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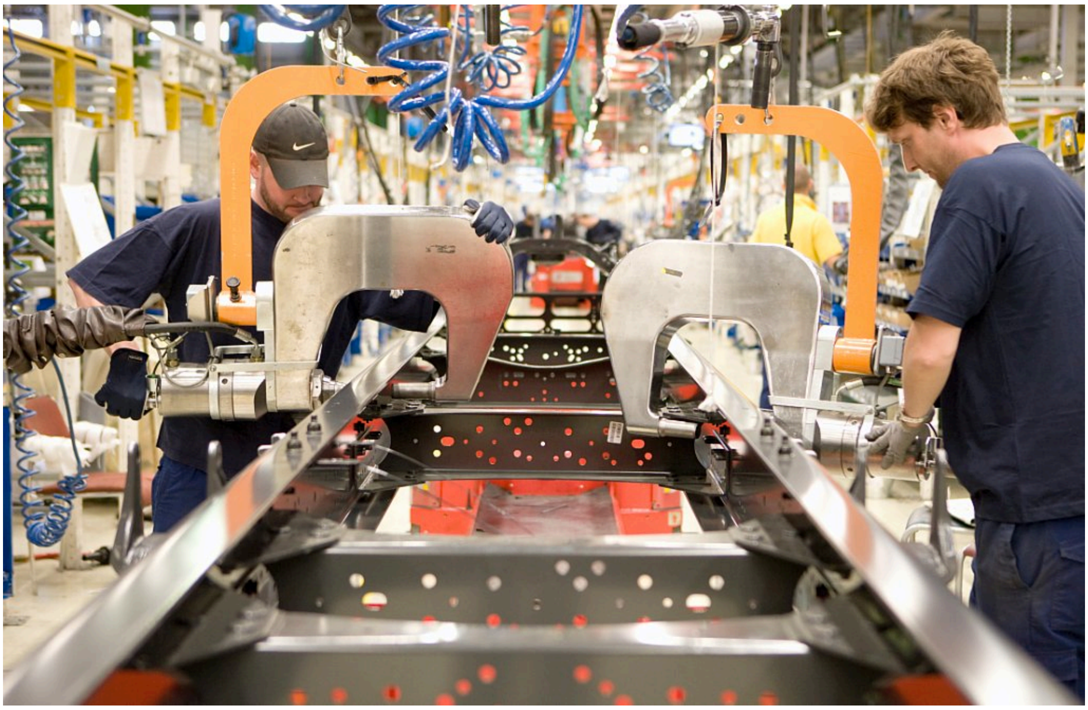

Process quality performance for assembly processes

Development of a performance measurement system for manual assembly

Master of Science Thesis in Production Engineering

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David Danielsson *Jakob Krozer*

Abstract

The quality of an assembly process can be divided into two different quality measures, which are product quality and process quality. The product quality concerns how the customer experiences the assembled product, while process quality concerns the ability of the assembly process to assemble the product without process deviations. Deviations in the product are results of deviations in the assembly process, while process deviations are not always resulting in product deviations. This implies that it is important to have knowledge of the process quality as complementary knowledge to product quality.

Constructing and implementing a quality performance measurement for assembly processes could provide knowledge about the assembly process quality. The data obtained could be used to improve the assembly system to increase the process quality of the assembly process.

The suggested quality performance measurement system for assembly process is constructed with process area indicators that are used to measure process quality deviations and to indicate in which process area the deviation occurred. The assembly process deviations that occur are measured according to an measurement structure based on six of the seven Ms. The measurements are suggested to be performed at all assembly areas where also all deviations of the assembly process should be measured, both deviations resulting in product deviations as well as deviations only affecting the assembly process.

The data from the quality performance measurement system could be used to identify improvement areas of the assembly process. By improving these areas the assembly process could be made more stable, which implies a more predictive assembly process.

Keywords: Process quality, performance measurement, assembly, process quality indicators, process stability.

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Abbreviations

DOK	Direct OK
EME	European Manufacturing Engineering
FTT	First Time Through
KPI	Key Performance Indicator
OMS	Operational Management Structure
PDA	Personal Digital Assistant
SMART	Strategic Measurement Analysis and Reporting Technique
STM	Steps To Milestone
TPS	Toyota Production System
VTC	Volvo Trucks Corporation
QCDSM	Quality Cost Delivery Safety Management
QMPMS	Quantitative Model for Performance Measurement System

1 Introduction

This chapter is aimed to inform why the thesis has been conducted and what the objectives and purpose are. The intention is to provide information so the reader could understand why there was a need to conduct the thesis. The introduction also shortly describes the current state of Volvo Trucks with respect to organizational structure, meeting structure and what performance measures are used to measure assembly process quality.

1.1 Background

Volvo Trucks Corporation, VTC, is a part of the Volvo Group, which consists of several different companies producing different products and acting on different markets. VTC itself represents about 2/3 of the total turnover of Volvo Group and is one of the biggest actors on the world market of heavy-duty trucks. VTC have several different production sites around the world, and three of them are located in Tuve and Umeå in Sweden and one in Gent, Belgium. In Tuve, the FH and FM trucks are assembled, in Gent FH, FM and FL are assembled as well as trimming of the cabs. At the production site in Umeå, cab parts are pressed and welded together and are supplied to the Gent production site. Besides producing the cab shells, cabs are also trimmed and supplied to the Tuve production site.

The top management at VTC has determined to work with process capability as a main topic for the company, and therefore an investigation of how to proceed with the subject was analyzed through this thesis. The thesis was requested by the European Manufacturing Engineering, EME, process department and therefore several production sites in Europe were regarded. The sites that were regarded have been pre-determined by EME. These are located, besides the production site in Tuve, in Umeå and Gent.

The desired result from the thesis is a measurement system that provides feedback of the assembly processes quality that could be used by VTC in the development of capable processes. At VTC, today, there is no feedback provided to operators or managers on the quality of the assembly process, instead the feedback is concerned with the quality of the product. This implies that there is no feedback on what process deviations have occurred during the assembly process. In this context of deviation, any occurrence that has disturbed the assembly process is regarded. The difference between product quality feedback and process quality feedback could be illustrated with an example. This could be that a bolt is missing on the truck assembled and the feedback considered in the product feedback would be that the bolt is missing. If the feedback would have been concerned with process quality, the feedback would cover what in the process induced the missing bolt; was it due to lack of the operator’s education or was it due to inferior work methods?

The current performance indicator for process quality at VTC is a measure that is quantified by dividing the amount of conforming trucks that passes a specified point of assembly line with the total amount of trucks. The measure is referred to as Direct OK, DOK. The DOK performance measure is not generally defined for the different production sites and is not measured in the same way. At some sites the assembly performance is measured directly at the end-of-line while at others the performance is measured 24 hours after the truck has left the production line, creating possibilities for more corrective actions. DOK do only provide the users with very general process quality feedback, and due to that the performance is measured differently at the production sites, the performance is not comparable between the sites.

A quality performance measurement system could be used for different purposes. According to Figure 1 below there are seven different purposes of a measurement system. These purposes are: look back, compare, look ahead, motivate, roll up, roll down and compensate (Hon, 2005). Look back and look ahead are connected to a time perspective and refer to looking back on previous performance and to predict future performance. Predicting the future performance could for example be used to ease planning processes. Roll up, roll down and compare, are from an organizational perspective. Roll up is feeding back information about performance of the operative units; roll down is feedback about organizational performance down to the operational units; and compare to enable horizontal comparison of units within the organization. Compensate and motivate are connected to a human perspective and refer to compensate for past performance and to motivate for future (Hon, 2005).

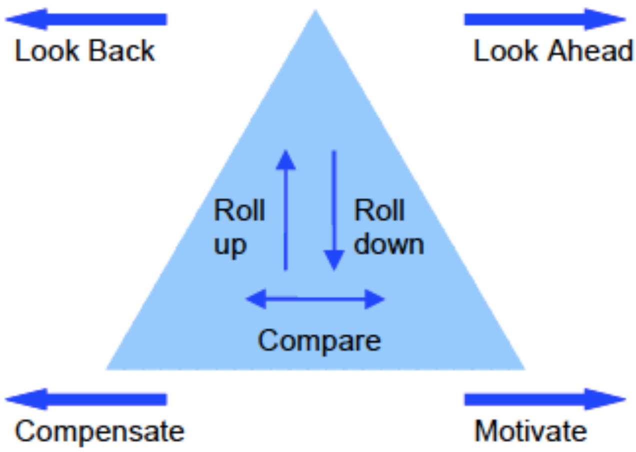

Figure 1 Purposes of a measurement system (Hon, 2005).

The performance measurement system that was developed in this thesis connected to four of the purposes discussed above. These are: roll up, roll down, compare, and look ahead. The roll up-purpose is concerned providing the users of the measurement system with feedback of the assembly process quality and roll down with feeding back information of the performance to the operators. The compare purpose should achieved by allowing for comparison between different production units or production sites. The look ahead-purpose is concerned with providing the users with feedback allowing them to plan improvements of the assembly process in the development of process stability.

1.2 Purpose

The result from this thesis is expected to be a measurement system to measure assembly process quality performance. The performance measurement system should allow for traceability of the measures, meaning that the measures should aid the user in finding areas of the assembly process that are in need of improvements. The data obtained from the measurement system should also enable decision-making since the output of the system should be based on actual performance and be provided to right users. Users from different levels of the VTC organization should be identified and be able to use the measurement system in their work when improving the assembly and obtain data that is adjusted for their organizational level.

The purpose above is summarized into the following requirements. The quality performance measurement system should:

- Allow for traceability of the assembly process quality performance measures.
- Allow for users at different levels of the organization to use the measurement system.
- Allow for assembly process quality performance comparison within production sites and in-between production sites.
- Allow for identification of process areas that are in need of improvements.
- Allow for data to be based on actual process quality performance.

1.3 Problem definition

From the Introduction- and Purpose chapter above, key questions that are important to answer to reach the purpose of the thesis will be stated in this section. These questions will be referred to as research questions.

What potential deviations could be identified that affects the quality performance of an assembly process?

To answer this question it is necessary to identify what affects the output from the assembly process. The investigation should be used to find indicators that will be used to indicate the quality performance of the assembly process. It is important that the indicators are reflecting the actual performance since these will be used when evaluating the assembly process.

To benefit from data obtained by the performance measurement system, it is important that the process is measured in the right way providing the right data.

How should a quality performance measurement system be designed so that it captures the actual performance?

When the performance indicators have been specified, the next step is to determine how these indicators should be measured. The measurement system needs to be simple to use and easy to understand at the same time as it captures the actual performance. Data that is easily understood and that is based on actual performance is valuable for decision making. This is important since measure the right indicators in the wrong way would not provide the right data.

How could the suggested quality performance measurement system allow for traceability in the assembly process and in the organization?

The performance measurement system should allow for traceability in the assembly processes, making it possible to identify the assembly area where the process deviation was identified. The measurement system should allow traceability within the organization according to the already established ISA95 standard. The ISA95 standard is described in more detail in the Volvo Trucks description-chapter.

A traceable measurement system would produce better input to the improvement process since specific process- and assembly areas can be identified. This is important since it could be used to identify assembly areas that are in need of improvement actions.

1.4 Delimitations

What will not be considered in the project is presented in this section.

