Designing a Quality Plan to Enhance Production Process Quality at VMI Group

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ABSTRACT

This research focuses on analysing the current quality process at VMI group and designing a new quality plan based on these findings. VMI is currently performing a lot of reactive behaviour on quality issues by internal problem-solving within production but wants to be more proactive in preventing quality issues. The scope of the project starts with the development of a product until the internal acceptance of the product in the factory. Alongside the desire to be more proactive, another focus is a documented and structured approach that is uniform and can be used by all departments and production locations.

The project follows a Define, Measure, Analyse, Improve and Control (DMAIC) research approach. In the define phase, the literature study is performed to understand quality management, create a specific analysis model and study suitable alternatives for improvement of quality models. After defining the available literature, the current process is 'measured' by modelling the current situation into a framework for analysis. The analysis phase includes the performance analysis of the created quality analysis model based on the three levels of performance: Organisational, Process and Job/Technique, together with Quality Function Deployment (QFD) against the current situation of VMI. This performance analysis resulted in the following focus points: deliverables and responsibilities per phase/department, data management between processes, and strategy in performing quality control tools/techniques. These focus points are compared to the management's desire to see if these findings align with their views.

Based on these findings, a new quality plan is created in the improve phase by combining the suitable alternatives with the three levels of performance: TQM, configuration management, and integrated QFD. Combining these three solutions creates a new quality plan, which builds on the detailed QFD model for integrated quality information systems. This model is transformed for application at VMI based on the focus points of VMI together with the TQM and configuration management philosophy. TQM organisations benefit from a centralised organisation, which is the focus of this quality plan and is influenced by three main factors: Technology and type of production, Internal relationships between departments and Workforce's level of training and reliability.

The main changes to this integrated QFD model are made in the first two phases: product planning and product development. These phases only contain some deliverables that document critical parts and component characteristics based on techniques such as internal experience, supplier experience, and design FMEAs. With these changes, this new quality plan does not have to replace the current development process but add some deliverables that enable other departments to view these choices and proactively maintain and improve the quality process.

To validate this new quality plan, a use-case example is executed by using an example in the factory and checking how this new quality plan would have worked with this example. This new scenario is validated through Likert-scale questions based on the focus points of the performance analysis with relevant stakeholders in the production and engineering process. This validation shows that this new quality plan has improvement possibilities on the process quality according to these stakeholders at VMI. The last section, the control phase, describes the Quality Implementation Framework (QIF) and its four phases: Initial considerations, structure for implementation, ongoing structure after implementation, and improvement of future applications. These different phases are described for the situation at VMI and what steps would have to be taken to implement this quality plan successfully. Implementation would have to be executed in different cycles. First, a cycle towards the 'proof of concept' with a pilot project that can be performed on a new development. This pilot will show the usage of this quality model and its advantages, and involve all the relevant departments for implementation. Moving from a successful pilot, a new implementation cycle towards implementation across the whole factory in Epe should be executed. This cycle will face new challenges, since this will involve all the departments and should work on every project.

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1 INTRODUCTION

This chapter starts with general information about VMI and its products. Section 1.1 describes general information about the company, followed by Section 1.2 on the internal company structure. Section 1.3 introduces general product information at VMI, with an introduction to one of the main machines that VMI creates. This general information is followed by a problem description in Section 1.4 and the research question in Section 1.5. The final two sections contain information on the research approach in Section 1.6 and the initial scope of the report in Section 1.7.

1.1 Company introduction

VMI is an innovative, high-tech company located all across the world with its headquarters in Epe, The Netherlands. VMI employs around 1800 employees worldwide, working from nine facilities on four continents. VMI was founded in 1945 and produced many different machines over the years with its main focus on rubber and tire machines. VMI is currently split up into five different business lines: Tire, Rubber, Can, Care and Services. VMI is acknowledged as a respected market leader offering innovative machinery which is continuously developed and further enhanced [10]. VMI Group is part of the Twentsche Kabel Holding (TKH) Group, a company on the Amsterdam Stock Exchange, specialising in smart technology companies. TKH started in 1930 as the Twentsche Kabel Fabriek (TKF) and added a portfolio of companies over the years. TKH specialises in smart technologies, which are divided into three sectors. Smart vision, smart manufacturing and smart connectivity. VMI Group is part of the smart manufacturing systems and is the most important company TKH group has in this sector [26].

VMI Group

As detailed before, VMI Group operates production facilities in multiple countries, including The Netherlands, Poland, China, Germany, and Brazil. The three main locations are located in The Netherlands, Poland, and China. The focus of the report is at the headquarters in Epe, The Netherlands, which is shown in Figure 1.1. The implementation plan is specific to the factory in Epe. Successful implementation in Epe may be a model for other production facilities to adopt similar quality management practices.

Figure 1.1: VMI's headquarter in Epe [10]

1.2 Company structure

VMI has different service and production locations all around the world, the three central production locations are located in Epe (Netherlands), Leszno (Poland) and Yantai (China) [10]. VMI's headquarters is in Epe, where most departments are located together with part of the production department. Since most of the departments are located in Epe, this is where more of the complicated modules and first of series/production are produced. This report is executed for the production quality department of Epe, which belongs to production engineering. The company structure for VMI is given below in figure 1.2.

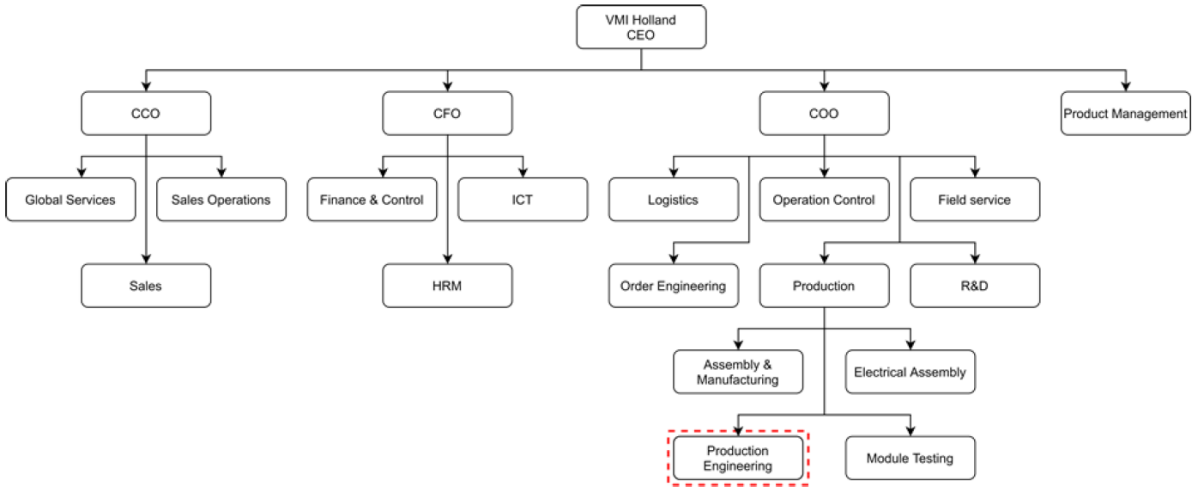


Figure 1.2: Organizational chart VMI Group[11]

1.3 Product information VMI

The following section provides preliminary insights into VMI Group, explaining the main business lines and some factory/company information. This sets the the base for a more detailed discussion of internal processes, the scope of the assignment, current quality control methods, and the desired quality levels.

A machine produced by VMI consists of different modules. The machines can be built across different production locations and the final modules come together at the customer where they will be assembled completely. One of the main products sold by VMI is the MAXX, a tire manufacturing machine that consists of different modules. The module that is the most important for this machine is the Tire Building Machine (TBM), which is only produced in Epe. A final MAXX generally consists of three to five modules, depending on the specification of the client. A model is built up by different sub-systems which consist of smaller sub-subsystems, as shown in figure 1.3.

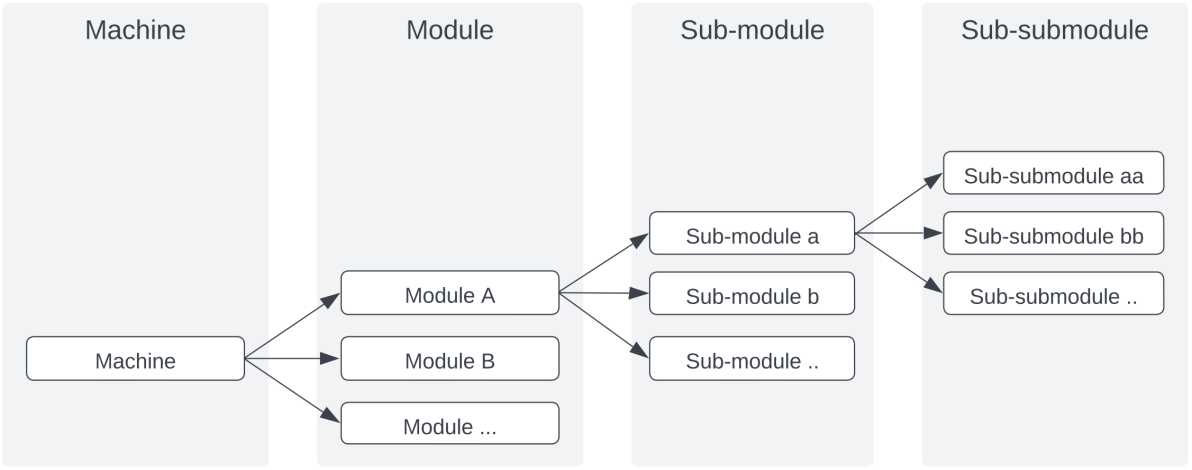


Figure 1.3: Overview subdivisions of a machine at VMI [12]

The R&D department performs the development of a new machine. A machine consists of a standard configuration, combined with some options that can be picked by a customer. Together with the customer VMI checks if the desires of the customer are possible for this standard machine, if this is not the case Order Engineering (OE) can modify or create new parts for a machine. Because of this, there are almost no machines the same. The difficulty for the production department that comes with these customisation options is that because of the variety, mistakes are more likely to happen.

To show the concept of customisation at VMI an internal example is shown. In Figure 1.4 a simplified TBM, the part of the MAXX that produces the actual tire, is shown. This overview shows the configuration or standard options and custom options. In this case, the green options are extra options, added on the blue standard options. The green boxes are part of the options that a customer can choose from, in this case the Breaker and Tread monitor (BTMO), Carcass Monitor (CCMO) and the moving laser. A customer can pick these options for a new machine if the customer desires these options. In this case it provides extra monitoring and measuring options to ensure a higher quality in the tire production. If these options do not fulfill the demands by the customer, they can be adjusted or completely new parts can be developed by the Order Engineering (OE) department.

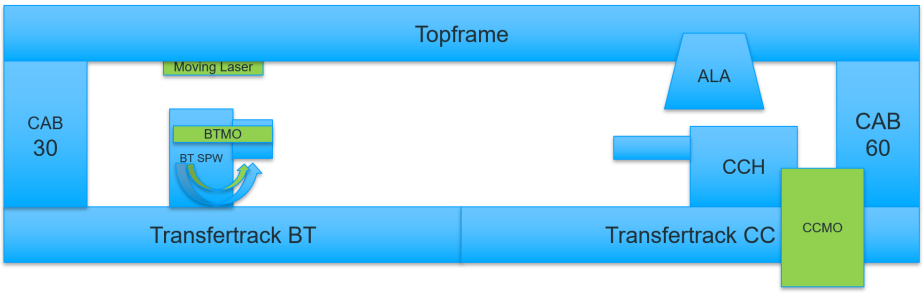


Figure 1.4: Simplified TBM with possible options [13]

CAB	Cabinet	**CC**	Carcass
BT SPW	Breaker Tread	**CCH**	Carcass Housing
BTMO	Breaker Tread Monitor	**CCMO**	Carcass Monitor
BT	Breaker Tread	**ALA**	Applicator Lifting Assembly

Figure 1.5: Simplified TBM Legend

1.4 Problem description

The current quality management system at VMI lacks a structured approach to maintain and increase the overall production process quality. Different processes by different departments are set up throughout the company to ensure process quality but these do not always align. Different departments in the development process such as Research and Development (R&D) and Order Engineering (OE) develop documents to ensure quality such as test reports and control plans.

To ensure quality in the production process, operators and foremen often use different internal documents alongside the test report supplied by engineering. Neither the test reports nor the checklists have a structured quality approach with direct input from different departments. The test reports do not always align with the desires of the production process, and the production process does not correctly share and control these internal checklists.

Because of this missing structure, most of the problem-solving is performed in a reactive way. The internal problem-solving processes, mainly guided by production issues, are successful in preventing reoccurring mistakes in the factory.

The objective of this report is to create a quality model to control and maintain a high level of production process quality. This model should be used across the whole company by all the departments and is supposed to continuously improve and learn from mistakes. By implementing such a quality plan, VMI can focus on more proactive problem-solving, instead of the current reactive model.

1.5 Research questions

The research question is: **"What is a suitable quality plan for VMI to maintain and increase the overall production process quality?"**. To answer this research question, the following sub-questions will be answered:

1. **How can the performance of a quality process be analysed and what are quality improvement methods for a new quality plan?**
2. **What is the current situation of the production process quality at VMI?**
3. **What is the current measure of quality at VMI?**
4. **What is the current performance of the quality process at VMI?**
5. **What would be a suitable quality plan to increase and maintain the quality of the production process at VMI?**
6. **What would a validation of the Quality Plan look like?**
7. **What would an implementation plan look like at VMI for this quality plan?**

1.6 Scope of the report

The scope of this report is focused on the steps and processes within the development and production phase of VMI. Different models, such as Advanced Product Quality Planning (APQP) and Design for Manufacturing (DfMA) [27], suggest that optimal attention to production quality is critical from as early as the concept design until the final factory acceptance. For VMI this would result in the product development phase until the production acceptance, as shown in Figure 1.6. These processes are further explained in Chapter 3.

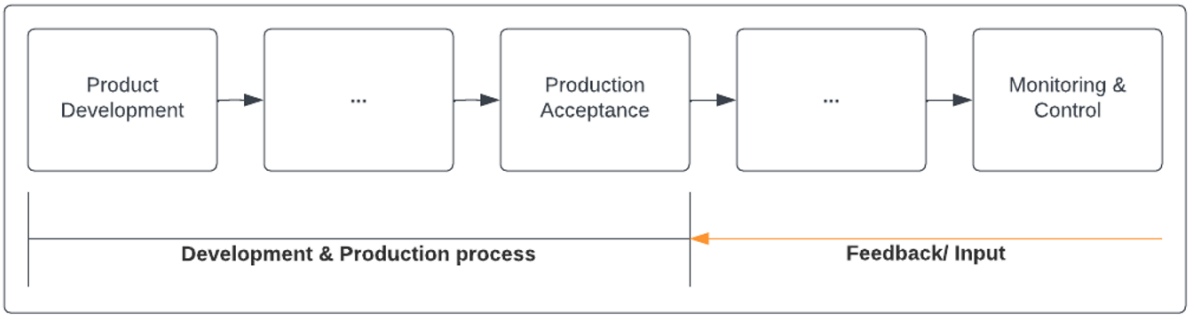


Figure 1.6: Scope of the report

1.7 Research model

The research method will be performed with a Define, Measure, Analyze, Improve and Control (DMAIC) approach, chosen for its structured framework, which supports a better understanding and analysis of the report. This method is proven to enhance productivity, quality performance and to make a process robust to quality variations [28, 29].

The initial phase of this research approach is the ”Define” phase, which consists of two parts. Firstly, a literature review is conducted to establish a foundational understanding, analysis approach and quality improvement methods for VMI. This literature study will be performed in three sections, with the first section focusing on the understanding of quality management and process quality. The second section is focused on creating an analysis model to measure the performance at VMI. The third section of the literature study is a study towards quality improvement methods that can be used for a new quality plan. The second part of the define phase is mapping the current situation. This is performed by studying internal documents and interviewing different departments within the company to get a better understanding of the internal development and production process.

The PQAM model and the current process at VMI will still be hard to compare since they are defined in different models that work with different phases. The second phase, the ”Measure” phase is used to measure the current performance of the process at VMI. The current process is put into the same type of phases that are included in the PQAM model to have an efficient analysis.

The third phase, the ”Analysis” phase, combines the define and the measure phase by comparing the PQAM model against the current process at VMI. The outcome of this phase is a list of differences of the two models, based on the three levels of performance described by the literature review. Following this phase the ”Improve” phase is split up in two steps. The first one is the designing of a new quality plan. The information from the performance analysis is used on what could be improved and from there the literature review into suitable alternatives is used. The combination of these possible solutions creates a new quality plan which is validated in the second step of the improve phase.

Finally, the ”Control” phase is the final section of the report. This phase describes an implementation plan on what steps can be executed in the future to implement such a quality plan at VMI. Figure 1.7 shows the research model as described in this section.

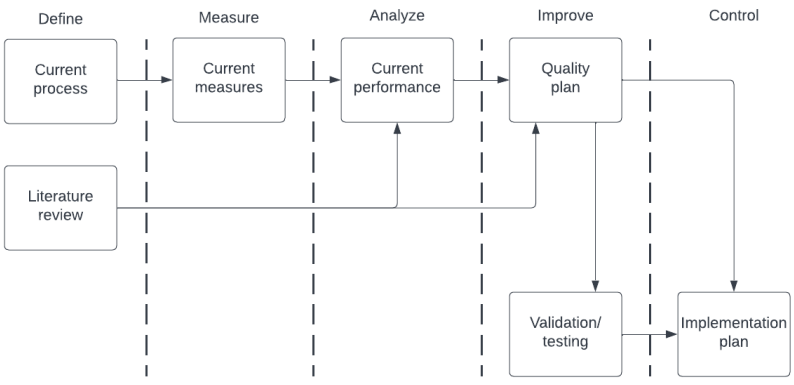


Figure 1.7: Research model

2 LITERATURE STUDY

This chapter answers the sub-question: **"How can the performance of a quality process be analysed and what are quality improvement methods for a new quality plan?"**. The literature study is divided into Terminology, Quality Management Analysis and Quality Improvement Methods. Section 2.1 describes the terminology and provides information on quality management, relevant terms, well-known quality models and influential people in the history of quality management. Section 2.2 contains a literature study on how a quality process/model can be analysed by providing different models that can be combined for an analysis framework. Lastly, a literature study on quality improvement methods is performed. This section focuses on suitable quality improvement methods for quality management on the three levels of performance by Brache and Rimmler: Organisational, Process and Job/Technique, which will be further explained in Section 2.3.

2.1 Terminology

This section focuses on discussing terminology for the continuation of the report. Since different models, terms, and views on quality management are widely described, this chapter is used to explain certain items. The two famous quality models, Total Quality Management (TQM) and ISO 9000/9001, are reviewed with some well-known quality experts that started the modern-day quality thinking described to create a clear view on quality management. Next to these models and quality experts, a lesser-known quality model called the Aachen Quality Model is reviewed to better understand of process quality and its focus.

2.1.1 Quality management

Quality Management (QM) has become a more critical aspect of organisational success over the past decades. Juran started to focus on quality control in management processes in the early 1950s, and this concept has evolved over the years [4]. QM is integral to the organisational movement to achieve world-class product/service quality and market success [20]. One of the key strengths of QM is gaining a competitive advantage in the market [30].

The quality management system can be broken down into three parts: strategic planning of vision and goals, deployment techniques for converting vision/goals into reality, and an information system to collect, analyse, and report data [31]. Two well-known quality models are Total Quality Management (TQM) and ISO [4, 31]. Next to well-known models, some early quality experts of QM, including Deming, Juran, Ishikawa, and Taguchi, have played crucial roles in shaping the understanding of quality and creating models and methods for its effective implementation. Joseph Juran is one of the founding fathers of modern quality management and describes quality management in three phases [31]. The quality goals by the Juran's Quality Trilogy are shown in Table 2.1 [1]:

Quality planning	Quality control	Quality improvement
Establish goals	Determine the control subjects	Prove the need with a business case
Identify who are the customers	Measure the actual performance	Establish a project infrastructure
Determine the needs of the customers	Compare actual performance to the target goals	Identify the improvement projects
Develop features which respond to customers' needs	Take action on the difference	Establish project teams
Develop processes able to produce the products	Continue to measure and maintain the performance	Provide the teams with resources, training, and motivation to: Diagnose the cause, stimulate remedies
Establish process control transfer the plans to the operating forces		Establish controls to hold the gains

Table 2.1: Juran's quality goals [1]

In essence, QM is an integrated approach focused on achieving and sustaining high-quality outputs, continuous improvement, and defect prevention at all levels of an organisation to meet internal and external customer expectations [32]. This concept involves four key components: quality planning, quality assurance, quality control, and quality improvement [33].

Leading organisations like Samsung, Quest Diagnostics, Oracle, and Telefonica integrate QM into their overall quality strategies. These companies, known for their competitiveness and high-quality standards, have learned and proven that managing quality is not performed by a specific department but is the responsibility of every department within an organisation [1].

One of the well-known quality models is the ISO Quality Management System (QMS) norm, which consists of two documents. ISO 9000 sets the terminology for quality management, while ISO 9001 establishes specific requirements for quality management systems. ISO describes a quality management system as: "a set of interrelated or interacting elements of an organisation to establish policies and objectives, and processes to achieve these objectives with regard to quality [34]". These standards consist of four components: quality planning, quality assurance, quality control, and quality improvement [2], further explained in Table 2.2. The ISO 9000 standards are built on seven quality management principles: Customer focus, Leadership, Engagement of people, Process approach, Continuous improvement, Evidence-based decision making, and Relationship management [31, 4].

Phase	Description
Quality planning	Focused on setting quality objectives and specifying necessary operational processes and related resources to achieve the quality objectives
Quality assurance	Focused on providing confidence that quality requirements will be fulfilled
Quality control	Focused on fulfulling quality requirements
Quality improvement	Focused on increasing the ability to fulfil quality requirements

Table 2.2: ISO quality description [2]

Another widely used model describes quality management slightly differently than other models. The Total Quality Management (TQM) approach suggests that it is faster and cheaper to concentrate effort during the early development phases of a product and detect and correct defects as early as possible in the product life cycle [35]. TQM describes product quality as customer needs, conforming to the specification, assured performance, safety, proper packaging, timely delivery, efficient technical service and incorporating effective customer feedback [4]. Process quality is a focus on achieving the maximum tolerance concerning the end result [4, 36].

A quality planning process typically includes the following steps: Project establishment, Customer identification, Discovering customer needs, Product development, Process development, Control transfer. Furthermore, it is used to improve efficiency and productivity in areas like Product design, Product development, Manufacturing, Packaging, Content marketing [4].

2.1.2 Aachen quality model

This report focuses on process quality, although the terms of a QMS and its focus points can have different interpretations by different models. The Aachen model, developed by Beaujean, Kristes and Schmitt, is a good example of a standard development process and production process with its supporting processes. Within this model, distinct terms are defined, providing a framework for understanding different focus directions in quality management [37, 14, 38].

The Aachen quality model offers a bird's-eye view that shows the different parts of the quality model as seen in Figure 2.1.2. It shows the development process and production process as the main flow of the model. This flow gets assisted from the top and bottom by the management and by supporting resources and services.

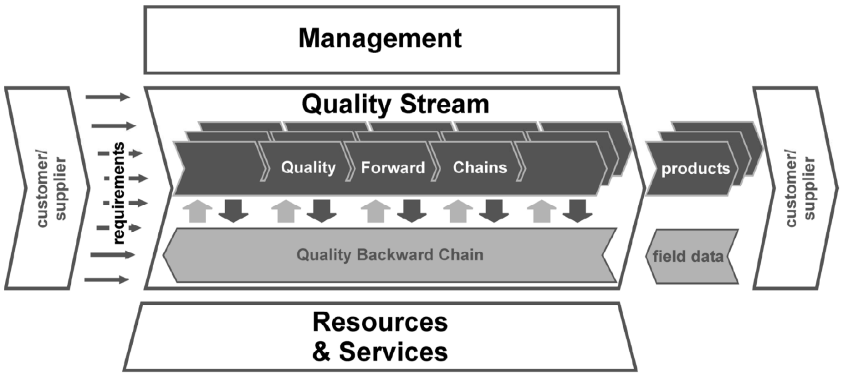


Figure 2.1.2 shows the three different focus points on quality from three different perspectives: customers, management and operations. The customer mainly focuses on the product quality, which is set at the beginning by customer wishes together with other technical requirements, and all these should be met in the final product. The management perspective is focused on system quality. This influences the process by creating the organisational and managerial structure together with setting the targets and strategies for the product. The operations perspective is focused on creating a product that complies with all the requirements in the most effective way.

The aim for process quality is adjusting different resources and services such as equipment, staff, technologies and methods to optimise the process towards the goal set by the management. These goals could have different directions, such as the most cost-effective within the set boundaries or the least amount of error.

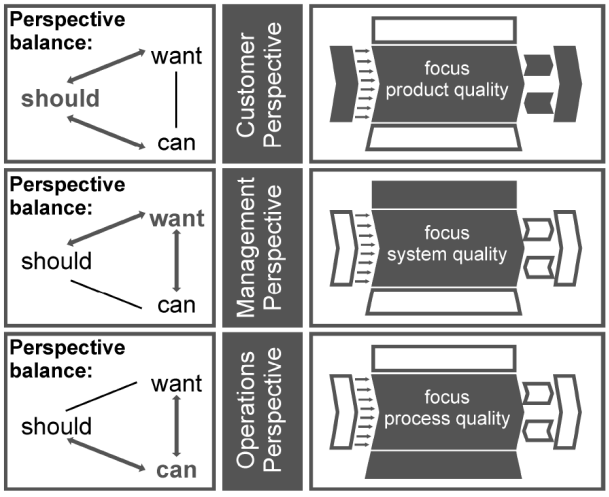


Figure 2.1: Process, system and product quality in the Aachen model [14]

2.2 Analysis of a Quality Model

This section describes the creation of the quality analysis model. This Process Quality Analysis Model (PQAM) is created by combining different parts of Quality Function Deployment (QFD) and Three Levels of Performance (TLP) for an effective analysis. In section 2.2.1, the approach is discussed, followed by the three levels approach in section 2.2.2 and research towards QFD and its processes in section 2.2.3. These different parts are summarised in the final section, where the steps for the design of the Process Quality Analysis Model (PQAM) are described.

2.2.1 An Approach to Process Quality Analysis

To analyse shortcomings or improvement possibilities in the current quality process of VMI a model has to be used or created to perform a quality performance analysis. When performing a literature study on current analysis models the following results have been found:

CMMI describes different process performance analysis methods such as the Organisational Process Performance (OPP) analysis. This model will describe the maturity of the process and possible process focus areas to improve [39]. Another model is part of the business process management techniques, called the Process Performance Index (PPI) analysis, which evaluates the organisation's process management environment [40, 41]. Both of these techniques are, however more focused on the general process performance or determining the readiness of the organisation.

Since the previously named models do not provide the type of model that would be sufficient in the analysis, a custom analysis model should be created. The Three Levels of Performance (TLP) approach by Brache and Rummler is a proven quality approach that tackles analysis on three levels of the organisation. This is a description of three levels of performance: organisational, process and job/technique, but this model does not describe a detailed analysis approach. Combining a quality approach with this model could create an analysis model to compare against the VMI process. QFD is used for its proactive and structured quality approach for the analysis but could be a suitable solution in the new quality plan as well. By combining the TLP approach with the QFD model an analysis framework can be created. The goal of the analysis model is to show weak or improvement possibilities based on the combination of QFD and three levels of performance. Based on these findings, suitable alternatives can be studied to find improvements for VMI's quality process.

2.2.2 Three levels of performance

Brache and Rummler's conceptualisation of performance contains three levels: organisational, process, and job/technique [15]. At the organisational level, the focus is on the broader organisational relationship, this includes the entire process from conceptualisation to product delivery based on customer needs and desires. This level outlines global processes and activities, providing a general overview of the process [15]. The process level is described as the second level of performance. This level shows the framework given in the first level but is now filled with techniques and processes within these phases. The process level shows the connection between these activities and how they use the information from previous techniques or deliverables. The final level, the job/performer level, describes the actual activity, tool or technique used in the specific processes. The focus of this level is not only on the quality of the processes themselves but also on the efficiency of how they are executed and their use. This three-levelled framework offers a perspective on the performance of a process and can be used for analysing a process [15]. The three levels of performance are further explained in the figures given below.

