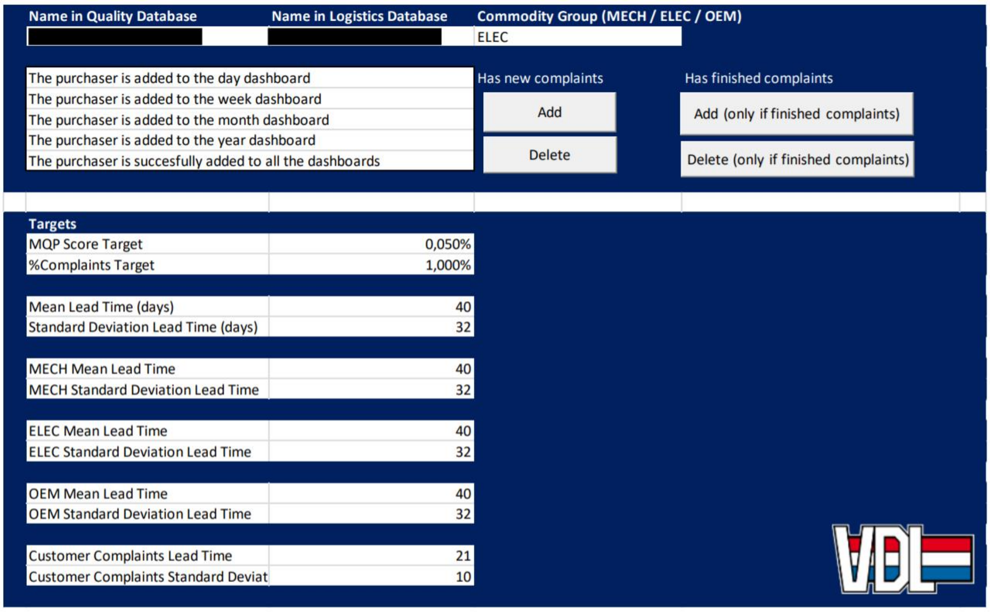
Open Complaints

Complaint Nr.	Item	Responsible	4D/8D	Failure Code	Status	Confirmed	Lead Time
2012695	[redacted]	[redacted]	8D	Maatfout	Ready until D4	2-9-2020	316
2012847			8D	Maatfout	Ready until D7	15-9-2020	303
2018739			4D	Algemene afwerking	Ready until D7	22-12-2020	205
2102185			8D	Oppervlaktebehandeling	Inventory at Supplier	22-2-2021	143
2108970			4D	Contaminatie	New	11-6-2021	34
2109028			4D	Contaminatie	Inventory at Supplier	9-7-2021	6
2109749			4D	Compleetheid	Inventory at Supplier	24-6-2021	21

Figure 11. Supplier dashboard.

6.5 Maintainability

Maintainability is an important requirement of VDL ETG Almelo, it is the purpose of the dashboard to be used, also after the thesis. New data is loaded automatically while refreshing and refreshing automatically happens when opening the dashboard. The main threat for maintainability is when new purchasers are hired and all pivot tables should be adjusted. This problem is tackled by creating a sheet where a new purchaser can be added to the list, once with the format in the Quality Database and once with the format in the Logistics Database. Now with one push at a button the new purchaser will be added to all the pivot tables. In this sheet it is also possible to adjust the targets of the KPIs, when needed.



Name in Quality Database	Name in Logistics Database	Commodity Group (MECH / ELEC / OEM)
[redacted]	[redacted]	ELEC

The purchaser is added to the day dashboard
The purchaser is added to the week dashboard
The purchaser is added to the month dashboard
The purchaser is added to the year dashboard
The purchaser is succesfully added to all the dashboards

Targets	
MQP Score Target	0,050%
%Complaints Target	1,000%
Mean Lead Time (days)	40
Standard Deviation Lead Time (days)	32
MECH Mean Lead Time	40
MECH Standard Deviation Lead Time	32
ELEC Mean Lead Time	40
ELEC Standard Deviation Lead Time	32
OEM Mean Lead Time	40
OEM Standard Deviation Lead Time	32
Customer Complaints Lead Time	21
Customer Complaints Standard Deviat	10

Figure 12. Maintainability sheet.

7 Evaluation

The first six steps of the MPSM are elaborated in chapter *1 Problem Identification*, chapter *2 Theoretical Framework*, chapter *3 Research in the Company*, chapter *4 Solution Generation* and *5 Solution Choice* and chapter *6 Implementation of the Dashboards*. This chapter elaborates the last step of the MPSM: evaluation. The evaluation is the step where is evaluated to what extent the core problem is solved.

7.1 Evaluation

At the end of the thesis the Supplier Quality Manager is again asked to fill in the scores for the indicators of "insight". The overall score of "insight" should have been increased from 2,5 (unsatisfied/neutral) to at least 4 (satisfied) in order to solve the core problem. *Table 15* below shows that this goal is achieved.

Table 15. The increase in the variable "insight" because of the project

Indicators	**Before**	**After**
Insight in overall Long-Term Quality Performance	2	4
Insight in Long-Term Quality Performance per Supplier	3	4
Insight in overall failure codes	3	4
Interpreting the data	2	4
Analyzing time	3	5
Maintenance time	2	4
Average	**2,5**	**4,2**

The insight in supplier quality performance can be further increased by creating a dashboard per item and a dashboard per platform. The VDL ETG Almelo department where the dashboards are created for manufactures four different platforms, a dashboard showing the performance of the items for each separate platform also increases the insight in supplier quality performance. These dashboards are not created in the thesis because of the 10 weeks' time restriction. The platforms are not stored in the database but can be derived from the code of the item.

Also an overview is missing where the improvement of supplier quality can be monitored after an improvement program is implemented. Such an overview should not have to be a dashboard, but can also be a KPI report. These two improvement points can improve the value of 'insight' even further to a score of 5 (very satisfied).

7.2 Limitations

During the process of dashboard building, limitations were encountered. These limitations might influence the results following from the dashboard analysis. In this section the limitations are discussed in depth.

First of all, the limitation in Business Intelligence software was encountered. VDL ETG Almelo does not use BI software like Microsoft Power BI, Tableau or Qlik to create dashboards. The purchase of this kind of BI software is costly and this decision should be made by the management. Therefore the decision is made to create the dashboard in Microsoft Excel. It is doable to create dashboards in Excel but it is not ideal, because creating multi-dimensional views can only be achieved by adding more pivot tables to the Excel file. This makes the size of the Excel file big, which makes the Excel file slow to work with and slow to startup. To solve this problem, not all data from the databases are loaded. However, this results in a new limitation, namely when the Supplier Quality Manager double clicks on specific data showed by the pivot tables, not all data is showed for the specific complaint. This limits the Supplier Quality Manager in the investigation of suppliers and complaints.

Further, there are some limitations encountered caused by poor data quality. One limitation is caused by the different database design used in the two databases used to create the dashboard and the other limitation is caused by errors during data input.

1. The different database designs can lead to errors in the dashboard. Because all pivot tables should be filtered to show the data from different cross-sections, the different names in data structures and the different formats to store data can result in bugs when filtering the data. A good example is the purchaser data structure that in the Quality Database is stored as *Responsible* with the format *Jansen, Peter* whereas the Logistics Database stores purchasers under the name *Buyer* with the format *260439 – Dhr. P. Jansen*.
2. Errors during data input can also cause serious misrepresentations of data. For instance, complaints that are finished but not documented as finished in the database will be an open complaint. The lead time of this open complaint can get an extremely high value which gives a misrepresentation of the average lead time of open complaints.

The dashboard should also be maintained by the users. New purchasers should manually be added to the dashboard. This process is speeded up with the use of VBA code. However, the user of the dashboard should know when the purchaser can be added. The purchaser can only be added when the purchasers has finished a complaint, otherwise the dashboard gives an error message when the selecting the corresponding purchaser.

8 Conclusion, Limitations and Recommendations

This chapter will evaluate to what extent the core problem is solved, how the solution contributes to theory and practice, recommendations to the company and a discussion.

8.1 Conclusion

The goal of the thesis is to solve the core problem “no structural insight in supplier quality performance” as established in section *1.2.3 Core Problem*. Solving the core problem will make it easier for the company to analyze supplier quality performance and communicate continuous improvement plans back to the suppliers. The core problem is solved with a dashboard as performance measurement system as recommended by Monczka et al., 2016. The purpose of the dashboard is to be a steering mechanism with backwards and forwards decision making capabilities based on quality performance. The dashboard should give insight in the quality performance of suppliers and should be used as a tool to spot potential suppliers where improvement programs can improve quality in the future. In addition to the KPIs already used to analyze supplier quality performance, the lead time of complaints and insights for each commodity group (mechanical, electrical and OEM purchasers) should be visualized. The requirements of VDL ETG Almelo established in section *3.2 Desired Situation* are met by the final dashboard. Furthermore the guidelines for aesthetic appeal and chart types from section 2.5 Visualization of KPIs are incorporated. The overall score for the “insight” in supplier quality performance has been increased from 2,5 (unsatisfied/neutral) to 4,2 (satisfied) according to the Supplier Quality Manager. The target was an increase to at least 4 and therefore it can be concluded that according to the Supplier Quality Manager the dashboard is a solution to the core problem.