The project result will not:

- consider how the measurement system will be used to improve the assembly processes after data is obtained.
- consider how the measurement system will connected to current IT systems at VTC.
- consider how the data will be presented at different levels in the organization.

- consider how applicable the result is at other production sites within VTC except the ones included in the thesis.
- consider how to measure quality performance other than quality performance in the assembly process.
- consider aspects of assembly performance other than process quality performance.
- consider how process quality target levels will be set for the indicators at the different organizational levels at VTC.

1.5 Volvo Trucks description

At VTC, the organization is structured according to the ISA95 standard. The standard is dividing the organization of the company into levels with different users who have different responsibilities of managing the company. The separation of users also indicates different requirements of process quality data and feedback that these different users have and need, to perform and manage their responsibilities. The ISA95 standard is described in Figure 2.

The ISA95 is a standard used internationally for integration of enterprise and control systems. The standard is used to determine what information that has to be transferred in-between and to the different levels of the organization. One of the aims with ISA95 is to reduce the risk and errors associated with implementing enterprise and control systems, which is reduced by improving and making communication within the enterprise and the organization easier and clearer (ISA-95.com, 2011).

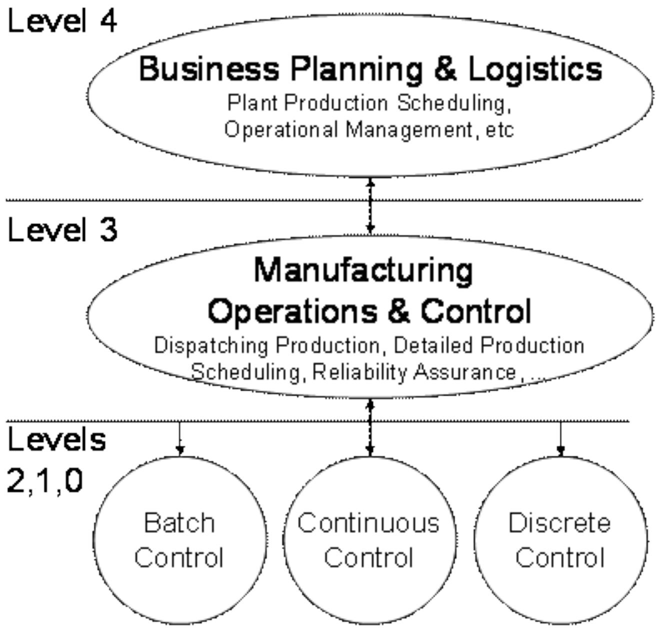

Figure 2 The ISA95 standard.

The levels 2,1,0 are considered to be on operational level, meaning where the product processing takes place. It is on these levels that the assembly performance should be measured. Level 3 is representing the planning operations at production site level. At this level the processes within the production site are planned and scheduled. Level 4 is the level where the business objectives are planned and controlled. At this level, the highest managerial level of VTC performs the functions.

Operational Management Structure

There is a specific structure for the meetings treating production performance held at VTC, called Operational Management Structure, OMS meetings. The purpose of the OMS structure is to quickly deliver information throughout the organization. In the different meetings held, there are different participants and the information is transferred from the lowest level to the highest level of the organization. These meetings are held at daily basis. In the first meeting, leaders for the different operator teams have a meeting with the team regarding the current situation and status of the assembly process. Team member's observations are also forwarded to the leader of the team. In the next meeting the leaders of the teams and leaders responsible for several team leaders discuss information from the first meeting. The information from this meeting is then transferred to the next meeting, one organizational level higher. In Figure 3, a principal structure of OMS can be seen. The number of meetings is determined by the number of hierarchal levels in the organization and therefore can vary between the different production sites.

Figure 3 Meeting structure for OMS-meetings.

Depending on which hierarchical level of the organization the meeting is held at, the character of the information is changing. Higher up in the meeting hierarchy, the focus of the discussed topic is of more general process performance. During the meetings process support functions such as the quality-, logistic- and material department are present. Depending on at what level of the organization the meeting is held, the participants from the supporting function are altering. At meetings higher up in the organization, the participants have a wider responsibility compared to meetings held further down in the organization.

Process quality performance measures at Volvo

The current way of measuring internal assembly quality performance at VTC is with a Key Performance Indicator, KPI, referred to as Direct OK, DOK. All production sites use DOK, but there is no common standard of how to measure it.

DOK is measured at pre-defined places and is calculated by dividing the amount of conforming assemblies with the total amount of assembled products. It is therefore a measure of how many products that have passed the measuring place correctly assembled. The feedback obtained from DOK is a KPI that provides general data about line performance. The data is not showing process areas where deviations occurred or what part of the line that caused the non-conformity.

Depending on how the assembly process is designed, different ways of measuring DOK are used and therefore it is not measured in the same way at the different productions sites. At some production sites the DOK is measured directly when the product leaves the line and at other production sites the DOK is measured 24 hours after the product has left the line. The difference depends on if there is test equipment connected to the line or not. Measuring as in the latter example will not represent the actual line performance since corrective actions can be taken during the 24 hours. This would increase the DOK value and hide actual shortages in the assembly process.

There are plans to introduce a performance measure that is defined and measured in the same way at all production sites to allow for performance comparison. This future performance measures is referred to as First Time Through, FTT. FTT is similar to DOK and is calculated in the same way, and is calculated as the number of products passing the measuring point without any deviation divided by the total amount of assembled products. The difference lies in that the measure should be applied and measured in the same way at all production sites, making the data obtained from the measures comparable.

2 Theory

The theory chapter first describes two different types of variations that could be identified in an assembly process. Then an explanation of the two types of quality measures that have been identified for a manual assembly process and how the performance of the processing quality could be measured and managed. In the end of the chapter it is presented how the results from the measurement could be used to improve the assembly process.

2.1 Different types of variation

Everything comes with variation, nothing can be exactly identical. The variation is in many cases a source of uncertainty that needs to be measured and controlled. Literature often refers to two types of variation, which are grouped according to their nature of occurrence (Juran & Godfrey, 1998). The first type of variation is the one induced by assignable causes. The source of an assignable cause could often be identified and eliminated. The second type is the variation induced by random causes, which occurs due to natural variation and therefore is very hard to eliminate. To reduce the effect of a random cause, process designers can design the process with regard to this variation (Juran & Godfrey, 1998) (Bergman & Klefsjö, 2010).

These two types of variations are often present in all different kinds of assembly processes. To become aware of their presence and to handle the variations, process measurement can be used (Bergman & Klefsjö, 2010). Depending on what is measured and is to be controlled, different indicators and deviations are used as input to the control system. A method that has been developed and is widely used is statistical process control, SPC. The aim of SPC is to identify and thereby be able to eliminate the assignable causes (Juran & Godfrey, 1998). When the assignable causes have been eliminated, SPC can be used to monitor the process to verify that the process is stable and no assignable causes are introduced. The founding idea of SPC was to use it as a measuring and improvement tool for manufacturing processes (Bergman & Klefsjö, 2010).

2.2 Quality measures

The quality of an assembly process can be divided into two partial quality measures. The first measure deals with *processing quality* and is the ability of the assembly process to assemble products without defects (Park & Son, 1987). The second part deals with the *product quality* and is the degree of excellence of the finished product. The product quality can take forms of the product not satisfying the quality standards determined by the company (Park & Son, 1987). This is supported by Ahire and Dreyfus (1998) who claim that the internal and external quality outcome is affected by both design- and process management. Process quality management means that critical parts of the manufacturing process are identified and improved in order to secure a certain process quality.

Both design management and process management demands for different tools. Employees need to understand how and why these tools are used in order to receive the best results. Long-term thinking is a prerequisite when improving designs and processes, and multi skilling helps employees to obtain a general understanding of the system to identify critical parts that are need improvements (Ahire & Dreyfus, 2000).

2.3 Performance measurement

A performance measurement system, if structured and designed correctly, provides a basis for an effective and rigorous performance management process used as a management tool for strategic, tactical and operational levels of management (Bitici, Carrie, & McDevitt, 1997). The performance management process is described in the chapter Performance management below. In the Figure 4 below, the position of the performance measurement system and the performance management process is described. In the figure it is described that the information system and performance measurement system are parts of the performance management process. The objective of the performance management process is to provide a proactive, closed loop control system where the company policies are deployed and feedback obtained from the performance measurement system as illustrated in Figure 6 (Bitici, Carrie, & McDevitt, 1997).

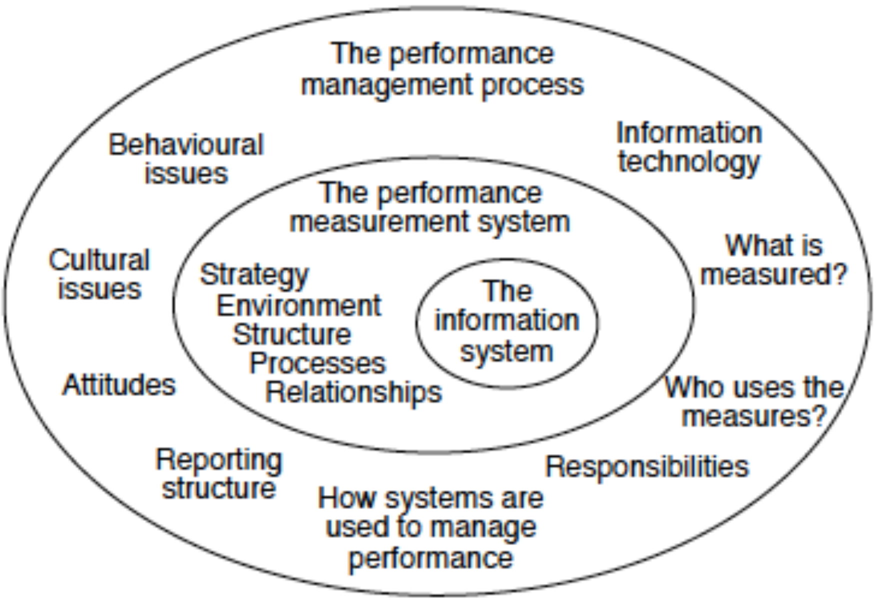

Figure 4 The position of the information system and performance measurement system in the performance management process (Bitici, Carrie, & McDevitt, 1997).

To have a successful quality performance measurement system, the system needs to consider the strategic and environmental factors of the company, the organizational structure, the processes and the functions and their relationships (Bitici, Carrie, & McDevitt, 1997). It is necessary to ensure that the data obtained from the feedback system strengthens the company's best interest and is congruent with the company strategy (Bond, 1999). To ensure survival of the company in the long term it is vital to measure deviations correlating to customer service, which could for example refer to quality (Bond, 1999).

An effective quality performance management system provides the management with both hard and soft factors, where hard factors are for example reporting structures and responsibilities; while for example culture, behavior and attitudes are often referred to as softer factors (Bitici, Carrie, & McDevitt, 1997). In order not to provide the data receivers with too much information key performance variables should be identified. The purpose of identifying the key performance variables is to filter out information that is not useful or necessary to provide the user (Bond, 1999). This is essential since providing the managers with too much information would only cover-up the actual picture of the business performance (Bond, 1999). The information obtained should be used to create an understanding of the system, inform decision makers and measure the progress towards established goals (Veleva, Hart, Greiner, & Crumbley, 2001).