Organisational level

The first level is looking at the organisation's macro system, shown in Figure 2.2. This level focuses on the relationship between the global functions per phase and its variables. Some variables at this level that affect performance include strategies, organisation-wide goals, organisational structure and deployment of resources [15].

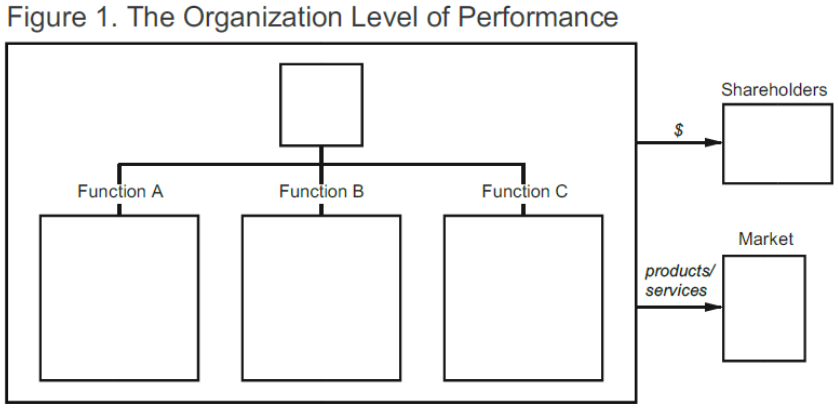


Figure 2.2: Brache and Rummler Organisational level of Performance [15]

Process level

The second level of an organisation's performance can be analysed at the process level. If you put the organisation's "body" under an x-ray machine, you would see the skeleton of level one and all of the musculature of the processes of level two [15] as shown in Figure 2.3.

An organisation is only as good as its processes. To manage the Performance Variables at the Process Level, one must ensure that processes are installed to meet customer needs, that those processes work effectively and efficiently, and that the process goals and measures are driven by the customers and the organisation's requirements [15]

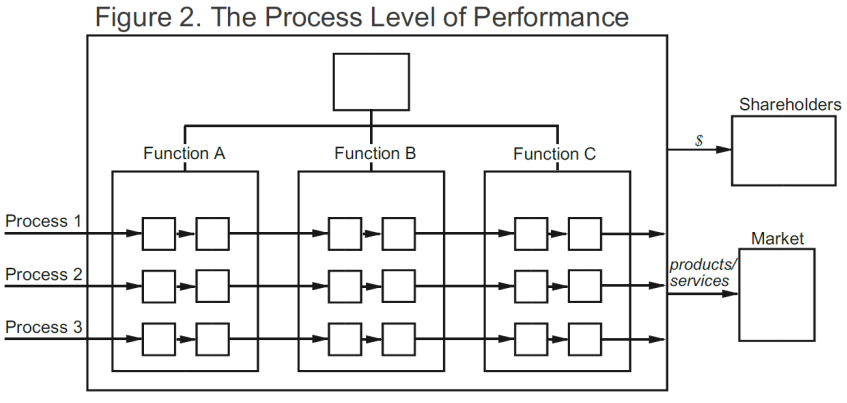


Figure 2.3: Brache and Rummler Process level of Performance [15]

Job-technique level

This level focuses on the connection between the activities to show how efficient a process operates. By creating this overview the internal processes and the connection between these activities is shown in order to assess if logical steps are taken in this process management. By focusing on these specific activities the performance of the final output is measured, since these processes are responsible for the actual creation of the product/service. Some of the variables at this level that can influence performance are hiring, promotion, job responsibilities, standards, feedback, rewards, and training [15]. An overview of this level is shown in Figure 2.4

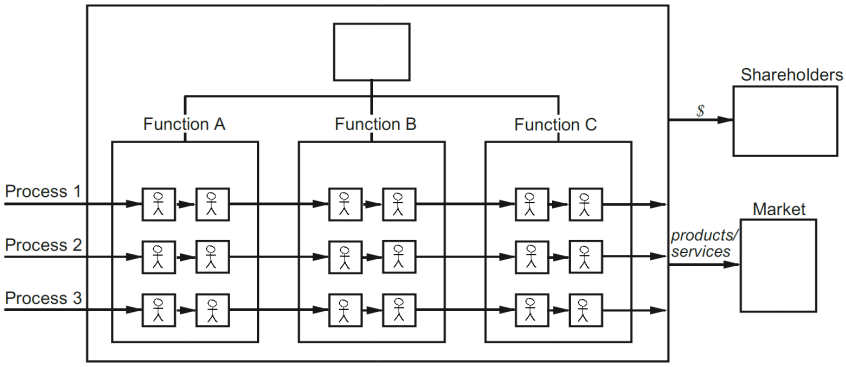


Figure 2.4: Brache and Rummler Job/technique level of Performance [15]

2.2.3 Quality function deployment

Quality Function Deployment (QFD) is a method developed by Japanese engineers with the primary objective to ensure and increase the product quality through a proactive approach [42]. QFD does this by providing a planning process with a quality approach to new product design, devlopment and implementation driven by internal and external customer needs and values [4]. The founder of the QFD process, Akao, described QFD as “a method for developing a design quality aimed at satisfying the customer and then translating the customer’s demand into design targets and major quality assurance points to be used throughout the production phase” [43]. The QFD process involves the use of different ”houses” for different phases, which are connected to each other creating an information flow with different focus points on each phase of development process.

The Japanese characters for QFD have the following meaning [5]:

- Hinshitsu, which means quality, feature, attribute or qualities
- Kino, which means function or mechanisation
- Tenkay meaning deployment, diffusion, development or evolution

As a quality framework QFD finds use in many different quality approaches and industries. Some quality models/methodologies such as Lean Six Sigma (LSS), TQM, Design for Six Sigma (DfSS) and more [4, 16, 18, 36]. Next to these applications, QFD is especially suited to large-scale products such as airplanes, automobiles, and major appliances because these products have heavy tooling, high design costs, and many optional features that must be selected and then produced or procured [31].

The advantages of QFD extend from the creation of clear documentation, minimising post-delivery changes and contributing to an overall higher quality product with a satisfied customer [44]. Next to these advantages, there are some disadvantages which include the additional time required for preparation, execution, improvement and evaluation of different steps in the development process[45].

The purpose of QFD is not to replace existing processes within an organisation but to support, improve and refine the development processes [46]. QFD can be used a as a valuable tool to shift an organisation into a more proactive product and process development process [47, 43]. Figure 2.5 The House of Quality (HoQ) is divided into five different sections. The QFD method has four main phases: product planning, product development, process development and production planning. Each of these phases has its own HoQ which is in connection with the following HoQ, as shown in Figure 2.6. For each of these phases, the HoQ looks similar, the main difference is that the flow input changes from the initial customer to the internal customer within the company.

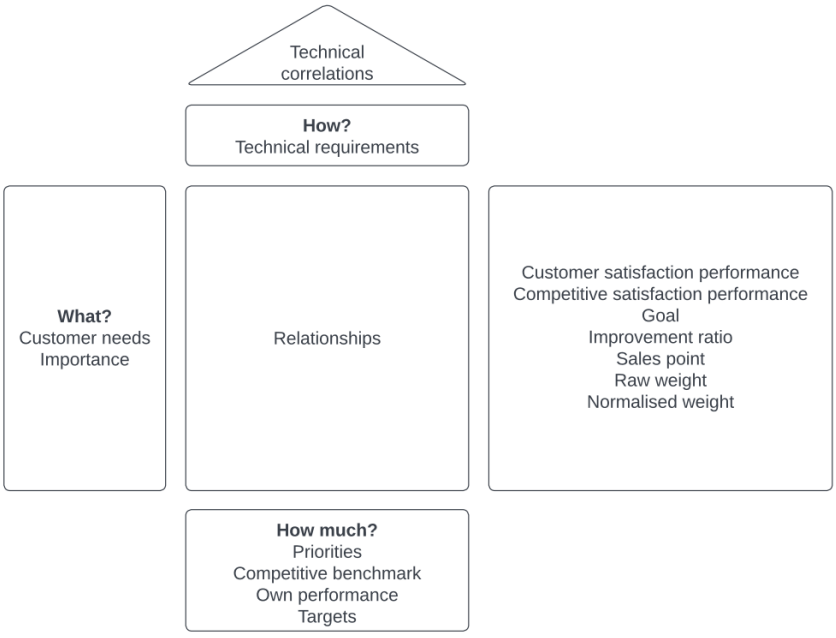


Figure 2.5: House of Quality [16]

Figure 2.5 shows the House of Quality as described by different models, such as Lean Six Sigma. The first section is the What? section, this section contains the customer requirements and the importance of these requirements. Since the QFD contains different levels the 'customer' is the previous level, which can be the customer or the previous department. The How? shows the technical requirements. These technical requirements show different technical design features which are compared against each other in the relationship section. The relationship section shows the relation between the customer requirements and the technical requirements.

The How much? focuses on the performance goals or targets. In this section, the importance for the own development is rated. Based on what technical requirements are important compared to the customer's requirements the scores can be determined and the main focus of the product is visualised. The right box of the HoQ shows the product and the alternatives, based on competitor or customer data. In this section the requirements get compared to customer performance and competitor performance.

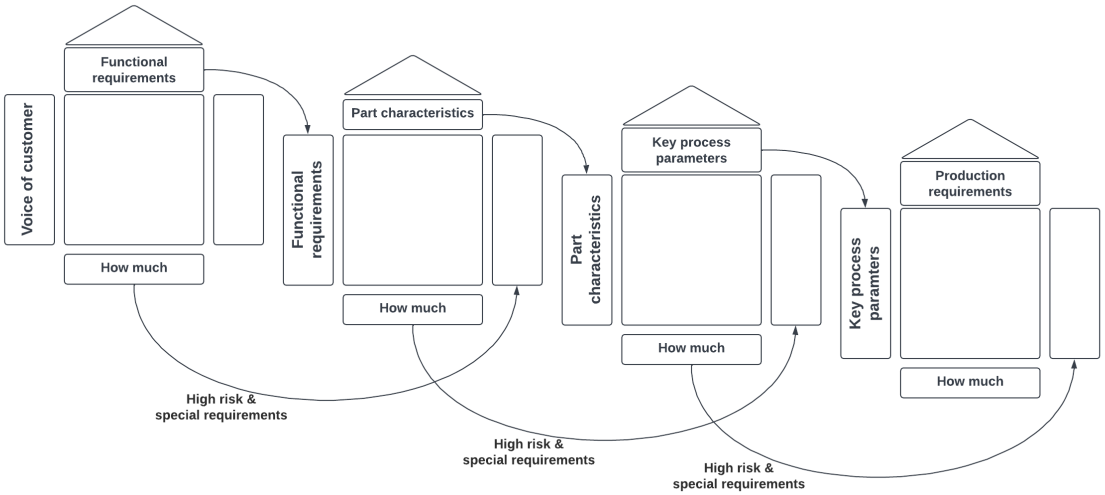


Figure 2.6: Cascaded house of quality [16]

The House of Quality is the first level of the four levels of QFD. In figure 2.6 the cascaded house of quality is shown. This shows the different development levels and how each level provides information for the next level. The top part of the house of quality, the how, is the input for the next house of quality's what. By following the QFD model the requirements of the previous phase become the 'customer' needs for the next one. The 'how much' part of the previous HoQ is also used as input for the next phase.
For example, the process development phase used the How and How much input from the product development phase. In this case, the technical requirements are transformed into the customer needs and the priorities/targets to the weighs. The technical requirement could be a specific tolerance of the product. The first level contains the first step in global development; the product definition. In this house, the main input is the Voice of Customer (VoC). This contains different desired and necessary requirements from the customer.

the second level, the product development, continues on the requirements set in the first phase. Techniques such as DMFEA are used to assess risk for the product that is developed. This phase mainly compares the initial custom requirements to the product features to visualise this decision process.

The third level is the process development phase. In this phase, the product characteristics are compared to the process parameters. This phase visualises the effects of certain product characteristics on certain process parameters and their importance. Different techniques such as a Process FMEA (PFMEA) can assist in this process by determining the real effects of certain choices.

The fourth phase is the final phase of QFD is the process quality control phase. This phase is not always applied in all QFD examples but is an important phase for this research. This phase is use to create different items to enhance the quality such as work instructions, inspection sheets or control plans [46]. In the table below a summary of what activities happen in what phase and what tools and techniques can be used for these activities[3, 4, 6, 5].

Phase	Activities	Tools
Product planning	- Identify customer requirements - Translate VOC into design specifications or product control characteristics - Prioritize requirements - Evaluate competition	- Market study/research - Trend analysis - Competitor analysis - Competitive benchmarking - Regulatory requirements
Product development	- Generate ideas of concepts - Develop alternative products and concepts - Evaluate the design - Analyze the relationship between the design requirements for each product feature - Identify critical part characteristics - Translate the outputs of the product planning phase into individual part details that define part charateristics - Detail characterstrics for product design and componenents, functions defined, reliability and cost estimates	- Fault Tree Analysis (FTA) - (Design) FMEA
Process development	- Analyze and evaluate alternative designs for processes - Compare relationship between process parameters and critical part characteristics - Identify process risks/check/control points - Identify and eliminate non-value adding elements - Identify part/process relationships	- Flow diagrams and process sheets - (Process) FMEA - Design for Production - Design for Assembly - Test planning
Production planning	- Develop specific process controls - Set up Production Planning and Controls - Prepare visuals of the critical process parameters for everyone to understand (Seiketsu) - Train workers and ensure on the job guidance and supervision - Translate control plan into procedures - Develop production operating plan/work instructions - Define performance indicators to monitor the production process	- Master flow diagram - Operation instruction charts - Production layout - Proces charts - Poka-yoke - Maintenance plans and schedules - Control plan - Logistics - Test instructions

Table 2.3: Overview activities and tools used in QFD [3, 4, 5, 6]

2.2.4 Approach for combining the literature

In order to have a successful comparison of the analysis literature against the current process at VMI a model is created. This model is created in Section 4.1 and uses the three levels of performance by Brache and Rummler and creates this model by describing the standard QFD approach on these three levels. This information is combined and put into one model that will be called the Process Quality Analysis Model (PQAM) and this is used for the performance analysis in Section 4.3.

2.3 Quality Improvement Methods

This section described possible quality improvement methods based on the three levels of performance. Section 2.3.1 describes narrowing down the possible alternatives and executing a more successful research. This approach on selecting the alternatives is followed by Section 2.3.2, describing quality improvement methods on the Organisational level, and Sections 2.3.3 and 2.3.4 to describe the quality improvement methods on Process and Job/Technique level.

2.3.1 Selection of alternatives

To research different quality improvement methods the three levels of performance is used, as described in Section 2.2.2. This creates research towards the Organisational, Process and Job/Technique levels, which all have different options for quality improvement. The first step is to study at the organisational level by comparing different quality management models to see what quality management philosophy will fit VMI. The process level's goal is not to get a detailed process management overview, but a good philosophy on tackling the data management between different processes and versions of a large quality model. The final part of the research is towards the Job/Technique level and looks at quality tools and techniques often used in quality management.

Organisational Level
For the literature study towards the organisational level the research by Kumar, Maiti, and Gunasekaran is used to compare different QMS approaches. They identified the six most popular QM principles/practices/approaches and systems followed worldwide by various industries. These six QM principles/practices/approaches and systems will be further researched in Section 2.3.2 [20]:

1. Total Quality Management
2. Total Productive Maintenance
3. Six Sigma
4. ISO 9001
5. Lean manufacturing (Toyota Production System)
6. Theory of constraints

Process level
The maturity models are reviewed for suitable alternatives for the process level of a quality plan. The purpose of maturity models is to outline the characteristics of stages and the relationship between these stages [41, 48]. Since all the different maturity models have different specific goals and targets, the universal model, the Capacity Maturity Model Integration (CMMI), was chosen. The CMMI is a further developed Capacity Maturity Model (CMM) and can be used on different maturity levels. CMMI is a framework containing best practices for developing products and services [49, 50]. CMMI is a further developed model from CMM, which originates from software development back in 1993 [50, 51]. CMM/CMMI is a general approach to business process management and, therefore a model that can provide a good overview of a maturity assessment of models and processes. CMMI is based on 5 levels of maturity. The following five levels are viewed [39, 51]:

1. Initial: Processes unpredictable, poorly controlled and reactive
2. Managed: The status of work products is visible to management
3. Defined: The organisation further improves its processes that are related to levels 1&2
4. Quantitatively Managed: Performance of project and selected sub processes is controlled
5. Optimising: The organisation is concerned with overall organisational performance

CMMI contains two phases, the assessment view and process improvement view [51]. CMM originates from software development, where many companies, such as Motorola, improved their internal quality processes by implementing CMM-based processes to increase their maturity levels [52]. The processes at maturity levels two and three are most suited to analyse/define a process since these are not too complicated for assessment and initial implementation. The CMMI institute has specific cases, with one being: ”Establish and maintain the project’s defined process from project startup through the life of the project.” which described the following processes [39]:

- Project planning
- Project monitoring
- Supplier management
- Quality assurance
- Risk management
- Decision analysis and resolution
- Requirements development
- Requirements management
- Configuration management
- Product development and support
- Code review Solicitation

From these processes, a selection for process development can be made for data management, including risk management, requirements management and configuration management. Other suitable options only apply indirectly to the data management problem or require a level four or five of maturity, which defines a detailed approach. These suitable solutions will focus on these three processes to see if they can be applied in the quality plan for VMI or if certain parts are usable. The following three subjects will be further researched in Section 2.3.3:

- Risk management
- Requirements management
- Configuration management

Job/Technique level
The final part of the research contains the job/technique level. This section focuses on standard and/or effective quality techniques and tools to see if some could be implemented in a quality plan for VMI. The focus for these tools and techniques is based on three papers reviewing quality management tools and techniques (Bunney and Dale, Bamford and Greatbanks, Fotopoulous and Psomas) [53, 54, 55]. The tools and techniques for quality management are summarised and categorised in Tabel 2.4.

Commonly used tools and techniques

The seven basic quality control tools	The seven management tools	Other tools	Techniques
Cause and effect diagram	Affinity diagram	Brainstorming	Benchmarking
Check sheet	Arrow diagram	Control plan	Departmental purpose
Control chart	Matrix diagram	Flow chart	analysis
Graphs	Matrix data analysis		Design of experiments
Histogram	method	Force field analysis	Failure mode and effects
Pareto diagram	Process decision	Questionnaire	analysis
Scatter diagram	programme chart	Sampling	Fault tree analysis
	Relations diagram		Poka yoke
	Systematic diagram		Problem solving methodology
			Quality costing
			Quality function deployment
			Quality improvement teams
			Statistical process control

Table 2.4: Overview Commonly Used Tools and Techniques for Quality Improvement [7]

Ferguson and Dale describe the interaction between the most important techniques for achieving quality in the development process [17]. Figure 2.7 shows the most important quality techniques and their relation to each other. From this overview, the most important parts are the grey areas since these are more connected to the development process. Other techniques, such as Fault Tree Analysis (FTA) and Statistical Process Control (SPC) are more focused on finding the core problem and monitoring. The main focus for suitable alternatives for development is at QFD, FMEA and Test/Evaluation/Verification. The check sheet and control chart techniques mostly cover the test/evaluation/verification, as shown in Figure 2.4. Combining these techniques will help avoid problems in the downstream production and delivery process and make a new product development process more efficient. This concept is focused on promoting proactive behaviour, rather than reactive development [17]. The three tools/techniques that will be further researched in are the check sheets/control charts, FMEA and QFD.

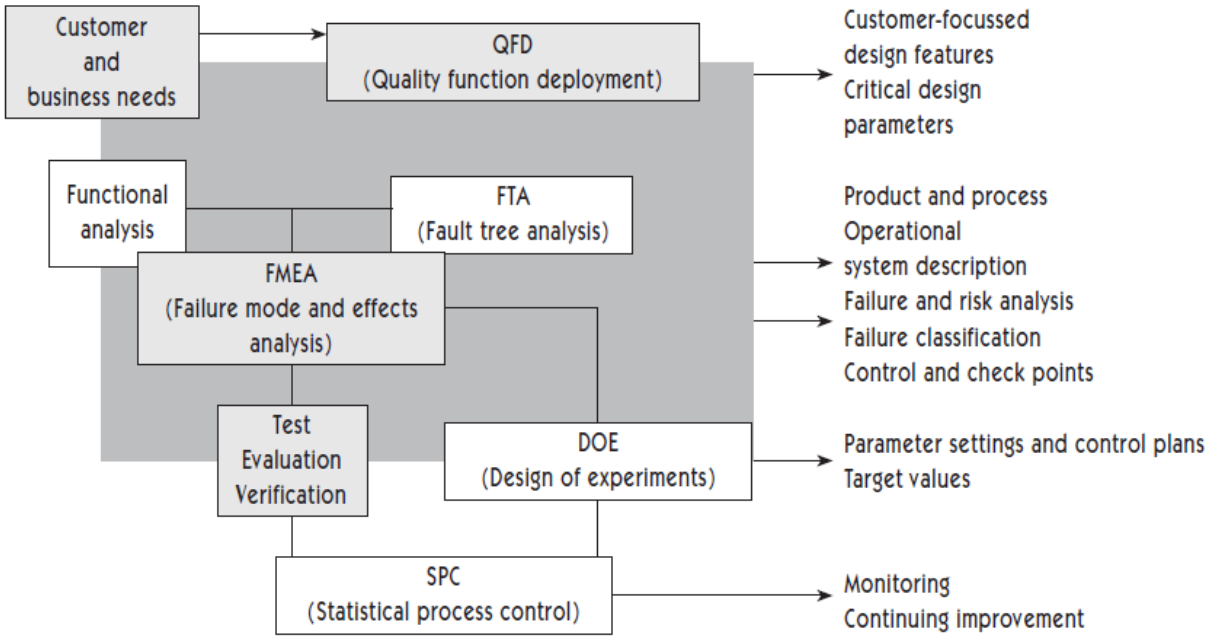


Figure 2.7: Integration and relationship of techniques [17]

Conclusion

In summary, for each of the levels of performance, a selection is made on what will be reviewed further. For the first level, the organisational level, the six most common quality models are used, and all of these six models will be further studied in Section 2.3.2. The process level is focused on the Business process maturity models, and the three data management approaches will be further researched in Section 2.3.3. For the final level, the most common tools and techniques that directly affect the process quality are chosen. The Check sheets/Control charts, FMEA approaches and QFD variants will be researched further in Section 2.3.4. The overview is shown in Figure 2.5.

Level of Performance	Models for alternatives	Specific research subjects
Organizational level	Six most common used QM principles/ practices/ approaches/ systems	TPM, TQM, TPS, SS, ISO, TOC
Process level	Business Process Maturity Models (CMMI-DEV)	Configuration management, Risk management, Requirements management
Job/Technique level	Quality management tools and techniques	Check lists/Control lists, FMEA, QFD

Table 2.5: Overview of the suitable alternatives per level of performance

2.3.2 Organisational level

Total Quality Management (TQM)

TQM consists of organisational-wide efforts for an integrated system of principles, methods and best practices to create a continuously improving environment that delivers high-quality products and services [4]. TQM is a management approach focusing on improving the quality of all the departments and processes within a company. TQM follows a strategic management approach aimed at achieving quality across all the departments within a company by creating a base for continuous improvement processes and aims to achieve long-term success in the quality of the process [56, 57]. TQM provides the culture and climate that supports an innovative structure for technological advancements [4, 58].

The main critical aspects of the TQM process are aimed towards the difficulty of implication and measuring the effectiveness. Since many variables are related to an organisation's overall process, measuring this and improving with a TQM philosophy can be hard to quantify [4]. The TQM approach suggests that it is faster and cheaper to concentrate effort towards the early development phases of a product and prevent mistakes as early in the process as possible [35, 59]. Different studies have shown that TQM has a positive impact on the overall process quality, more than some of the other quality models such as ISO 9001 [60, 61].

ISO defines the TQM approach word by word. The *Total* is focused organisationally, meaning it focuses on all functions, levels, and persons having a stake in the process, which means all departments, operators, managers, supervisors, suppliers, and shareholders. The *Quality* of TQM has five main focus points: customer satisfaction, Customer driver, Functional requirements of the product, Product specification and Process Parameters. These points can be used to measure the quality of TQM [4, 36]. *Management* focuses on Effective directions and control of the process, continuous improvement and well-planned and effective decision-making [4].

A TQM model can have either a centralised or a decentralised organisation. A disadvantage of a centralised organisation is that some activities may take longer due to different documentation and procedure steps. Generally, a TQM organisation benefits from a centralised organisation. These advantages include [4]:

1. Efficient use of technology and opportunity for further development of personnel skills, with good scope for sending employees for higher training. Skill preservation and skill development are possible for different trade personnel.
2. Less total number of departmental personnel required, due to the possibility of emergency mobilisation of staff from one section to another of the centralised department, as this helps in better redistribution of resources.
3. Better feedback to the management.
4. Less chance of quality inspection standards relaxed or bypassed by production managers, who are reluctant to stop production in their eagerness to have more production time.
5. Better utilisation of the specialised quality measuring instruments and tools.
6. Departmental costs can be better isolated and analysed for the efficient running of the company.
7. Ready availability of data and past quality history.

The factors that can influence the degree of centralisation are the following [4]:

1. Size of the company, number of employees, turnover, etc. Actual plant size sometimes dictates the strength of the maintenance staff, and the amount of supervision needed for this staff. Many more subdivisions in both line and staff may be justified because the overhead can be distributed over more of the department.
2. Geographical distances of the individual units, the maintenance that works in a compact area differs from that dispersed in several buildings over a large area.
3. Technology used, and type of production.
4. Number of working shifts, for example, during the day shifts, the maintenance function may be more centralised, while the same company's maintenance activities during the night shifts may be more decentralised, that is done by the production personnel themselves.
5. Possible use of subcontractors.
6. Internal relationships between each department, as well as with the top management.
7. Level of training and reliability of the workforce. In industries where sophisticated equipment predominates with high wear or failure rate, more skilled mechanics and supervisors would be required, and they generally are under centralised control.
8. Management policy.

Total Productive Maintenance (TPM)

Total Productive Maintenanc (TPM) is a company-wide approach focusing on overall plant effectiveness and availability or 'ideal manufacturing situation', a vision encompassing zero breakdowns, zero abnormalities, zero defects and zero accidents [62]. TPM was first defined in Japan in 1971, with the first implementation in the Western world in the late 1980s. Since TPM focuses on the effectiveness of a production environment the up-time of machines is the main focus. The uptime is managed by two types of maintenance approaches: preventive and corrective where preventive is before a failed has occurred and corrective after a failure has occurred. Preventive maintenance can be split into three conditions: calendar-based, condition-based and predictive. For corrective maintenance, there are two possibilities: planned and unplanned [62, 63, 64].

TPM can be divided into eight pillars on which the TPM philosophy is built:

1. Continuous improvement
2. Autonomous maintenance
3. Preventive maintenance
4. Training and Education
5. Start-up monitoring
6. Quality management
7. TPM in administration
8. Safety and health at work, environmental protection

TPM describes six types of losses, these 6 types of losses are then split up into 3 categories, the first two are time losses (availability), the next two are speed losses (performance) and the last ones are quality losses [62, 63]:

1. Breakdown losses
2. Set up and adjustment losses
3. Idling and minor stoppage losses
4. Reduced speed losses
5. Quality defects and rework losses
6. Start-up losses

A continuously improving methodology/model from TPM would start with collecting data, timing and records to start the analysis [63]. For this data analysis, TPM focuses mainly on four performance indicators [64]: Availability, Performance efficiency, Quality rate and Overall Equipment effectiveness. The final measurement of the performance of a TPM process is the Overall Equipment Effectiveness (OEE), the following formula calculates this [63]:

$$OEE = Availability \times Productive\ efficiency \times Qualityrate = A \times PE \times QR \tag{2.1}$$

$$Quality\ rate = (processed\ amount - Defect\ amount)/processed\ amount \tag{2.2}$$

$$Performance\ Efficiency = (processed\ amount \times Actual\ cycle\ time)/Operating\ time \tag{2.3}$$

$$Availability = (Loading\ time - Downtime)/Loading\ Time \tag{2.4}$$

Nakajima described 12 steps for when a company wants to introduce the TPM philosophy to their processes. These twelve steps are divided into three main stages: the preparation stage, the preliminary implementation stage and the TPM implementation stage. These three stages are followed by the stabilisation stage, which focuses on perfecting the implementation and raising the total TPM levels, as shown in Table 2.6 [8].