8.2 Contribution to Theory

The thesis is based on a literature review study. The literature study is focused on the knowledge needed to construct a performance measurement system. Chapter *6 Implementation of the Dashboards* is the chapter where all the knowledge gained in the literature study is practically implemented in an organization to enhance supplier quality performance and validate the theory. Therefore the contribution of this thesis to the already existing theory can be seen as a case study to construct a supplier quality performance measurement system. The cornerstone of this case study is the systematic dashboarding approach constructed in section *6.1 Systematic Dashboard Building Approach* which is constructed by the author and therefore a new contribution to theory.

8.3 Contribution to Practice

The contribution to practice is that the dashboard will be used to monitor the supplier quality performance. Suppliers that stand out in a negative way can be further analyzed with the supplier dashboard. The analysis of individual suppliers should lead to insights with respect to reoccurring failure codes and items. Based on this data, continuous improvement programs can be created to improve the long-term quality performance of the supplier. Improving the long-term supplier quality performance will increase the customer satisfaction and profits.

Furthermore the business process of rejecting delivered products of the suppliers is never mapped out by VDL ETG Almelo and therefore the Business Process Model in *Figure 3. Business Process Model of the Rejection Process* is also a contribution to practice. The same holds true for the Business Intelligence Architecture of the purchasing department in *Figure 4. Business Intelligence Architecture of the purchasing department of VDL ETG Almelo*. But not only the Business Intelligence Architecture is mapped out, there are also entity-relationship diagrams constructed of the Quality and Logistics Database in *Figure 8. Entity-Relationship Diagram for the Quality Database* and *Figure 9. Entity-Relationship Diagram for the Logistics Database*. The threats with respect to data quality of the Quality and Logistics Database are also evaluated and is a new contribution to practice.

In addition to the contributions mentioned above, the systematic dashboard building approach in section *6.1 Systematic Dashboard Building Approach* can also be adopted as an instruction manual by the other departments of VDL ETG Almelo to generate dashboards in Excel.

8.4 Future Work

A lot of the limitations discussed in *7.2 Limitations* can be prevented. How these limitations can be prevented and recommendations to further improve the dashboards are elaborated in this section.

Because Microsoft Excel has serious limitations, the recommendation is to switch to Business Intelligence Software in the future. VDL ETG Almelo uses iQBS for collecting company data, iQBS offers two BI applications for dashboarding: Microsoft Power BI and SAP. Because also Gartner Inc. advice to use Microsoft Power BI over Tableau and Qlik (see section 5.3 Tool Selection), the advice is given to choose Microsoft Power BI as Business Intelligence software.

Further, the advice is given to have the same database design for each database, this recommendation will prevent a lot of the limitations but is a serious operation. Therefore a more feasible solution can be to let the IT department combine the two databases into one database. This allows the purchasing department to analyze suppliers based on the MQP score and %Complaint.

To prevent data quality issues caused by errors during data input the recommendation is given to create a data input instruction for the Quality Engineers when adding data to REM.net. A further analysis should be done to map out all errors in the data caused by data input. When all these threats to data quality are known an instruction manual can be created.

The dashboards can be used to analyze the supplier quality performance of suppliers, the dashboards show the suppliers with the most quality complaints. However, the ability of a supplier to influence a buyer's total quality (the 20% suppliers influencing 80% of the buyer's total quality) is not considered in the dashboards. Certain suppliers offer high-impact or key parts and materials that are critical to a company's success. The advice is given to create an overview with suppliers delivering the most high-impact parts (this data is available at VDL ETG Almelo) and the worst score on MQP and %Complaints. This overview can only be created when the Quality Database and Logistics Database are combined by the IT department.

8.5 Discussion

The discussions points in this thesis are discussed in this section.

The problem quantification in section *1.2.4 Problem Quantification* is based on six indicators that concretize the variable "insight". Every indicator is scored on a 1-5 satisfaction scale and the average scores of the indicators represent the total score on insight. However, it can be argued that not all indicators are of equal importance and therefore a weight should be attached to the indicators. This is not done and can be seen as a discussion point. Even though the scores between the indicators before and after the thesis do not differ that much (before the thesis scores differ between 2 and 3 and after the thesis the scores differ between 4 and 5).

In section *2.1 Supplier Quality Improvement* is concluded that a performance measurement system is good tool to continuously improve supplier quality performance. The remainder of the thesis after this conclusion is focused on a dashboard as solution to the core problem. However, other options to solve the core problem are not investigated in the literature review. The other options are discussed later in chapter *4 Solution Generation*.

Another discussion point is that the KPI selection and established requirements are done together with one employee in the company: the Supplier Quality Manager. This is a small sample size in a company with over 700 employees. It can be argued that this is not a problem because the Supplier Quality Manager is the one using the dashboard. But it can also be argued that this forms a threat when other departments adopt the same dashboard like the sales department or the finance department.

The KPIs are selected based on giving a score per KPI on the SMART criteria. The weights attached to the criteria are based on the opinions of the Supplier Quality Manager and the student. Therefore the importance of each SMART criteria used in this thesis can differ for different projects and decision makers.

In the supplier dashboard it is not possible to compare the quality performance between different years. Therefore it is hard to measure the improvement of suppliers with the supplier dashboard after a continuous improvement plan is executed at the supplier.

Reference List

Bera, P. (2016). How colors in business dashboards affect users' decision making. *Communications of the ACM*, 59(4), 50-57. [CrossRef]

Berkling, K.M. & Zundel, A. (2015). Change Management: Overcoming the Challenges of Introducing Self-Driven Learning. Accessed 5 February 2021. [CrossRef]

Cao, Y., Zhao, K., Yang, J., Xiong, W. (2015). Constructing the integrated strategic performance indicator system for manufacturing companies. International Journal of Production Research, 53(13), 4102-4116. [CrossRef]

CAQ. (2020). Complaint Management / CAPA software. Accessed 28 February 2021. [CrossRef]

Chaudhuri, S., Dayal, U., Narasayya, V. (2011). An overview of business intelligence technology. Communications of the ACM, 54(8), 88-98. [CrossRef]

Cleveland, W. S., & McGill, R. (1984). Graphical perception: Theory, experimentation, and application to the development of graphical methods. Journal of the American statistical association, 79(387), 531-554. [CrossRef]

Collins, A. J., Hester, P., Ezell, B., & Horst, J. (2016). An improvement selection methodology for key performance indicators. Environment Systems and Decisions, 36(2), 196-208. [CrossRef]

Collins, A. J., Hester, P., Ezell, B., & Horst, J. (2016). An improvement selection methodology for key performance indicators. Environment Systems and Decisions, 36(2), 196-208. [CrossRef]

De Montis, A., De Toro, P., Droste-Franke, B., Omann, I., & Stagl, S. (2000). Criteria for quality assessment of MCDA methods. In 3rd Biennial Conference of the European Society for Ecological Economics, Vienna (pp. 3-6). [CrossRef]

Evergreen, S. D. (2019). Effective data visualization: The right chart for the right data. SAGE publications. [CrossRef]

Few, S. (2006). Information Dashboard Design: The Effective Visual Communication of Data. 29-37. [CrossRef]

Heerkens, H. & Van Winden, A. (2017). Solving Managerial Problems Systematically. Accessed 18 February 2021.

Hester, P., Ezell, B., Collins, A., Horst, J., & Lawsure, K. (2017). A method for key performance indicator assessment in manufacturing organizations. International Journal of Operations Research, 14(4), 157-167. [CrossRef]

HSO. (2021). De verschillen tussen Power BI, Tableau en Qlick. [CrossRef]

Jochem, R., Menrath, M., Landgraf, K. (2010). Implementing a quality-based performance measurement system. The TQM Journal, 22(4), 410-422. [CrossRef]

Kang, N., Zhao, C., Li, J., Horst, J. A. (2016). A hierarchical structure of key performance indicators for operation management and continuous improvement in production systems. International Journal of Production Research, 54(21), 6333-6350. [CrossRef]

Kaplan, R. S., & Norton, D. P. (1992). The balanced scorecard: measures that drive

Laudon, K. & Laudon, J. (2014). Management Information Systems: Managing the Digital Firm. 241-266. [CrossRef]

Maestrini, V., Martinez, V., Neely, A., Luzzini, D., Caniato, F., Maccarrone, P. (2018). The relationship regulator: A buyer-supplier collaborative performance measurement system. International Journal of Operations & Production Management, 38(11), 2022-2039. [CrossRef]

Malik, S. (2005). Enterprise Dashboards: Design and Best Practices for IT. 45-57. [CrossRef]