The objective with providing feedback of process quality to employees is that it should be provided continuously and direct to the user. The information should then be regarded through discussion and evaluation by the receivers (Karlsson & Åhlström, 1996). According to Karlsson and Åhlström (1996) information can have two different characters, strategic and operational. Strategic information is concerned with the overall performance and has a longer time perspective and should also be provided less frequently than operational information (Karlsson & Åhlström, 1996). In the strategic information it is important to consider what information should be supplied, to only supply the amount of information that is necessary. Operational information has a shorter time perspective and should be provided more frequently compared to strategic information. The operational information can for example cover the performance of a team of operators. Karlsson and Åhlström (1996) mean that the final goal with information distribution is to display the information directly to the receivers, which could be directly to the concerned team of operators.

2.3.1 Purposes of process measurement

There could be different purposes for measuring a process. It is necessary to know the purpose before designing the system since different purposes demand for different data (Lebas, 1995). According to Bond there are four different levels of process management, these are: process maintenance, process improvement, process reengineering and process stabilization (Bond, 1999). For process improvement the process owners are seen as the main users, using the data for improvements and to align the process according to goals set for the set process (Bitici, Carrie, & McDevitt, 1997).

Process management

A management process control system is aimed at measuring process performance on a more general level. According to Daniel and Reitsperger (1991) normative process control systems used by management are designed to support the management's objectives and strategies. The information provided to management should act as input to the processes of planning, control and decision-making. A process control system used by the management needs to be adjusted and modified to be able to complement the company strategy and the strategic objectives and goals (Daniel & Reitsperger, 1991). Goold and Quinn (1990) describe a strategic management control system as a process that allows management to evaluate and determine if the observed unit is performing satisfactory. Birnberg and Snodgrass (1988) describe a management control system to limit the decision space for the individuals within the organization, thereby affecting their behavior. The purpose of the control system is to allow the management to easier control and steer the company towards the organization's goals, by coordinating decisions. This is done by controlling the flow of information (Birnberg & Snodgrass, 1988). To achieve the most effective management process control system for improved performance, the control system should provide specific and challenging goals included in the feedback to the individuals (Locke, Saari, Shaw, & Latham, 1981). It should also relate to the manufacturing strategy of the company and change over time as the company goals and strategies changes. Different companies have different strategies, for this reason the control system should vary between companies (Suwignjo, Bititci, & Carrie, 2000).

Process performance is often measured and used to verify that the process result is according to expectations (Bond, 1999). The purpose of such a measurement system is to make sure that the process is performing in a desired and predictive way. If the process performance is not sufficient, the process could be improved with small improvements by process maintenance, or by improving the process with larger reconstruction through process reengineering. A process measurement system is aimed at identifying process deviations and the causes of the deviations. Sustained actions should be taken to prevent future deviation occurrences and to make the process stable (Bergman & Klefsjö, 2010).

When a process is stable it can be improved using continuous improvement. Process stability is described in more detail in Appendix B. By measuring the processes, data about the performance can be obtained (Bond, 1999). The data used for the continuous improvements should specify what creates variations in the process. Removing these variations should improve the process performance. Continuous improvements should be done by the operators at the lowest level of the organization (Liker, 2004).

2.3.2 Design and use of performance measurement systems

The design of a performance measurement system is schematically described in Figure 5. To design a performance measurement system it is first important to choose the control subject. The control subject differs depending on what type of feedback is desired. The next step is to establish measurements of what is to be measured in the process. Establishing measures is according to Juran and Godfrey (1998) one of the most difficult tasks in quality management. Establishing the measures is important according to Neely *et al* (1996) because it induces certain courses of action. An ideal measure should be simple in the sense of collecting data and at the same time be informative (Hon, 2005). When establishing measures it is important to regard the means of the measurement, frequency of measurement, how the data will be recorded, the reporting format, how to make the data usable and who will perform the measures (Juran & Godfrey, 1998). To be able to compare the measured data, standards of performance levels need to be set. These standards should be set at a level to which the process is aimed to achieve (Juran & Godfrey, 1998) (Liker, 2004). The data from the process measures need to be evaluated and interpreted and actions need to be taken to align the process (Juran & Godfrey, 1998).

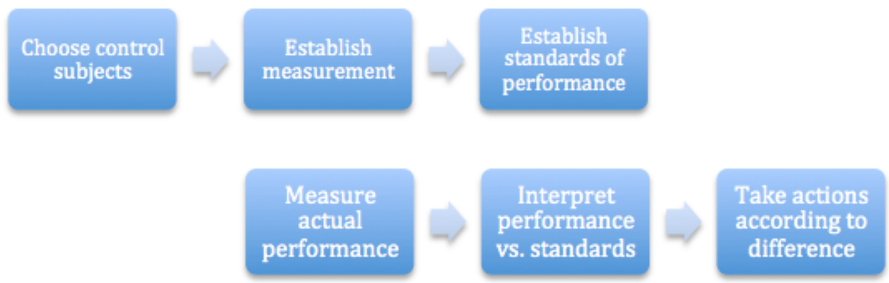

Figure 5 How to design a process measurement system according to Juran and Godfrey (1998).

2.4 Performance management

Performance management is the process where the company manages its performance according to company strategies and objectives. The aim is to make sure that the business strategy is deployed throughout the organization, but also to provide feedback enabling management to make the right decisions (Bitici, Mendibil, Martinez, & Albores, 2005) (Bitici, Carrie, & McDevitt, 1997) (Daniel & Reitsperger, 1991). To manage the company performance it is important to verify proper strategy deployment, this to ensure that all parts of the organization strive towards common goals (Bitici, Carrie, & McDevitt, 1997). Functions of the company need to be measured and feedback of the performance needs to be provided back to the management of the organization. Feedback is necessary for a company to be able to perform according to the set goals (Karlsson & Åhlström, 1996), and effective feedback is important in performance management. The policy deployment illustrated by Bitici *et al.* (1997) is seen in Figure 6.

Figure 6 Policy deployment.

2.4.1 Performance management according to Hoshin Kanri

Hoshin Kanri is the way Toyota is cascading down the objectives from the top management down to the process level. All of the objectives are broken down from a level above to the level below making it clear and visible what should be achieved to support the goals on top management level (Liker, 2004). The way to break down the goals can be seen in Figure 7 below. According to Liker (2004), all these goals should be measureable and very concrete. If this is not the case, they are not accepted by Toyota.

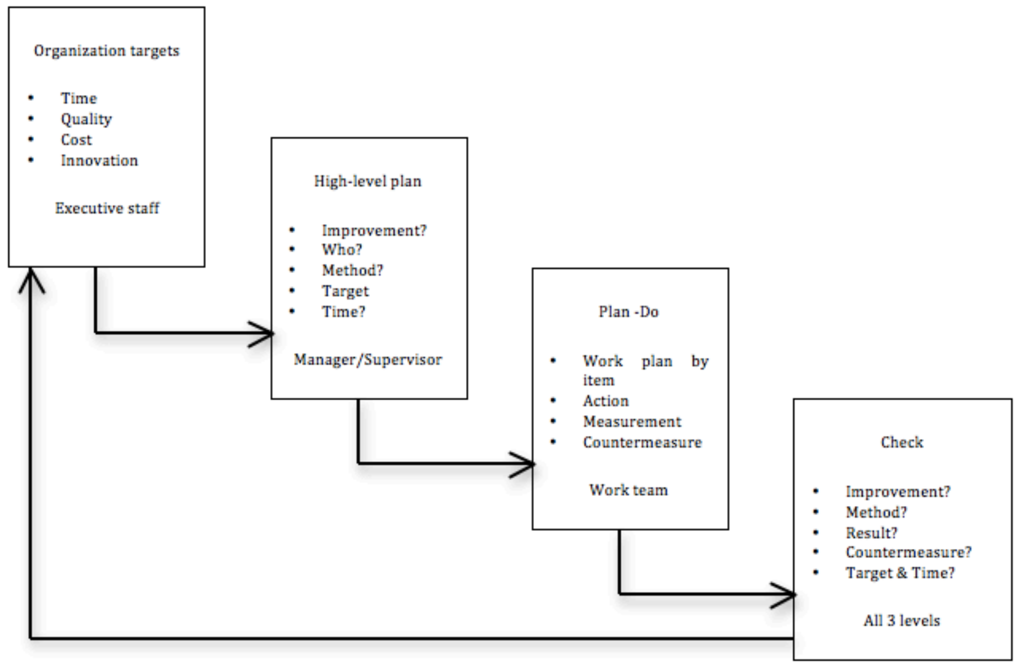

Figure 7 Schematic description of how goals are broken and cascaded down at Toyota (Liker, 2004).

Liker (2004) means that aligned goals and objectives are required to get everyone involved in the continuous improvement work, but this requires constant measurement of the progress towards the set goals. The goals that are set and cascaded down at Toyota are of a stretched character, meaning that they should be hard to reach but it is where the organization is striving. One step of Toyota's learning process is to monitor the progress towards these stretched goals. The results obtained from the measurements are continuously compared to the stretched goals and the performance is evaluated according to them (Liker, 2004).

2.4.2 Performance management according to SMART

The purpose of the Strategic Measurement Analysis and Reporting Technique, SMART, is to establish a management control system with performance indicators that define and sustain success (Cross & Lynch, 1988). The foundation of managing performance according to SMART is the operational measures. These operational measures should be derived and aligned according to the business strategy of the company (Cross & Lynch, 1988). Measures should provide users in the organization with information and feedback of the process depending on the set objectives. These objectives originate from the top management and are deployed from the top of the organization and down. The further down in the organization the goals are set, the more they need to be tangible (Cross & Lynch, 1988).

When established measures are related to fixed goals, the goals are usually set higher (Cross & Lynch, 1988), which can be compared to stretched goals.

It is important that the measures and goals are determined in a way that it encourages continuous improvement. It is also important that the obtained feedback is not too negative and only focuses on shortfalls, since negative feedback often decreases or kill motivation to continuous improvement (Cross & Lynch, 1988).

Figure 8 illustrates the performance pyramid from the SMART-approach. At the top of the pyramid the vision of the company is set. This vision is broken down in the organization in form of objectives which are rolled down and deployed in the organization. According to these objectives, feedback from measures is rolled up supplying different users in the organization with information about performance.

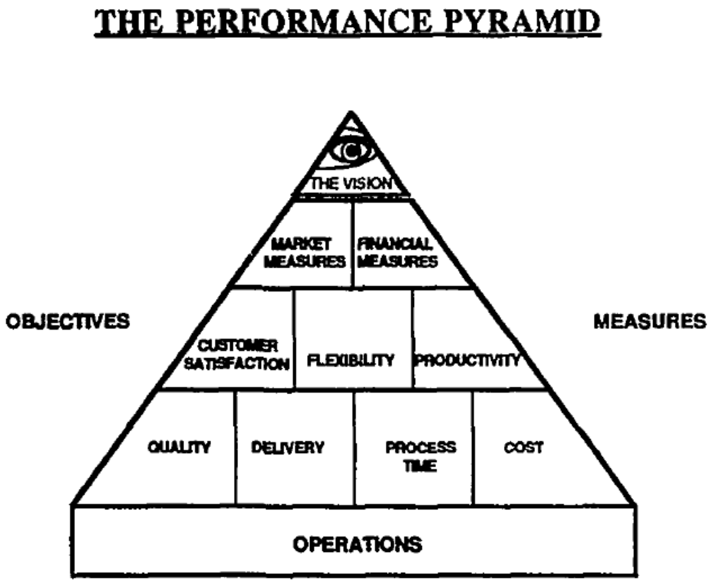

Figure 8 The performance pyramid that forms the basis for SMART (Cross & Lynch, 1988).