Stage	Step (Nakajima's 12 steps)
Preparation Stage	Step 1: Announce top management's decision to introduce TPM
	Step 2: Introductory education campaign
	Step 3: TPM Promotion
	Step 4: Establish basic TPM policies and goals
	Step 5: Preparation and Formulation of a master plan
Preliminary Implementation Stage	Step 6: TPM kick-off
TPM Implementation Stage	Step 7: Develop and equipment managament program
	Step 8: Develop a planned maintenance program
	Step 9: Develop an autonomous maintenance program
	Step 10: Increase skills of production and maintenance personnel
	Step 11: Develop early equipment managament program
Stabilisation Stage	Step 12: Perfect TPM implementation and raise TPM levels

Table 2.6: The 12 TPM implementation steps by Nakajima [8]

Six sigma quality

Motorola was one of the founders of Six Sigma, a continuous improvement philosophy from the 1970s to address the problem of decreasing product quality. The Six Sigma philosophy consists of methodologies and tools to increase the overall quality by reducing errors and effects in a process [18]. Six Sigma has developed different versions, with LSS and DfSS. LSS is a relatively recent continuous improvement approach for quality improvement that has been proven to be successful across manufacturing as well as services.[65, 66]

DfSS is a Six Sigma approach that will involve changing or redesigning of the fundamental structure of the underlying process [18]. A DfSS process usually consists of four main stages. These four stages consist of the ideation, concept development, process design and process routine operation stages. These four development stages are followed by the process improvement stage, which follows after the process routine operation phase, as seen in figure 2.8. DfSS mainly focuses on creating the best product in 'one time right' approach [18].

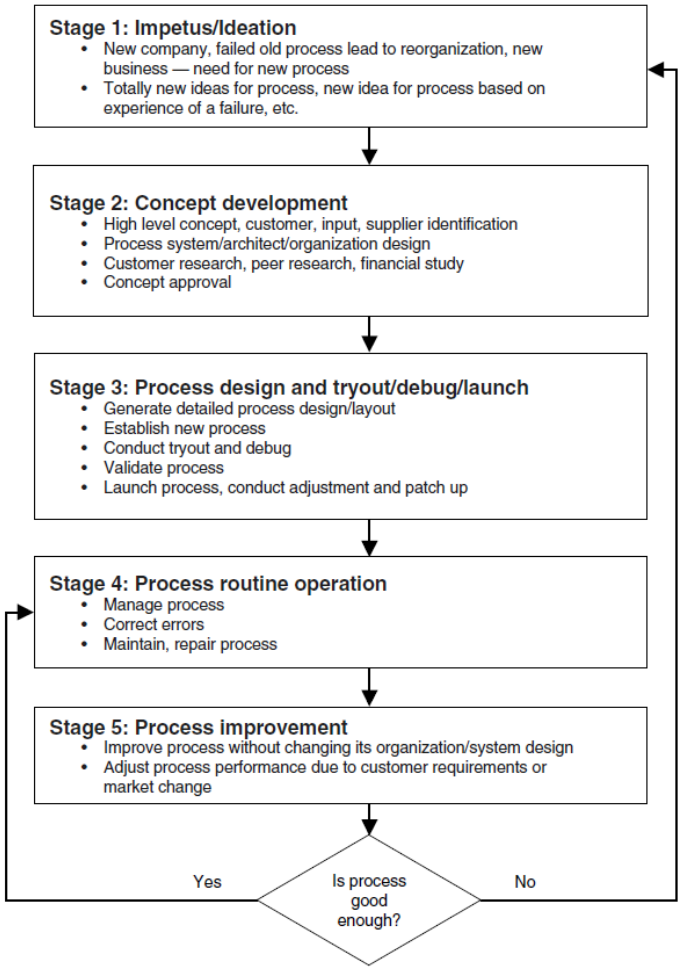


Figure 2.8: A typical DfSS process life cycle [18]

ISO 9001

ISO 9000 is a series of guidelines companies can focus on and show their credentials on quality systems including procedures, control and documentation. The first ISO 9000 was produced by the Internal Organization for Standardization (ISO) in 1987, and the certifications for quality management systems were started [34, 2].

Some researchers claim that ISO 9000 is the foundation of a quality management system and that it is necessary to stay in business [67, 68]. On the other hand, some researchers claim that many people within the industry claim that ISO 9000 is not the guaranteed ticket to achieving the best quality and competitiveness possible [60, 69]

Since ISO 9001 is a well-known and accepted standard, companies often use this to prove that they meet certain requirements. The main focus point from the ISO 9000 philosophy is quality improvement by processes and procedures and a cost reduction focus, while these are guidelines and general procedures, but do not provide a detailed approach or model for quality improvement [70, 71].

Lean manufacturing (TPS)

Lean manufacturing is a quality approach originated from Toyota Production Systems (TPS) focusing on removing process waste and non-value-added activities that add unnecessary cost to production or service [72]. Lean manufacturing is mainly used as a waste reduction technique; in practice, the product value is maximised by performing this waste reduction technique [73]. Understanding customer value and the internal value streams are two important parts of the TPS philosophy. The TPS principles can be split into three sections: process, people and tools/technology.

These different sections each contain a number of principles, shown in the figures below. Figures 2.9, 2.10 and 2.11 describe the principles of the people, process and tools/techniques from lean product development. TPS does not provide a structured quality method, but an approach to keep removing waste in the processes of the company.

Process Principles of Lean Product Development

Principle	Description
1. Establish customer-defined value to separate value added from waste.	Lean is a never ending journey of waste elimination. Waste is non-value added defined by first defining customer value.
2. Front load the product development process to thoroughly explore alternative Solutions while there is Maximum Design Space.	Defining the wrong problem or premature convergence on the wrong solution will have costs throughout the product life cycle. Taking time to thoroughly explore alternatives and solve anticipated problems at the root cause has exponential benefits.
3. Create a leveled Product Development Process Flow.	Leveling the flow starts with stabilizing the process so it can be predicted and appropriately planned. This allows product planning to reduce wild swings in work load. Predictable work load swings can be staffed through flexible labor pools.
4. Utilize Rigorous Standardization to Reduce Variation, and Create Flexibility and Predictable Outcomes.	Standardization is the basis for continuous improvement. Standardization of the product and process is a foundation for all the other process principles.

Figure 2.9: Process principles of Lean Product Development [19]

People Principles of Lean Product Development

Principle	Description
5. Develop a "Chief Engineer System" to Integrate Development from start to finish.	The chief engineer is the master architect with final authority and responsibility for the entire product development process. The chief engineer is the overarching source of product and process integration.
6. Organize to balance Functional Expertise and Cross-functional Integration.	Deep functional expertise combined with superordinate goals and the chief engineer system provides the balance sought by matrix organization.
7. Develop Towering Technical Competence in all Engineers.	Engineers must have deep specialized knowledge of the product and process that comes from direct experience at the *gemba*.
8. Fully Integrate Suppliers into the Product Development System.	Suppliers of components must be seamlessly integrated into the development process with compatible capabilities and culture.
9. Build in Learning and Continuous Improvement.	Organizational learning is a necessary condition for continuous improvement and builds on all of the other principles.
10. Build a Culture to Support Excellence and Relentless Improvement.	Excellence and *kaizen* in the final analysis reflect the organizational culture.

Figure 2.10: People Principles of Lean Product Development [19]

Tools and Technology Principles of Lean Product Development

Principle	Description
11. Adapt Technology to Fit your People and Process.	Technology must be customized and always subordinated to the people and process.
12. Align your Organization through Simple, Visual Communication.	Aligned goals must be cascaded down and joint problem solving is enabled by simple, visual communication.
13. Use Powerful Tools for Standardization and Organizational Learning.	Powerful tools can be simple. Their power comes from enabling standardization which is necessary for organizational learning.

Figure 2.11: Tools and Technology Principles of Lean Product Development[19]

Theory of Constraint (TOC)

Theory of Constraints (TOC) is a management philosophy that focuses on the weakest part of the process to continuously improve the quality of the performance of the process [74]. TOC focuses on a constraint or bottleneck in the system. TOC can be described in two main components. Firstly a working principle which described five steps of constant improvement in a process. The second component is a generic approach for investigating, analysing and solving problems called the thinking process (TP) [75]. This thinking process is an important tool used within TOC and addresses policy, contains and develops specific solutions. To develop these solutions, TP has five different tools to assist managers with three main questions: what to change, what to change, and how to change the cause [76].

As described above, the TOC is an important theory focusing on the weakest links in the chain [74]. The improving process helps to TOC's five steps of improving a process (5 focus steps by Goldratt and Cox [77]):

1. Identify the system's constraint(s)
2. Decide how to exploit the system's constraint(s)
3. subordinate everything else to the above decision
4. Elevate the system's constraint(s)
5. If in any of the previous steps, a constraint is broken, go back to step 1, do not let inertia cause a new constraint.

TOC has a continuous improvement philosophy by dealing with the (most critical) constraint. This philosophy is not often used as a quality plan, TOC is generally used as a mechanism/technique to assist in implementing another quality model, such as TQM [76].

Next to the five focus steps, Goldratt and Fox also describe a set of nine rules which have to be followed for an optimised TOC process.

1. Balance flow, not capacity
2. The level of utilisation of a non-bottleneck is not determined by its own potential but by some other constraint in the system
3. Utilisation and activation of a resource are not synonymous

Summary

Several quality management models have been discussed, each with their own strengths and areas of focus. The overview was combined using Kumar, Maiti, and Gunasekaran's overview and supplementing it with additional relevant information about each model [20]. The revised overview of the six quality management models and their focus points and philosophy/tools is presented in 2.12.

Description	TQM	TPM	ToC	TPS	SS	ISO 9001
Focus	Quality of products and processes in new product development	Loss/Waste reducation, availabilit,y production rate, quality rate	Bottlenecks (constraints)	Inventory, pull, material and informartion flow, speed	Variation reducation	Quality of products and processes
Methodology	Policy management, daily management, cross functional management, employee involvement initiatives	Eight Pillars: Autonomous Maintenance Planned Maintenance Focused Improvement Quality Maintenance Education and Training Development Management Safety Health and Environment TPM in Offices	5 focus steps: Identify constraint, Exploit constrraint, Subordinate to the constraint, Elevate the constrains, Return to step 1	Three foundations: Just in time, Production levelling and Autonomation	Five step process: Define, measure, Analyze, Improve/Design, Control/Verify	Seven clauses: Context of the organization, Leadership planning, Support operation, performance evaluation, Improvement
Tools/technology	Seven basic Q tools, Seven advanced QC tools, Advanced tools	5S, Visual management, Observaton, 4M analysis	Buffer management, bottleneck analysis, inventory visualization	VSM, visual management, waste indentification, kanban, cell manufacturing	Basic statistical tools, advanced statistical tools	Corrective and preventice actions, statistical tools, data collection

Figure 2.12: Summary of suitable alternatives, based on 'Synthesis of QMS' by Kumar, Maiti and Gunasekaran [20]

2.3.3 Process level

Configuration management

Configuration Management (CM) is a process to determine and maintain versions of products or processes. CM is often used in the development process to control process elements [21]. NASA describes configuration management as a crucial part of overall systems engineering. Successful implementation will provide visibility of an accurate product representation and ensure that across the development process, all changes will be transferred in different configurations and track these changes [78]. Electronic Industries Alliance (EIA), which provides documentation and standards on configuration management, states that improper usage of CM can result in ineffective, incorrect, and unsafe products and processes.

A configuration consists of several configuration units (CU), where each of these CU can have different versions and configurations [21]. Figure 2.13 shows the base principle of configuration management. The configuration versions are listed above, and they contain certain configuration units. Each time a version updates, the latest version of the CU is picked. By updating the general version each time one or more CU get updated, the latest versions always use the latest updates of all versions. This is a simplified example, but this philosophy can be extended further to include different parts under each configuration unit to work towards a central version continuously.

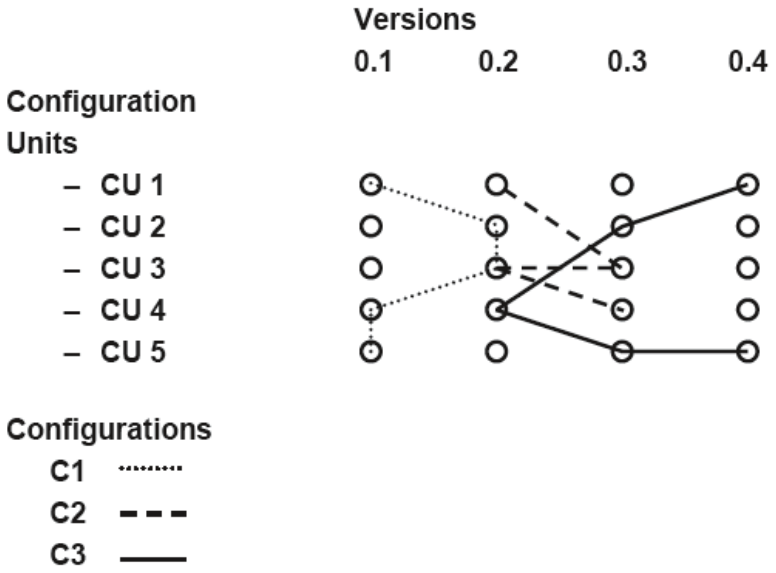


Figure 2.13: Versions and Configurations [21]

Requirements management

Requirements management determines and manages different requirements in a development process. Requirements management's purpose is to ensure that an organisation creates an overview of all requirements within a configuration and uses this information to manage the data of requirements. Product Lifecycle Management (PLM) software describes the connectivity between departments and different requirements as important in a manufacturing company [21]. PLM software describes four phases that work together when delivering the product. The different phases are the requirements, functions, logical, and physical parts. These are connected as shown in figure 2.14. For example, the requirements set at the beginning depend on the functional, logical and physical parts later in the process. This connection is vital for configuration management and ensures the different parts work together and always use the latest version [21].

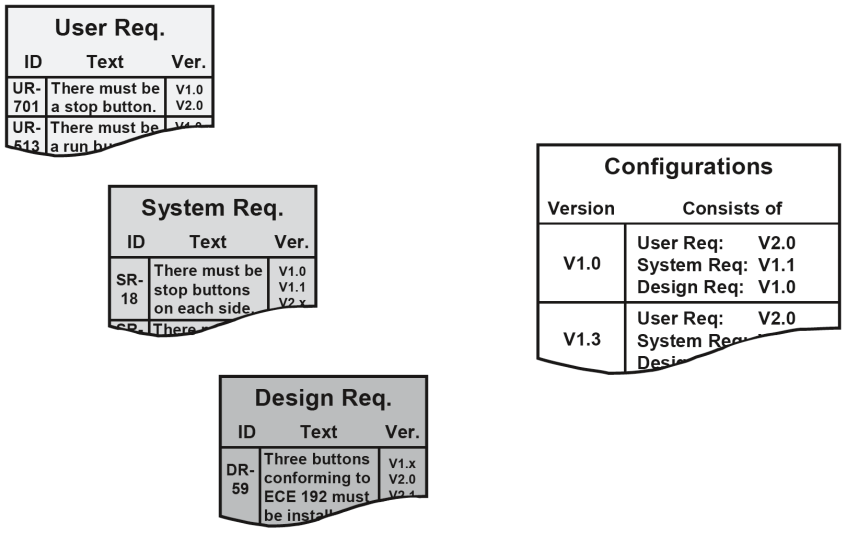


Figure 2.14: Example configuration information [21]

Risk management

Risk management aims to identify potential problems before these occur [39]. Risk management is a continuous process that identifies, assesses, prevents and monitors the risk of a product or process [21]. Risk management should consider all factors such as internal, external, technical, non-technical and cost [39]. Figure 2.15 shows an overview of these processes and how the processes align with each other. One of the tasks within project management is the prediction and assessment of any possible outcome that may negatively influence the quality of a project. Negative impacts for this project would be delay, extra costs, or loss/decrease of quality [21]. Ian Sommerville describes three classifications of risks: Project risk, Product risk and Business risk [79]. Risk management consists of four steps to reduce these risks [21]:

- Identification of risks
- Assessment of risks
- Definition of countermeasures
- Monitoring of risks

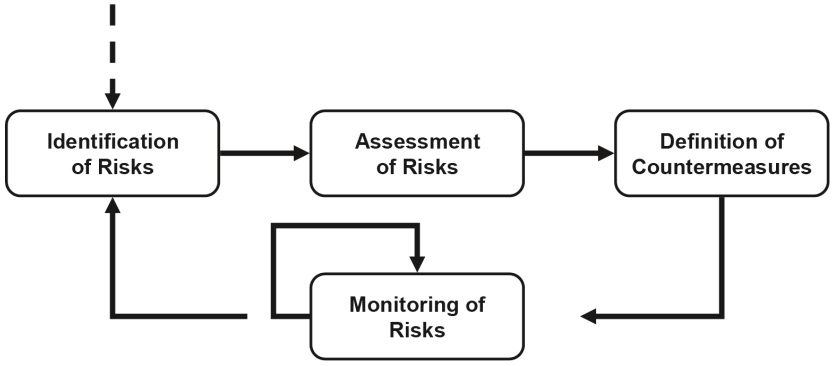


Figure 2.15: Simple example of a Risk Management Process[21]

The following seven steps can be followed to perform risk management on an organisation [39]:

1. Determining risk sources and categories
2. Determine risk parameters
3. Establish a risk management strategy
4. Identify and analyse risks
5. Evaluate, Categorise, and Prioritise Risks
6. Develop risk mitigation plans
7. Implement risk mitigation plans

Summary

This section summarised three different approaches to data management of a process. Even though all three processes focus on some data management, only configuration and requirements management describe the data management of products and processes. While risk management identifies and monitors risks, it does not provide a data management model approach for managing processes.

Both configuration management and requirements management provide data management approaches, with requirements management more focused towards specific functions of a product or process. Configuration management provides a system to match different configuration units to a central version for a clear data management approach that can be further expanded with the same philosophy.

2.3.4 Job/technique level

Check sheet

Check sheets are simple documents with a certain format that is used to record data of a process. A check sheet can be used to record key data during the production process. An important factor of a check sheet is that it has to be flexible and meaningful. The purpose of a check sheet is to provide a structured way to collect quality data to asses if a process is functioning compared to goals or previous examples. If these are not the case, the check sheets only deliver more unnecessary steps. A check sheet can be made more effective by questioning the purpose of the check sheet based on the five why questions [80]:

- Who filled in the check sheet?
- What was collected?
- Where is the location of the measuring of quality?
- When was this measuring of quality?
- Why is this data collected?

Ishikawa describes five uses for check sheets, based on these five why questions [80]:

- Process performance
- Defect frequency
- Defect locations
- Defect causes
- Task conformation

The check sheet is an often used technique within companies since it is a simple and relatively cheap technique to control specific steps in a process [54, 55]. Check sheets can be used as documentation to find the root causes of problems since recording important data can show potential failures [39].

Quality Function Deployment (QFD)

An often-mentioned technique for quality improvement is Quality Function Deployment (QFD). Apart from the original QFD technique, as described in Section 2.2.3, different approaches have been described over the years. Mehrjerdi describes the following five different extensions of QFD [81]:

1. AHP and QFD
2. Fuzzy QFD
3. Statistically extended QFD
4. Dynamic QFD
5. Other QFD extensions/mixes

AHP and QFD
The Analytical Hierarchy Process (AHP) QFD process still has the same structure as the traditional QFD, but uses AHP to rank the relative importance weight for customer needs and functional characteristics [82]. AHP assists in decision-making by ranking the importance of different choices to make a more realistic choice. The combination of AHP and QFD is to use AHP philosophy when determining different targets or ranking against competitors' designs.

Fuzzy QFD
Fuzzy QFD requires various inputs from judgements and evaluations. Typically, these are acquired by questionnaires, interviews or relevant focus groups. This technique can raise uncertainty when trying to quantify the relevant data. Fuzzy logic helps by reducing the uncertainty during the data collection. Fuzzy logic does not use only a one or a zero for an answer to a question but uses different options in between choices [6]. If a statement can be between 0 (not true) and 1 (true), an answer such as 0.2 can be seen as (not really true). This assists QFD to not only see a statement as true or false but gives QFD the ability to get a better understanding of, for example, the customer's desires.

Statistically extended QFD
Rajala and Savolainen describe a connection between statistical analysis and QFD to support a systematic procedure for business process analysis and redesign [83]. The statistically extended QFD takes the standard QFD and increases focus on customer needs associated with operational business process design. By using these statistical business approaches, a better understanding of the customer is determined, which means a higher input of information for the QFD process. This approach combines Business Process Modeling (IDEF0), QFD and statistical analysis. The customer data, acquired by QFD and the Process data acquired by (IDEF0) are combined in a statistical analysis [83].

Dynamic QFD
Adiano and Roth described the limitations of the traditional approach with strategic post-design implications. The traditional QFD proved to be more efficient for initial product designs by fewer start-up problems, fewer design reworks and an overall shorter development process [84]. Adiano and Roth describe a problem with traditional QFD: "How can a firm narrow the gaps created by static QFD applications?" Dynamic QFD improves this process by combining QFD and statistical process control techniques on core process parameters. Adjusting the regular QFD approach can make dynamic QFD a critical methodology for improving manufacturing capabilities [84]. This model incorporates a customer feedback loop to all the other responsible departments, such as manufacturers, designers, suppliers and after-sales (service). By implementing dynamic QFD the company can monitor the changing behaviour of the customer and, with this information, fine-tune important product and process parameters continuously [84]. This approach limits unnecessary work since it focuses on the essential input but requires a lot of collaboration between the different processes[44].

Other QFD extensions/mixes
Many small changes are made to QFD since it is a widely used model for development processes, resulting in many variations on QFD. One example of a QFD variation takes the standard QFD approach but models it into an integrated information system. This integrated QFD (iQFD) approach creates a very detaild approach with many steps and deliverables within each of the development phases. This model describes three main phases: preproduction, production and postproduction. The main focus is on the preproduction phase, with some implementation and feedback processes in the production and postproduction phase. The preproduction

phase is split into five stages: Market study and product planning, Part/mechanism deployment, Process development and quality control planning, Production operation planning and incoming inspection.

The iQFD model is in-depth and has different steps and deliverables per phase. In Figure 2.16 the overview for the preproduction phase created by Chang is shown [3]. This shows the first four phases and their input and main (deliverable) outputs. The incoming inspection is not specified since this is a continuous process on incoming parts and products. The iQFD model described detailed versions inside of each of the stages, but the main inputs and outputs with the external stakeholders for each stage are shown in Figure 2.16.

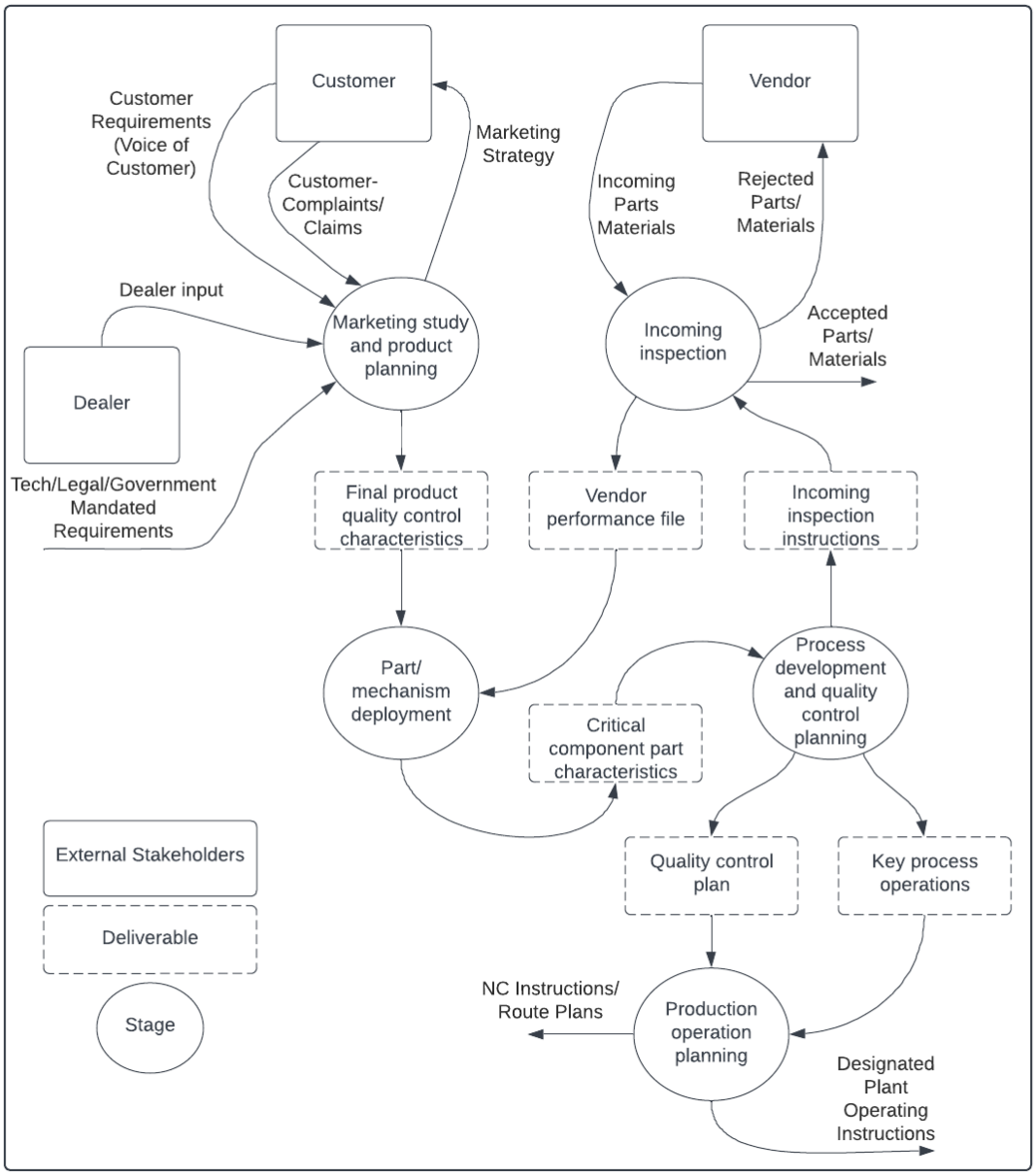


Figure 2.16: Overview Preproduction Stage Integrated QFD [3]

Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effect Analysis (FMEA) is an analysis tool used to determine possible failures and their effects on different products of processes. The FMEA method was developed during the sixties by NASA and used for the aeronautics and aerospace industry. After application, the technique spread to the automotive industry and is now a globally applied technique [85]. The FMEA method focuses on determining the possible risks and their effects with a team of relevant stakeholders to that process phase. Thinking about possible mistakes early in a process allows different departments to share their knowledge and experience on specific development or design choices. Successfully executing these types of FMEA processes can prevent extra costs and save possible delays.

Many different approaches and adjustments to the standard FMEA process have been developed, but the FMEA process can generally be split up into three main categories of FMEA approaches [86, 85]:

- System FMEA
- Design FMEA
- Process FMEA

The System FMEA is used to identify possible failures or risks before an actual design is created. The system FMEA should be used very early in the product development process. The system FMEA is a team-oriented method for preventing early mistakes in design possibilities and possible project schedule delays and stimulates the cooperation between departments early on [85]. This is mainly focused on customer requirements and the possibilities. The follow-up FMEA is the design FMEA focused on when an actual design is created, and a more thorough FMEA can be performed [85]. The design FMEA inspects the required functions of the product and determines possible failures by all different possible uses [85].

The Process FMEA is useful when specific process parameters are known, and the product is designed. The process FMEA then focuses on different steps during the production of parts of the process of assembly of different components. When looking at the different steps for these processes, new risks occur. The process FMEA's main goal is to limit these production and assembly risks and proactively find solutions to prevent high-risk outcomes of the process FMEA.

Conclusion

This section summarises three quality techniques to improve the overall production process quality. The first section focuses on check sheets and the five main reasons to use the check sheets to measure: Process performance, Defect frequency, Defect locations, Defect causes and Task confirmation. The second section describes QFD and the five main alternative models to QFD. The first four examples of alternatives describe slight changes in determining requirements or customer input. The fifth example, the internal QFD approach, describes a full detailed quality model. The last section describes different FMEA variants: System, Design and Process. The three FMEA approaches are all similar, but are used in different periods in a production process. The system FMEA during the product planning, design FMEA during the product development and the process FMEA during process development.