Monczka, R. M., Handfield, R. B., Giunipero L. C., James, L. (2016). Purchasing and Supply Chain Management. South-Western College/West. (pp. 285-321)

Nadelhoffer, E. (2016). 10 Best Practices for Building Effective Dashboards. *Tableau* [CrossRef]

Okfalisa, O., Anugrah, S., Anggraini, W., Absor, M., Fauzi, S., Saktioto, S. (2018). Integrated analytical Hierarchy process and objective matrix in Balanced Scorecard Dashboard model for performance measurement. TELKOMNIKA (Telecommunication Computing Electronics and Control), 16(6), 2703. [CrossRef]

Payaro, A., & Papa, A. R. (2016). A dashboard for LEAN companies: A proposed model with the collaboration of ten Large Italian Enterprises. Eurasian Studies in Business and Economics, 317-326. [CrossRef]

Podgórski, D. (2015). Measuring operational performance of OSH management system–A demonstration of AHP-based selection of leading key performance indicators. Safety science, 73, 146-166. [CrossRef]

Razzouk, R., & Shute, V. (2012). What Is Design Thinking and Why Is It Important? Review of Educational Research, 82(3), 330–348. [CrossRef]

Slack, N., Brandon-Jones, A., Johnston, R. (2016). Operations Management. (pp. 572-602)

Smith, M. (2003). Dashboards or scorecards: What's the difference. [CrossRef]

University of Twente. (2017). Student-driven learning at the University of Twente. *Information for educational staff.* Accessed 11 February 2021. [CrossRef]

VDL Groep Almelo. VDL Enabling Technologies Group (ETG) Almelo. Accessed 16 February 2021. [CrossRef]

VDL Groep. (2019). Annual Report 2019. Accessed 12 February 2021. [CrossRef]

Verhaelen, B., Mayer, F., Peukert, S., Lanza, G. (2021). A comprehensive KPI network for the performance measurement and management in global production networks. Production Engineering. [CrossRef]

WallStreetMojo. (2020). Power BI vs Tableau vs Qlikview. [CrossRef]

Winston, W. L., & Goldberg, J. B. (2004). Operations research: Applications and algorithms. Belmont, CA: Thomson/Brooks/Cole.

Wolk, A., Dholakia, A., Kreitz, K. (2009). Building a performance measurement system. A Root Cause How-to Guide. [CrossRef]

Appendices

Appendix A – Figures introduction VDL ETG Almelo

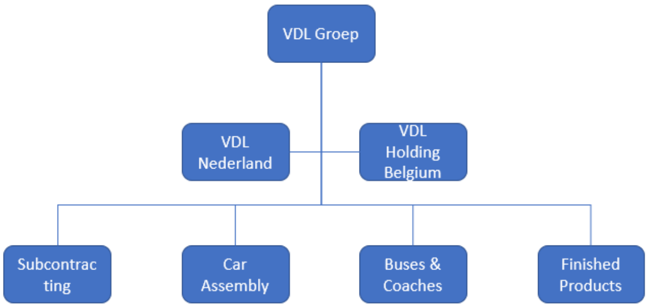


Figure 13. Overview VDL Groep. Source: [VDL Group, 2019.]()

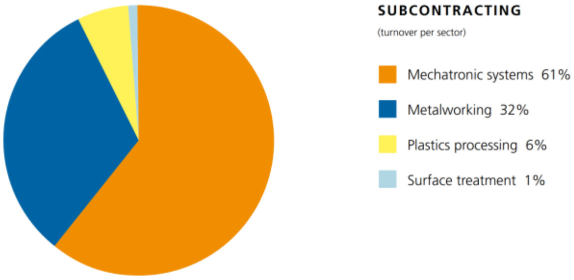
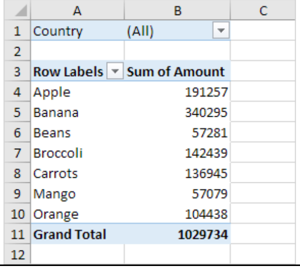
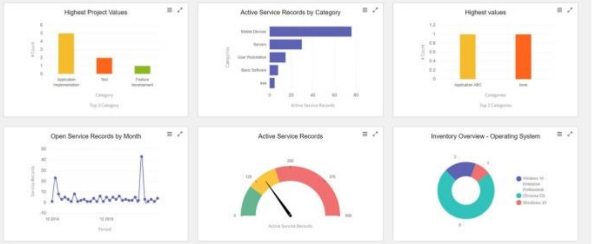


Figure 14. Turnover ratio subcontracting VDL. Source: [VDL Group, 2019]().

Appendix B – Survey to determine the value of variable “insight”

Table 16. Concretized indicators by the Supplier Quality Manager.

Reality	**Norm**
 A B C 1 Country (All) 2 3 Row Labels Sum of Amount 4 Apple 191257 5 Banana 340295 6 Beans 57281 7 Broccoli 142439 8 Carrots 136945 9 Mango 57079 10 Orange 104438 11 Grand Total 1029734 12	
Insight in overall Long-Term Quality Performance	
Currently the overall long-term quality performance is analyzed by using pivot tables.	The norm is that the long-term quality performance is visualized in graphs and charts, it should automatically show the best and poorest performers.
Current score: 2	Goal: > 4
Insight in Long-Term Quality Performance per Supplier	
Currently the long-term quality performance is analyzed in pivot tables, this gives not the desired insight into the suppliers.	The norm is that the long-term quality performance is visualized in a performance measurement tool per supplier. This separate performance measurement tool will show all the quality performance of this specific supplier.
Current score: 3	Goal: > 4
Insight in overall failure codes	
The insight in overall failure codes are now given with pivot tables.	The norm is that there is also a performance measurement tool from the perspective of failure codes only.
Current score: 3	Goal: > 4
Interpreting the data	
Because the data is now analyzed based on pivot tables, it is hard to analyze the data. The amount of failures can be compared between companies but things like the percentage of failures are not really compared	The norm is that interpreting the data is easy. The student is free to choose the type of performance measurement tool to accomplish.
Current score: 2	Goal: > 4
Analyzing time	
Now it takes the Supplier Quality Manager at least 1 hour per week to get insight into the quality performance.	The norm is that it takes the Supplier Quality Manager max 10 minutes to get an insight of the quality performance.
Current score: 3	Goal: > 4
Maintenance time	
Currently some features have to be refreshed manually which takes the Supplier Quality Manager at least 2 hours per week.	The norm is that everything is refreshed with one push at a button.
Current score: 2	Goal: > 4

Appendix C – MPSM

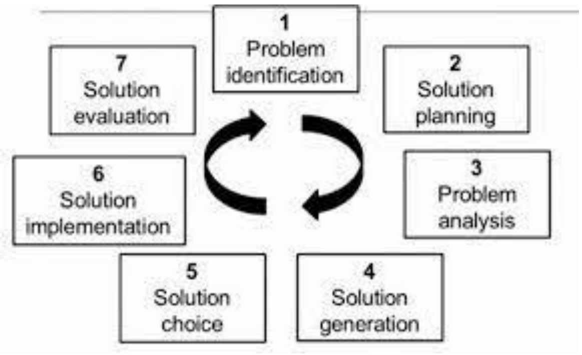


Figure 15. Managerial Problem Solving Method. Source: (Heerkens & Van Winden, 2017)

Appendix D – Systematic Literature Review

In this chapter the systematic literature review assignment is done for research question number 3 about the KPI selection for the dashboard.

Search Terms

Because the research is about finding KPIs for a dashboard on the field of supplier quality performance the search terms are: KPI, dashboard, quality, supplier. The search terms “quality” and “supplier” are used to make sure that the articles cover KPIs and frameworks to cluster KPIs that are useful to indicate the quality performance of suppliers, therefore these search terms are never used together. To search terms “KPI” and “dashboard” are used to indicate what we are looking for, those two search terms are not used together. This lead to four different combinations including the four different search terms, the combinations are showed in Table 17.

Table 17. Search terms.

	Quality	Supplier	KPI	Dashboard	Search Term
Search 1	x		x		“Quality” AND “KPI”
Search 2	x			x	“Quality” AND “Dashboard”
Search 3		x	x		“Supplier” AND “KPI”
Search 4		x		x	“Supplier” AND “Dashboard”

Inclusion and Exclusion Criteria

To filter the list of articles even further, inclusion and exclusion criteria are selected. Inclusion criteria must be available in the article and exclusion criteria will disqualify the article. The inclusion and exclusion criteria used and the reason why, is visualized in Table 18.

Table 18. Inclusion and exclusion criteria.

Inclusion criteria	**Reason**
Keywords: Key Performance Indicators, supplier, quality, performance, KPI, supply chains, measures, management, optimization	At least one of these keywords should be part of the keywords section of the articles.
Exclusion criteria	**Reason**
Subjects: Civil Engineering, Construction Building, Healthcare, Health Policy, Biochemistry, Chemical, Neuroscience, Energy, Environment	These subjects do not refer to the company
Keywords: Public Transportation, Traffic	These keywords do not refer to the company
Non-Dutch and non-English articles	Hard to interpret the language

Search Results

The search results of the different search terms and different databases are given in Table 19. The following protocol is used to make a selection out of the articles: (1) Use the defined search terms, (2) Apply inclusion and exclusion criteria, (3) Selecting based on screening titles, (4) Remove all the duplicates and (5) Select based on screening the text. The list with the final selected articles is given in Table 20.