2.4.3 Prerequisites for a manageable process

To manage a process it is important that the process is measured. Without measurement and feedback of the process it is not managed (Daniel & Reitsperger, 1991) (Juran & Godfrey, 1998). For a process to be manageable it needs to fulfill six criteria (Juran & Godfrey, 1998), these are:

- It has an owner.
- It is defined.
- Its management infrastructure is in place.
- Its requirements are established.
- Its measurements and control points are established.
- It demonstrates stable, predictable, and repeatable performance.

The first criterion concerns that there is a need to know who owns the process since it is usually the one having the authority to make decisions concerning it. The second criterion is important since the definition covers the extent of the process and where the process limits are located. The management infrastructure is defining who has the responsibilities of what and who controls what in the process. The requirements are important since they describe what needs to be fulfilled to have the process operating. The fifth criterion means that the process needs to be measured and data need to be obtained to make it possible to control the performance of the process. The last criterion demands that the process is stable. Without a stable process, the behavior is not predictable and therefore hard to control, this is verified by Bergman and Klefsjö (2010).

2.5 Process measurement for different types of improvements

The data obtained from a process performance measurement system is often used to align the process if the performance deviates from the desired path (Bitici, Carrie, & McDevitt, 1997). The data can be used to improve the assembly process, which can be done in two different ways; continuous improvement, consisting of small incremental changes and discontinuous improvements which implies larger changes in fewer occasions with greater impact to the assembly process.

By measuring the process performance the data obtained can be used as basis for the continuous improvement work (Bond, 1999). Continuous improvement work should be performed bottom up and should be executed by operators at the lowest levels of the organization (Liker, 2004). The continuous improvement encourages the operators to take responsibility for the strategic aims (Bond, 1999).

In contrast to continuous improvement, the discontinuous improvement is associated with innovative steps, as for example process re-engineering. The changes are of a larger character, which are also often associated to larger costs and long time scale (Bond, 1999). The process re-engineering is a way for management within the organization to affect the system, since in continuous improvement the changes made are often outside management control where they play a supportive role (Bond, 1999).

3 Method and realization

The general method for conducting this thesis is the Deming cycle, which consists of the four different phases *Plan-Do-Check-Act.* During the P*lanning*-phase, efforts were put to outline the project and to obtain relevant knowledge. In the *Do*-phase the knowledge obtained was used to produce recommendation, which was evaluated in the *Check*-phase. The last phase which is *Act,* is where the results of the evaluation in the *Check*-phase were analyzed and used to improve the result obtained in the *Do*-phase. The thesis plan is illustrated in Figure 9.

In the *Plan*-phase, the pre-study phase was divided into two main parts; the first was theoretical research, which consisted of literature studies, analyzing the Volvo Production System material and analyzing similar solutions. The second part was practical studies of companies performing well in the sense of measuring process performance. This part consists of benchmarks from the companies identified in order to make use of their experiences. The current state analysis was conducted to obtain knowledge about how Volvo is currently working.

In the *Do*-phase the results from the planning-phase were used to formulate a result for the thesis. The results obtained in the do-phase were analyzed and possible improvements evaluated, in the *Check*-phase. During this phase a pilot was conducted to verify that the obtained result is applicable at VTC. Aspects that were not considered or missed were identified and used as a basis for the corrective actions taken in the *Act*-phase.

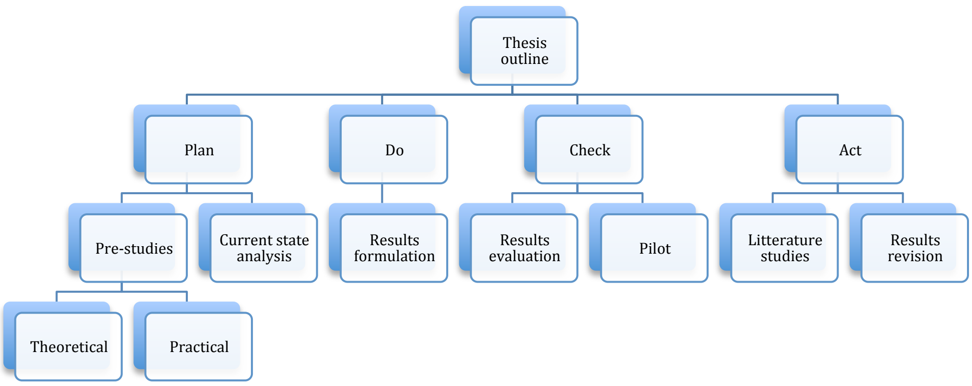

Figure 9 General thesis plan.

3.1 Literature studies

Literature studies are good ways of receiving knowledge about the problem and for obtaining approach angles (Patel & Davidson, 2003). They helped to form the problem formulation and informed about other similar studies, their results and their advantages and disadvantages.

There are three main ways of performing information collection (Backman, 1998). The first is *consultation,* which means that communication with experts, colleagues, institutions etc. is carried out in writing or verbally. This is a good method for receiving information, fast and is often used as an early introduction to the subject. *Seeking manually* is the second way and implies to use libraries, books and articles as the main source for information. This could be a tedious method and could also demand for a thoroughly defined problem (Backman, 1998). The last way is to use a *data based* method for searching the Internet and scientific databases. This method is often fast but calls for a great attention particularly concerning the validity of the source (Backman, 1998).

It was important to make sure that the sources used in the literature study were valid and to be aware that literature studies as the only source of information and knowledge might not give a complete picture of the subject (Patel & Davidson, 2003).

When analyzing the current state at VTC, material from Volvo's intranet was also used as a part of the theoretical research. Material from the intranet was used to create an understanding of how VTC and other companies within Volvo Group are working with the subject of the thesis.

3.2 How to identify process indicators

In the industries there are few methods or suggestions available for how to determine performance measures or indicators for measuring the production (Suwignjo, Bititci, & Carrie, 2000). Many of the available methods are based on subjective evaluation methods such as cognitive maps and cause-and-effect diagrams. The theory described below is a compilation of the literature that is affecting the research area and is used as a guide to determine which process deviations affect the process quality of an assembly process. These methods will be used together with interviews and observations in order to lower the level of subjectivity.

How to determine which process deviations that affect assembly process quality

Performance measurement systems usually contain performance measures from a number of different process areas, areas that in some way are affecting the quality of the product or the performance of the assembly process. To aggregate the data into a single unit or into comparable units can be a difficult task. The Quantitative Model for Performance Measurement System, QMPMS, proposed by Suwignjo *et al.* (2002), gives a methodology to accomplish such aggregation.

The QMPMS method consists of three steps:

- Identify the deviations that are affecting the performance and the connections between these deviations. For this cognitive maps can be used.
- Structure the discovered deviations hierarchically. Cause-and-effect diagrams and tree diagram can for example be used.
- Quantify the effect of the deviations on performance. The Analytical Hierarchy Process can be used for this.

Identification of the deviations is the most important step in the method. All the deviations that are affecting the quality performance of the assembly process need to be included. Failing to accomplish this will cause the result to be unreliable and the outcome will not reflect the actual performance (Suwignjo, Bititci, & Carrie, 2000).

It is preferable that people from different departments work together to find the deviations, since individual opinions often differ. Cognitive maps are useful tools for gathering and finding all the influencing deviations in brainstorming meetings. The tool is useful to gather thoughts, ideas, and opinions from the participants about the deviations and shows how the different deviations are connected to each other. Since the cognitive maps also display the deviations graphically the tool is useful as a basis for discussion and analyses. When the investigated area is big and the maps for that reason tend to be very extensive, there is a possibility to split the investigation in to several smaller areas (Suwignjo, Bititci, & Carrie, 2000). These areas results in cognitive maps covering parts of the desired result which then should be compiled into an over arching map.

The effect of a deviation on quality performance can be classified into three levels. Direct effecting deviations are those that directly affect quality performance. Indirect effecting deviations are those that affect performance through other deviations and self-interacting deviations, which have an effect on quality performance through the deviations effect on itself. When categorizing the effect of the deviations, one could use a plus or a minus sign to see in what direction the deviation is affecting quality performance (Suwignjo, Bititci, & Carrie, 2000).

When the deviations, and the connections between the deviations, have been established the hierarchy between them needs to be clarified. A cause-and-effect diagram is useful to identify the hierarchical structure of the deviations and to sort them into groups. The cognitive maps should serve as a basis for the cause-and-effect diagrams. To further emphasize the hierarchical structure a tree diagram can be useful, to which the cause-and-effect diagram should serve as a basis (Suwignjo, Bititci, & Carrie, 2000).

When the relationship and hierarchical structure of the deviations is known it is easier to categorize the deviations in a more natural way.

When the affecting deviations have been established and their connection and the hierarchy between them are known the relative effects of the deviations can be quantified. The quantification procedure is carried out through a pair vise comparison between the deviations. A score between one and nine will be given to each analyzed pair after asking the questions: In comparing deviation A and B which one has the strongest effect on the other and how strong is the effect? These pairwise comparisons and their values are then gathered in a matrix and the deviations relative effect can be calculated (Suwignjo, Bititci, & Carrie, 2000).

How QMPMS was used in this thesis

The last part of the QMPMS-method, where relative effects are quantified was not used in this thesis. The reason for not establishing the relative effects of the deviations were that it is thought to be impossible to evaluate how all deviations affecting each other and the assembly process at Volvo, during the duration of the thesis. Using relative effects in the method also introduces more subjectivity since the weights are composed of personal opinions. By weighing the relative effects, changing the chosen deviations will be more difficult since these new deviations would then have to be related to the other deviations.

One of the biggest drawbacks with this method is the subjectivity. The persons participating in the brainstorming activities need to determine which deviations that were important. It is possible to lower the level of subjectivity by having as many sources of information as possible, for example through interviews, observations, literature and a large number of participants at brainstorming meetings (Suwignjo, Bititci, & Carrie, 2000). It is also possible to verify the methods using a pilot study. With the results from a pilot it is possible to verify if the chosen indicators are relevant or not and after that update the method. Since all methods and indicators should be adapted according to a specific company it is impossible to use objective methods, this would result in too many methods (Suwignjo, Bititci, & Carrie, 2000).

Cause-and-effect diagram

The cause-and-effect diagram is a way of illustrating the relationships between causes and effects in a process (Ishikawa, 1989). The diagram is constructed similar to a fishbone, see Figure 10. At the head of the fish the effect is noted. Along the main bone the causes to the investigated effect are structured according to the character of the cause. Man, machine, method, material, management, milieu and measurement could for example represent these characters, which are referred to as the 7 Ms (Ishikawa,

1989) (Bergman & Klefsjö, 2010). According to Ishikawa, the Ms need to be managed when implementing quality control (Ishikawa, 1989).