3 CURRENT SITUATION AND PERFORMANCE

In this chapter, the sub-question **"What is the current situation at VMI?"** is answered in four sections. Section 3.1 covers a general introduction to VMI's development and production process, followed by Section 3.2 on current steps and methods of the production quality process and the internal structures to control process quality. To validate these structures and to create a better overview of the processes, a use-case on an example in the factory is used in Section 3.3. Section 3.4 describes the quality level expectations and quality level desires by the production management team.

3.1 Current process

In order to understand the current development and quality process better at VMI an internal study of the process is performed. In Figure 3.1 the development process is shown according to the internal document 'VMI main process for order scheme'

The R&D department is split up into two different streams, the Research department and the Development department. The Research department called 'technology' in the figure is looking at the new state-of-the-art technology and how to use this in the current or new machines. The Development department called 'Market' listens to the customers and the market and uses this information to figure out what machines to upgrade or design. [87, 22]. After the development of the standard machines the New Product Introduction (NPI) process is performed, which introduces and prepares the departments for a new module or machine.

After the development of the standard configuration specific customer orders can be created, almost every order for the customers is custom. The customers have the choice of choosing some of the standard options or completely adjusting the machine for their use. From changing these orders work preparation executes the logistical and technical work preparation from where the production process can start. After the production process, which can be combined from any of the production sites of VMI, fieldservice installs the machines at the customer.

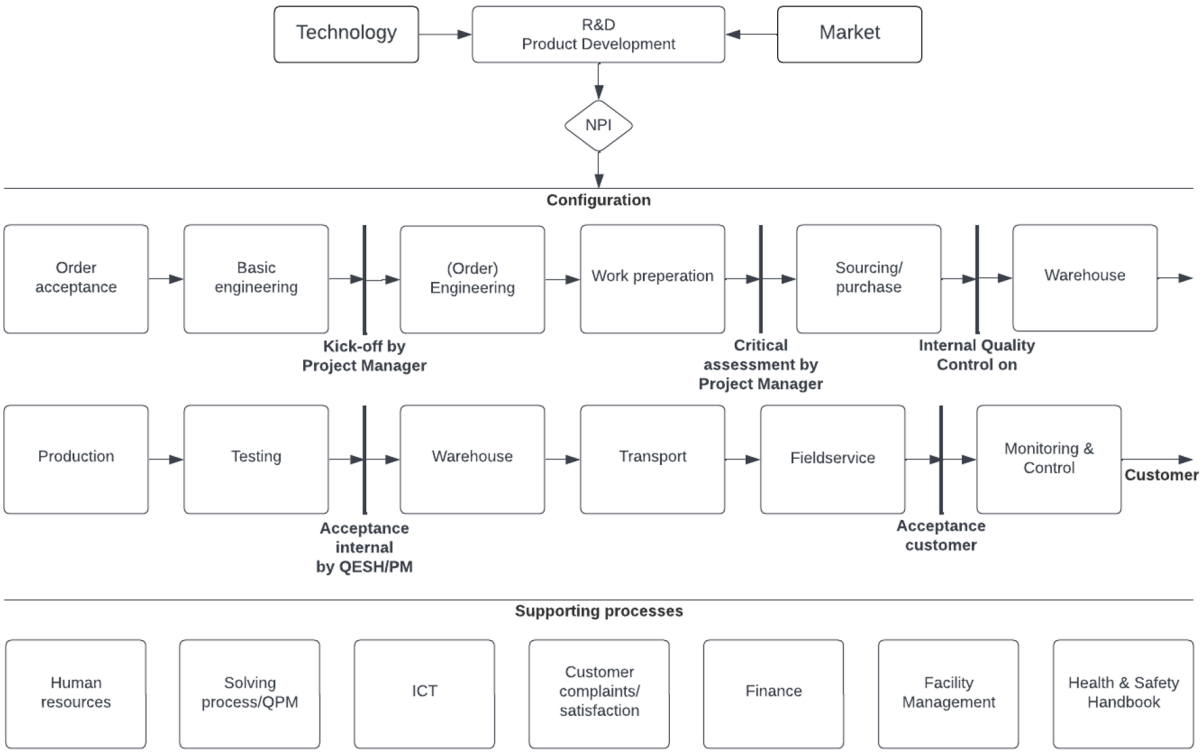


Figure 3.1: VMI internal process from development to delivery of a machine. (VMI Main Process For Order Scheme) [22]

Main influences and stakeholders in production process quality

To get a better understanding of what happens exactly in some of these steps from Figure 3.1 further investigation is performed in this section. Based on internal documents from what deliverables are created in what step and interviews with people from the departments the departments in Figure 3.2 are highlighted. Different departments such as structuring engineering, R&D engineering, Order engineering, production engineering, and test engineering were the only departments that had relevance to the process quality of VMI. Next to the departments with influence an important factor is the solving processes/QPM which is an internal process created by production for mostly reactive problem-solving.

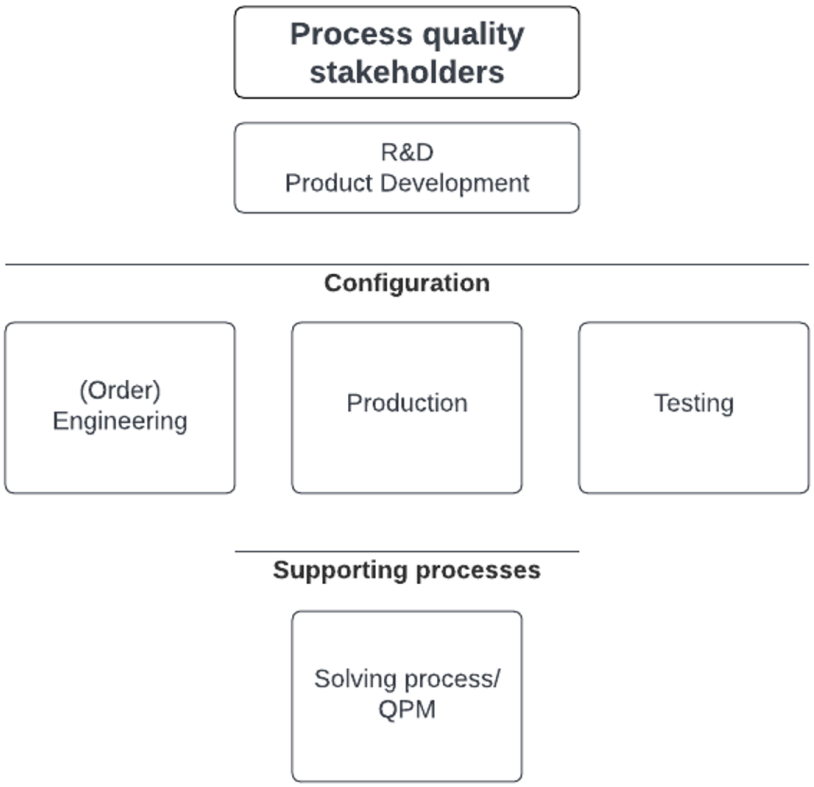


Figure 3.2: Overview stakeholders with influence on quality process

3.2 Current steps and methods in the quality control process at VMI

To understand the current process, is it important to view all the different quality control processes and deliverables present in the current process at VMI. Based on Figure3.2 the departments are interviewed in detail on what their deliverables and processes are to achieve a higher production process quality.

3.2.1 R&D Product development and Order Engineering

There is no fixed structure for developing quality control processes/deliverables in the engineering process toward the production process. The deliverables contain two main inputs from engineering towards production: test reports and a control plan. A control plan at VMI is the collection of different test reports with a table of contents to see if all the necessary test reports are complete. The control plan is on module level and contains all the test reports from subsub, sub and modular level of that module.

Since there is no structured process, R&D engineers and OE engineers have the freedom to choose any approach to create this test report themselves. The Critical To Quality (CTQ) list can assist the engineers in developing these test reports, to see if those points require extra attention or testing. During the production process, feedback from the operators on these test reports can be adjusted on these test reports to increase possible problems over time.

The difference between the R&D and OE test reports is that the R&D department is responsible for the test reports of the main/standard machine configuration and options. When a customer makes changes to this standard configuration, OE has to see if the standard test report is still valid, if they have to change this test report because or new/removed features or if they have to create an entirely new test report. OE is also responsible for combining/creating the control plan used by production.

3.2.2 Production

The production process contains documented and undocumented steps in the quality control process. The main input for the quality process is from R&D and OE. The test reports get added per sub-module, until every test report is completed and it gets combined into one final control plan. The overview in Figure 3.3 shows the current quality processes in the production process. The top layer, is the documented layer. These are inputs from the control plan/test reports that are used in each of the subsub-/cabinet, sub- or module levels.
The transfer parts are the changes in between locations (Epe, Leszno and Yantai), since different sub-modules and modules of a machine can be produced in different locations. Different documented test reports are supposed to transfer when the subsub, sub or module travels to another locations. The undocumented steps are not shared across different locations, and not even between different foremen.

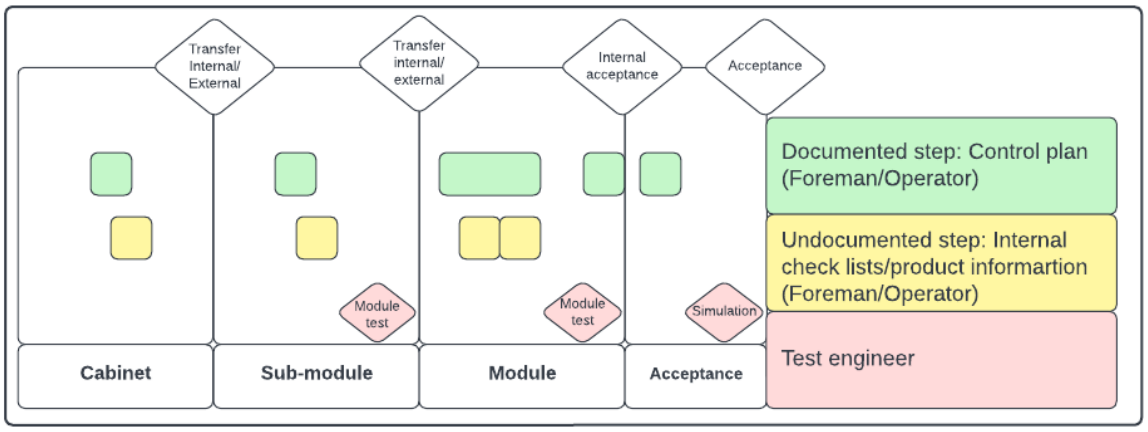


Figure 3.3: Production Quality Process Flow [23]

The process steps included in the production process that support the product quality can be split into three groups. First up the documented checklists/test reports supported by engineering to production, the undocumented checklists created by production foremen themselves and (sub-)module tests created by the test engineers. The final acceptance is executed by the QESH department and focuses on different standards, including if all the test reports in the control plan are filled in correctly.

3.2.3 Testing

Within the factory, there are three main test moments: acceptance, sub-module, and module testing. In figure 3.3 the two activities in the bottom row include the testing moments. The main test moment is the module testing which is performed on every module that leaves the factory. The module testing includes slow movements to test if the functionalities are working as intended and if the software is performing on the module. The final test is the acceptance

test, which is after the production process is finished and everything is accepted by QESH. This simulation takes one to two hours and is performed at full speed. The simulation has two possibilities: 'wet' and 'dry'. A wet simulation means a simulation with full material to actually produce tires and a dry simulation which simulates the full performance movements, without the production of actual materials. This choice is already made early in the development process, dependent on customers and requirements since a wet simulation requires more preparation and therefore money.

Next to the two test moments that always happen for every module a sub-module test is possible. This is not a common practice since it requires specific test settings or specific test parts. To identify critical failures early in the process the sub-module testing can be used, but is not often performed.

3.2.4 Supporting processes/ QPM

Next to the control processes in the department the control methods used across the company are studied as well. The supporting process/QPM is the main supporting process, as show in Figure 3.1. The Quality Pulse Meeting (QPM) is the global meeting focusing on solving multidisciplinary issues. The different possible internal problem-solving meetings are shown in Table 3.1 and Figure 3.4 shows on what location they are held and how they fit in the 8D problem solving approach.

Name	Full process name	Purpose
QPM	Quality Pulse Meeting	Process to solve multidisciplinary issues
QM-P	Quality Meeting Production	Process to solve structural issues only production related
QM-E	Quality Meeting Engineering	Process to solve structural issues only engineering related
QM-L	Quality Meeting Logistic	Process to solve structural issues only logistic related
SIP	Supplier Improvement Program	Process to improve suppliers performances
TIER1-5	Improvement boards production	Process for daily management
QMM	Quality Management Meeting	Presentation of different department KPI's
P-QMS	Production Quality Management System	Map of all production standards
Q (shop floor)	Quality production theme day	Process to analyse date with the crew to find structural issues
8D	8 Disciplines process	Structural problem solving method

Table 3.1: Different meetings for reactive problems solving [9]

The meetings described in Figure 3.1 describe receiving different types of inputs. The following points are used as input for the meetings:

- Customer Complaint
- Form 511/711
- Fieldservice feedback
- As-built

A customer complaint is a problem that occurs at the customer after delivery, a 511/711 form is an internal form for problems that occurred during the production process, Fieldservice feedback is a problem that occurs during the installation of a product and as-built is an engineering-related issue.

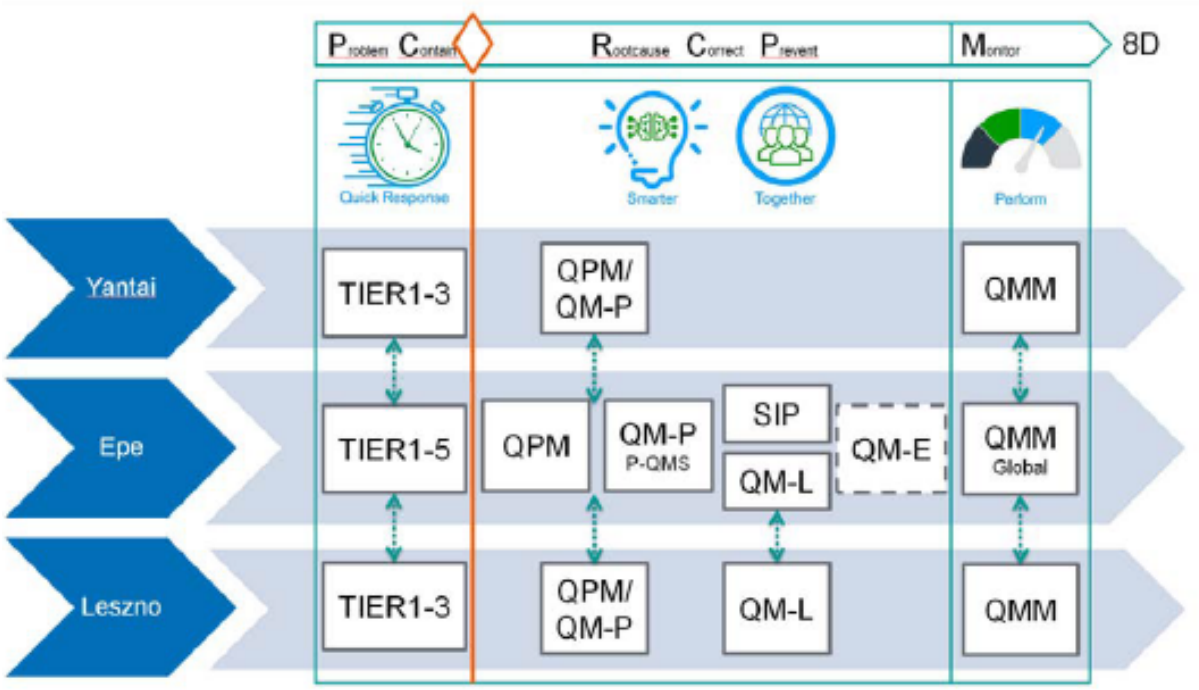


Figure 3.4: Overview of different reactive meetings across the sites [9]

Generally, VMI tries to solve problems internally with the tier board. In Figure 3.5 the example used by VMI with the tier levels. The operators have daily meetings with the foremen and address the issues that they come across in the factory. These foremen have daily meetings with the department management in order to solve issues, if they can not fix the problems at these meetings the department team discusses this with the department management team (tier 4). If they can not solve the issue, the issue can even go to the COO of the company (tier 5). By following this problem-solving method, a lot of smaller mistakes get fixed early on and if a big problem occurs it can quickly be escalated to a management level.

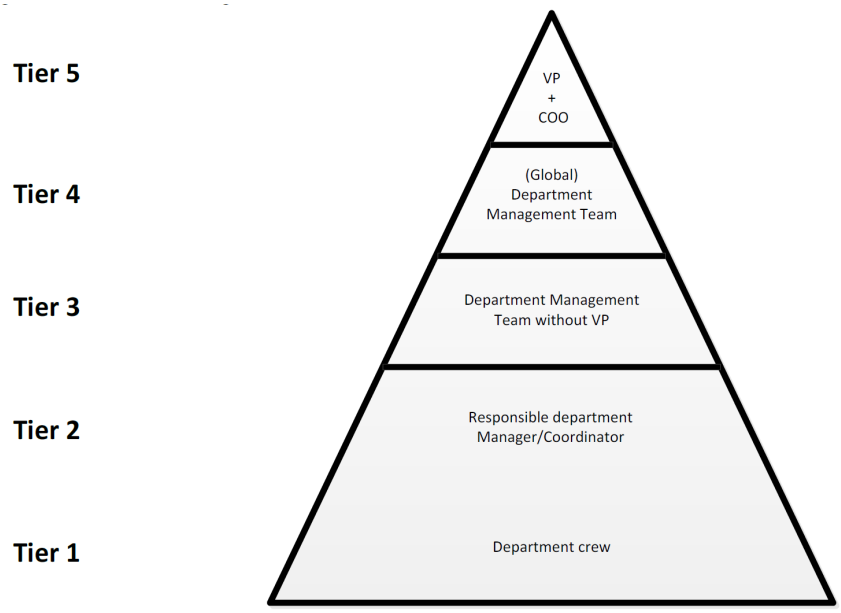


Figure 3.5: Different tier levels quality meetings [24]

If these processes can not be solved internally, or if it is not sure what caused this problem an 8D-analysis is performed. This is an internal reactive solving approach of issues found by production, or different feedback points from processes after the production process. The 8D method approach is a widely known problem-solving approach which VMI has slightly changed in order to increase effectiveness within the factory. The following steps are included in the internal (reactive) solving process [88]:

- D0: Describe the symptom and describe the actions already taken to contain the problem.
- D1: Form a multidisciplinary team.
- D2: Describe the problem (Who, What, Why, Where, When, How much, How often; Is/Is not).
- D3: Define and implement ”Interim Containment Actions”.
- D4: Find the root cause of the problem (Root Cause Analysis (RCA)). Use ”Brainstorming”, ”5 x Why”, ”Ishikawa (fish bone) diagrams” to do this. Also determine the ”Escape point” (what is the closest point in the process where the problem could have been discovered but was not discovered?).
- D5: Determine corrective action(s).
- D6: Implement corrective action(s) and monitor the effect.
- D7: Identify preventative actions (process improvements, including for similar problems).
- D8: Congratulate the team, review jointly how well the process worked.

3.3 Use-case Example

To support and verify the information from Section 3.1 and 3.2 a use-case is performed. This use-case is used on a sub-submodule and will help understand how certain documents are created and used in the production process. The following results have been found by interviewing different departments and studying different internal documents. The use-case is performed on the Carcass housing (CCH) arms, which is part of the Tire Building Machine (TBM) shown and explained in Section 1.3.

Due to Intellectual Property (IP), the detailed processes are not described but in process steps. The use-case is performed on the four parts described in the current quality control steps: Engineering, Order engineering, production and testing. The process is further explained or checked for each department using the CCH arms as an example. The CCH arms move the drum, on which the tire is built, in a horizontal displacement. The TBM and its part are explained in the figure 3.6 below and show where the CCH and CCH fit in the TBM in Figure 3.7.

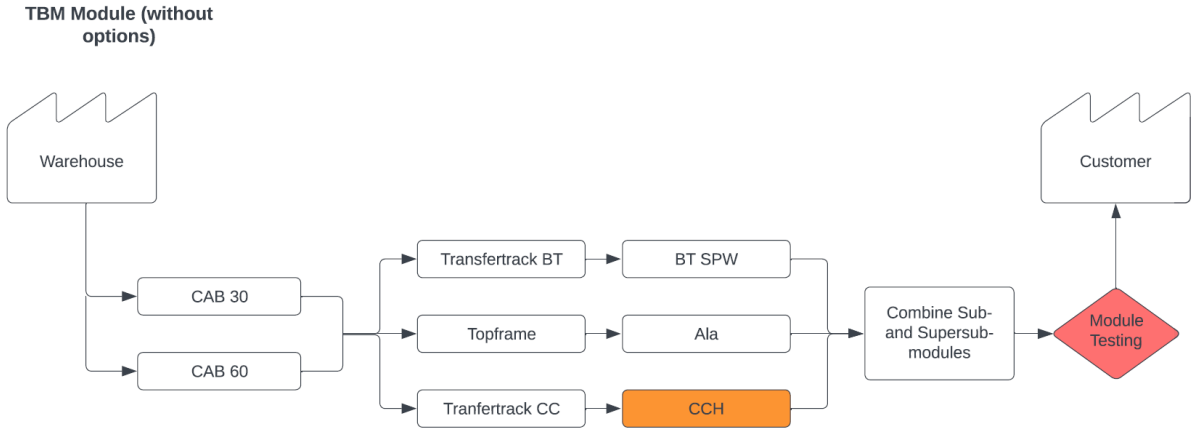


Figure 3.6: Sub-module overview TBM

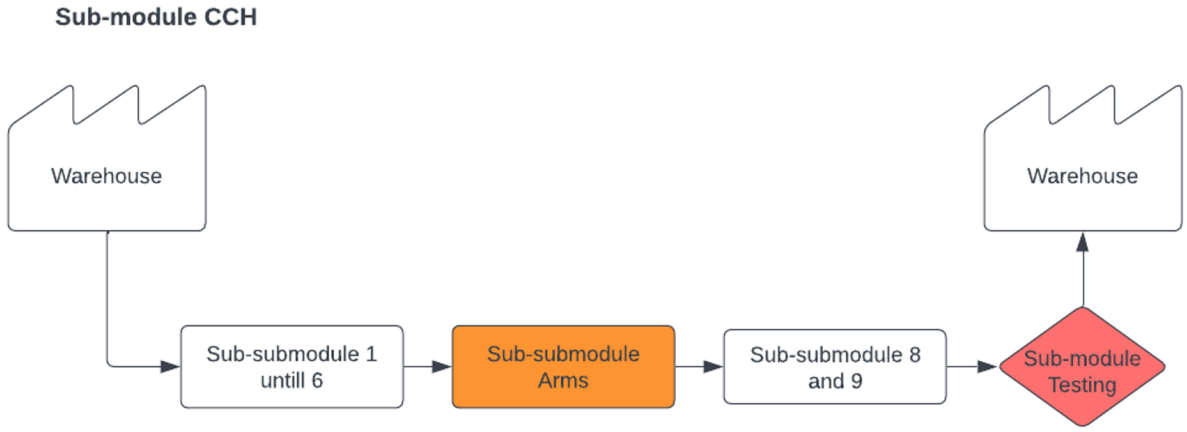


Figure 3.7: Production steps CCH

Engineering

The first process is the engineering process from the R&D process. As described before in Sections 3.1 and 3.2, this process delivers one item for achieving process quality: the test reports. The creation of these documents is not structured, and therefore this use case is explained by the responsible R&D engineers. Figure 3.8 shows the process that the R&D engineers took in order to create the test reports necessary for the CCH arms. The engineers start by listing critical items that they think can be a problem at assembly from experience and combine this information with possible information on critical parts by the supplier. This combined list is used to first produce the full CCH sub-module themselves in the workshop and see if the critical items are actually critical and if other possible problems occur. This renewed list is used for a 'first of production series' to see if the operators in the factory will face different problems that are not found by the prototype. This list is then renewed again and this is the final test report that is used for full-scale production, which can be updated through feedback during future production series.

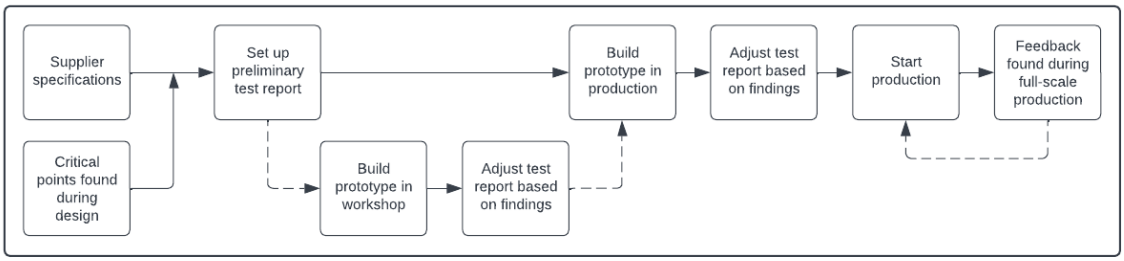


Figure 3.8: R&D CCH test report process

Order Engineering

The second phase that has an influence on the process quality is the order engineering phase. As described in Section 3.2, the Order Engineering department is responsible for creating/adjusting test reports and combining them in a control plan. For the example of the CCH arms the two options were using the existing test report created by the R&D department, or slightly changing this test report. Since this is a complicated module, creating new test reports is not an option for the CCH arms.

In Figure 3.9 the general steps are shown with the two options that were used for the CCH arms. The OE department addressed that whenever the main configuration is used in a machine they use the standard version for the test report, and when there is a change/option added they check if the test report is still valid. If there are changes that can go wrong they will address this and slightly change the test report.

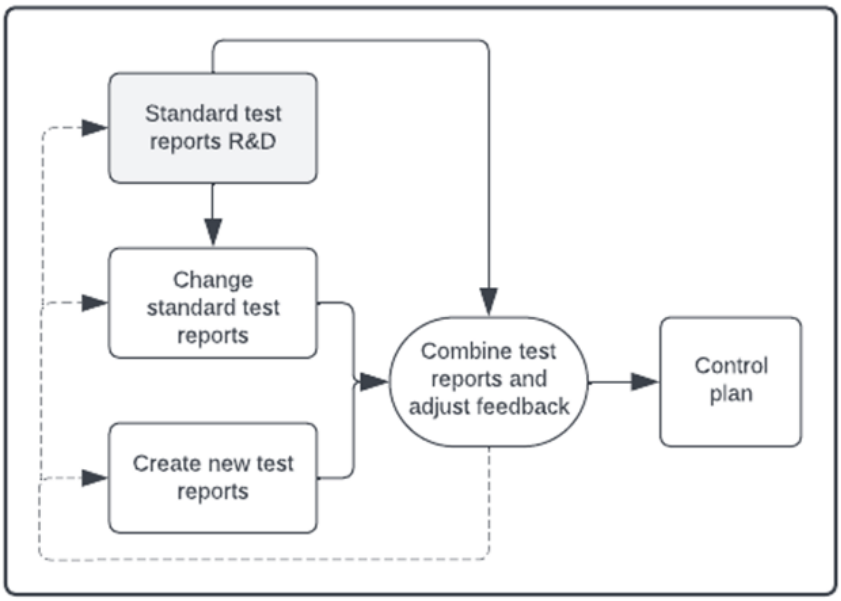


Figure 3.9: Order Engineering process steps in Use-Case

Production

The use-case for the production process is performed by checking if the actual processes described in the work instructions match the actual procedure. The CCH arms are defined as 'cabinet/sub-submodule' in the general production process. A few changes were noticed when comparing the actual process with the documented process. The operator had some changes made to his personal work instruction, in order to optimise the assembly process. Next to these small changes, experience was needed to effectively assemble the product such as special grease methods that were not documented.

Testing

Testing can be performed two times in the production process. Since the CCH arms belong to the CCH, a sub-module, sub-module testing could be an option. However, for the CCH, this is not possible, and the first option would be full module testing. The test plan created for the full module, including the CCH arms, has two test functions performed. The test engineers test two parts of the CCH arms in the main test: rotation and horizontal movement. The tests documented are the same as within the actual process and have built-in safety features. This is performed at a slow movement speed to minimise big failures if there is a fault in the production process. To test if the software matches the actual product, a check within the test software is programmed. With this test, the test engineer is forced to measure part of the movement of the CCH arms and check these data with the software. This software has a random deviation, which makes it impossible to skip this check without actually measuring if it is correct. A full test of a module can take from a few weeks up to eight weeks for completely new modules.