Table 19. Overview of the search results.

Search Terms	Scope	Date	Date range	Results
Scopus				
"Quality" AND "KPI"	Title, abstract and keywords	5-4-21	1990-present	1240
"Quality" AND "Dashboard"	Title, abstract and keywords	5-4-21	1990-present	1397
"Supplier" AND "KPI"	Title abstract and keywords	5-4-21	1990-present	104
"Supplier" AND "Dashboard"	Title abstract and keywords	5-4-21	1990-present	75
Web of Science				
"Quality" AND "KPI"	Title, abstract and keywords	6-4-21	1990-present	511
"Quality" AND "Dashboard"	Title, abstract and keywords	6-4-21	1990-present	815
"Supplier" AND "KPI"	Title, abstract and keywords	6-4-21	1990-present	41
"Supplier" AND "Dashboard"	Title, abstract and keywords	6-4-21	1990-present	19
Total in Endnote				**4202**
Selecting based on inclusion/exclusion criteria				-3891
New Total				**311**
Removing duplicates				-37
New Total				**274**
Removed after manually screening titles				-231
New Total				**43**
Removed after screening the text				-36
Total				**7**

Table 20. Selected articles for the Systematic Literature Review.

Nr.	**Author (year)**	**Title**	**Citations**	**Publisher**
1	Verhaelen, B., et al. (2021)	A comprehensive KPI network for the performance measurement and management in global production networks	0	SPRINGER HEIDELBERG, TIERGARTENSTRASSE 17, D-69121 HEIDELBERG, GERMANY
2	Payaro, A., et al. (2016)	A Dashboard for Lean Companies: A Proposed Model with the Collaboration of Ten Large Italian Enterprises	0	SPRINGER INTERNATIONAL PUBLISHING AG, GEWERBESTRASSE 11, CHAM, CH-6330, SWITZERLAND
3	Kang, N., et al. (2016)	A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems	42	TAYLOR & FRANCIS LTD, 2-4 PARK SQUARE, MILTON PARK, ABINGDON OR14 4RN, OXON, ENGLAND
4	Okfalisa, et al. (2018)	Integrated Analytical Hierarchy Process and Objective Matrix in Balanced Scorecard Dashboard Model for Performance Measurement	4	Universitas Ahmad Dahlan
5	Maestrini, V., et al. (2018)	The relationship regulator: a buyer-supplier collaborative performance measurement system	18	Emerald Group Publishing Ltd.
6	Cao, Y., et al. (2015)	Constructing the integrated strategic performance indicator system for manufacturing companies	11	Taylor and Francis Ltd.
7	Jochem, R., et al. (2010)	Implementing a quality-based performance measurement system A case study approach	2	The TQM Journal

Appendix E – Tables of KPI selection

Table 21. Theoretical framework: KPIs mentioned by the articles.

▨ Quality related KPIs	Non quality related KPIs

Source	**Financial**	**Customer**	**Internal Operations**	**Learning & growth**
Verhaelen, B., et al. (2021)	Shareholder-Value	Customer acquisition rate	Productivity	
	Revenue	Re-buyer rate	Material stock	
	Profitability	Customer satisfaction index	Capacity utilization rate	
	Market share		Product unit costs	
	Customer value		▨ On-time-delivery rate	
	Product unit cost		▨ Quality rate	
	Utilization production network		▨ Complaints rate	
			▨ Non-conformity costs	
			Throughput time	
			Throughput time deviation	
			Product flexibility	
			Batch size	
			Out-of-stock rate	
			Life-cycle costs	
			Misdelivery rate	
			Inventory range	
			Handle rate	
			Innovation rate	
			Ramp-up time	
Payaro, A., et al. (2016)			▨ # of complaints	
			▨ Products without reprocessing rate	
			Value stream Index	
			% Increasing Inventory	
			▨ Difference promise date and delivery date	

			Difference delivery date and requested date	
			# of observations per year of an unsafe condition with no consequences	
			Lost time (in hours) due to accidents/total workable hours a year	
			% employees working in teams	
			Total of hours dedicated to lean project/total workable hours	
Kang, N., et al. (2016)			Actual to planned scrap ratio (SQR)	
(only KPIs with respect to quality)			Scrap ratio (SR)	
			Rework ratio (RR)	
			Fall off ratio (FR)	
			First time quality (FTQ)	
			Quality buy rate (QBR)	
Cao, Y., et al. (2015)	Rate of new products output value	Timely review rate of orders	# of universalised products	Employee turnover rate
	Investment in R&D	Times of drawing errors	Implementation rate of R&D projects	Labour productivity of all employees
		On-schedule completion rate of samples	One-time eligibility rate of new products production	Promotion rate of employees
		Eligibility rate of customer check of samples	Completion rate of SOP preparation	Employee satisfaction
			Completion rate of process preparation	Company information index
			% of major accidents	Investment in charity and education

			Eligibility rate of spot check of outsources finished goods	
			# of newly developed products	
			# of completed projects of process innovation	
			# of technical improvement projects	
			Number of patent applications	
Jochem, R., et al. (2010)			Cost of Quality	
(only KPIs with respect to quality)			Inventory demand	
			Accumulated Failures (%) trend	
			Internal Failure cost	
			Project amendments	
			Outstanding corrective actions	
			Suppliers rating	
			Suppliers Reliability	
			Cost of Scrap/rework	
			Inspection cost	

Appendix F – Consistency check in the AHP

There can exist a problem when filling in the matrix A, namely inconsistency may occur when for instance the criterion Specific is valued as twice as important as Measurable, and Measurable is also twice as important as Time-bound. This would imply that Specific is 2*2=4 times as important as Time-bound, but what if not value 4 but value 5 is filled in here? Now there is a slight inconsistency in the comparisons, slight inconsistencies are common and do not cause serious problems, however big inconsistencies do. The consistency index (CI) can be calculated with the following four steps:

1. Compute A**w**.
2. Compute $\frac{1}{n}\sum_{i=1}^{i=n}\frac{i\ entry\ in\ A\mathbf{w}}{i\ entry\ in\ \mathbf{w}}$ (where n is the total number of criteria)
3. Compute the consistency index (CI) as follows:
$$CI = \frac{(Step\ 2\ result) - n}{n-1}$$
4. Compare the CI to the random index (RI) for the appropriate value of n, shown in *Table 22*.

If $\frac{CI}{RI} < 0.10$, the degree of consistency is satisfactory, but if $\frac{CI}{RI} > 0.10$, serious inconsistencies may exist, and the AHP may not yield meaningful results.

Table 22. Random Index (RI). Source: (Winston & Goldberg, 2004)