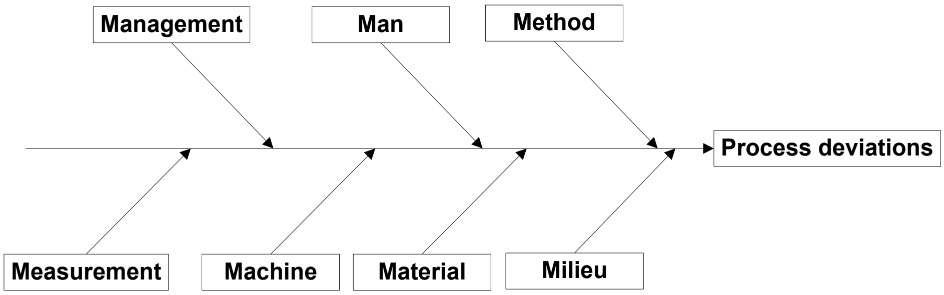

Figure 10 Cause-and-effect diagram with the 7M.

3.3 Reference persons

The authors' supervisor at Volvo Tuve chose reference persons from the production sites in Umeå and Gent. The purpose with the reference persons was to obtain feedback from the different production sites, to ensure that the result from the thesis was developed in the right direction. The reference persons were used as initial contact when performing the internal benchmarks of VTC production sites, and aided the authors in finding the right persons to interview during the benchmarks.

3.4 Interviews

The interviews that were performed were aimed at collecting qualitative data. The purpose of qualitative interviews is to capture experience from the interviewees (Patel & Davidson, 2003). For this reason key persons should be used and the focus of the interview should be on experience.

There are three types of structures for interviews (Denscombe, 1998). *Structured* interviews follow a predetermined pattern of questions that the interviewee should answer. *Semi structured* also follows a pattern but not to the same extent as *structured* interviews and they allow for the interviewee to ad information other than the specific answer to the question. *Unstructured* interviews only follow a topic and are organized more as a discussion between the interviewer and the interviewee, which of these types to choose from depends on the wanted result (Denscombe, 1998).

Structured interviews are often better in newly started projects since the information received is easy to compare and the interviewer needs knowledge about the subject (Denscombe, 1998). The more knowledge the interviewer has the greater are the benefits with *semi structured* and *unstructured* interviews. One problem with these types of interviews is that the information received from the interviews is hard to compare since the interviewee are allowed to talk more freely. By using an interview-script the problem can be decreased (Denscombe, 1998). It is also very important to critically review the information gathered, so that facts can be separated from personal opinions and for verification of the validity. By comparing facts from different interviews the validity can be verified.

The interviews that were held during the thesis were physical meetings. The benefits are, according to Denscombe (1998), that they are easy to arrange. A strength is that the interviews are easy to control since the interviewers only have one person to focus on and guide through the interview (Denscombe, 1998).

The arrangement of the interviews

The interviews were arranged with help from the reference persons at the respective production site. The references persons were prepared in beforehand with the questions that, according to the authors, needed to be answered. These questions are available in Appendix A. Before the interviews were performed, the reference persons were also given a short explanation to the purpose of the interviews. This was done so that the reference persons could arrange the interviews in the best possible way.

At the production sites, representatives from different departments were interviewed. These persons either had connection to the production and regularly participated in the meeting structure at the production site or were positioned at the quality department. The reason for choosing these two functions were that they had knowledge regarding the questions that needed to be answered.

The arrangement of interviews outside VTC was generally conducted the same way. The interviewees were provided through contact with the author's supervisor at Chalmers and other personnel working at the department for Product and Production development. These persons were prepared in the same way, with the same questions sent in on beforehand as the interviews performed at Volvo.

3.5 Benchmarks

In order to receive knowledge about the current state and how other production sites of VTC work with process improvement measurement and improvements, benchmarks were performed. The production sites that were included in the benchmarks were the production sites in Umeå and Gent, since this was where the references persons were positioned. These benchmarks were important for the development of ideas and as input to new approaches for the result of the thesis that was suggested. Experiences obtained at the production sites needed to be considered as important input for the result of the thesis.

In addition to the internal benchmarks of VTC, two external benchmarks were performed. These two benchmarks were performed at Toyota Material handling in Mjölby, and Autoliv Sverige AB in Vårgårda.

3.6 Pilot study

A pilot study was performed at Volvo Tuve to make sure that the suggested measurement system is suitable and realistic for implementation at VTC. The pilot was important as it gave indications if the measurement system is applicable or not and if any parts of the results needed to be improved. The pilot was conducted with the method of participative observation, which means that the authors were participating in the pilot. According to Denscombe, there are normally two types of observations that are used; systematic and participative (Denscombe, 1998). The systematic observation is normally associated with generating quantitative data while the participative observation is associated with qualitative data. For the pilot performed in this thesis, the participative observation was more suitable since the aim of the study was not to generate qualitative data; instead it was to evaluate the use of the suggested measurement system. The strength with using observations is that it creates data based on direct observations (Patel & Davidson, 2003). Another benefit is that the observation is performed in a natural environment that gives an opportunity to evaluate the result from a condition that would normally have occurred (Denscombe, 1998). A drawback with using a participative observation is that the data obtained could be unreliable since it is registered by the observers and is based on their interpretations of the experiences (Denscombe, 1998)

3.7 Reliability and validity

Reliability and validity are two important aspects that need to be handled before reflections about the quality of the result are made. To achieve validity there is a need of high reliability (Yin, 2003).

Reliability

Reliability is connected to how the tools used affect the results from a study and how repetitive the results are. A reliable study can be observed several times where the variations in the observed data only depend on variations in the observed object (Denscombe, 1998). According to Yin, the goal of reliability of a study is to minimize the errors and biases (Yin, 2003).

To make the data collection in this project more reliable, the benchmarks were evaluated by using an interview script with a set of standardized questions. These questions are available in Appendix A. To ensure qualitative data as input for the thesis, the data obtained from the benchmarks was discussed and recorded by the authors as soon as the visits were finished. When the data had been recorded the authors answered the questions stated. By recording the data directly and by using the standardized questions a minimum amount of data was lost.

To make the pilot more reliable, the procedure for the execution of the pilot is documented in the report. This type of documentation is according to Yin a prerequisite for reliability (Yin, 2003). Since the purpose of the pilot was to evaluate the result from the operators' perspective, the pilot was conducted by letting operators perform the process deviation measurements. The indicator structure can be seen in the Results chapter. The authors were available at the side of the production line to answer the operators' questions. The help the authors provided were only explanations and not answers to how the measurement should be performed. Another reason for the authors to be present at the line was to ensure that the operators followed the developed indicator structure and to ensure that pilot was performed according to instructions.

Validity

Validity is according to Denscombe (1998) concerned with how well the data is reflecting the reality and how well it is covering the key questions. This can be regarded as answering how well a result is matching the reality. There are two types of validity according to Yin (2003), internal and external. Internal validity is concerned with analyzing the obtained data, which for example could be explanation building and addressing rival explanations. External validity is concerned with the possibility of generalizing the results obtained in the performed study to other studies.

In this thesis, the pilot was conducted to investigate how well the indicator structure matched the real production environment and how the measurements were experienced by the operators. Opinions from the operators where obtained by asking the operators that performed the pilot what they consider about the quality performance measurement system. Other operators, from the same areas as the pilot was conducted, were also asked the same question. The internal validity of the pilot was aimed at being raised by collecting opinions from the operators. Performing another pilot, with other operators at a different part of the line, could mean that other opinions and explanations could be obtained, which would increase the internal validity of the pilot. Since the pilot was performed in a short period of time and only at one station of the production line, it could be difficult to generalize the conclusions. This decreases the external validity. The external validity is also decreased through that the pilot is only performed at Volvo Tuve and therefore the findings could be difficult to apply to other companies. The aim has not been to achieve high external validity, hence it is considered as sufficient.

3.8 Generated concepts

Two different concepts of how to measure process quality performance of an assembly process are presented below. The measurements are performed with indicators that cover process areas that are affecting the quality performance of the assembly process. Both concepts use process indicators that have been broken down to increase the level of detail in the measurements to identify process areas in need of improvements. The data from the measured indicators can be aggregated for users at different levels of the organization. The main difference between the two concepts is how the process quality measurements are performed.

The concepts have been created after having performed literature studies, were the two principles for measurements were identified. The principles were presented for and discussed by the reference persons, where their comments were regarded and used to create the two suggested concepts.

3.8.1 Concept 1

This concept is constructed to measure the quality of the assembly process by quantifying the level of predefined indicators through detailed measurements. The user of the measurement system defines what should be measured and what measurements should be used to aggregate data for users at different levels of the organization. The indicators could be set according to process areas, for example: operator, equipment and material handling. These indicators should be determined according to what type of data the user needs to improve the quality of the process. In order to obtain more specific data about the process quality, the indicators that should be measured could be broken down into sub-indicators and lower level indicators, see Figure 11. The indicators are broken down as far as needed to obtain the desired level of detail of the quality performance measures. When the desired level of indicators is determined, lower level indicators are identified which are measured in the process. The indicators can be measured at assembly areas, for example at assembly stations, end of assembly section or end of line. The user of the measurement system determines where to perform the measures.

The performed measurements are graded according to scales based on the severity of the process deviation that has been measured. These scales could be designed so that the value 1 represents the least severe deviation and 10 is the worst on a scale from 1-10. By using a scale to grade the severity it is possible to identify what deviations are affecting the quality performance the most.

This concept is supported by a FTT value that is quantified at the end of the assembly line and is measuring the general quality performance of the entire line. By improving the quality of the assembly process, the measured indicators can be improved, which in turn hopefully will also affect the FTT value. To identify a prioritized process area in need of improvements, the user can analyze the data from the quality performance measurement system presented by the indicators. By improving the assembly process according to the data obtained from the indicators, the FTT value should be improved and the indicators can therefore be regarded as guidance to where improvement actions should be focused.

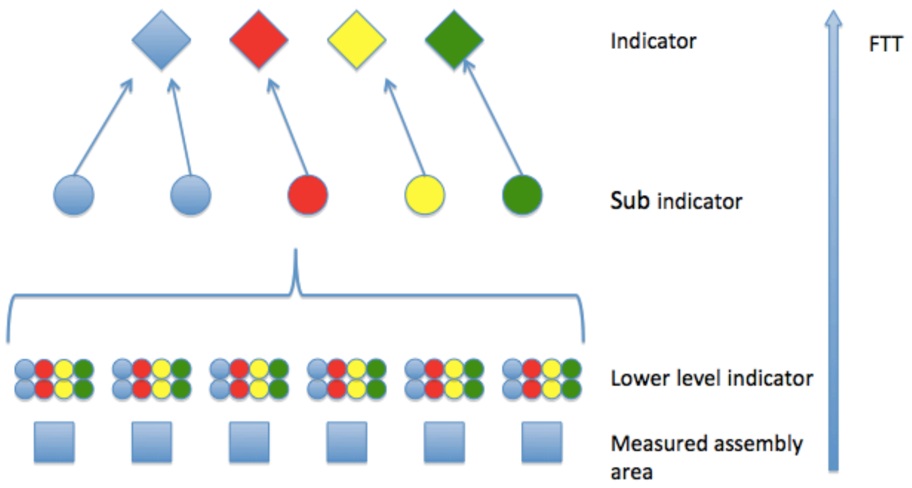

Figure 11 Schematic description of concept 1

To illustrate how the measurement system could work, the blue indicator represents an indicator for how the operator affects the process quality. The operator indicator is measured by the operator's performance with respect to process quality. Ergonomic deviations and the stress-rate, which are two sub-indicators of the operator indicator that have been considered as important by the user, determine the quality performance of the operator. Lower level indicators that are measured in the assembly process quantify these sub-indicators. When the lower level indicators have been measured, their results are used to quantify the sub-indicators for the ergonomic and stress rate. When these sub-indicators have been quantified, they are handled together with their severity to quantify the operator indicator. The lower level indicator measurements are performed at every assembly area where measures are desired.