3.4 Quality process VMI overview

Finally, the quality of different steps is combined with the measurement points in Figure 3.10 and 3.11 to give an overview of the global steps of the production quality control process. This process combines the different information from the engineering and the production processes from the official structured documents, added with information from the use case.

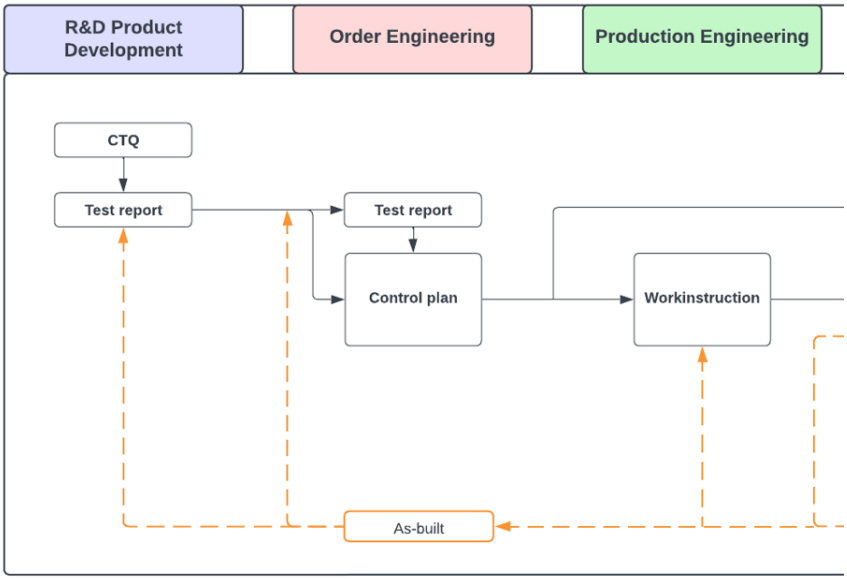


Figure 3.10: Part1: Current steps in the quality process of VMI

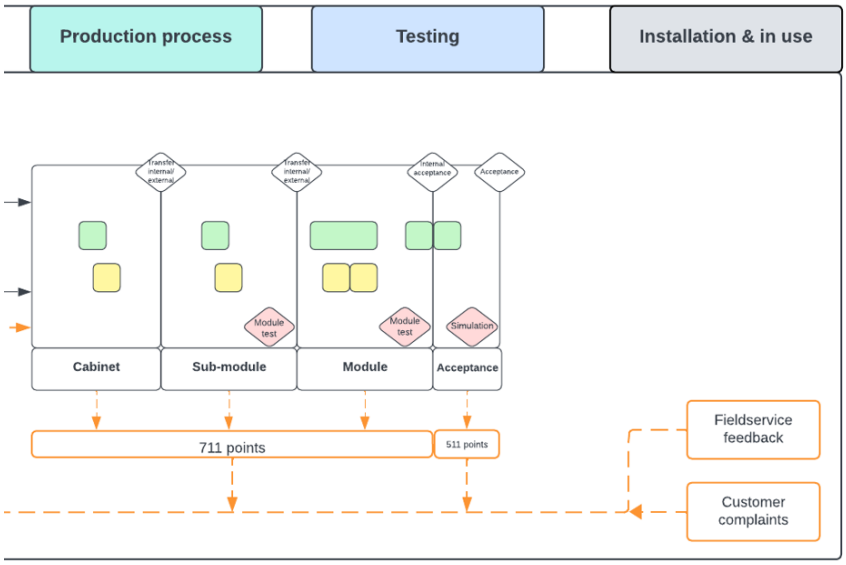


Figure 3.11: Part2: Current steps in the quality process of VMI

3.5 Expected and desired level of quality

The current expected and future desired quality levels are not documented but have to be acquired from the people responsible for setting the targets and monitoring the production process. The production management, consisting of the vice president global production and the three production managers, is responsible for these processes in Epe as well as Yantai and Leszno. This section is split up in two parts, first up the current expected level of quality that is present in the factory in Epe, followed by the desired level of quality in the future.

Expected level of quality

The expected level of quality by the production management, on the production process quality can be summarised by a few different points: uniform process, correct engineering drawings/standards, <1% of mistakes. The production management has the same expectations of quality across the different factories. Since different subsub/sub or modules travel across the different factories, each of the factories has to be able to assume that the product is of the same quality as when they would have produced it. The production management team strongly believes that in order to have a high-quality process with high-quality output, having a high-quality input is important.

Desired level of quality

To get to the desired level of quality different goals are discussed, short and long-term with the production management team. The production management team monitors the quality process and sets the targets. This resulted in the following statements: VMI would like to be more proactive in process quality-related activities, eliminate extra/unnecessary steps, have quality measure (report) points at the right time in the process and see whether or not test reports can be made digital in new or existing software.

Adding to these process improvements VMI would like a global overview with an adaptive plan/have a controlled process and use a structured 8D/root-cause technique to solve problems that do occur during the production process. Next to these points, there were other desires which were relieving field service of 'extra work' by creating sub-modules that are easier to install/align at the customers and seeing if all the sub- and subsub-modules are tested as efficiently/at the right time.

Having optimistic quality level desires is good, but VMI is not an aircraft or spacecraft manufacturer, some mistakes are allowed to happen. Even though mistakes are allowed, VMI still has the goal to achieve the least amount of mistakes possible. The return on the level of quality has to reflect the cost that this level of quality requires. Zero mistakes would be ideal, but this is not realistic [89].

The desires by the production management team can be summarised:

- A more proactive approach
- Finding root causes of the problems (8D)
- Change the current test reports (possible digitisation)
- Eliminate extra/unnecessary steps
- Relieve fieldservice of 'extra' work
- Testing the right modules effectively/at the right time
- Quality measure (report) at the right time in the process
- Global overview for an adaptive control plan/controlled quality process

3.6 Conclusion

The sub-question **"What is the current situation at VMI?"** is answered in this chapter by studying the internal document 'VMI Main Process for Order Scheme' and focusing on the relevant departments/processes in this overview. The main departments that influence the process quality are R&D, OE, Production and Testing departments, with support from the problem-solving/QPM process. A use-case is performed on a sub-module in the factory to verify these processes and to create a structure for an undocumented quality process. This use case helped describe the R&D and OE processes for creating test reports/control plans since there is no structure in internal documentation. Adding to these findings, the expected and desired levels of quality are described based on the production management perspective. The production process is satisfied with the internal reactive process within the production department but would like to be more proactive in quality management and have a structured approach towards problem-solving and quality tools and techniques.

4 PERFORMANCE ANALYSIS

This chapter consists of two sub-questions. The first sub-question is **"What is the current measure of quality at VMI?"** This sub-question is aimed towards measuring the current situation at VMI and putting it in a model from where it can be analysed. Section 4.1 focuses first on developing a model based on three levels of performance and QFD as described in Section 2.2. This section is followed by Section 4.2, which describes the current situation at VMI in the three levels of performance and the phases of QFD. By creating this model, an efficient analysis between the literature model and the current situation can be performed.

The second sub-question that is answered in this chapter is **"What is the current performance of the Quality Process at VMI?"**. This performance analysis is executed in Section 4.3, which highlights all the differences between the two models, based on the three levels of performance. Section 4.4 focuses on determining the focus points for the quality plan by discussing the most important differences between the two models. The final step in this section is comparing these determined focus points with the management's focus points from Section 3.4.

4.1 The PQAM Model

For the performance analysis, the literature from Section 2.2 is used to analyse the current situation at VMI. As described in this section, the literature is used to create an analysis model, which is called the Process Quality Analysis Model (PQAM). This model used the information from the standard QFD approach and described the model of the three levels of performance (TLP) by Brache and Rummler. The PQAM is shown in Figure 4.1 below and will be used for the comparison of this chapter.

The analysis framework combines the three levels of quality performance with the QFD model to create a structured model to analyse the VMI quality process. By taking the TLP approach the QFD method can be described in the same three levels. The first level, the organisation level, is the main level on which the global activities and focus is described. The activities per phase are described in the previous section in Table 2.3. The second level, the process level, is shown in Figure 2.6 with the information out from from the How? and How much? to the following phase. The final part is the job/technique level which is given by the different tools and techniques that are performed in each of the QFD phases shown in Table 2.3.

The combination of these three focus levels with the information from the QFD model creates an analysis model shown in Figure 4.1. This model, the Process Quality Model (PQAM), is used for the analysis of the current situation in Chapter 4.

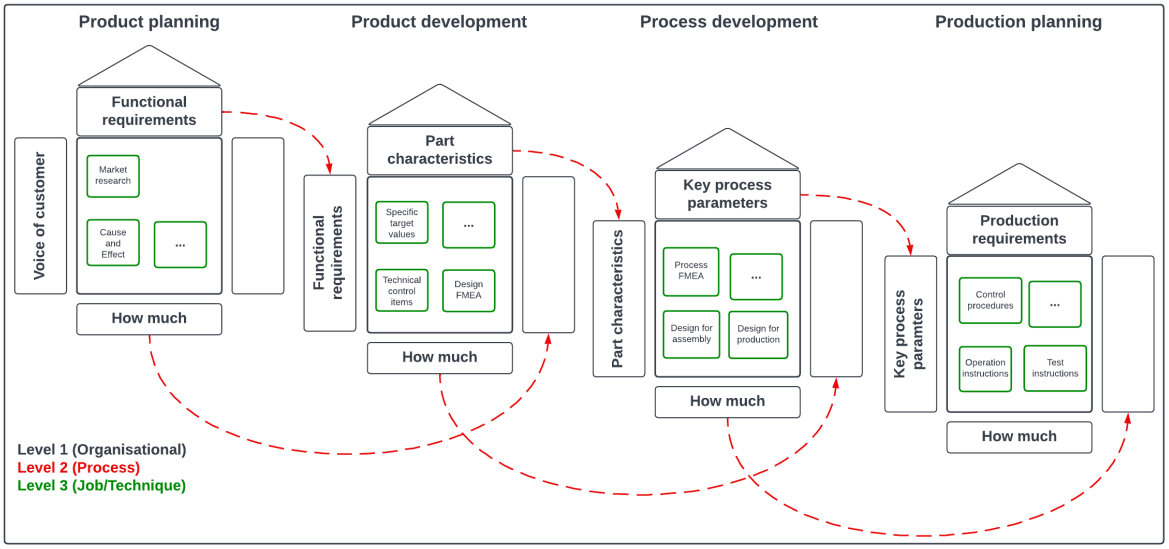


Figure 4.1: The combined literature model: The Process Quality Analysis Model (PQAM)

4.2 Current Situation Measure of Quality

To have an effective analysis, the current process has to be measured. If this measure is not performed correctly, the performance analysis in Section 4.3 will be ineffective. The current process is described in an analysis framework based on the same three levels of performance (TLP), as used in the literature study.. Each of these levels is described in analysis framework by explaining the current steps into the four phases of QFD: product planning, product development, process development and production planning.

4.2.1 Organisational Level Situation at VMI

To explain the current development process into the four phases of QFD the internal document of the development in Figure 3.1 is used. This model is split up into two different phases. The first phase is the general development process. In this phase, the development and preperations for the general machine is made. The second phase includes the development of the order-specific machine for the customer, which can verify from being close to the original machine or completely changed with different options. The first split is shown in figure 4.2 of describing the current process into the four development phases on two different levels.

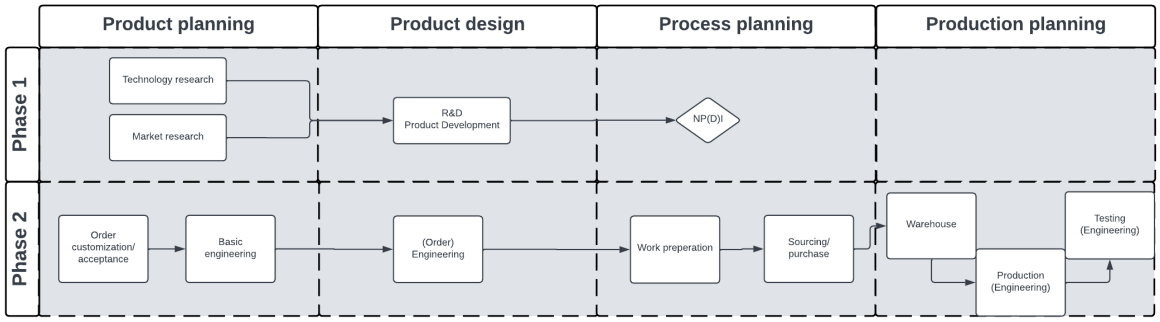


Figure 4.2: The development process split into two configurations, divided across four phases.

The second step in creating this framework is shown in Figure 4.3. The non-essential departments are removed and the connection between the departments in the two split levels is shown.

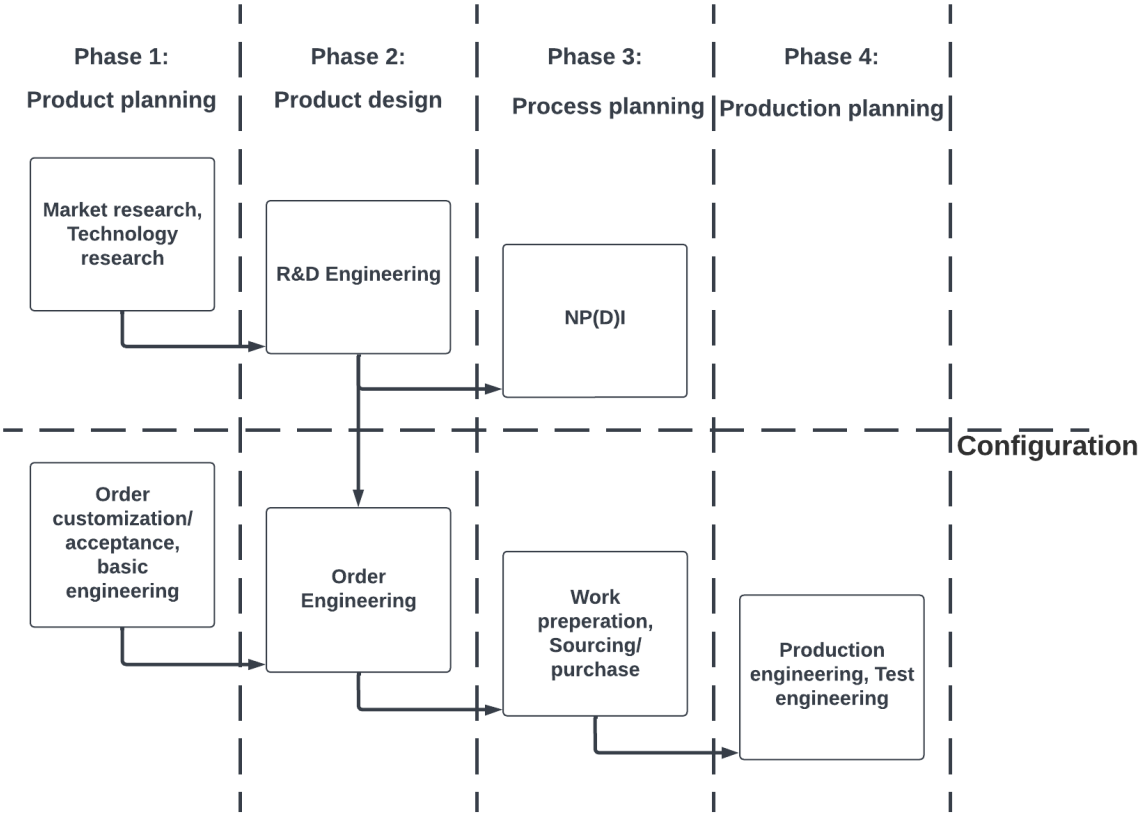


Figure 4.3: Analysis framework of the current situation at VMI.

The last step is describing the global goals and deliverables per phase, based on the department. Table 4.1 below describes the different aims per phase, as the QFD model described in Table 2.3. This overview will be used for the performance analysis on organisational level in Chapter 4.

Activities VMI	Product planning	Product development	Process development	Production planning
Original phase	Market research, customer satisfaction, technical requirments, technology push	Design new products, adjust existing products	Prepare product for logistics/sourcing/production	
Configuration phase	Customer satisfaction, Technical requirements/changes	Design new products, adjust existing products	Logistical work preparation, technical work preparation	Prepare production for new machines/modules

Table 4.1: Deliverables per phase of the current VMI process

4.2.2 Job/Technique Level Situation at VMI

According to TLP, the Job/Technique level would be the third level after the process level, but for this creating the models it is changed. Since the process level describes the techniques between the activities, first the activities have to be detailed. Table 4.2 describes the process quality tools and techniques in the current process at VMI, based on the departments and their

deliverables from Figure 4.1. This model is used for the performance analysis on Job/Technique level in Section 4.3.3.

Tools and Techniques VMI	Product planning	Product development	Process development	Production planning
Original phase		Test report		
Configuration phase		Test report, Control plan		Work instruction, Training manuals, test plan

Table 4.2: Tools and technique framework of the current situation at VMI

4.2.3 Process Level Situation at VMI

To describe the process level of the current situation at VMI, the tools and techniques from Figure 4.2 are used. Figure 4.4 shows the connection between the activities of the quality process at VMI. Next to the activities, the feedback points from the solving processes/QPM from Section 3.2.4 is added. This example is used for the process level comparison from Section 4.3.2.

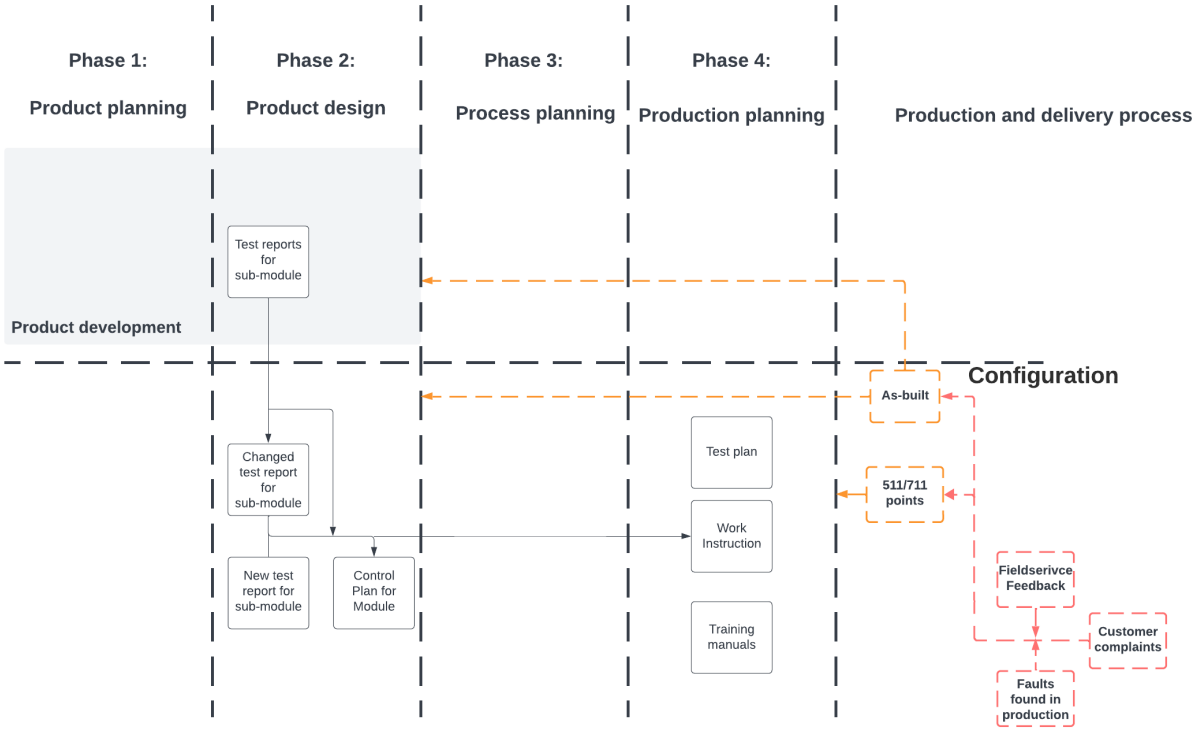


Figure 4.4: Configuration overview VMI

4.3 Performance analysis of the quality level

4.3.1 Organisational level

The first analysis level is on the organisational level, which includes an analysis of the global processes. This analysis is assisted by the general process used at VMI, compared to the PQAM model. In Figure 4.3 the main focus points from each of the models are shown, based on the four phases of QFD. The first phase, product planning has a similar intent. Since there is an in-depth description of this first phase in Chapter 3, not all the exact focus points of this phase at VMI are shown.

The first big difference in activities is in the product development phase. The VMI example is mainly focused on the development of the product, and creating test plans/control plans. Inside the development phase of VMI many many different activities are present, but these are not focused towards the production process quality. The PQAM model shows the design of a product/concept as well, but adds deliverables for thinking about process quality-related issues. For example, the analysis of the relationships of the design requirements and the identification of critical part characteristics shows this philosophy. These deliverables focus on determining possible critical parts early on in the process.

The following phase, the process development phase, the focus from VMI and PQAM is quite different. PQAM focuses on determining critical parts and seeing how these can be minimised or eliminated by evaluating these risks in assembly/production. VMI focuses on preparing the actual product for the production process, but none of these activities focus towards process quality. These activities do influence the quality process indirectly, such as the quality of the parts or product that are bought, or how well logistical or technical work preparation prepare the production process.

The production planning phase has different focuses between the models. In the VMI situation, the final preparation for the production process starts, with focus on supplying the factory with documentation or training instructions to prepare for a new or changed machine. The PQAM model focuses on setting up actual processes in for the production process to minimise the possible issues found in the process development phase. Next to these activities, the PQAM model sets up production planning and production control with a monitoring process.

Activities Comparison Table			
Phases	Quality Function Deployment	Current VMI Situation	
		General	Customization
Product planning	- Identify customer requirements - Translate VOC into design specifications or product control characteristics - Prioritize requirements - Evaluate competition	- Market research - Customer satisfaction - Technical requirements - Technology push	- Customer satisfaction - Technical requirements/changes
Product development	- Generate ideas of concepts - Develop alternative products and concepts - Evaluate the design - Analyze the relationship between the design requirements for each product feature - Identify critical part characteristics - Translate the outputs of the product planning phase into individual part details that define part charateristics - Detail characterstrics for product design and componenents, functions defined, reliability and cost estimates	- Design new products - Develop test plans	- Design new products - Adjust existing products - Adjust/develop test plans - Create Control Plans
Process development	- Analyze and evaluate alternative designs for processes - Compare relationship between process parameters and critical part characteristics - Identify process risks/check/control points - Identify and eliminate non-value adding elements - Identify part/process relationships	- Prepare for logistics - Prepare for sourcing - Prepare for production/testing	- Logistical work preparation - Sourcing/supply buying - Technical work preparation
Production planning	- Develop specific process controls - Set up Production Planning and Controls - Prepare visuals of the critical process parameters for everyone to understand (Seiketsu) - Train workers and ensure on the job guidance and supervision - Translate control plan into procedures - Develop production operating plan/work instructions - Define performance indicators to monitor the production process		- Prepare production for new machines/modules

Table 4.3: Comparison on Organisational level between QFD and the VMI quality model

4.3.2 Process level

For the process level, the connection between the different phases of the VMI quality process is compared to the QFD process. In the PQAM model in Figure 4.1 the connectivity between functional requirements and the Voice of Customer (VOC) is seen together with the connection between the different activities

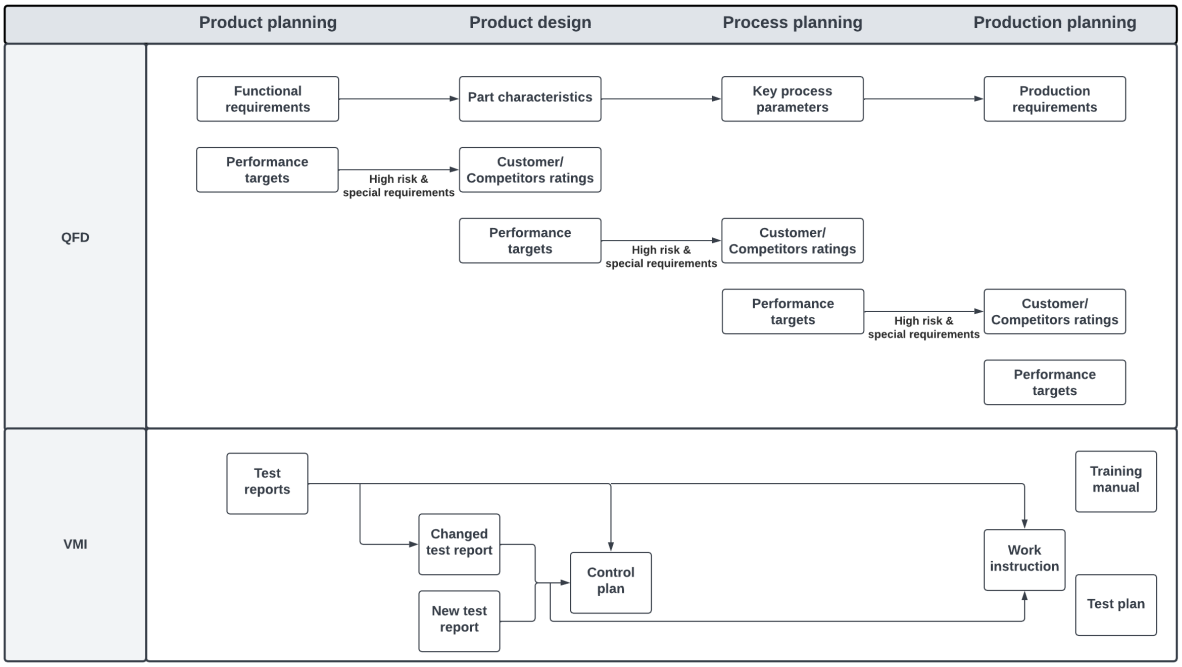


Figure 4.5: Comparison on process level between QFD and the VMI quality model

4.3.3 Job/technique level

For analysis on the third level, the techniques and tools from the QFD approach are compared to the ones used at VMI. Table 4.4 shows the differences between the tools and techniques between the PQAM model and the current situation at VMI. It can be seen that VMI only offers a few deliverables in the product development and production planning phase. The product development phase at VMI is used to design the product and cover the quality issues directly. There are no process development steps to think about how to address these possible quality issues in the assembly process effectively and followed by the actual step in the factory. The current situation at VMI is that the product development phase delivers certain test reports and control plans, and that in the final stage at production extra documentation is created to support the production process. For work instruction or training deliverables, there is no structured approach as well, for complicated items they create work instructions or trainings, but these are often adjusted or created during the production process.

Tools and Techniques Comparison Table			
Phases	Quality Function Deployment	Current VMI Situation	
		General	Customization
Product planning	- Market study/research - Trend analysis - Competitor analysis - Competttitive benchmarking - Regulatory requirements		
Product development	- Fault Tree Analysis (FTA) - (Design) FMEA	- Test reports	- Test reports - Control plan
Process development	- Flow diagrams and process sheets - (Process) FMEA - Design for Production - Design for Assembly - Test planning		
Production planning	- Master flow diagram - Operation instruction charts - Production layout - Proces charts - Poka-yoke - Maintenance plans and schedules - Control plan - Logistics - Test instructions		- Work instructions - Test plan - Training manuals

Table 4.4: Comparison of Job/Technique level between QFD and the VMI quality model

4.4 Main process improvement focus points

With the overview of all the differences from the previous section, some issues stand out more than others. From each of the TLP a main focus point is picked, starting with the organisational level. On this level, the main difference between the PQAM and VMI models is the responsibility of what happens in what phase and by whom. the activities from the PQAM model align well between the phases and create a good overview. The VMI model has a few activities, but the connection between these deliverables needs to be more structured and explained how these effectively connect.

When looking at the differences between the process level of the PQAM and the VMI level the connection between phases and activities is indicated. While the PQAM model uses a structured approach of what gets used for the next activity, the VMI model has different deliverables that do not align with other activities.

The Job/Technique level has similar results to the previous two phases, but in this part, the need for an actual structured approach to techniques is shown. While the PQAM model has techniques such as DFMEA and PFMEA that align for each phase and tackle different issues on different levels this is not present in the VMI model. For the PQAM model, the information such as the critical parts from the previous phases, gets used to minimise failures by techniques such as poka-yoke further, and otherwise inserted in a control plan.