n	**RI**
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.51

Appendix G – BPM intended manufacturing process without quality issues

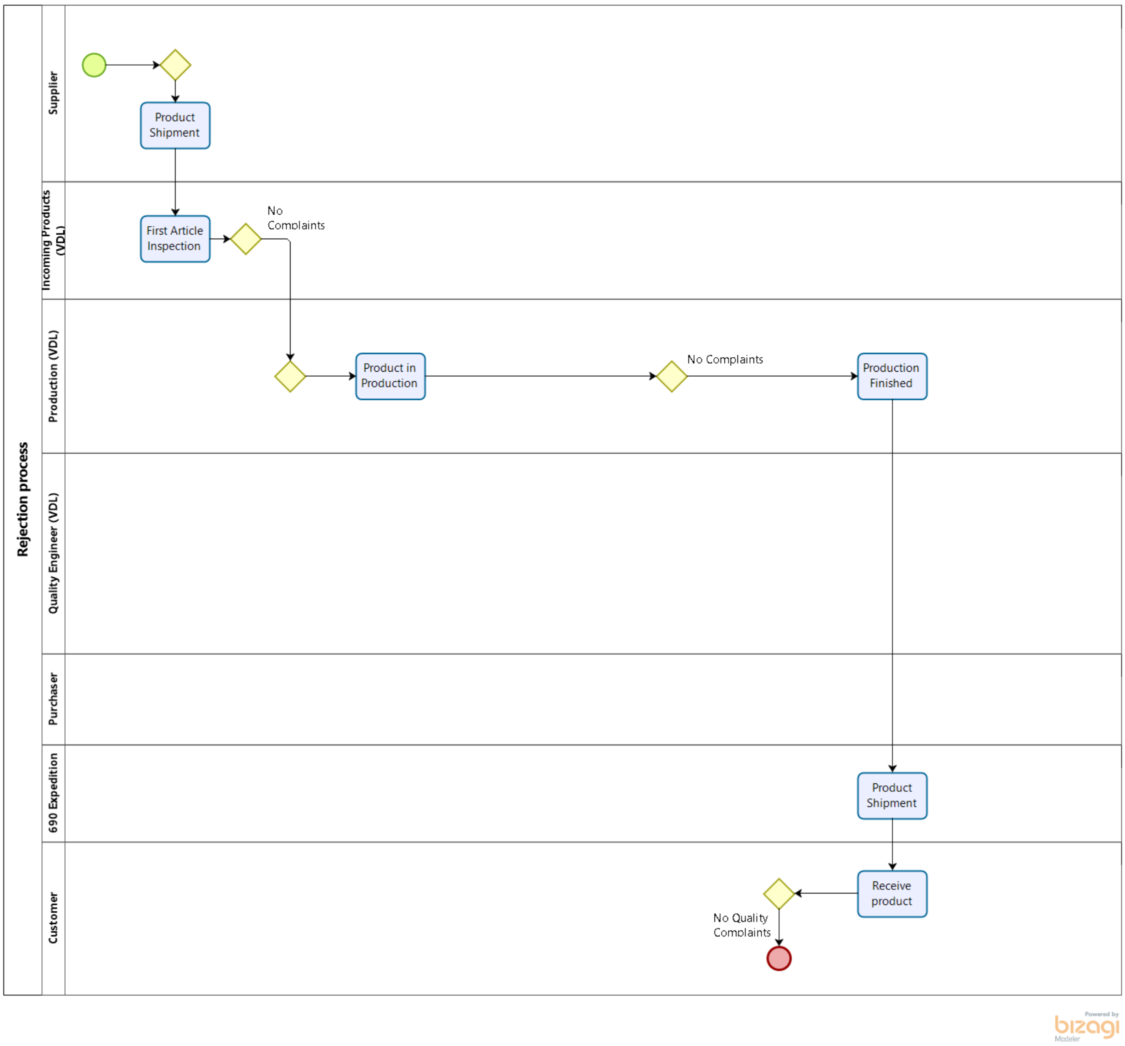


Figure 16. Business Process Model for the intended manufacturing process without quality issues

Appendix H – Table with failure codes

Table 23. Failure Codes

Failure Code	Explanation
General finishing	Burrs, roughness, sharp edges, machining traces
Damaged	Deformation, dents
Coding, engraving	Unique serial number, location, completeness, adhesion of sticker, readability
Completeness	Quantity, loose parts, spare parts, not present, swapped, wrong parts
Contamination	Finger prints, bacteria, CO2, outgassing, oxidation
Defect critical surface	Scratch or incorrect finishing on CtQ surface
Documents	Missing, incomplete, inaccurate towards customer
Electrical connections	Properly installed, contact resistance, ESD, shielding
FAI rejected	First Article Inspection rejected and will be sent back to supplier
Functional	Operation of components, test results
Calibration	Wrong calibration, out of calibration, reject measurement tool at calibration
Weld and solder joint	Density, strength, inclusions, staining, sealing
Glue and kit joint	Adhesion, contamination sealing
Air- and liquidconnections	Leakage, hoses kinked, damaged, vacuum
Dimension error	Length, width, height, diameter
Surface treatment	Adhesion, smoothness, color tolerance, masking
General assembly	Fit, turned, location, accessibility
Thread	Friction, thread quality, finishing, torque, loose
Base material	Composition, pre-treatment, milling direction, hardness, casting holes, leaking
Environment and safety	Unsafe situation, spilling
Packaging	Not present, damaged, wrong

Appendix I – Calculation of the weights for the KPI selection

The first step in the AHP method is to create a matrix A, where all criteria are compared with each other. The SMART criteria are compared on importance in the matrix A below:

$$A = \begin{array}{c} \\ S \\ M \\ A \\ R \\ T \end{array} \begin{array}{c} \begin{array}{ccccc} S & M & A & R & T \end{array} \\ \begin{bmatrix} 1 & 1/6 & 1/2 & 1/7 & 1/2 \\ 6 & 1 & 3 & 1/3 & 5 \\ 2 & 1/3 & 1 & 1/4 & 3 \\ 7 & 3 & 4 & 1 & 6 \\ 2 & 1/5 & 1/3 & 1/6 & 1 \end{bmatrix} \end{array}$$

The meaning of the numbers in matrix A representing the importance between the criteria can be found in *Table 7. Rating scale for pairwise comparison of criteria in the AHP method.*. Because matrix A is known, the normalized matrix A$_{norm}$ can be calculated:

$$A_{norm} = \begin{bmatrix} 0{,}06 & 0{,}04 & 0{,}06 & 0{,}08 & 0{,}03 \\ 0{,}33 & 0{,}21 & 0{,}34 & 0{,}18 & 0{,}32 \\ 0{,}11 & 0{,}07 & 0{,}11 & 0{,}13 & 0{,}19 \\ 0{,}39 & 0{,}64 & 0{,}45 & 0{,}53 & 0{,}39 \\ 0{,}11 & 0{,}04 & 0{,}04 & 0{,}09 & 0{,}06 \end{bmatrix}$$

With the normalized matrix A$_{norm}$ the column vector **w** representing the weights for the criteria can be calculated:

$$\boldsymbol{w} = \begin{array}{c} S \\ M \\ A \\ R \\ T \end{array} \begin{bmatrix} 5{,}11\% \\ 27{,}69\% \\ 12{,}42\% \\ 47{,}91\% \\ 6{,}88\% \end{bmatrix}$$

It is possible that the importance between criteria in the pairwise comparison is given inconsistent values. Therefore the CI (consistency index) and RI (random index) are used to calculate the level of consistency. The four steps in

Appendix F – Consistency check in the AHP to check consistency is elaborated below:

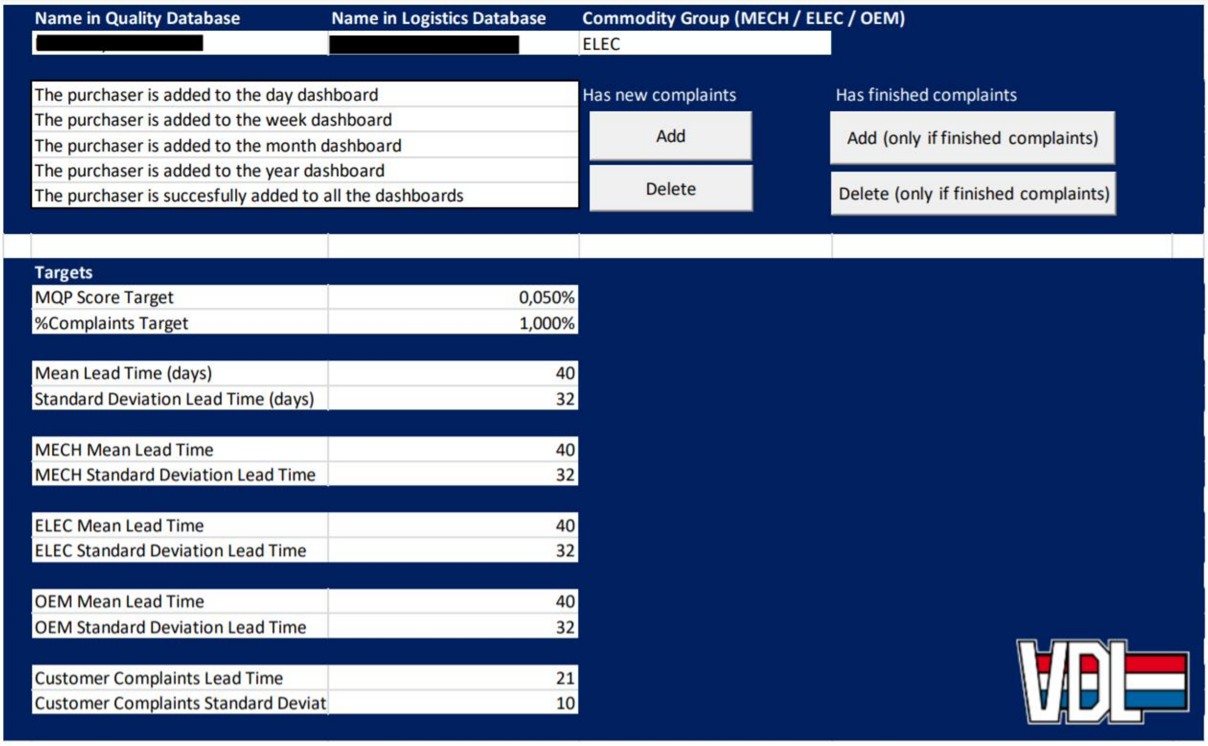
1. $A\boldsymbol{w} = \begin{bmatrix} 0,26 \\ 1,46 \\ 0,64 \\ 2,58 \\ 0,35 \end{bmatrix}$

2. $\frac{1}{n}\sum_{i=1}^{i=n}\frac{i\ entry\ in\ Aw}{i\ entry\ in\ w} = \left(\frac{1}{5}\right)\left\{\frac{0,26}{0,0511} + \frac{1,46}{0,2769} + \frac{0,64}{0,1242} + \frac{2,58}{0,4791} + \frac{0,35}{0,0688}\right\} = 5,21$

3. $CI = \frac{(Step\ 2\ result)-n}{n-1} = \frac{5,21-5}{4} = 0,051$

4. The CI is 0,051 and the RI is 1,12. The consistency level is $\frac{CI}{RI} = \frac{0,051}{1,12} = 0,046$, which is lower than 0,10 and therefore it can be concluded that the degree of consistency is satisfactory.