Example of how the concept can be used

A process deviation occurs at an assembly station. The deviation occurs due to that the operator cannot reach the point of assembly on the product. The operator evaluates the posture that induced the deviation and grades the severity of the ergonomic deviation. The ergonomic measure of the posture together with the grading of the severity, are used to quantify the value of the ergonomic sub-indicator. The ergonomic sub-indicator is then evaluated together with the other sub-indicators and the user quantifies the impact of them on the process quality according to the operator indicator.

3.8.2 Concept 2

In this concept, the assembly process is measured according to pre-defined indicators. The indicators have been defined as important for the quality performance of the assembly process. These indicators could be set according to the 7 Ms. If these indicators are too general they are broken down into lower level indicators making the quality performance measurement simpler. This hierarchy of indicators is presented in Figure 12 below. The aim is not to have as many levels of indicators as possible; instead sufficient levels of indicators should be used to obtain the level of detail desired. The measurement system should provide an indication of where process deviations occur and to which indicator these deviations belong. The same indicators are supposed to be used for all measured assembly areas in the assembly process.

The measures performed are of a discrete character and are quantified by the deviation frequency. When a deviation occurs, a mark is made at the indicator to which the deviation can be categorized, and the mark is made on the highest suitable indicator. All processes should be measured at specified measuring points. The points of measure in the assembly process could follow the natural separation of the production line, for example before a marriage point. These points could be located as seen in Figure 13. The data obtained from these measures are used to construct section FTTs according to the indicators for the specific process areas.

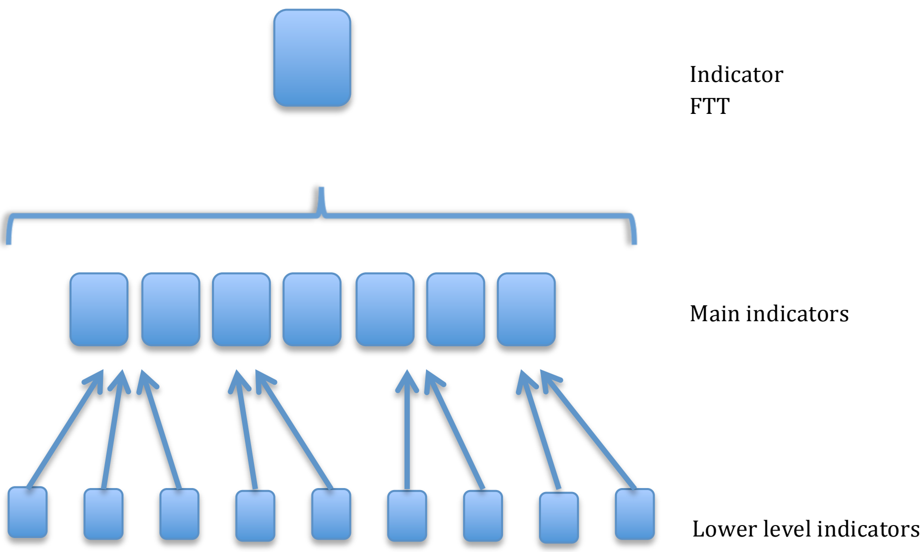

Figure 12 Hierarchy of indicators concept 2

Example of how the concept can used

The FTT is calculated at the process measuring points, and the data from the measures are presented according to the specified indicators. One of these indicators could be Material. This main indicator is considered to be too general for mapping material deviations and is therefore broken down into lower-level indicators such as deviations due to material handling at the station and external material supply to the station. If the operators at the assembly station identify a deviation connected to the indicator and the deviation can be categorized as external material handling to the station, a mark is made in the measurement system report. The results of the lower-level indicators are aggregated to the more general material handling-indicator from where a FTT of the measured assembly area is received.

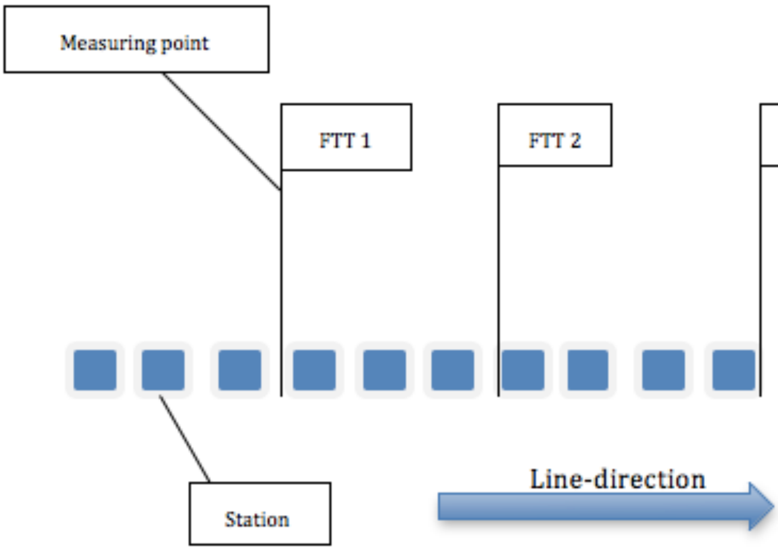

Figure 13 Measuring points used for concept 2

3.8.3 Selection of concept

The concept selection was performed by evaluating the presented concepts with regard to the demands on the measurement system that were presented in the Purpose of the thesis. To complement the concept evaluation, differences of the proposed concepts are presented and the differences are evaluated according to if these are beneficial or not for the quality performance measurement system.

3.8.3.1 Evaluation according to demands defined in the thesis' purpose

The concepts are in this section evaluated according to the demands defined in the Purpose chapter.

Traceability of the measures

Both of the process quality performance measurement systems presented are constructed in a way that allows the user to trace which assembly area that has affected the general quality performance, since the measures are performed at several locations along the assembly line.

Aggregation of measured data

The data obtained from measurements in both of the concepts can be aggregated in different ways since all data is measured in the assembly process. Both of the quality performance measurement systems allow for aggregation of data and allow for adaption of data to different users at different levels in the organization.

Possibility of comparing data

Concept 1 is constructed in a way that demands the user to determine what to measure in the assembly process. The quality performance indicators could be set to a common structure, but how these quality performance indicators are quantified is not generally determined. This introduces difficulties in the aspect of comparing data between different assembly areas. Concept 2 is described to use predefined indicators for measuring process quality deviations, which makes it possible to compare data between different assembly areas.

Identification of deviating process area

By measuring on several locations along the production line knowledge of where deviations occur will be obtained, and will increase the resolution of the quality performance measures. Both of the concepts allow the user to find assembly areas of the assembly process that are in need of improvement.

Data based on actual process quality performance

Both of the concepts are supposed to be used when process quality deviations occur. This implies that the measurement data is created when the process quality deviation are detected. Therefore the measured data is based on passed on actual performance.

3.8.3.2 Evaluation according to identified differences

This evaluation is based on differences between the presented concepts that have been identified through discussion between the authors.

Objectivity of the process quality measures

Concept 1 uses severity grading of the deviations to quantify the impact of the deviation to the process quality. The person performing the measurements determines the severity grading. Concept 2 measures the process quality by presenting the frequencies of process quality deviations.

Simplicity of performing the measurement

As concept 1 is constructed, there are additional routines connected to the concept except for only identifying and calculating the number of deviation occurrences. This requires more education compared to concept 2 of how to use the quality performance measurement system. By using scales to grade the severity of the process quality performance, knowledge is needed of how the deviations affect the process quality performance. Concept 2 is constructed in a way that the person measuring process quality only calculates the number of deviation occurrences and categorizes them according to the defined process quality indicators.

Measurement data connection to current performance indicators for process quality

Concept 1 is constructed to provide data to the user of the quality performance measurement system according to the chosen process quality indicators. The process quality indicators and DOK have an indirect connection and can be used as a complement to each other. Concept 2 is constructed to measure the process quality deviation frequency. The measures used to calculate the DOK are similar to the frequency calculation in concept 2, and therefor there could be a connection between the measures.

3.8.3.3 Evaluation by reference persons

The concepts were presented for the reference persons from the different production sites. It was done through a *live meeting* with the aid of a computer where the authors and the reference persons shared the desktop of the computer.

The results from the reference person's evaluations were consistent. All of the reference persons preferred the second concept. The main reasons for preferring the concept were:

- It seemed easier to understand and to perform the measurement compared to concept 1
- Implementing concept 2 would be much easier since the measures are less advanced
- The measurements are less time consuming to perform
- The data would reflect the reality in a better way

3.8.3.4 Decision of concept for continuous development

In this section, the concepts are compared to each through comparison of the evaluation criterion presented above. The comparison is performed and the superior concept obtains a "+" and if the concepts are equal to each other a "=" is obtained for both concepts. The concept with the most "+" is chosen as the concept which will be used for continuous development. The results are presented in Table 1.

Table 1 Pairwise comparison of the suggested concepts

Criterion	Concept 1	Concept 2
Traceability of the measures	=	=
Aggregation of measured data	=	=
Possibility of comparing data		+
Identification of deviating process area	=	=
Data based on actual process quality performance	=	=
Objectivity of the process quality measures		+
Simplicity of performing the measurement		+
Measurement data connection to current performance indicators for process quality		+
Evaluation by reference persons		+
Sum +	0	5

The concept that had the most benefits compared to the other is concept 2. Therefore this concept is chosen for further development. According to five evaluation criterion the concepts were equal.

4 Results

In this chapter, the experiences obtained from the performed benchmarks are combined with knowledge from theoretical research into developing a process quality performance measurement system.

4.1 Benchmarking – Process quality measurement in other organizations

The empirical studies performed consisted of benchmarks at the concerned production sites within VTC (Tuve, Gent and Umeå) and of two other production sites of companies outside the Volvo Group. The two external companies were, Toyota Material Handling since they are using the Toyota Production System, TPS, and Autoliv Sverige AB who won the Swedish lean price 2010. The purpose of the benchmarks was to analyze how the production sites are working with process feedback and to use the experience for developing the result of this thesis.

The results from the benchmark studies gave a possibility to identify both positive and negative work methods for how process quality performance is measured and reported at the production sites. The benchmark description presented in this section is based on important differences that were experienced between the production sites. These questions were stated after having performed the benchmarks and are used to create a summary of the important findings from the visits. All benchmark visits are presented in detail in Appendix E. The differences experienced from the benchmarks are summarized in Table 2.

How is process quality feedback supplied to the operators?

All production sites visited are reporting quality performance of the assembly back to the operators. There are differences in how this data is fed back and how the data is created. In Tuve and Umeå, printouts from an IT-system are made available at the stations. The data is not communicated in meetings with the operators but is available at dedicated process information areas. In Gent, there are regularly held meetings with the operators at the production line. The data presented in the meetings is also available at process tables in connection to the stations along the production line. At Toyota Material Handling and Autoliv, the operators feed back information to themselves. This is done at Toyota Material Handling by letting the operators evaluate process data and manually print the quality performance on a paper containing a process performance graph. The performance graph is available on a process information board at the concerned station. At Autoliv the operator evaluates the quality performance according to specified criteria with target values and from this draw the conclusion if the process succeeded or failed to pass the requirements. This status of pass or fail is manually printed on process diagrams at a process board at the concerned line.