To summarise the main differences between the two models, the differences can be translated into three main focus points:

- Deliverables per phase/ responsibilities per department
- Data management between processes
- Structured approach to quality management techniques

The selected focus points are compared to the management's perspective from Section 3.4 to see if the focus points align with the desires of VMI. In Table 4.5 below, the management goals are shown and which focus point can fulfil/improve this goal and what parts are left out.

Management goals\ Focus points	Deliverables and responsibilities per phase/department	Data management between processes	Structured approach to quality management techniques
More proactive	x	x	x
Root-cause of problems/structured (8D) approach			x
Change in test reports (possibly with digitalization/maximo)		x	x
Eliminate extra/unnecessary steps	x	x	x
Relieving fieldservice of 'extra' work			
Testing the right modules as effectively/at the right time			
Quality measure (reports) points at the right time in the process		x	x
Global overview for an adaptive control plan/controlled quality process	x	x	x

Table 4.5: Focus points per management goal

4.5 Conclusion

This chapter answers the sub-questions: **"What is the current measure of Quality at VMI?"** and **"What is the current performance of the quality process at VMI?"** by comparing the current quality process at VMI against the PQAM model. The first section creates the PQAM model, which combines Quality Function Deployment and the Three levels of performance: Organisational, Process and Job/Technique. To get an effective performance analysis, the current situation is divided into the same phases described in QFD: product planning, product development, process development, and production planning. This section focuses on describing the steps in order to model the current situation in the same phases. The difference is that this process is split into two phases: standard configuration and custom order.

After describing both models, the performance analysis is performed. This analysis does not describe what is right and wrong about the current quality process, but it shows the main differences between the two models. Four focus points for improvement are chosen based on these differences and the production management's desires. The main focus points are the deliverables and activities within the phases and the responsibilities, the data management of all the quality (control) documents and the structure and connectivity between quality techniques.

5 DESIGNING A QUALITY PLAN

This chapter covers the sub-question: **What would be a suitable quality plan to increase and maintain the quality of the production process at VMI?** This question is answered in five sections, the first three sections are towards the alternatives based on the three levels of performance: organisational, process and job/technique. The first section focuses on the first level of performance; the organisational level. For this level the six quality management models from Section 2.3.2 are compared and assessed on what approach would suit VMI's situation best.

The second section focuses on the second level; the process level. For this section the different CMMI-DEV process management models from Section 2.2.3 are compared and which data management model would be the most applicable for this quality plan. The third section contains the job/technique level. This section assesses the tools and techniques from Section 2.3.4. The fourth section combines the different choices into a quality plan and adjusts different models to create a suitable quality plan that is applicable to VMI and uses the strengths from each of the philosophies from each level of performance.. The fifth section summarises the steps into a final quality model.

5.1 Organisational level

The first level of performance, the organisational level, looks at the macro systems of the organisation. In this case, the general quality model approach and its focus points. From the performance analysis, the main focus point on the organisation level is the deliverables per phase and responsibilities per department. When studying the possible alternatives of Table 2.5 a few of these QM models do not suit this approach immediately. Lean manufacturing (TPS) and Theory of Constraints (TOC) do not describe activities or steps in the development process. Because of this reason, these models are not the best solution for this focus point of the quality plan.

Next to these two models, the following two models do not find the best application for the problem at VMI: TPM and Six Sigma. TPM is focused on overall equipment effectiveness and availability, which is not a VMI focus for the quality process. VMI does not have a production line that produces thousands of products per hour but mainly focuses on assembly. For the same reason, Six Sigma is not a fitting solution since it focuses on statistical approaches to high-quantity production, which is not applicable at VMI. Another variation of Six Sigma, DfSS, which is mentioned as well is focused on delivering 'first time right' and 'zero mistakes' in the development process, which is not the main goal for VMI.

Two of the best-suited alternatives are the ISO QMS and the TQM approach. Both of these models focus on the quality of products and processes, but the effectiveness on companies' performance is different. Since ISO is a more generic approach, companies do not always make a positive impact with the implementation of a complete ISO QMS. Kumar, Maiti and Gunasekaran executed research into the performance differences when implementing ISO and TQM and reported that only 63% of companies had a positive impact on the firm's performance when implementing ISO 9000 QMS, and 87% had a positive impact when implementing TQM [20]. Because of this reason together with TQM focusing more on the new product development process the TQM philosophy is used.

Although TQM focuses on the quality of products and processes, especially during the development phase, TQM does not have a structured model or approach available. TQM uses a collection of many tools and techniques to manage the processes, which is further researched at the job/technique level in Section 5.3. One strength of TQM is to be a centralised organisation, to achieve this TQM has eight factors that influence the degree of centralisation [4]:

1. Size of the company
2. Geographical distances of individual units
3. The technology used and the type of production methods
4. Number of working shifts
5. Possible use of subcontractors
6. Internal relationship between each department, as well as the management
7. Level of training and reliability of the workforce
8. Management policy

On factors one, two, four, five and eight the quality plan has little to no influence. The main focus is on Technology and type of production, internal relationships between departments, and the workforce's level of training and reliability. The primary influence of the quality plan is focused on these three points to get a more centralised organisation for a suitable quality plan for VMI.

5.2 Process level

As described before, the TQM philosophy supports a centralised organisation, which should also mean the processes are well aligned. To have correctly aligned processes, some form of data management approach is required, as described in the performance analysis in Chapter 5. A further look into these subjects gives the following results that can be implemented into a new/re-designed quality model.

Risk management and requirements management share the data management philosophy from the three types of data management discussed in Chapter 2. Still, they are less suitable for application for the data management of the process steps and activities. Configuration management describes a configuration as a set of configuration units. These configuration units are connected and have to be updated when the 'parent' gets changed. The configuration unit philosophy is displayed in the four development phases, such as used in the analysis framework. The different phases are connected and when changes are applied, they have to be solved as high up in the chain as needed. To follow the philosophy of the Configuration Units (CU) sub-units can be added to align the information within the phases called Configuration Sub-Units (CSU).

5.3 Technique level

When looking into the third level of quality performance, the job-level, a look into the possible techniques is performed. The commonly used tools in quality management, as reviewed in Chapter 2, contain check/control lists, PFMEA and QFD. Check/control lists and different types of FMEA are helpful to implement in a new quality plan, depending on what phase of the development. QFD does however describe a more detailed process.

The different alternatives of QFD in Chapter 2 have different approaches, but QFD in Integrated Quality Information System (iQFD) by Chang describes an actual process in different phases and steps and is focused on production performance and preventing defects. Those factors will lead to better performance, products, service and eventually sales [3, 90]. The other QFD approaches

The iQFD approach describes three stages: preproduction, production and postproduction. The quality plan focuses on the preproduction phase, which is the development phase. The different steps in the preproduction phase of iQFD are described below in the four phases: production planning, product development, process development and production planning. The base framework is given in the next section, with removed out-of-scope activities.

5.4 Combining the alternatives

The three suitable solutions based on the three levels of performance are shown above. In order to design a new quality plan the different philosophies from section 5.1 have to be supplemented and used to create a base for designing the quality plan. A tailored Quality Control Plan (QCP) is recommended to increase the chance of a successful implementation and adoption by an organisation [91]. For the development of the quality plan for VMI the base of integrated QFD is picked, as mentioned in the previous section. The design of the quality plan starts with a base model by iQFD and from there the changes towards this model are given.

5.4.1 Changed Integrated QFD model

The integrated QFD (iQFD) model can be used as a base. The four phases of preproduction, as described by Chang, are put in the 'standard' QFD phases to show what parts are used where. As described in Section 2.3.4, the integrated QFD approach has many different steps and deliverables in each phase. To simplify this model, a selection of in-scope and out-of-scope activities is made.

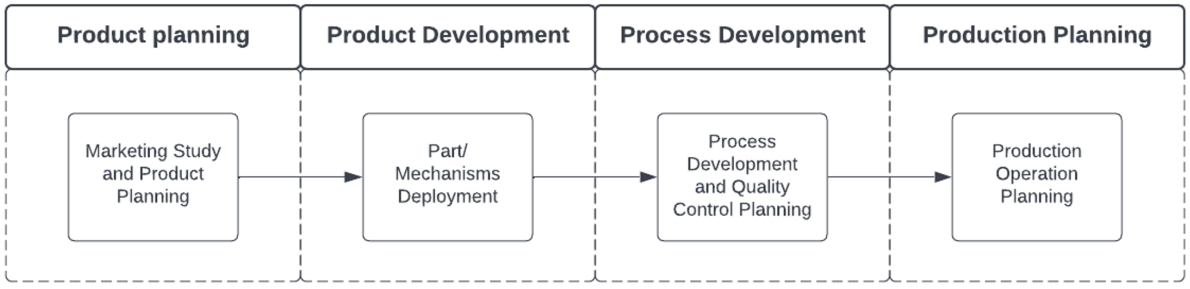


Figure 5.1: Overview Preproduction phases of iQFD [3]

Product planning

The first phase, product planning, consists of different activities before the product design/development. In this phase, iQFD describes activities such as competitor benchmarking and gathering market information, which applies to this quality plan. Figure 5.2 shows the process described by iQFD with different considerations, with its main deliverable output being the Manufacturer Controllable Production Quality Features.

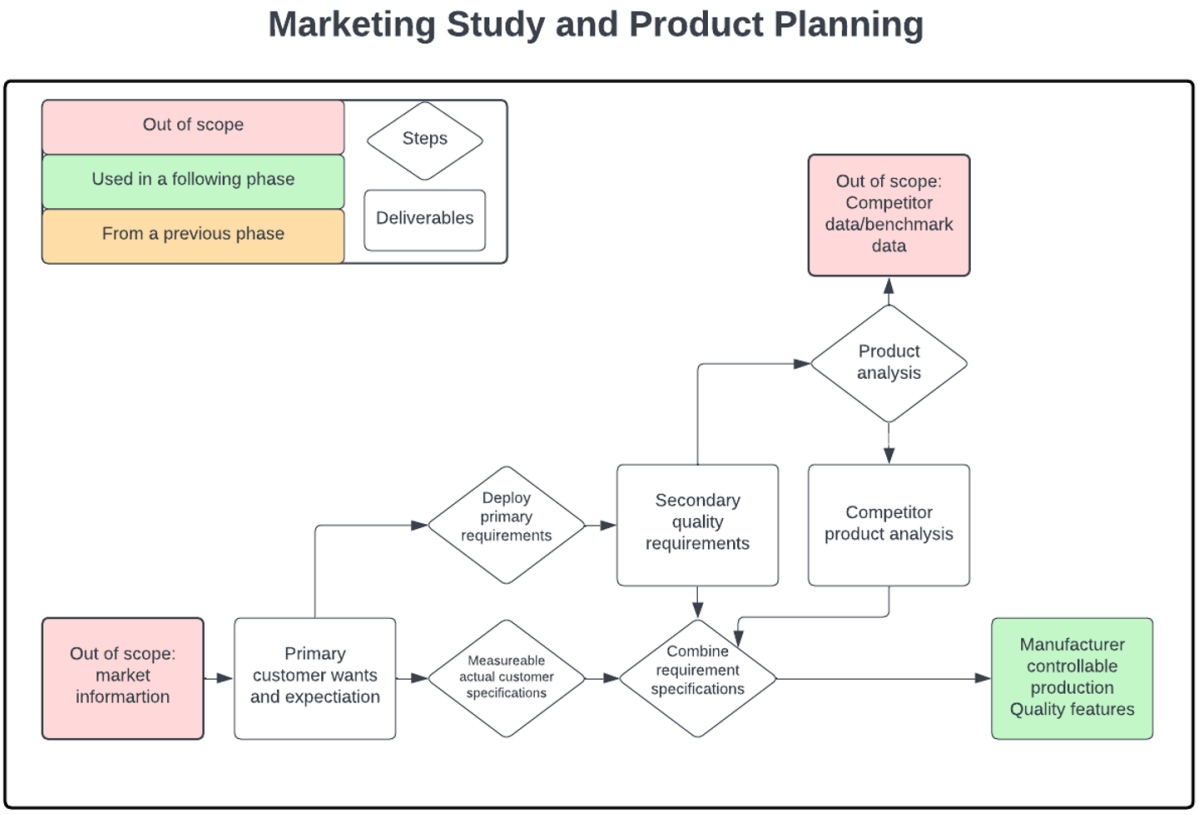


Figure 5.2: Product planning activities iQFD [3]

Product Development

The following phase consists of two steps within the phase. First, the product design focuses on using data from the previous phase or other departments, as shown in figure 5.3. This data gets used to make quality related product design choices, to finally output the Final Product Quality Control Characteristics (FPQCC). The FPQCC is the main deliverable output from the product design that gets used in the Part/Mechanism Deployment. The information from the FPQCC gets used together with supplier information to determine possible new combined components risks and set up a Critical Component-Part Characteristics list.

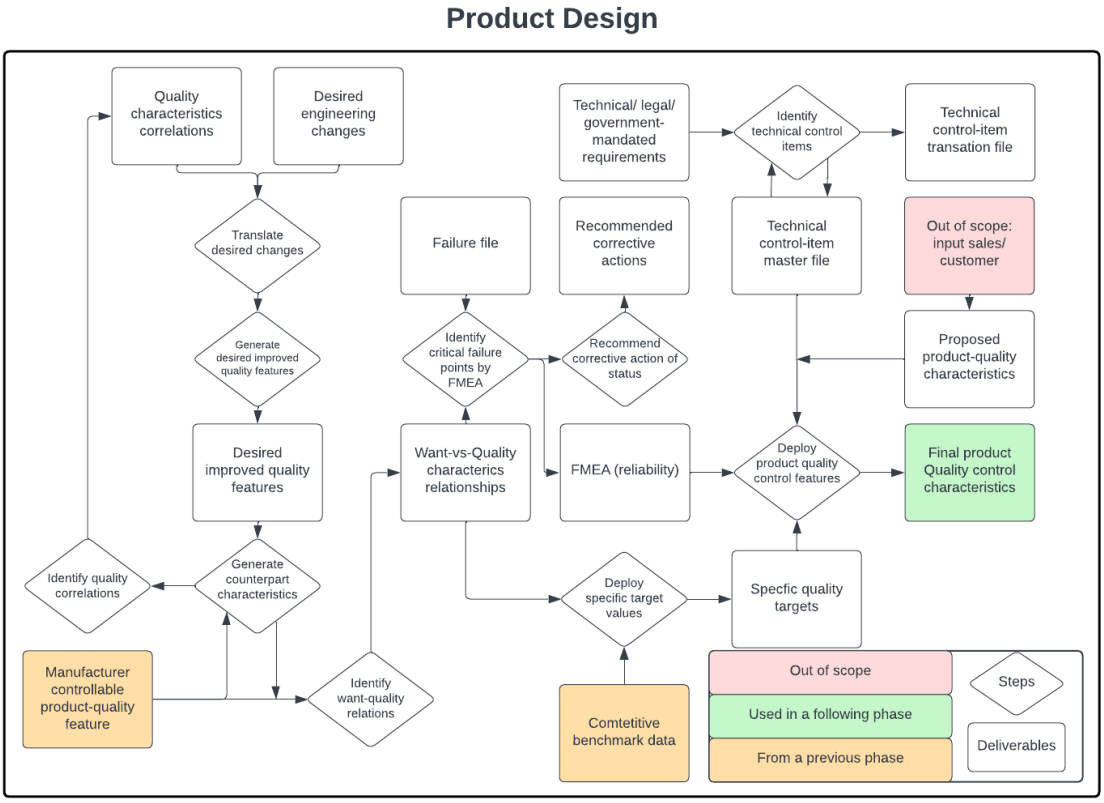


Figure 5.3: Product Design Stage (Part of Product Development)

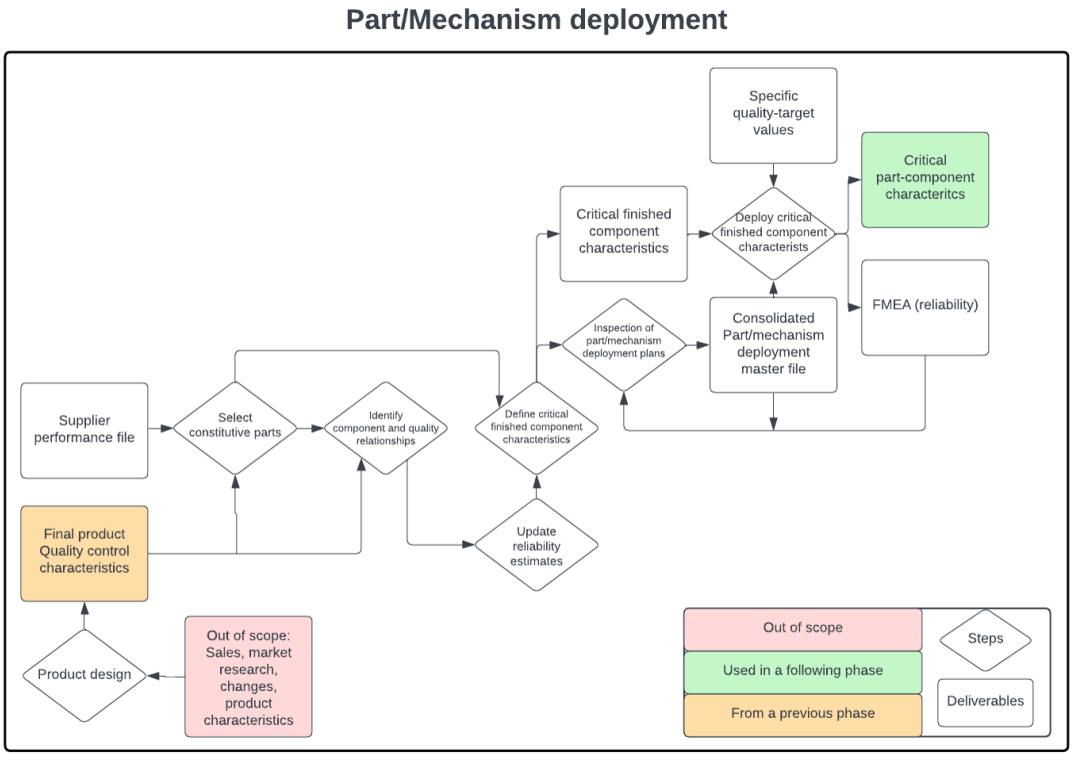


Figure 5.4: Product development activities engineering and supplier

Process Development

The process development phase, shown in Figure 5.5, takes the FPQCC as an input and starting point for determining the process risks. The first step of this phase is creating a key process operation list and a critical part/process relationship list. The key process operation is the predicted, rough idea of how the module and sub-modules will be assembled. After creating the lists the part/process relationships are divided into three groups: inspections, checks and control. These differences are based on the risk of the possible problems and how they can be prevented. The key process operation risks together with the control points from the part/process relationships are used in a Process FMEA (PFMEA) to determine the risks, based on personal experience and the failure mode reliability file. These risks get added together with the check points to set up a Quality Control Plan, containing the possible failures and how to prevent them.

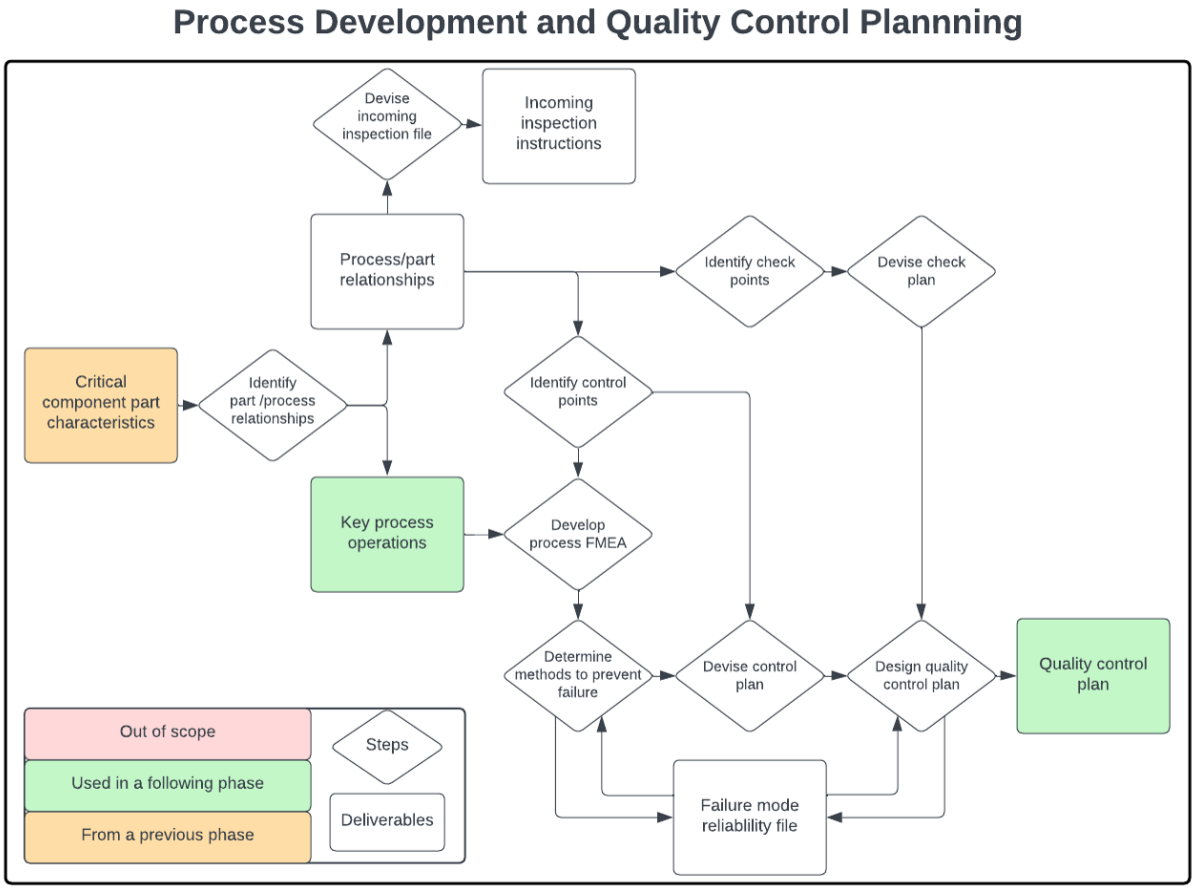


Figure 5.5: Process development activities

Production planning

The fourth phase, production planning, focuses on using the process development phase information and translating these prevention methods into actual documents or processes. The two inputs are the Key Process Operations and the Quality Control Plan. Within this phase choices are made such as are there specific equipment requirements for some of the assembly processes, are there check/control procedures are needed and are any instructions or standard training necessary. The main outputs of this phase are standard procedures, Training instructions, Operation plans, (Work)Instructions and check/control plans.

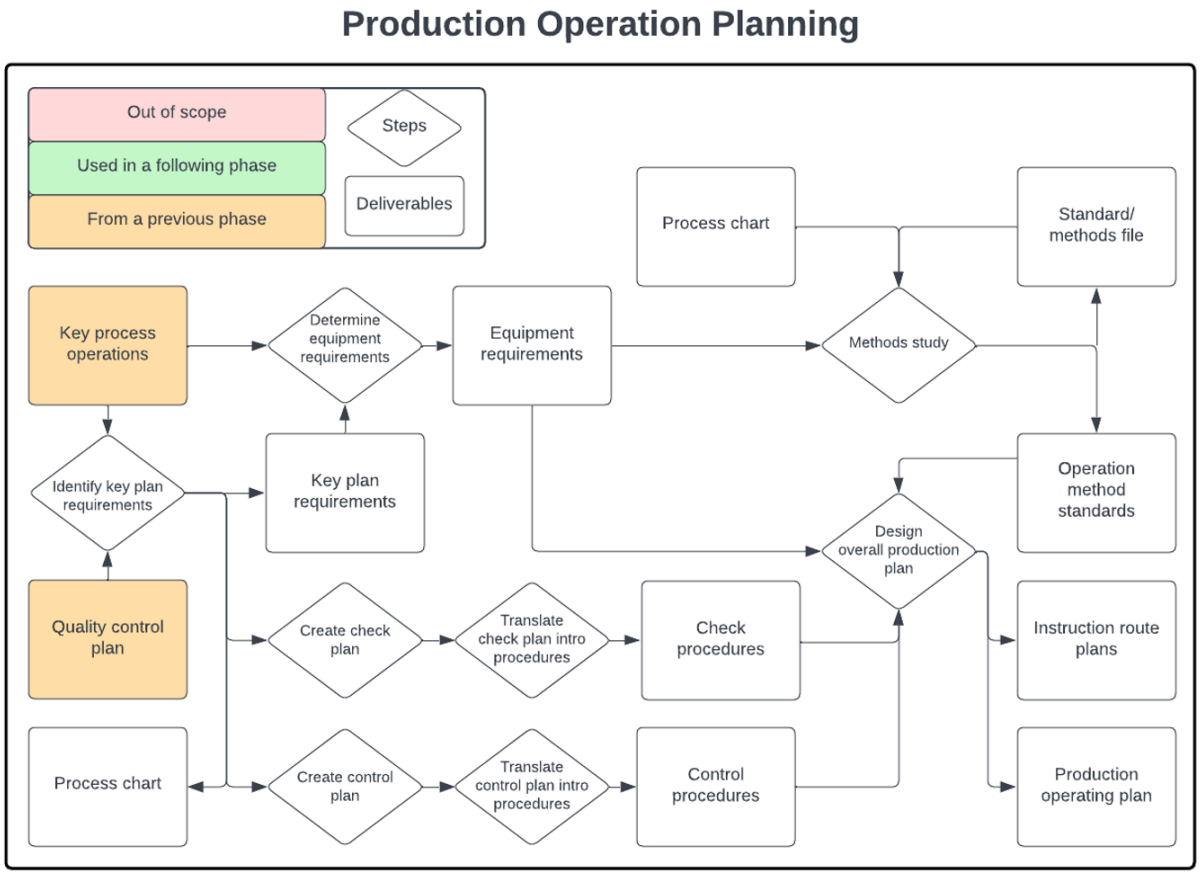


Figure 5.6: Production planning activities

This model sets the base for the development of the quality plan. The different parts are added and divided into four phases, as shown in Figure 5.1. From this base, the improvement method from the other levels of performance can be added. The organisation level described the TQM method as a beneficial approach for a possible quality plan at VMI. The main focus from the TQM philosophy that could benefit the quality plan is the degree of centralisation and the model's simplicity.

The first part is the degree of centralisation as described in Section 5.1 there are eight main influences based on the TQM philosophy. A centralised organisation would benefit the quality plan since the overall goals and processes would be created and documented from a central point. This way all the departments know what happens in what phase and can align based on the focuses. The centralisation of this model would mean that all the departments know what is expected at what stage of the development process and that multiple departments can have influence early on in the development process.

Part of this change means adjusting the first and second phases of the quality plan to a simpler approach. Product planning and product development should assist the engineering development process, not replace it. By removing the design steps, the engineering will still be free to engineer within the design process but deliver critical points for other departments to review. These changes result in a simpler version of the quality plan. This detailed quality approach by integrated QFD will be intrusive and unnecessarily complicated for use within VMI. Based on this quality model and the changes, a more effective quality model for VMI is created.

The second level of performance, the process level, describes configuration management as a beneficial method for VMI. This is based purely on the process quality activities and the philosophy of using the different configuration units with different versions to keep all the documents up to date. Figure 5.7 shows how the four Configuration Units (CU) align with each other and how they process a change request in the documentation. The important part of this approach is to apply the feedback in the correct phase and see if the following configuration units need to be updated with this new information. By following this general approach, the documents will always contain the latest changes. Maintaining up-to-date versions of all the documentation will prevent reoccurring mistakes and continuously update the technical master file for knowledge within the system.