Appendix J – Maintainability



Name in Quality Database	Name in Logistics Database	Commodity Group (MECH / ELEC / OEM)
[redacted]	[redacted]	ELEC

The purchaser is added to the day dashboard
The purchaser is added to the week dashboard
The purchaser is added to the month dashboard
The purchaser is added to the year dashboard
The purchaser is succesfully added to all the dashboards

Targets

MQP Score Target	0,050%
%Complaints Target	1,000%
Mean Lead Time (days)	40
Standard Deviation Lead Time (days)	32
MECH Mean Lead Time	40
MECH Standard Deviation Lead Time	32
ELEC Mean Lead Time	40
ELEC Standard Deviation Lead Time	32
OEM Mean Lead Time	40
OEM Standard Deviation Lead Time	32
Customer Complaints Lead Time	21
Customer Complaints Standard Deviat	10

Figure 17. Maintainability program.

Appendix K – Dashboard Demonstration

In chapter *6 Implementation of the Dashboards* the dashboards are built, this chapter shows the created dashboards. The choice is made to create seven dashboards, because the Supplier Quality Manager indicated in section *3.2.2 Main Insights* that there should be seven cross-sections. The day, week, month and year dashboard will give an overall insight in the quality performance of the suppliers. If anything stands out in these dashboards, the supplier, purchaser or failure code dashboards can be used to drill down and come closer to the bottle neck. There are two excel files for the dashboards, one excel file shows the operational dashboards: day, week, month and year. One excel file shows the analytical dashboards: supplier, purchaser and failure code.

K1 User Panel

Every dashboard has a user panel at the left. The user panel can be used to filter the data for different cross-sections. All the possible cross-sections are covered in this section. First of all it is possible to adjust the graphs for only 4D complaints, only 8D complaints or both 4D and 8D complaints combined. Second, it is possible to adjust the graphs for only the Mechanical commodity group, only the Electrical commodity group, only the OEM commodity group or all commodity groups combined. The user panel can also be used to switch between the different dashboards. For the operational dashboards there is a possibility to switch between the day, week, month and year dashboard. For the analytical dashboards there is a possibility to switch between the supplier, purchaser and failure code dashboards. In the user panel of the analytical dashboards there is also a GO button. This button should be used as follows: first select a supplier, purchaser or failure code in the drop down menu, then click on the GO button and the dashboard will adjust all graphs for the selected supplier, purchaser or failure code.

K2 Day Dashboard

This dashboard covers the requirements of looking back seven days in time and give insight in the open complaints, see section *3.2.2 Main Insights*. This information can be adjusted for 4D and 8D complaints and commodity group, which is also a requirement in section *3.2.2 Main Insights*. In *Table 24* below, a summary of the dashboard is given, in *Table 25* the KPIs in the day dashboard can be found and in *Figure 18* the dashboard itself is showed.

Table 24. Summary of the Day Dashboard

Purpose	Users	Contents	Support in decision making
The purpose of the dashboard is to give information about the current situation with respect to the quality performance of suppliers.	The dashboard is created for the Supplier Quality Manager.	The day dashboard gives an overview of quality performance of supplier in the last seven days and all the complaints not yet solved (open complaints).	When for instance a lot of quality complaints are newly created this week the Supplier Quality Manager can respond quickly. Also when it takes too long to solve complaints, the Supplier Quality Manager is warned in this dashboard and can respond to mitigate the lead time (short-term strategic planning).

Table 25. KPIs in the Day Dashboard

KPIs	Graph name
Total Open Complaints	Open Complaints
Average Lead Time Open Complaints	Average Lead Time
New Complaints over Time	New vs Finished Complaints
Finished Complaints over Time	New vs Finished Complaints
Open Complaints over Time	New vs Finished Complaints
Lead Time Open Complaints over Time	All Lead Time Open Supplier Complaints
Top10 Underperforming Suppliers Open Complaints	Top10 Underperformers ALL (Open Complaints)
Top10 Failure Codes Open Complaints	ALL Failure codes Open Complaints
Top10 Items Open Complaints	Top10 Items ALL (Open Complaints)

Top10 Underperformers ALL (Open Complaints)		4D	8D	Total
1	[redacted]	5	3	8
2	[redacted]	4	3	7
3	[redacted]	5	1	6
4	[redacted]	2	2	4
5	[redacted]	4	0	4
6	[redacted]	2	2	4
7	[redacted]	3	0	3
8	[redacted]	0	3	3
9	[redacted]	3	0	3
10	[redacted]	0	3	3

Top10 Items ALL (Open Complaints)		4D	8D	Total
1	[redacted]	3	0	3
2	[redacted]	1	0	1
3	[redacted]	1	0	1
4	[redacted]	0	1	1
5	[redacted]	1	0	1
6	[redacted]	1	0	1
7	[redacted]	1	0	1
8	[redacted]	1	0	1
9	[redacted]	2	1	3
10	[redacted]	0	1	1

Figure 18. Day Dashboard.

K3 Week Dashboard

This dashboard covers the requirements of looking back six weeks in time and give insight in the new and finished complaints, lead time, most occurring failure codes and the most underperforming suppliers, see section *3.2.2 Main Insights*. This information can be adjusted for 4D and 8D complaints, which is a requirement in section *3.2.2 Main Insights*. In *Table 26* below, a summary of the dashboard is given, in *Table 25* the KPIs in the day dashboard can be found and in *Figure 19* the dashboard itself is showed.

Table 26. Summary Week Dashboard

Purpose	**Users**	**Contents**	**Support in decision making**
The purpose of the dashboard is to give information about quality performance of suppliers by comparing the last six weeks.	The dashboard is created for the Supplier Quality Manager.	The week dashboard shows the new, finished and open complaints through the last six weeks. The dashboard also indicate the lead time of complaints finished in the last six weeks.	When for instance this week less quality complaints are finished compared to other weeks this is signal for the Supplier Quality Manager to investigate the reasons behind this event (short-term strategic planning).

Table 27. KPIs in the Week Dashboard.

KPIs	**Graph name**
Average Lead Time Open Complaints	Average Lead Time
New Complaints over Time	New vs Finished Complaints
Finished Complaints over Time	New vs Finished Complaints
Open Complaints over Time	New vs Finished Complaints
Lead Time Finished Complaints over Time	Doorlooptijd Finished Complaints

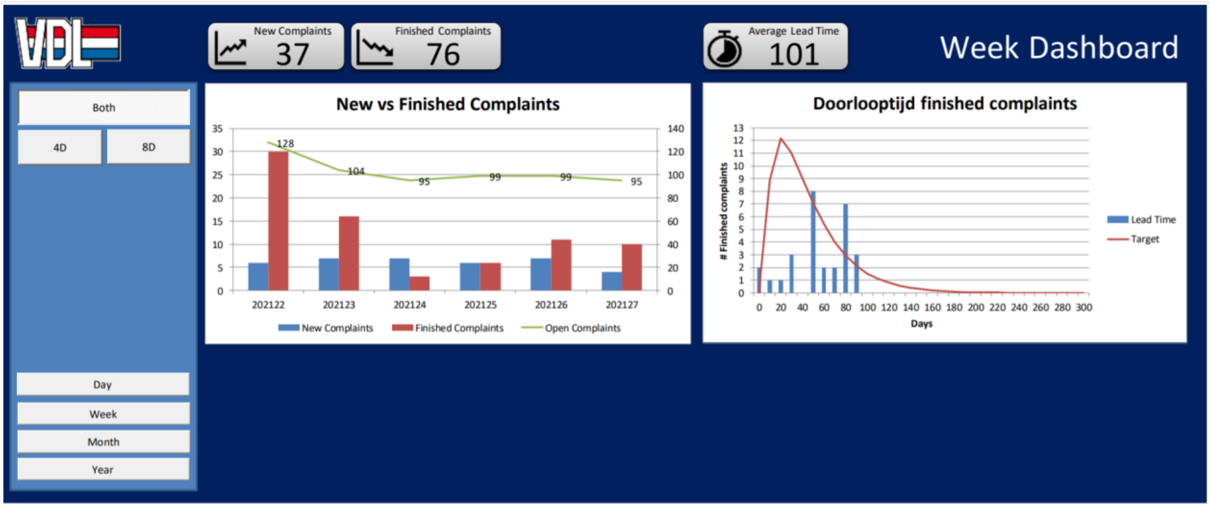


Figure 19. Week Dashboard.