Are established quality performance measures followed up?

At Volvo Tuve there is a quality performance measure for the assembly operations that is reported generally for the line. There is no direct feedback to the stations about their performance and contribution to the line performance. This quality performance measure is reported at a daily basis. In Gent and Umeå there are several performance measures that are treated and reported daily. In Umeå the established quality performance measures are reported down to sections of the line, while in Gent quality performance can be obtained down at operator level. At Toyota Material Handlings the quality performance measures at the line are determined and are evaluated and reported daily. The quality performance is compared and evaluated according to a target limit determined for the specific processes. At Autoliv, the whole organization, from line level up to global level, is evaluated daily according to established performance measures based on quality, cost, delivery, safety and management, QCDSM. These measures create a basis for the information flow in the whole organization.

Are there regular meetings with a structured content?

The production sites within VTC all have an organizational meeting structure. The difference between the meetings at the production sites is what is reported and how. Umeå and Gent have a structured meeting content that is based on key measures. Every meeting is structured the same from day to day, concerning the reported data. In Tuve the headlines of the meetings depend on what has occurred and what needs to be reported, making the meeting content less structured compared to Umeå and Gent. At Toyota Material Handlings, the quality department is responsible for the meetings held and they are also the ones structuring the content. All information that is treated in the meetings is handled in a standardized way. The data reported depends on what has occurred, similar to how content is treated in Tuve. In Autoliv all the meetings from lowest level in the organization to top global level follow the reporting by the QCDSM-structure.

Is process quality included in process feedback?

At the production sites of VTC, there is no detailed feedback that is based on the process; instead general feedback of the assembly quality performance is reported by a DOK measure. The DOK-measure provides general feedback of process quality, but the more detailed feedback of the process quality is missing. At Toyota Material Handling, all deviations that occur are evaluated according to if there is a standard or not for the deviation and if the standard has been followed or not. This is a type of process feedback since there is consistent work at Toyota Material Handlings to establish standards for all operations. Autoliv do not categorize their process deviations according to what in the process has caused the deviation, but they have data of where in the assembly process the deviations occurred.

Table 2 Summary of the key questions treated during the benchmark evaluation

	Tuve	Gent	Umeå	Toyota Material Handling	Autoliv
How is the feedback supplied to the operators?	Quality performance is printed and the data is accessible at the line. Some data tables are not updated continuously.	Data is presented and discussed at line. The groups own quality performance is reviewed and compared to overall site performance	Data is made visible at the side of line. Data is continuously updated and structured according to quality performance goals.	The operator enters quality performance feedback on a paper at the side of line. This creates forced performance feedback.	Operators evaluate their quality performance and enter feedback by themselves. This creates forced performance feedback.
Are established quality performance measures followed up?	The established measures are followed up at line level and not at the operational level.	Measures are followed up on operational level. The data is used to aggregate feedback on higher level.	Measures are followed up on operational level. Data is reported up to higher levels in the organization.	Quality performance is measured and compared to target levels that have been determined.	Key measures are evaluated and reported throughout the whole organization. The goals are specific for different levels in the organization
Are there regular meetings with a structured content?	There is a meeting structure but the content is not structured. Deviations are reported by occurrence.	There is a clear meeting structure with key questions that are reported from operational level and up.	Meeting structure with clear content where key questions and measures are always reported and evaluated.	There is a meeting structure held by the quality department. Quality performance is reported according to a standardized structure.	There are no structured meetings at operational level. Meetings are planned when needed. Quality performance is reported.
Is any feedback given on the process?	General process quality is reported as DOK. Product feedback is used at all production meetings.	Process feedback is given on a general level by reporting DOK for the stations at the line.	Process feedback is given on a general level by reporting DOK for the stations at the line.	All deviations are evaluated according to if there is a standard or not and if the standard was followed or not.	Micro breaks are reported from line. The data is used for prioritization for focused improvement actions.

4.2 Determine measures

When designing a process measurement system it is important to take the goals and the strategies defined for the process in consideration, this is illustrated in Figure 14. Daniel and Reitsperger (1991) describe three levels of strategies in the strategy hierarchy. These three levels are corporate strategy, business unit strategy and functional strategy. The corporate strategy is the highest level of strategy and could be regarded as the strategy of Volvo Group and VTC strategy as business unit strategy. The manufacturing strategy is associated under the functional strategy (Daniel & Reitsperger, 1991). When comparing these strategic levels with the ISA95, see Figure 2 page 5 there are similarities. In ISA95, the corporate strategy is focused on level 4, the business unit strategy at level 3 and the functional strategies with levels 2,1,0.

The goals regarded for the strategic levels can be business performance goals, management goals and process goals. The goals set below the business performance goals are derived from the top and deployed in the organization as discussed in the Performance management chapter. Policy deployment is a method for breaking down goals for different levels in the organization, where all the goals are derived from the goals set for the organizational level above.

It is important that the goals of the organization are deployed and aligned to the goals set at the strategy level. If the goals are not deployed and derived from the goals set above, it is difficult to control the organization towards the desired strategic direction. Without knowing the desired development direction it is impossible to control the process in the right way (Bitici, Carrie, & McDevitt, 1997) (Bitici, Mendibil, Martinez, & Albores, 2005). This implies that when designing a process measurement system, the data obtained from it should be useful to manage the process. This shows the importance of proper policy deployment and the importance of having defined goals to which the process is aimed to reach. To make all parts of the organization contribute in the progress of the company, all levels of the organization need to have defined goals and feedback based on these goals. Without feedback based on the goals it is difficult to control the process in the desired direction; feedback from the measures induces courses of action (Neely, Mills, Platts, Gregory, & Richards, 1996).

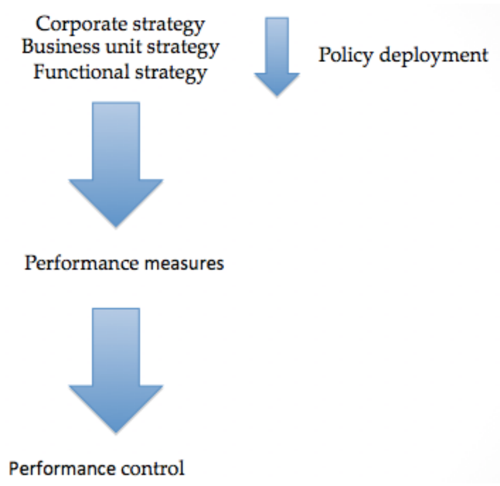

Figure 14 This figure shows the relationship between policy deployment and performance control.

In the Theory chapter it is described that there are two different types of quality measures, product quality and process quality. Both of the quality types are important since they affect how the customer is experiencing the product. After having performed the benchmarks of the VTC production sites, the conclusions were drawn that the production sites lacked routines and methods for reporting feedback based on process quality. To be able to manage the quality performance of the assembly processes it is necessary to obtain knowledge of the assembly process. A good way to obtain this knowledge is through a quality performance measurement system.

The benchmarks showed that VTC is reporting process quality performance on a general level in form of DOK. The data obtained in the DOK-measure is general assembly quality performance since it only measures the fraction of conforming assemblies divided by the total amount of assemblies performed. To be able to improve the process, it is therefore important to establish more detailed measures of assembly quality performance that provides data about which sections of the line that are in need of improvements.

The way the process feedback is constructed at VTC today, deviations that occur at the line but are solved during the process, are not included in the DOK-measure. When measuring a process with the aim of making it stable, it is important to identify all deviations before improving the system.

4.3 How quality performance data could be used

The results from measuring production performance can be used for different purposes as described by Hon, where one purposes is to motivate (Hon, 2005). This together with what Neely *et al.* (1996) describes about measurements and their influence on courses of action, implies that measurements are very important in the development of improving process quality. Therefore, if the aim is to develop and improve the assembly process quality it is important that there are process quality measures established and that their values are followed up regularly. The data from the measurement system can be used to identify areas in the assembly process in which deviations occur, and use this data as a basis when improving the assembly quality. Measuring the quality of the process and obtaining data about the assembly according to the 7M's, will help the organization supporting the decision making regarding process quality improvements. The 7Ms could be used to structure the measured deviations according to the parts of the assembly process that affect the process quality. Supplying the right user in the organization with the right data creates opportunities for process improvement.

For an assembly process to become capable, the prerequisite is that the process first is stable. Process capability is measured as how well the process is meeting the desired performance and how the process performance is aligned according to established specification limits (Juran & Godfrey, 1998). Therefore achieving process stability through process quality improvements is an important part of developing the assembly processes into becoming capable. The definition of capability is given in Appendix C. Measuring process quality deviations occurring, and improving the system in order to reduce the assignable causes and reduce process quality deviation will make the process more stable, see Appendix B for the definition of a stable process. Process stability is desirable since the performance will become more predictable. A stable and predictable assembly process, will reduce the need of corrective actions, both at and after the trucks have left the line, and simplify the task of planning and controlling the assembly process.

4.4 The suggested measurement system

This chapter explains how the suggested process quality performance measurement system is constructed. The description covers how the indicators are used to measure the quality performance of an assembly process and how the data can be used to aggregate data for feedback to different users of the organization.

The suggested measurement system is a development of concept 2. In the suggested measurement system, the levels of the indicators do not result in a FTT value, instead the indicators present frequencies of process deviations.

4.4.1 Measurement system description

The suggested quality performance measurement system uses indicators to measure deviations occurring in the assembly process. The indicators are used to measure and to present feedback on the assembly process quality performance. The indicators, to which process deviations will be categorized, are intended to be based on 6 of the 7 Ms. The Ms selected are *measurement, man, method, machine, material and milieu*. The reason for not using all 7 Ms, is that the indicators identified under the 7th M could be derived from the other Ms. These main indicators are intended to be broken down into sub indicators to cover as many deviation areas as possible.

The indicators that are too general should be broken down into sub indicators to simplify the deviation measurements and to provide a higher level of detail of the process area that affected the quality performance, see Figure 15. The aim is not to have as many levels of indicators as possible, instead sufficient levels of indicators should be used to obtain data that is regarded as sufficient.

When measuring the deviations it is important to evaluate the cause of the deviations. This could be performed by questioning *why* the deviation occurred, as in performing a commonly used *5 why* analysis. The deviation measurement should be performed as soon as a deviation occurs at all process areas in the assembly process. The purpose of this is to follow were deviations occurred along the assembly line. Connecting the deviation measurements to the assembled product, information about what deviations are introduced by specific products can be obtained.