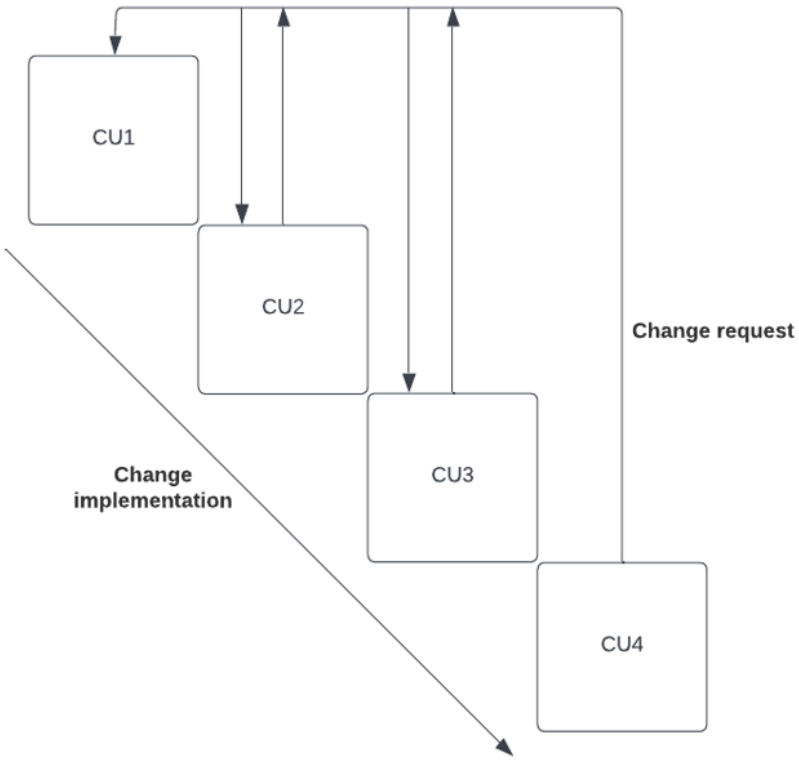


Figure 5.7: Change implementation framework

Adding to this configuration management philosophy, an approach within the configuration units is preferred. Otherwise, with every change, all the deliverables within an activity would have to be reviewed after every change. Figure 5.8 shows how, within a configuration unit, in this case, CU3, different configuration sub-units are determined. Each step contains a specific configuration sub-unit, and this approach is updated the same way as the main configuration unit approach. After every change, the newest update of the CSU gets added to the CU update and will be present in the newest overall version.

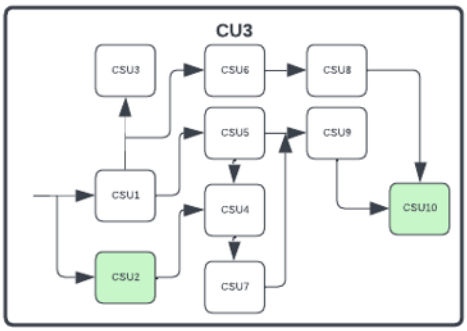


Figure 5.8: CSU Example

5.5 Quality plan for VMI

The Quality Plan for VMI contains a combination of information from the previous two sections. As explained in Section 5.2 the first two phases of the iQFD model are reduced to only a few deliverables, as shown in Figure 5.9. This provides a total of four deliverables all aimed towards determining critical features/parts or components and sharing and documenting this information early on in the development process. Knowledge can be stored in this system, since the critical product and critical component list are continuously in connection with different engineering processes and a database from suppliers and internal knowledge.

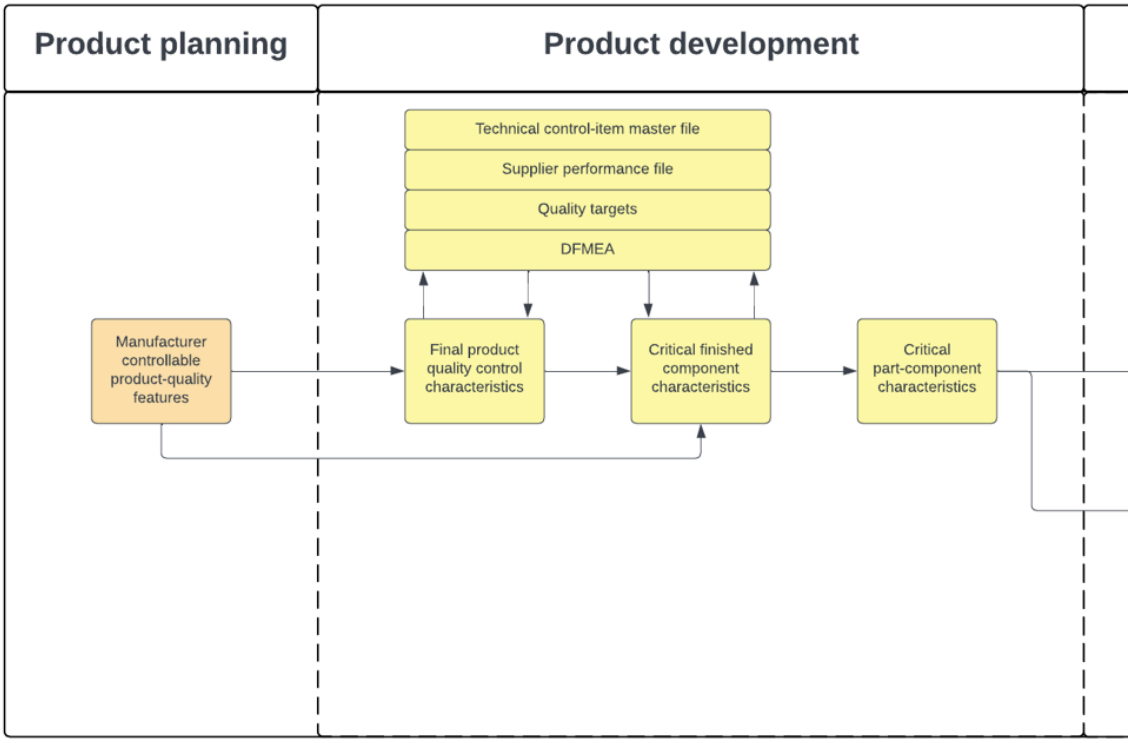


Figure 5.9: Part 1: Quality plan VMI

The second part of the quality model, shown in Figure 5.10, contains the following two phases. These phases are similar to the iQFD model and are focused on changing the critical parts and components into actual production risks with correct measures. A change made in these phases, compared to the iQFD model is that the check, control and inspection points are changed. The inspection points are focused on possible inspections on product arriving from external or internal suppliers. An example for this is seeing if the actual correct part is supplied, if there is no external difference for this part and changing this later on in the assembly process will take a lot of time. The check points are aligned with the test moments, or earlier checks based on the movement (part) of the (sub)-module. The control points focus on points on the actual production/assembly process such as tightened with the right amount of torque or the correct distance between parts.

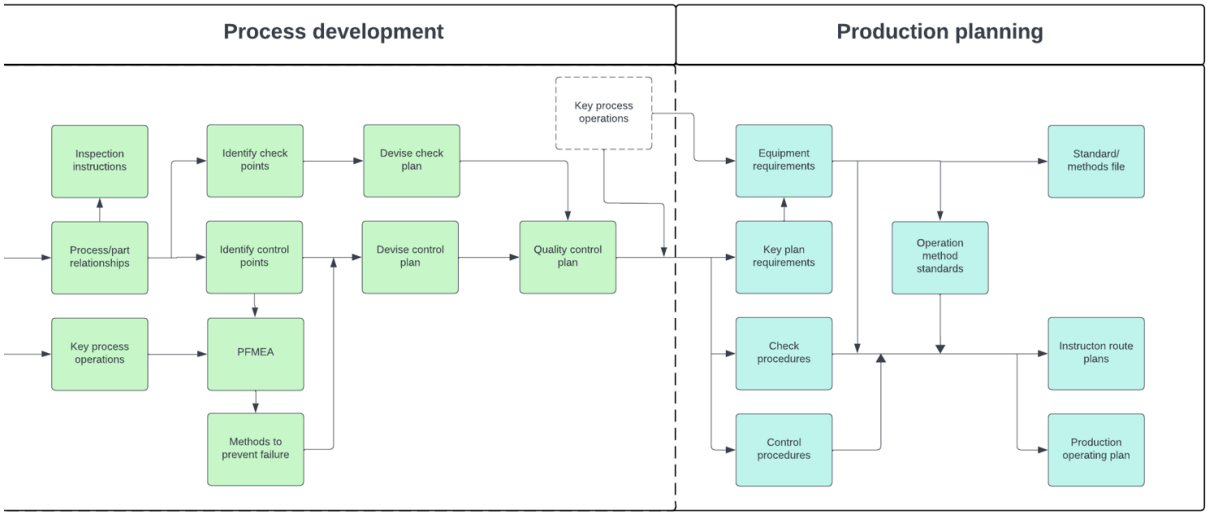
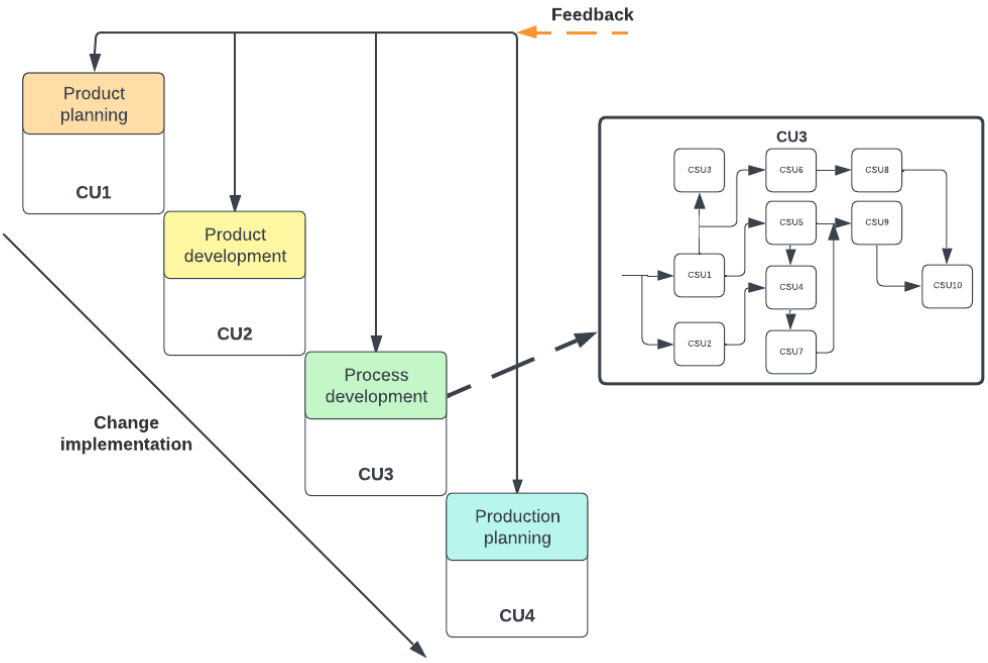


Figure 5.10: Part 2: Quality plan VMI

These four new phases are connected with the configuration management philosophy, as described in the previous section. Figure 5.5 shows the four phases, and how they process the possible feedback. This feedback finds the phase in which the feedback can be solved, and if changes are necessary all the following phases are checked for possible updates. For example, an update is required for the process development level on the Key Process Operations since certain steps are missed in the first assessment. If this deliverable changes, indicated as CSU2 in Figure 5.5, not every step in this phase should be checked. Only the deliverables that are directly connected to the Key Process Operations which will be steps CSU4, CSU7, CSU9 and CS10 have to be reviewed if they need a change.



Configuration management for the new Quality plan

Although the quality plan is focused on the proactive development approach, it gives a good overview to combine this with the current production process and see what this new situation could possibly look like. By removing the extra (undocumented) steps from Chapter 3, the different responsibilities per production phase (sub-submodule, submodule and module) can be split into documented actions and testing moments.

This overview shows the new, proactive approach from the development process combined with the current and effective reactive approach that is currently used as described in Chapter 3. The combination of these approaches makes a good approach to consider if this is a problem that has to be adjusted at the base of the quality process, or if the production step is not well executed/processed. The separation from development towards production does not indicate that these are completely separate activities. This is a general overview, but as described in this chapter the quality plan works interdepartmentally and production is involved earlier on in the process as well.

The test moments are not changed in the new quality plan. However, critical components that are found with the Check Points can be considered for extra attention during the module test or get a sub-module test. Ideally, the tests can be performed directly on a new module but in practice, this is only sometimes the case. This new approach can process this feedback and add such considerations in the process development or the production planning phase, combining and optimising the production and testing possibilities.

Figures 5.11 and 5.12 show the quality plan, connected with the current reactive production process. This gives a good overview of how this quality plan would work with the current processes.

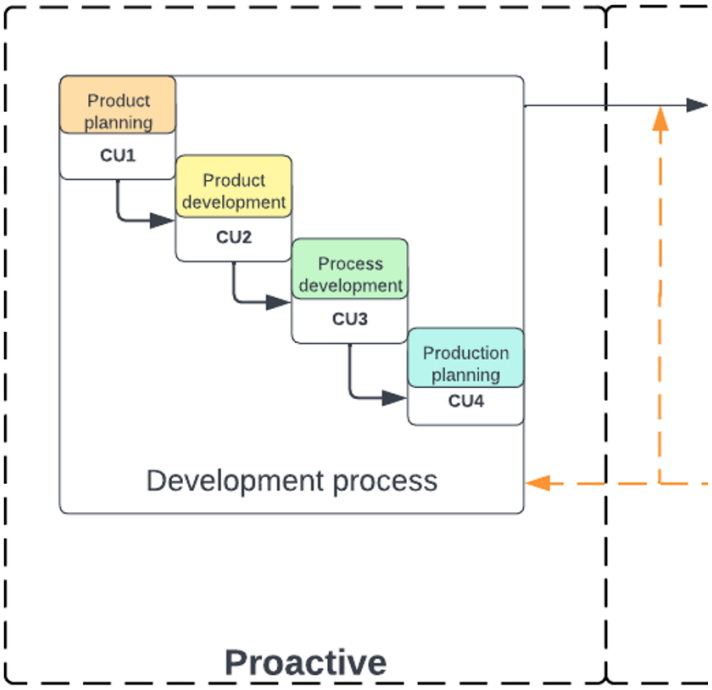


Figure 5.11: Overview of the quality plan, combined with the current production process (1)

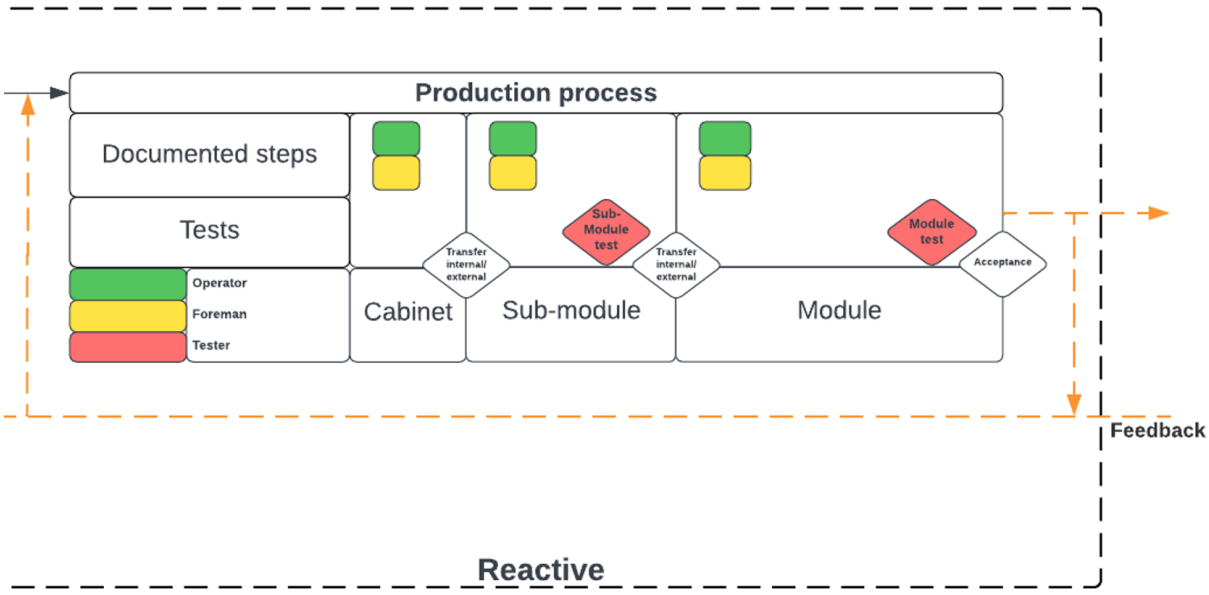


Figure 5.12: Overview of the quality plan, combined with the current production process (2)

5.6 Conclusion

The sub-question: **"What would be a suitable quality plan to increase and maintain the quality of the production process at VMI?"** is answered in this chapter, based on the focus points from Chapter 4 and the literature study in Chapter 2. The first section focuses on selecting different quality approaches on each of the three levels of performance: organisation, process and job/technique. The comparison on the organisational level determined that the TQM philosophy is the best fit for VMI. This results in a focus on three points of the eight from TQM's degree of centralisation to get a more centralised organisation.

The Process level provides the philosophy of configuration management, which is the best suit for this quality plan. Configuration management describes the version consisting of the configuration units, which fits perfectly with the different phases of development and deliverables within the phases. The Job/Technique provides a QFD framework called the integrated QFD approach. This approach describes a detailed model for three main phases of production: preproduction, production and postproduction. From this model, the steps from the preproduction phase are picked as a base model, with the out-of-scope parts of this report removed.

The main changes to this base model were made in the first two phases of the development process: product planning and product development. Many steps are removed, and only the deliverables for critical parts and components are kept; these are updated with a database on critical items and assessed by techniques such as a design FMEA. By simplifying this model, the current engineering process can be kept, and these deliverables are added to share and discuss these points early on with other departments.

6 VALIDATION OF THE QUALITY PLAN

This chapter includes validating the quality plan and answers the sub-question, **"What would a validation of the Quality Plan look like?"**. Section 6.1 addresses the goals of the validation with the main focus points. Section 6.2 describes changes to the quality plan, for it to be more suitable for a use-case-based validation. Section 6.3 shows the execution of the validation by using the same use-case example, the CCH arms, as used in Chapter 3 to describe the current situation. The final section, Section 6.5, shows the assessment of the new quality plan. This assessment is performed by different departments that influence and oversee the overall development and production process.

6.1 The goal of the validation

The validation's main goals align with the performance analysis's focus points. A use-case is performed to validate the quality plan created in the previous section. For the validation test, the following targets are set: Structured, uniform, and knowledge kept within the system. These three validation targets mainly apply to the product and process development phase, where the main focus will be on the validation phase. This is further explained in Section 6.2.

The structured system is tested by seeing if the quality approach is structured through the phases and if the responsibilities per phase/department are logical. It is important to see if the correct departments deliver the correct deliverables at the right time for feedback from different stakeholders. Uniformity is needed to expand and ensure the best connection between departments and factories. Uniformity between the departments in Epe is important to get everyone on the same page. Knowledge of the system is essential for VMI. Currently, a lot of knowledge is stored in some internal (department or factory) processes or employee heads. By preventing reoccurring mistakes and learning for new development processes the overall production process quality will improve.

6.2 Validation use-case

A use-case example is used to get a successful validation. To avoid over-complicating the validation, a sub-submodule example is picked. The example used is the CCH Arms, the same example used for the use-case in Section 3.3. Since validating a full development process would take years, the existing example is reproduced with the same stakeholders as if the quality plan was used.

The product planning phase is less relevant for this example since the product was developed over ten years ago. The two main focus phases are the product development and process development phases. The product development phase is executed with current documentation on possible faults and R&D Engineering input. Following this phase, the process development phase is executed. These steps are executed with current documentation and input from production engineering. The final phase, the production planning, is not completely detailed since

determining all the work instructions, operating plans and control items would take a lot of time and not create a clearer example. For the production planning phase, a few examples from the Quality Control Plan (QCP) from the process development phase are detailed and displayed in an overview of how an operator could use this information. The overview of the validation steps is shown in Figure 6.1.

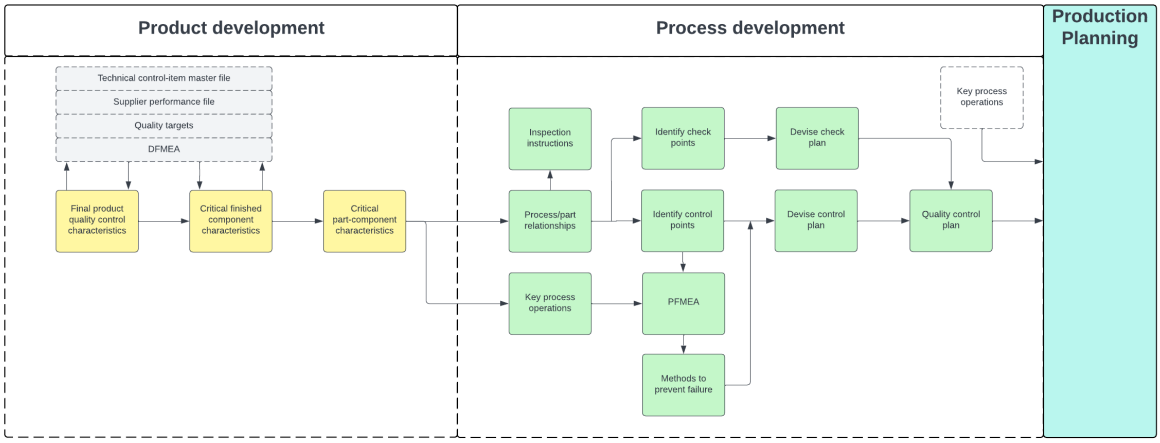


Figure 6.1: Validation version of the quality plan

Product development phase

The first phase of the validation is the product development phase. This phase contains three main deliverables: Critical Parts, Critical Components and the Critical Part-Component Characteristics. It starts with the full parts list and the standard parts get excluded. From this list, the critical parts list is created, by looking at each individual part and seeing if this part has specific characteristics that could cause quality issues. A similar list is created for each component, this is when certain parts are connected together to see if these cause new possible quality-related issues. An example used for this is when adding pulleys, bearings and a timing belt new problems can occur such as slip. Fogire 6.2 shows the use-case example for these first two steps.

Full parts list

Displacement arms	Screw	Lock nut	Set screws	Electro motor
Horizontal arm	Washer	Pulley	Fitting grease	Loctite
Rotation arm	Ball bearing	Clamping bush	M8 screw	
Clamping ring ball screw nut	Grease	Timing belt	M8 toothed washer	

Critical parts

Object/part number	Note
Displacement arms	-
Horizontal arm	-
Rotation arm	-
Clamping Ring Ball Screw Nut	-
Lock nut	Require special torque (nm), different than standard
Pulley	-
Clamping bush	Require special torque (nm), different than standard, requires loctite for secure connection
Timing belt	Material properties, max force/stretch
Set screws	-
Electro motor	Require special torque (nm) between servo motor and gearbox, different than standard
Ball bearing	Sufficienctly greased Require special torque (nm), different than standard

Critical components

Object/part number	Note
Pulley with the timing belt and bearings	Timing belt can missalign over time due to slip High wear on bearings can occur due to slip
Mounted spindles and shafts	Shaft and spindles can move under high force/speed which can break the shafts
Timing belt pulley with clamping bush	Timing belt can wear and misalign if pulleys are not all in the same locations with the clamping bushes
Spindle (Horizontal/rotation with Clamping Rings)	The clamping rings should be connected in the right directions to perform a full movement The clamping rings should be connected with the right distance to perform the correct movement The clamping rings should be conneted with the right torque (nm) to make sure for a reliable movement

Figure 6.2: Full parts list, Critical Parts and Critical Components

These critical parts and critical components have constant feedback with engineering and feedback processes. Different databases, such as the technical control-item master file assist with highlighting certain issues when for example pulleys are used. These different critical parts and components get assessed with a Design FMEA and from these results, the Critical Part-Component Characteristics (CPCC) is created, as shown in Figure 6.3.

Critical Part-Component Characteristics

Critical Components	Note	DFMEA Rating	Action
Pulley with the timing belt and bearings	Timing belt can missalign over time due to slip if there is not a high enough frequency	5	Adress critical point in process development
	High wear on bearings can occur due to slip if there is not a high enough frequency	4	Adress critical point in process development
Mounted spindles and shafts	Shaft and spindles can move under high force/speed which can break the shafts	3	Design problem > adjust bolt lengts to create a 'critical' zone at the bolts to save the shaft in case of a failure
Timing belt pulley with clamping bush	Timing belt can wear and misalign if pulleys are not all in the same locations with the clamping bushes	5	Adress critical point in process development
	The clamping rings should be connected in the right directions to perform a full movement	4	Adress critical point in process development
Spindle (Horizontal/rotation with Clamping Rings)	The clamping rings should be connected with the right distance to perform the correct movement	4	Adress critical point in process development
	The clamping rings should be conneted with the right torque (nm) to make sure for a reliable movement	3	Adress critical point in process development
Critical Parts	Note	DFMEA Rating	Action
Lock nut	Require special torque (nm), different than standard	3	Adress critical point in process development
Clamping bush	Require special torque (nm), different than standard, requires loctite for secure connection	3	Adress critical point in process development
Timing belt	Material properties, max force/stretch	1	No action needed
Electro motor	Require special torque (nm) between servo motor and gearbox, different than standard	3	Adress critical point in process development
Ball bearing	Sufficienctly greased	4	Adress critical point in process development
	Require special torque (nm), different than standard	4	Adress critical point in process development

Figure 6.3: Critical Part-Component Characteristics

Process development phase

The product development phase is followed by the process development phase. In this phase, the CPCC gets used as input for two deliverables: Process/Part Relationships and Key Process Operations. For the key processes, the PFlow is used. The PFlow is a document that is created to translate the Engineering Bill Of Materials (EBOM) into a Production Flow (PFlow). This PFlow on module level, shown in Figure 6.4 is used as a starting point in creating production documents such as work instructions or in what order to deliver the parts to the operator. The focus is on the arms which are part of the main process flow in step 6, which is further detailed in Figure 6.5. These PFlow steps are used as input for the Process FMEA (PFMEA) in the following step.

Process Steps	
1	Place and align mainframe
2	Place backplate and motor
3	Place two motors and supports
4	Mount shaft rotation
5	Place and mount shaft
6	Place and mount arms

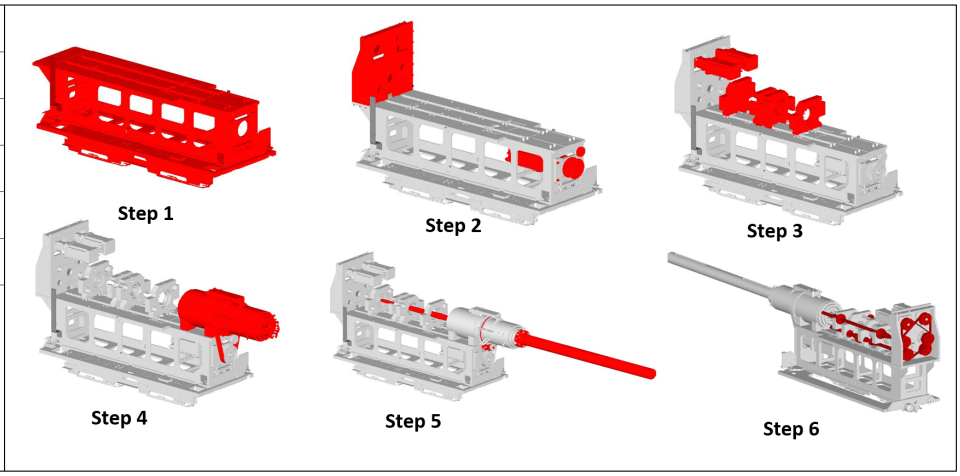


Figure 6.4: PFlow

Process Steps	
1	Spindle placement
2	Place bearings
3	Secure spindles
4	Mount pulleys
5	Mount first timingbelt
6	Mount pulleys and second timing belt
7	Remove set screw
8	Mount clamping ball screw nut
9	Mount motor

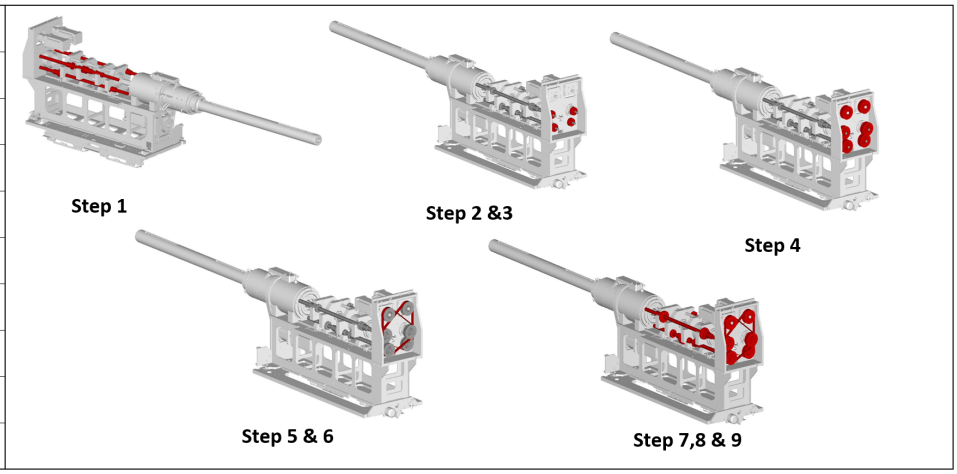


Figure 6.5: Production Flow CCH Arms and Process Steps

Next to the Key Process Operations with the PFlow, the Process/Parts Relationships step distinguishes the CPCC items into three categories: Inspection, Check and Control points. The three different points are summarised below in Figure 6.6.