K4 Month Dashboard

This dashboard covers the requirements of looking back six months in time and give insight in the new and finished complaints, lead time, MQP Score, %Complaints, most occurring failure codes and the most underperforming suppliers, see section *3.2.2 Main Insights*. This information can be adjusted for 4D and 8D complaints and commodity group, which is a requirement in section *3.2.2 Main Insights*. In *Table 28* below, a summary of the dashboard is given, in *Table 29* the KPIs in the day dashboard can be found and in *Figure 20* the dashboard itself is showed.

Table 28. Summary Month Dashboard

Purpose	**Users**	**Contents**	**Support in decision making**
The purpose of the dashboard is to monitor the supplier quality performance on a monthly level.	The dashboard is created for the Supplier Quality Manager.	The month dashboard shows the new, finished and open complaints through the last six months. The dashboard also indicate the lead time of complaints finished in the last six months. The MQP score and %Complaints are shown over the last 12 months and the top underperforming suppliers, items of the last six months and failures codes are visualized.	This dashboard can be used as a tool to investigate the overall supplier quality performance and indicate the most underperforming suppliers, items and failure codes. With this information a further analysis can be done in the analytical dashboards. This dashboard can be used for medium-term strategic planning.

Table 29. KPIs in the Month Dashboard

KPIs	**Graph name**
Total Open Complaints	Open Complaints
Average Lead Time Finished Complaints	Average Lead Time
Supplier MQP score last 12 months (%)	MQP
Supplier %Complaints last 12 months	%Complaints
New Complaints over Time	New vs Finished Supplier Complaints
Finished Complaints over Time	New vs Finished Supplier Complaints
Open Complaints over Time	New vs Finished Supplier Complaints
Supplier MQP Score over Time (%)	MQP Score
Supplier %Complaints over Time	%Complaints
Lead Time Finished Complaints over Time	Lead Time Finished Supplier Complaints
Top10 Underperforming Suppliers	Top10 Underperformers ALL (last 6 months)
Top10 Failure Codes	Top10 Failure Codes ALL (last 6 months)

Top10 Underperformers ALL (last 6 months)		4D	8D	Total
1	[redacted]	4	7	11
2	[redacted]	10	1	11
3	[redacted]	5	5	10
4	[redacted]	9	1	10
5	[redacted]	10	0	10
6	[redacted]	7	2	9
7	[redacted]	6	3	9
8	[redacted]	8	0	8
9	[redacted]	0	8	8
10	[redacted]	7	1	8

Top1[redacted]		4D	8D	Total
1	[redacted]	6	0	6
2	[redacted]	4	1	5
3	[redacted]	3	0	3
4	[redacted]	3	0	3
5	[redacted]	0	3	3
6	[redacted]	3	0	3
7	[redacted]	0	3	3
8	[redacted]	2	1	3
9	[redacted]	1	2	3
10	[redacted]	1	2	3

Top10 Failure Codes ALL (last 6 months)		4D	8D	Total
1	Maatfout	40	9	49
2	Compleetheid	33	5	38
3	Functioneel	19	16	35
4	Beschadigd	18	5	23
5	Algemene afwerking	18	3	21
6	Codering, gravering	12	3	15
7	Schroefdraad	9	5	14
8	Contaminatie	11	2	13
9	Oppervlaktebehandeling	8	2	10
10	Lucht- en vloeistofverbinding	5	3	8

Figure 20. Month Dashboard.

K5 Year Dashboard

This dashboard covers the requirements of looking back three years in time and give insight in the new and finished complaints, lead time, MQP Score, %Complaints, most occurring failure codes and the most underperforming suppliers, see section *3.2.2 Main Insights*. This information can be adjusted for 4D and 8D complaints and commodity group, which is a requirement in section *3.2.2 Main Insights*. In *Table 30* below, a summary of the dashboard is given, in *Table 31* the KPIs in the day dashboard can be found and in *Figure 21* the dashboard itself is showed.

Table 30. Summary of the Year Dashboard

Purpose	**Users**	**Contents**	**Support in decision making**
The purpose of the dashboard is to monitor the supplier quality performance on a yearly level.	The dashboard is created for the Supplier Quality Manager.	The year dashboard shows the new, finished and open complaints through the last three years. The dashboard also indicate the lead time of complaints finished in the last 12 months. The MQP score and %Complaints are shown over the last three years and the top underperforming suppliers, items and failures codes of the last 12 months are visualized.	This dashboard can be used as a tool to investigate the overall supplier quality performance and indicate the most underperforming suppliers, items and failure codes. With this information a further analysis can be done in the analytical dashboards. This dashboard can be used for medium-term strategic planning.

Table 31. KPIs in the Year Dashboard

KPIs	**Graph name**
Total Open Complaints	Open Complaints
Average Lead Time Finished Complaints	Average Lead Time
Supplier MQP score last 12 months (%)	MQP
Supplier %Complaints last 12 months	%Complaints
New Complaints over Time	New vs Finished Supplier Complaints
Finished Complaints over Time	New vs Finished Supplier Complaints
Open Complaints over Time	New vs Finished Supplier Complaints
Supplier MQP Score over Time (%)	MQP Score
Supplier %Complaints over Time	%Complaints
Lead Time Finished Complaints over Time	Lead Time Finished Supplier Complaints
Top10 Underperforming Suppliers	Top10 Underperformers ALL (last 12 months)
Top10 Failure Codes	Top10 Failures Codes ALL (last 12 months)

Top10 Underperformers ALL (last 12 months)		4D	8D	Total
1	[redacted]	20	4	24
2	[redacted]	16	7	23
3	[redacted]	18	1	19
4	[redacted]	7	9	16
5	[redacted]	13	3	16
6	[redacted]	15	0	15
7	[redacted]	8	5	13
8	[redacted]	12	1	13
9	[redacted]	12	1	13
10	[redacted]	12	1	13

Top10 Items ALL (last 12 months)		4D	8D	Total
1	[redacted]	8	0	8
2	[redacted]	7	1	8
3	[redacted]	5	1	6
4	[redacted]	2	3	5
5	[redacted]	4	1	5
6	[redacted]	1	3	4
7	[redacted]	4	0	4
8	[redacted]	3	1	4
9	[redacted]	3	0	3
10	[redacted]	1	2	3

Top10 Failure Codes ALL (last 12 months)		4D	8D	Total
1	Maatfout	76	17	93
2	Functioneel	39	21	60
3	Compleetheid	49	6	55
4	Beschadigd	38	8	46
5	Algemene afwerking	31	5	36
6	Contaminatie	26	8	34
7	Codering, gravering	24	3	27
8	Schroefdraad	17	7	24
9	Oppervlaktebehandeling	14	3	17
10	Lucht- en vloeistofverbinding	9	4	13

Figure 21. Year Dashboard.

K6 Supplier Dashboard

This dashboard covers the requirements of giving insight in the quality performance per supplier, see section *3.2.2 Main Insights*. This information can be adjusted for 4D and 8D complaints, which is a requirement in section *3.2.2 Main Insights*. In *Table 32* below, a summary of the dashboard is given, in *Table 33* the KPIs in the day dashboard can be found and in *Figure 22* the dashboard itself is showed.

Table 32. Summary Supplier Dashboard

Purpose	**Users**	**Contents**	**Support in decision making**
The purpose of the dashboard is to investigate one single supplier to spot potential improvement programs. In addition the dashboard can be used as a tool to communicate the supplier quality performance back to the suppliers.	The dashboard is created for the Supplier Quality Manager to investigate the suppliers. The dashboard can be used by the purchaser to communicate supplier quality performance back to the suppliers.	The supplier dashboard shows the new, finished and open complaints through the last 12 months years. The dashboard also indicate the lead time of complaints finished of a supplier in the last 12 months. The MQP score and %Complaints are shown over the last 12 months together with the most occurring failures codes.	This dashboard can be used as a tool to investigate the quality performance of supplier and indicate the most occurring failure codes. The decisions that follow the investigation are policies and procedures to improve future quality performance (medium-term strategic planning).