Inspection points

Part/Action	Note
Check if the correct motor is picked for assembly	
Supplier quality check	

Check points

Part/Action	Note
Movement push	
Movement pull	

Control points

Part/Action	Note
Ball bearing	Tightened within torque tolerance according to drawing
	Bearings should be greased sufficiently
	Bearing balls should be positioned on the right location according to the drawing
Pulley Horizontal/rotation arms	Tightened within torque tolerance according to drawing
	Distance between pulley and motor plate within tolerance according to drawing
Pulley Drum rotation	Tightened within torque tolerance according to drawing
	Distance between pulley and motor plate within tolerance according to drawing
Clamping rings	All clamping rings should be in the right direction according to drawing
	Distance between all the clamping rings should be according to drawing
Clamping bush	Tightened within torque tolerance according to drawing
	Clamping bushes should be secured with loctite
	Tightened within torque tolerance according to drawing
Locknuts	Tightened within torque tolerance according to drawing
Servo motors Horizontal/rotation arms	Tightened within torque tolerance according to drawing
Servo motors Drum rotation	Tightened within torque tolerance according to drawing
Timing belt	Timing belt should have a sufficient frequency within tolerance according to drawing

Figure 6.6: Part process relations

After the Process/Part Relationships and Key Process Operations, the Control points and the assembly steps are used as input for a PFMEA. A full PFMEA is executed with assistance from production engineering and is added in Appendix A. Based on the risks from the PFMEA and the information from the Inspection- and Checkpoints, a Quality Control Plan (QCP) is created. The QCP, shown in Figure 6.7, is the final output that is used together with the Key Process Operations in the following phases.

Quality Control Plan

Check points	Importance	Inspection points	Importance
Movement push	3	Check if the correct motors are supplied	1
Movement pull	3	Possible supplier check	1

Control points		Importance
Arms	Control if arms are mounted in the right position	3
	Make sure arm nut is removed correctly	4
	Make sure the set-screws are closed off correctly with loctite	3
	Make sure the clamping ball screw nut is mounted with the right angle	3
	Make sure the clamping ball screw nut is secured with the right torque	3
	Make sure the right gearbox and motor are connected	2
Bearing	Tightened within torque tolerance according to drawing	3
	Bearing balls should be positioned on the right location according to the drawing	3
	Bearing balls should be positioned on the right location according to the drawing	3
	Bearings should be greased sufficiently	2
Pulley Horizontal/rotation arms	Tightened within torque tolerance according to drawing	4
	Distance between pulley and motor plate within tolerance according to drawing	5
Pulley Drum rotation	Tightened within torque tolerance according to drawing	4
	Distance between pulley and motor plate within tolerance according to drawing	5
Clamping bush	All clamping rings should be in the right direction according to drawing	4
	Distance between all the clamping rings shold be according to drawing	4
	Tightened within torque tolerance according to drawing	3
	Clamping bushes should be secured with loctite	3
Locknuts	Tightened within torque tolerance according to drawing	3
Servo motors Horizontal/rotation up arms	Tightened within torque tolerance according to drawing	3
Servo motors Drum rotation	Tightened within torque tolerance according to drawing	3

Figure 6.7: Quality Control Plan (QCP) Example

Production planning phase

The final phase in the development process of the quality plan is the production planning phase. In this phase, the information on critical parts and processes is used to set up failure-preventing steps and processes in the factory. As explained before, executing specific steps for each fault will be unnecessarily complicated. Four examples are picked to get an idea of what deliverables this phase could deliver. One example from the inspection points is picked and three from the control points, as seen in table 6.1.

Critical point	Risk	Action 1	Action 2	Action 3	Action 4
Check for the correct electromotor	Low	Document in work instruction			
CCH arms greased suffienctly	Low	Document in work instruction			
Pulley torque with the right Nm	High	Indicate in work instruction to QCP	Correct equipment for torque	Measure in QCP	
Pulley and motorplate with the correct distance	Very high	Indicate in work instruction to QCP	Correct equipment for measuring distance	Control action in QCP	Checked by supervisor

Table 6.1: Example for four critical points in the Production Planning Phase

To get a view of these steps and how they could be used, Figure 6.8 shows an example of how an operator could use these production planning phase steps. It shows the different types of possible training knowledge an operator should have for the specific sub-module and what documents are available for the operator.

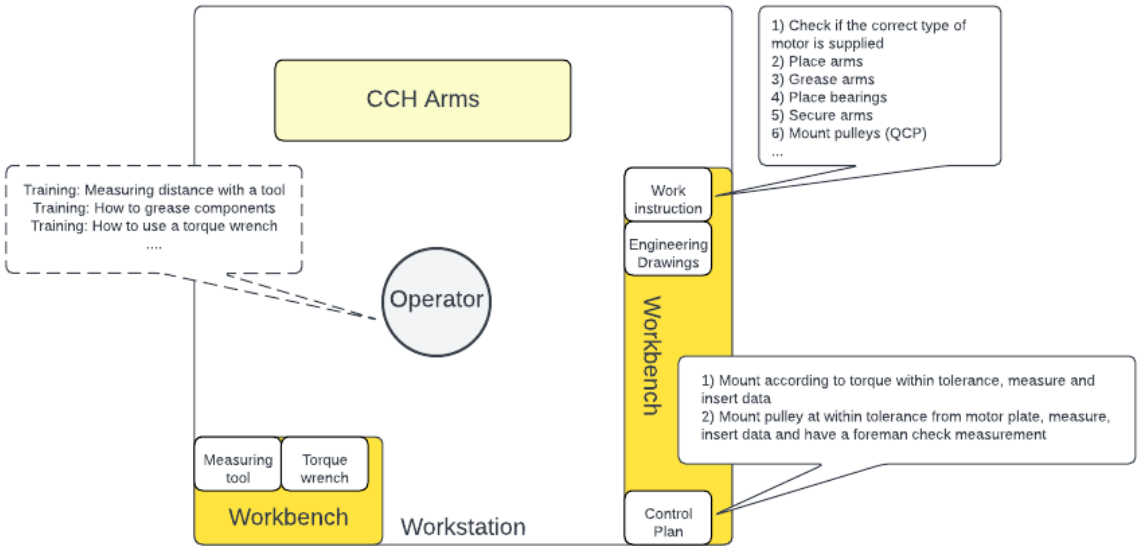


Figure 6.8: Example of deliverables Production Planning Phase

6.3 Assessing the new Quality Plan

To assess the new model against the old model the production management team and other stakeholders from the engineering department are asked to rate these models on a Likert scale to show if there are improvements and if the validation goals are met. The assessment is performed in three steps. First, the current situation is presented with a list of questions, regarding the focus points of the report. After this questionnaire is filled in the new quality plan is presented and the same questionnaire is tested again. After the two questionnaires are filled in separately the focus points of the report are discussed with the selected persons. For the assessment people are chosen who are responsible for parts of the development and production process and have an overview of the whole picture. For this assessment production management, structuring engineering and systems engineering are questioned.

Figure 6.9: Validation Assessment Steps

The validation goal is to test the focus points and if they are changed positively or negatively by this new quality model. The following three focus points are tested, based on the focus points from the performance analysis in Chapter 4:

1. Structured quality process
2. Efficient quality process
3. Knowledge within the system

Since some of these points are hard to verify by numbers, a Likert scale is used to validate the new quality model. The following questions have been asked on the old quality plan and on the new quality plan:

- Does the quality plan have a structured process and do the quality techniques effectively align?
- Is the quality plan clear for all the departments and what their expectations are?
- Does the quality plan have quality control processes/techniques that are used across different production locations?
- Does the quality plan have possibilities to secure/store knowledge in the system and use this to proactively prevent mistakes?

The different answers are given in Appendix B, a summary of the answers is given below in Table 6.2:

Question	Vmi Current process	New quality process	Increase
Q1	2,4	4,6	92%
Q2	2,2	3,2	45%
Q3	1,8	3,6	100%
Q4	1,6	4,4	175%

Table 6.2: Validation Likert Results

6.4 Conclusion

This chapter answers the sub-question **"What would a validation of the Quality Plan look like?"**. By following a practical example on part of the quality plan, an overview of how this quality plan could perform is created. The validation is mainly focused on the second and third phases of the development process: the product and process development phase. In the first phase, the product planning is too vague for example, since the product is already developed. By creating documents for the product and process development phase with internal documents and the help of R&D, OE and production engineers, a good example is created. The example shows an example of a small part produced in the factory in Epe. Since quantifying possible quality gains can be difficult, there is opted for a likert-scale interview with relevant stakeholders. These relevant stakeholders have an overview of the current quality processes at engineering and production and are asked four different questions focused on three focus points: Structured, Efficient and Knowledge of the system. The results show that for every focus goal the stakeholders see possible improvements, with the highest score on the possibility to store knowledge in the system.

7 IMPLEMENTATION POSSIBILITIES

This chapter contains steps for an implementation plan to answer the sub-question: **What would an implementation plan for this quality plan look like?** Creating a detailed implementation plan is very complicated since the model has to be adjusted to fit all the processes across the company, which needs a lot of information from experience from testing. This section does not provide the complete implementation plan but provides the framework for the implementation of the quality plan at VMI. The first section discussed the implementation steps according to a Quality Improvement Framework (QIF), translated to fit the VMI situation. Following these implementation steps, Section 7.2 uses information from the relevant stakeholders on their judgement of the possibility of implementation of such a quality plan.

7.1 Implementation steps

Past research into quality model implementation indicates that the implementation phase is an important element of any quality model and that this phase can affect the effectiveness of the overall model if not performed correctly [25]. These implementation step can go into deep details, to limit complexity only the top level of this implementation is discussed. Implementing such a new quality plan can take up to years and will continue developing over time. The Quality Implementation Framework (QIF) provides four phases to implement a new quality model. Based on this framework, the relevant phases for VMI are described and what these could look like. The QIF contains fourteen critical steps in an implementation process, divided into four phases to achieve successful implementation [25]:

1. Initial considerations regarding host setting
2. Creating a structure for implementation
3. Ongoing structure once implementation begins
4. Improving future applications

Since this report provides a quality plan and not a fully detailed quality model, the first phase cycle should focus on further detailing the process and creating internal structures for all the relevant departments. This can be performed with an implementation plan on a pilot example to prove the quality plan's effectiveness. From completing this cycle, one or more cycles can be performed to fully implement the quality approach across the whole factory in Epe and possibly by the different production locations from VMI.

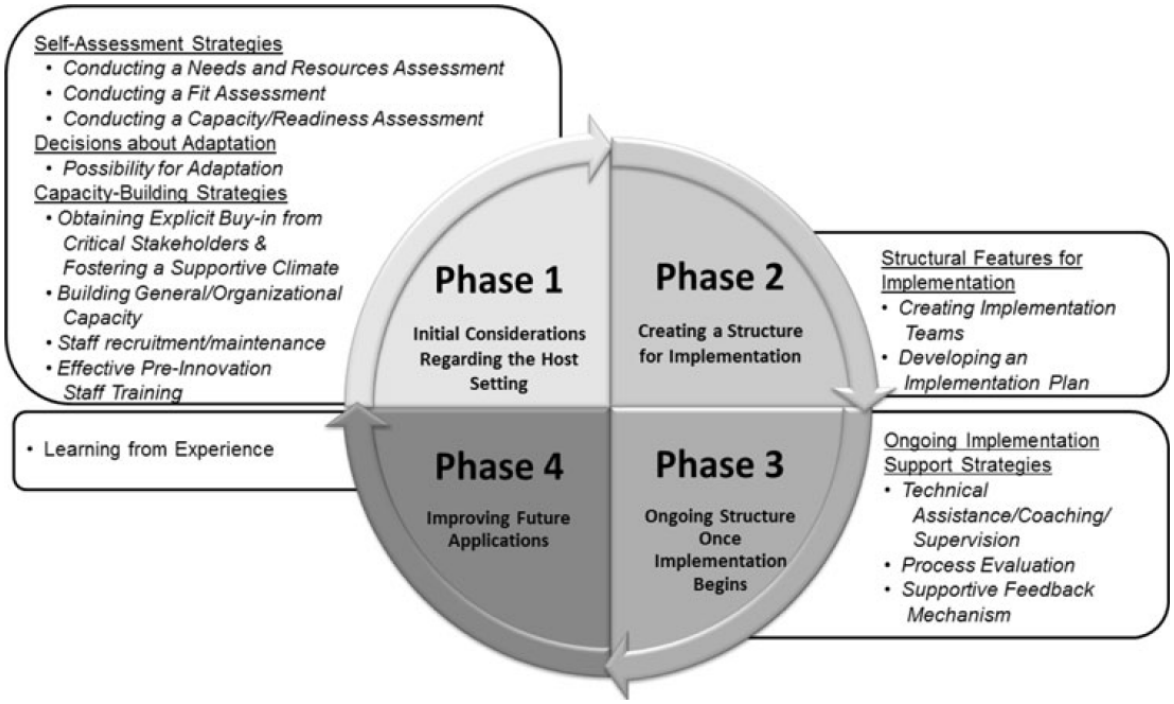


Figure 7.1: The Quality Implementation Framework (QIF)[25]

Phase 1: Initial considerations regarding the host setting

To answer these questions for VMI the following steps have to be executed. First up a self-assessment, which includes different factors such as needs/resources, fit assessment and a capacity/readiness assessment. It is important that before fully implementing such a system, preliminary projects should be executed across different departments to test it on a bigger scale. This would provide a fit assessment that shows how ready this model is for further implementation and where work is needed. The main focus for this first phase would be determining the current opportunities and possible obstacles to implementing the quality approach. An important part of this phase is to involve different departments to make sure there is support from all stakeholders in this process.

Phase 2: Creating a structure for implementation

The second step is to create a structure for the implementation, which includes creating a plan and a team based on the first phase's findings. From this first phase, the information from what departments are relevant for this process and how they can be involved. Throughout the process, this implementation team has to assist the project and represent the different departments. This team will continue to develop more detailed steps and processes for this model and its application.

An implementation plan should be created by the team which can follow an existing new development and add this model as a pilot alongside. This example will be on a single project, meaning only a few people from each department will be involved making it easier to execute. It is important to include people from as early in the development as R&D Engineering as well as operators and field service mechanics to fully show the quality plan potential.

Phase 3: Ongoing structure once implementation begins

The third phase focuses on setting up support strategies and processes for when this process would start implementation. The validation and the first implementation structure can be created in smaller teams. Still, this step will involve not only the departments in the development process but also all the departments in the factory. A lot of assistance from the 'experts' of the process is needed for the other people responsible for working with this system.

Techniques such as audits can be used to assist the process evaluation and feedback mechanisms. By performing these audits, the precision and effectiveness of the process (control) steps are continuously checked by internal/external members. This will ensure that specific procedures, work instructions, flowcharts or training will stay relevant for the implementation and quality process [31].

Phase 4: Improving Future Applications

The final phase is a continuous improvement process. When the implementation plan that is developed in phases two and three is successfully executed, improvements will still be possible. This implementation plan proved a pilot on a smaller project, the next step is to complete a new cycle for the implementation of this quality model across the whole factory in Epe. This first pilot brought the departments together and showed the quality model and its effectiveness, the next step is to determine all the details for implementation across all the departments based on the experience learned in the first implementation cycle.

7.2 Implementation validation

Validation of an implementation plan is challenging since you have to estimate if these changes will increase the overall production quality process. Based on the quality plan and the validation example the discussion point of Figure 6.9 was also aimed towards the possibility of implementation. With this discussion, both the engineering and the production side could discuss their views. Based on these discussions, both the engineering and production stakeholders brought up a few points:

- Implementation would take years
- Less intrusive would be more efficient
- There should be an advantage of the implementation

The relevant stakeholders mentioned that this implementation would take years before it could be fully operating in the factory in Epe, which the implementation plan covers. By performing the different cycles a slow approach to go from a pilot towards full implementation will be very effective since going from nothing to a full model directly will only bring problems and delay the implementation.

The less intrusive part covers part of the design of the quality plan within the product planning and product development but should be a focus during setting up the implementation framework as well. By not replacing current activities or needing all the previous steps of a deliverable, the process becomes more reachable for the departments. The final part is that there should be a general advantage in implementation. The new activities should add to the overall production process quality process and add value instead of creating only unnecessary work. When all the departments can see that the model improves the process, and even removes some of the current deliverables everyone will be more motivated to work toward a central goal of a successful implementation.

7.3 Conclusion

The answer to the sub-question: **"What would an implementation plan look like at VMI for this quality plan?"** is not straightforward. This chapter describes the first cycle of an implementation process, following the Quality Implementation Framework. The focus is on the first cycle of this implementation framework, which would be a pilot project to show the effectiveness of such a quality approach. An important step of this process is that all the relevant departments should be involved in this process since it is important that all the departments work together and are aligned. A discussion with the engineering and production department on this validation shows that they agree with this approach. Implementation of such a quality model is going to take a long time and should be done in different phases. A pilot project or a proof of concept is important to involve all the departments and show the value added by implementing such as model.

8 CONCLUSION, DISCUSSION AND RECOMMENDATIONS

This chapter starts with a summary of the results to answer the research question of this report in Section 8.1. In section 8.2 some limitations are discussed that came up during the report. Section 8.3 is the final section and describes possible future research and improvement points.

8.1 Conclusion

The research question is **"What is a suitable quality plan for VMI to maintain and increase the overall production process quality?"**. To answer this research question, this report starts with research towards quality analysis models where the Process Quality Analysis Model (PQAM) model is created. This PQAM is a combination of the three levels of performance: organisational, process and job/technique and Quality Function Deployment. After creating this quality analysis model, possible quality improvement methods are researched based on the same three levels of performance as mentioned in the PQAM model. To get a better understanding of the current process at VMI the current development and production process is shown based on internal documents and interviews with different departments that are involved with these processes, such as R&D engineering, Order Engineering, Production Engineering and Test engineers. To verify these processes or to create an overview of undocumented processes, a use-case is performed on a product within the factory.

To get an effective performance analysis the VMI situation is modelled into the same phases as QFD and described in the three levels of performance. Based on these results, a performance analysis is performed which results in the following three focus points: Deliverables per phase/responsibilities per department, data management between processes and a structured approach to quality management techniques. With these focus points, the quality improvement methods are compared and combined into a new quality plan for VMI. This new quality plan overlaps three philosophies: TQM, configuration management and an integrated QFD approach. The quality plan is designed based on a QFD model described for integration information systems and gets adjusted based on the TQM philosophy and made fit for application at VMI. The configuration management philosophy adds data management between different phases and versions, focusing on maintaining the newest version of each step in the development process. This combination creates a quality plan to increase and maintain the overall production process quality.

Since quantifying improvement for a quality plan is quite challenging, a validation based on a Likert scale is performed. To envision how this quality plan could work, a use-case is performed with a focus on product development and process development and an example for production planning. Internal stakeholders with influence on the overall processes are questioned on the old and new scenario on three focus points: structured process, efficiency, and knowledge in the system. This validation proves that the internal stakeholders at VMI see improvement possibilities for this designed quality plan, compared to the current situation at VMI. This new quality plan is suitable to maintain and increase the production process quality. However, for this model to be entirely successful and functioning, there is still a lot of work that has to be done to work out all the details and processes within this plan.

Overall, the quality plan can be seen as an new model to the current quality situation at VMI with significant potential for increasing the overall production process quality. This quality plan creates a good base to start working more proactively together and meet the focus points from multiple departments across the company. Implementation would take years and has to be executed in different steps. It is important to first start with a single project or machine to show the effectiveness of this quality plan, and not overcomplicate the process. From this pilot project, many improvements will be made based on experience from working together with the different departments. After a successful pilot project, the quality plan can be further detailed and slowly implemented across the factory in Epe.

8.2 Discussion

The suggested quality plan does have its limitations. The quality plan describes global deliverables for phases in the development process. Still, it does not describe in detail how these align with the current development process and how they are processed in the current production process. The deliverables are discussed with the relevant departments, which indicated that there are possibilities of this process but for a full implementation, these details should be detailed further and possibly slightly changed for a better fitment.

A limitation within this report is Intellectual Property (IP), since VMI is a highly competitive company in different sectors such as tire manufacturing machines. A lot of IP information can not be easily shared publicly or within the different production locations. Even within the company, certain details are not shared for specific engineering or production details. When discussing with R&D engineering the problem came up that some specific engineering or quality designs are not shared across the company. This problem is covered in the suggested quality plan since it does not replace engineering processes and forces them to detail all the steps. By creating specific critical parts and component lists during the development process, the exact reasoning behind these is not forced to be shared across the company.

The literature study towards the quality model and the quality improvement methods has some limitations. The comparison (PQAM) model was created since no suitable quality process analysis model was found. As described in Chapter 2, multiple models have been compared but these would not show different shortcomings of the current quality model. The same limitation applies to the quality improvement methods as well. Since a selection of quality improvement methods is picked at the beginning, only a few other possible options are compared later in the process when the focus points are further described. These solutions have potential, but it is hard to say these are the best solutions for VMI.

8.3 Recommendations

A few recommendations for further study can be mentioned from this report. One of these recommendations is the sub-module and module testing. Testing should be further investigated for a more effective quality approach. Currently, all the functions have to be tested to verify the software but many problems are found in this process delaying the testing. By having more proactive behaviour on testing by for example testing 'Check Points' earlier in the process this process can be sped up to reduce the overall throughput time of the machine.

Another recommendation is a point that is not detailed in this report but could work well with this model for the quality control process for outsourced products. VMI can decide that a product is moved from an internal production to an external supplier outside of the factories of VMI. When this is the case, do you provide quality deliverables and training manuals to all the customers? Is this possible due to possible IP issues? Questions like these are good to think about because in practice, this has happened before when outsourcing specific parts and caused reoccurring issues that were already solved in an internal process beforehand.

The final recommendation is to create different levels of a quality plan approach. Not every product needs the maximum amount of attention, the quality process has to add value otherwise, it will be a waste of time and resources. Some products that are produced continuously and are part of many different types of machine is for example the TBM, where one sub-module contains the use-case example of the CCH arms. Since this is continuously produced, more attention will pay off to prevent reoccurring mistakes. Some products at VMI are only produced a few times per year or are less complicated than other machines, for these machines not all the deliverables from this quality plan are required. One quality plan will not suit every application and will only result in unnecessary documentation which will most likely decrease the quality of this documentation. Different levels of application will become clear during an example in the implementation phase and can be further detailed from that information.

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A PROCESS FMEA

Process Name:	CCH - Arms	Prepared by:	
Responsible:		FMEA Date	

	Process Step	Function	Requirements	Potential Failure Mode	Potential Effects of Failure	SEV	CLASS
1	**Arms placement**	Mount Arms	Quality	Wrongly assembled/ positioned	Turn up/traverse arms do not perform (roll over)	8	
						8	
						8	
		Check Arms	Efficiency	Delaying production process	Bolt does not fit, last opportunity to change	4	
2	**Place bearings**	Plaatsen lager	Quality	Wrongly assembled/ positioned	Turn up/traverse arms do not perform (roll over)	8	
						8	
		Smeerpunten positioneren	Levensduur machine	niet voldoende gesmeerd	verminderde levensduur	6	
3	**Secure Arms**	Secure Arm	Quality	Wrongly assembled/ positioned or damaging machine	Turn up/traverse arms do not perform (roll over)	8	
						8	
4	**Monteren pulleys**	Align pulleys	Quality	Wrongly assembled/ positioned	Turn up/traverse arms do not perform (roll over)	8	
						9	
5	**Mount first timingbelt**	Align riem	Quality	Wrongly assembled/ positioned	Turn up/traverse arms do not perform (roll over)	6	
6	**Mount pulleys and second timing belt**	Align pulleys	Quality	Wrongly assembled/ positioned	Turn up/traverse arms do not perform (roll over)	8	
						9	
		Align riem	Quality	Wrongly assembled/ positioned	Turn up/traverse arms do not perform (roll over)	6	
7	**Remove set screw**	Smeerpunten positioneren	Levensduur machine	niet voldoende gesmeerd	verminderde levensduur	6	
						6	
8	**Mount clamping ball screw nut**		Quality	Wrongly assembled/ positioned	Turn up/traverse arms do not perform (roll over)	6	
			Quality	Wrongly assembled/ positioned	Turn up/traverse arms do not perform (roll over) will not perform due to damaged components	6	
9	**Mount motor**	Mount motor	Effiency	Wrongly assembled/ positioned	Turn up/traverse arms do not perform (roll over)	8	
		Check correct motor	Efficiency	Wrong motor connected	Turn up/traverse arms do not perform (roll over)	6	

Figure A.1: Process FMEA Validation Phase (1)

{}	Page 1 of 1

VMI GROUP

Potential Causes	Current Process Controls Prevention	OCC	Current Process Controls Detection	DET	RPN	Actions Recommended
Clamping ring ball screw in wrong direction		3		3	72	
Arm mounted at wrong position		6		3	144	Arm position has to be checked before continuing assembly process
Arm nut removed incorrectly		6		3	144	The removal of the Arm nut should be uniform to decrease failure possibilities
Bewerking niet goed uitgevoerd door leverancier		3		8	96	
Mounted at a wrong angle		7		6	336	Bearing placement should be documented or trained to ensure a perpendicular mounting
Wrong Torque		6		8	384	Bearing placement should be documented or trained with the correct tools to tighten with the correct torque
Verkeerde positionering lagers (greasing points)		8		8	384	
Wrong Torque		6		8	384	Make sure that the operator uses the right tool and right amount of torque
geen/slechte hechting loctite		6		8	384	Make sure that loctice is used
Wrong Torque		6		8	384	Make sure that the operator uses the right tool and right amount of torque
Wrong Allignment (afstand)		6		8	432	Ensure the pulley is in the right position by positioning with a tool or fixture
Wrong Allignment		6		8	288	Test/adjust the timing belt for the correct frequency (according to drawing) before continuing
Wrong Torque		6		8	384	Make sure that the operator uses the right tool and right amount of torque
Wrong Allignment (afstand)		6		8	432	Ensure the pulley is in the right position by positioning with a tool or fixture
Wrong Allignment		6		8	288	Test/adjust the timing belt for the correct frequency (according to drawing) before continuing
Verkeerde positionering lagers (greasing points) niet volgens tekening		8		8	384	Make sure the operator uses the right amount of grease and on all the necessary greasing points
Geen afdichting door set-screws (geen gebruik juiste loctite volgens tekening)		8		8	384	Make sure the set-screws are closed off correctly with loctite
Verkeerd gemonteerd (scheef)		9		8	432	Make sure the clamping ball screw nut is mounted with the right angle
Wrong Torque		6		8	288	Make sure the clamping ball screw nut is secured with the right torque
Wrong Torque klembus gearbox		6	Module testing	6	288	Make sure the right gearbox and motor are connected
Wrong type of motor connected		3	Module testing	6	108	Check if the correct motor is supplied before starting the assembly process

Figure A.2: Process FMEA Validation Phase (2)

B LIKERT RESULTS

The specific Likert results are listed here:

Current Situatio	Production Manager 1	Production Manager 2	Production Manager 3	Production Quality Specialist	Coordinator Release Engineering	Average
Q1	2	2	2	2	4	2,4
Q2	2	3	2	2	2	2,2
Q3	2	2	2	1	2	1,8
Q4	2	1	2	2	1	1,6

New Situation	Production Manager 1	Production Manager 2	Production Manager 3	Production Quality Specialist	Coordinator Release Engineering	Average
Q1	5	4	4	5	5	4,6
Q2	4	4	4	3	1	3,2
Q3	4	3	4	4	3	3,6
Q4	5	5	4	5	3	4,4

Figure B.1: All individual results Likert Assessment