Table 33. KPIs in the Supplier Dashboard

KPIs	**Graph name**
Total Open Complaints	Open Complaints
Average Lead Time Finished Complaints	Average Lead Time
Supplier MQP score last 12 months (%)	MQP
Supplier %Complaints last 12 months	%Complaints
New Complaints over Time	New vs Finished Complaints (last 12 months)
Finished Complaints over Time	New vs Finished Complaints (last 12 months)
Open Complaints over Time	New vs Finished Complaints (last 12 months)
Supplier MQP Score over Time (%)	MQP Score
Supplier %Complaints over Time	%Complaints
Lead Time Finished Complaints over Time	Lead Time Finished Complaints (last 12 months)
Top10 Failure Codes	Top10 Failure Codes (last 12 months)

[redacted]

Supplier Dashboard

Open Complaints 7

Average Lead Time 238

MQP last 12 2,08%

%Complaints last 4,45%

Last 12 months

	202007	202008	202009	202010	202011	202012	202101	202102	202103	202104	202105	202106	202107
Delivered Quantity	0	0	0	0	0	0	410	748	2420	2223	2678	1397	998
Rejected Parts	28	10	9	92	38	45	3	0	0	0	1	0	0
MQP	0,000%	0,000%	0,000%	0,000%	0,000%	0,000%	0,732%	0,000%	0,000%	0,000%	0,037%	0,000%	0,000%
Lines	0	0	0	0	0	0	20	56	87	95	71	75	45
Complaints	2	4	3	3	1	5	1	0	0	0	1	0	0
%Complaints	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	5,00%	0,00%	0,00%	0,00%	1,41%	0,00%	0,00%

Top10 Failure Codes (last 12 months)	4D	8D	Total
1 Maatfout	7	3	10
2 Contaminatie	5	0	5
3 Schroefdraad	3	0	3
4 Oppervlaktebehandeling	1	1	2
5 Algemene afwerking	1	0	1
6 Beschadigd	1	0	1
7 Codering, gravering	1	0	1
8 Compleetheid	1	0	1
9			
10			
Total	20	4	24

Open Complaints

Complaint Nr.	Item	Responsible	4D/8D	Failure Code	Status	Confirmed	Lead Time
2012695	[redacted]	[redacted]	8D	Maatfout	Ready until D4	2-9-2020	316
2012847	[redacted]	[redacted]	8D	Maatfout	Ready until D7	15-9-2020	303
2018739	[redacted]	[redacted]	4D	Algemene afwerking	Ready until D7	22-12-2020	205
2102185	[redacted]	[redacted]	8D	Oppervlaktebehandeling	Inventory at Supplier	22-2-2021	143
2108970	[redacted]	[redacted]	4D	Contaminatie	New	11-6-2021	34
2109028	[redacted]	[redacted]	4D	Contaminatie	Inventory at Supplier	9-7-2021	6
2109749	[redacted]	[redacted]	4D	Compleetheid	Inventory at Supplier	24-6-2021	21

Figure 22. Supplier Dashboard.

K7 Purchaser Dashboard

This dashboard covers the requirements of giving insight in the quality performance per supplier, see section *3.2.2 Main Insights*. This information can be adjusted for 4D and 8D complaints, which is a requirement in section *3.2.2 Main Insights*. In *Table 34* below, a summary of the dashboard is given, in *Table 35* the KPIs in the day dashboard can be found and in *Figure 23* the dashboard itself is showed.

Table 34. Summary of the Purchaser Dashboard

Purpose	**Users**	**Contents**	**Support in decision making**
The purpose of the dashboard is to give an overview of one specific purchaser. This overview can be used to determine the resource capacity of a purchaser. The dashboard can also be used as a tool for purchasers to compare their own performance with the targets.	The dashboard is created for the Supplier Quality Manager to investigate the purchasers and determine the resource capacity. The dashboard can be used by the purchaser to compare his own performance with the targets.	The purchaser dashboard shows the new, finished and open complaints through the last 12 months. The dashboard also indicate the lead time of complaints finished in the last 12 months. The MQP score and %Complaints are shown over the last 12 months and the top underperforming suppliers are visualized.	This dashboard can be used as a tool to investigate the supplier quality performance for individual purchasers. A decision that follows from an investigation is adding more purchasers to specific complaints to lower the responsibilities of purchaser with a too high workload (short-term strategic planning).

Table 35. KPIs in the Purchaser Dashboard

KPIs	**Graph name**
Total Open Complaints	Open Complaints
Average Lead Time Finished Complaints	Average Lead Time
Supplier MQP score last 12 months (%)	MQP last 12
Supplier %Complaints last 12 months	%Complaints last
New Complaints over Time	New vs Finished Complaints (last 12 months)
Finished Complaints over Time	New vs Finished Complaints (last 12 months)
Open Complaints over Time	New vs Finished Complaints (last 12 months)
Supplier MQP Score over Time (%)	MQP Score
Supplier %Complaints over Time	%Complaints
Lead Time Finished Complaints over Time	Lead Time Finished Supplier Complaints
Top10 Failure Codes	Top10 Underperformers (last 12 months)
Top10 Underperforming Suppliers	Top10 Failure Codes (last 12 months)

[redacted]

Open Complaints 5

Average Lead Time 56

MQP last 12 0,06%

%Complaints last 1,93%

Purchaser Dashboard

Top10 Underperformers (last 12 months)		4D	8D	Total
1	[redacted]	2	0	2
2	[redacted]	2	0	2
3	[redacted]	0	1	1
4	[redacted]	1	0	1
5	[redacted]	1	0	1
6	[redacted]	1	0	1
7	[redacted]	1	0	1
8	[redacted]	1	0	1
9	[redacted]			
10				
Total		9	1	10

Top10 Failure Codes (last 12 months)		4D	8D	Total
1	Maatfout	3	0	3
2	Compleetheid	2	0	2
3	Algemene afwerking	1	0	1
4	Oppervlaktebehandeling	1	0	1
5	Samenstelling algemeen	0	1	1
6	Contaminatie	1	0	1
7	Elektrische verbinding	1	0	1
8				
9				
10				
Total		9	1	10

Open Complaints

Complaint Nr.	Supplier	Item	4D/8D	Failure Code	Status	Confirmed	Lead Time
2104888	[redacted]	[redacted]	4D	Elektrische verbinding	Inventory at Supplier	29-3-2021	108
2106839	[redacted]	[redacted]	8D	Samenstelling algemeen	Inventory at Supplier	5-5-2021	71
2109212	[redacted]	[redacted]	4D	Compleetheid	Inventory at Supplier	16-6-2021	29
2109343	[redacted]	[redacted]	4D	Maatfout	Inventory at Supplier	17-6-2021	28
2109420	[redacted]	[redacted]	4D	Maatfout	Inventory at Supplier	18-6-2021	27

Top10 Items (last 12 months)		4D	8D	Total
1	[redacted]	2	0	2
2	[redacted]	1	0	1
3	[redacted]	1	0	1
4	[redacted]	1	0	1
5	[redacted]	1	0	1
6	[redacted]	0	1	1
7	[redacted]	1	0	1
8	[redacted]	1	0	1
9	[redacted]	1	0	1
10				
Total		9	1	10

Figure 23. Purchaser Dashboard.

K8 Failure Code Dashboard

This dashboard covers the requirements of giving insight in the quality performance per failure code, see section *3.2.2 Main Insights*. This information can be adjusted for 4D and 8D complaints and commodity group, which is a requirement in section *3.2.2 Main Insights*. In *Table 34* below, a summary of the dashboard is given, in *Table 35* the KPIs in the day dashboard can be found and in *Figure 23* the dashboard itself is showed.

Purpose	**Users**	**Contents**	**Support in decision making**
The purpose of the dashboard is to give an overview of one specific failure code. This overview can be used to investigate which suppliers stand out for specific failure codes.	The dashboard is created for the Supplier Quality Manager to investigate the failure codes amongst suppliers.	The failure code dashboard shows the new, finished and open complaints through the last 12 months. The dashboard also indicate the lead time of complaints finished in the last 12 months with the specified failure code. The top underperforming suppliers are also visualized.	Decisions that follow from an investigation are improvement programs for supplier based on a specific failure code that occurs a lot for the supplier (medium-term strategic planning).

Table 36. KPIs in the Purchaser Dashboard

KPIs	**Graph name**
Total Open Complaints	Open Complaints
Average Lead Time Finished Complaints	Average Lead Time
New Complaints over Time	New vs Finished Supplier Complaints
Finished Complaints over Time	New vs Finished Supplier Complaints
Open Complaints over Time	New vs Finished Supplier Complaints
Lead Time Finished Complaints over Time	ALL Lead Time Finished Supplier Complaints
Top10 Underperforming Suppliers	Top10 Underperformers ALL (last 12 months)

Maatfout

Open Complaints 18

Average Lead Time 104

Top10 Underperformers ALL (Last 12 Months)		4D	8D	Total
1	[redacted]	7	3	10
2	[redacted]	7	1	8
3	[redacted]	6	0	6
4	[redacted]	4	2	6
5	[redacted]	3	2	5
6	[redacted]	4	1	5
7	[redacted]	4	0	4
8	[redacted]	2	1	3
9	[redacted]	1	2	3
10	[redacted]	3	0	3
Total		74	19	93

Top10 Items ALL (Last 12 Months)		4D	8D	Total
1	[redacted]	2	1	3
2	[redacted]	1	2	3
3	[redacted]	2	1	3
4	[redacted]	2	1	3
5	[redacted]	2	0	2
6	[redacted]	2	0	2
7	[redacted]	2	0	2
8	[redacted]	2	0	2
9	[redacted]	2	0	2
10	[redacted]	1	1	2
Total		74	19	93

Figure 24. Failure Code Dashboard.