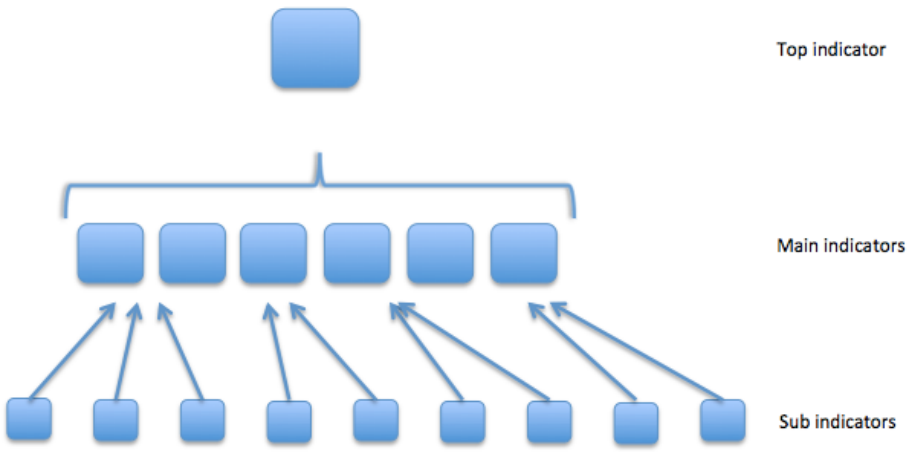

Figure 15 Indicator structure for the suggested measurement system.

The measurement of the indicators and the sub indicators is of a discrete character and will assume a value of either pass or fail. When a product is processed and a deviation occurs, a registration of the deviation is performed according to what process quality indicator the deviations affects. When a deviation occurs at an assembly station, the deviations are evaluated. The deviation is then categorized as far down in the indicators structure as possible according to the indicators that correspond best to the deviation. A mark is made in a system for reporting the deviation at the lowest level of the corresponding indicators. When desired, the data from the lowest indicator level could be aggregated to form more general quality performance indicators.

The received data from the measurements system will be a complement to the already existing system for deviation documentation. In the existing system, the data concerns product quality. This data will be complemented with process quality measures from the measurement system. Measuring process areas where deviations occur result in the quality performance measures. The measures could be presented in graphs showing within which process area the deviations have occurred, for more detail see the chapter Data presentation.

4.4.2 Data aggregation

Depending on who the receiver of the measured data is, the data aggregation can be adapted to suit the requirements of the user. Depending on if the user is at the assembly stations, sections of the assembly line, assembly line or production site level the data can be adapted by aggregating the data in different ways. On station level the data will treat only the specific part of the line that is occupied by the station or the group. This allows the station to obtain feedback on the quality performance and use it to improve the process area.

At section level, the data differs in how big the assembly area is from where the data is aggregated compared to station level. The section level data should be based from data obtained at the different stations included in the section of the assembly line. If there are several stations in the section the indicators for the section are constructed from the specific indicator from each of the station. This way of aggregating the data gives traceability of the indicators between the different levels of the assembly process.

At line level the data is aggregated from all the sections belonging to the line. All the data from station level to production site level will be based on the same data gathered from the process. The principle for how the data can be aggregated for the different organizational levels is described in Figure 16.

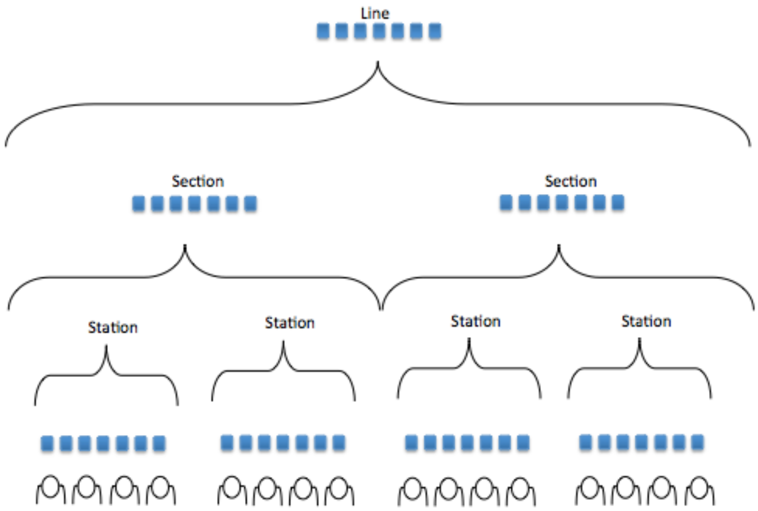

Figure 16 Data aggregation for different process areas of the assembly process.

4.4.2.1 Different types of data aggregation

The data obtained from the quality performance measurement system can be aggregated in different ways depending on what type of data is desired. The main indicators could be used to present the quality performance of each measured assembly area according to the indicators, or the data from the indicators could be aggregated into a general quality performance indicator, referred to as top-indicator. These two different types of aggregations are presented below.

Aggregating all the main indicators into one top indicator, see Figure 17, results in a quality performance indicator that can be used as complementary data to the FTT value for the specific part of the process. A top indicator can be received for the station, section or line. Aggregating the data from the main indicators into the corresponding indicators, the quality performance of the measured area can be presented according to the main indicators, see Figure 18. As for the top indicator this can give data about the station, section or line.

These different ways of aggregating the data is possible since all the data is measured in the assembly process. The aggregation allows for traceability of the indicators between the different levels of the organization and a possibility to see in which assembly area of the assembly process the deviation origins.

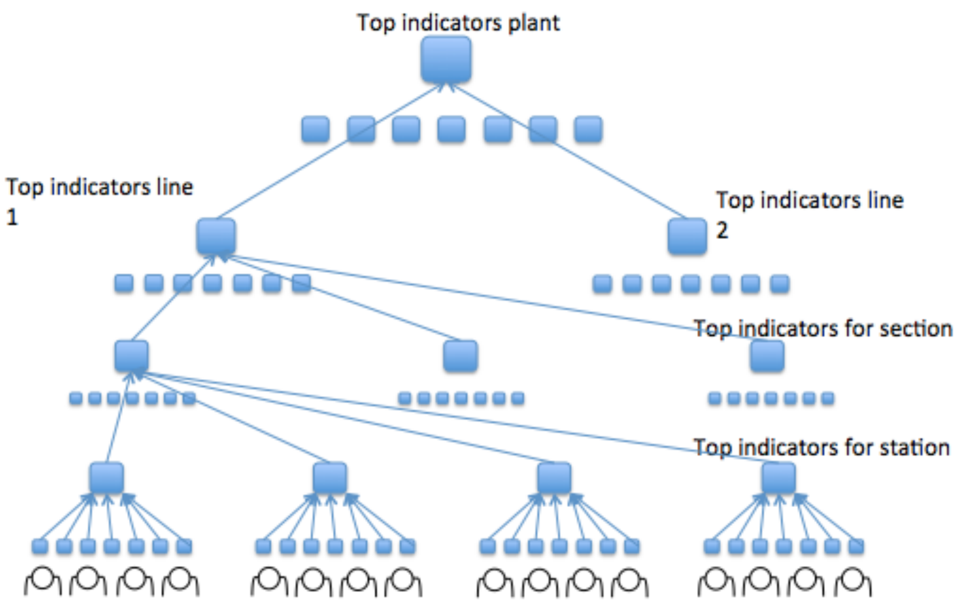

Figure 17 Data aggregation by using top indicators at every level.

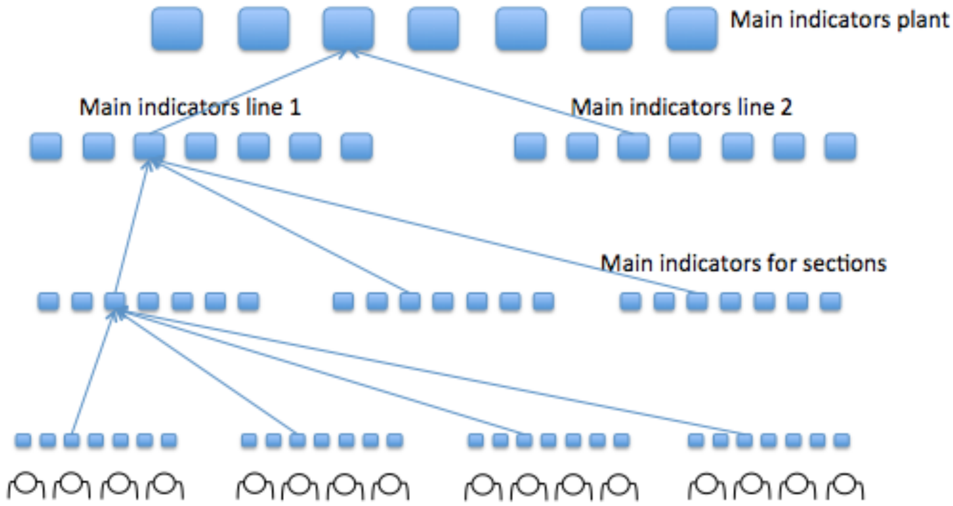

Figure 18 Data aggregation using the main indicators for every aggregation level.

4.4.3 Indicators to measure

Potential deviations of the assembly process were identified by using the QMPMS-method together with the 7 Ms. The deviations where grouped according to the Ms and are described more thoroughly in Appendix F. From the identified deviations different indicators and sub indicators were derived that were used when measuring the quality performance of the assembly process. The chosen indicators are based on 6 of the 7 Ms, where the Management M has been excluded. The reason for this is that the potential deviations identified in the Management M could be categorized to the chosen 6 Ms.

The chosen indicators are considered to be sufficient to cover possible deviations and at the same time provide process data that is detailed enough to categorize the potential deviations of the process quality. The indicators that have been chosen to use for process quality measurement are described below.

Measurement, process quality deviations due to lack of feedback connected to assembly operations.

- **Feedback**, is needed when deviations are discovered to avoid them to be repeated. Deviations could occur due to lack of information provided to the operator.

Man, deviations connected to the human in the assembly process are categorized to this indicator.

- **Ergonomics**, physical ergonomics are connected to demands put on the human body.
    - **Physical**, for example if the workers need to bend, reach, crouch making the assembly difficult.
- **Psychosocial factors**, is connected to the operators personal feelings induced by the assembly environment.
    - **Stress**, is when operators feel stressed due to lack of time in the assembly process.
        - **Absence**, stress due to absence created by understaffing.
        - **Assembly time**, the time planned for the operations is insufficient due to bad assembly balancing or assembly sequencing.

Method, deviations connected to how the work should be performed and how operator knowledge and experience affects the assembly quality performance.

- **Work method**, how assembly methods as standards and work descriptions affects the quality performance.
    - **Standards**, deviation induced due to lack of work standards.
    - **Knowledge & Experience**, the lack of knowledge and experience can cause deviations and mistakes.
        - **Education**, covers deviations that occur due to lack of education of how to perform the assembly.
        - **Training**, regards deviations that occur due to lack of training and practice of work methods.

Machine, deviations connected to machines used by the operators and in the assembly process.

- **Tools**, deviations regarding the equipment used by the operators and how these interfere with the assembly quality performance.
    - **Demand**, relates to the equipment's ability to function according to specifications.
    - **Maintenance**, equipment not functioning as intended due to bad maintenance.
- **Supportive infrastructure**, concerns equipment used to support the assembly, for example software and fixtures.
    - **Software**, deviations due to problems with software used to support assembly, for example deviations induced by automated systems.
    - **Mechanical**, machines and equipment used to support the assembly process, for example fixtures or AGVs.

Material, deviations connected to the material quality and the material handling to the assembly process.

- **Defect parts**, concerns the quality of parts being assembled to the product.
    - **Process damaged**, damages happened within the production site.
        - **Damaged on arrival**, parts already damaged when picked from the material facade.
        - **Self-caused damage**, damage of material caused during the assembly process.
- **Material handling**, concerns supply of materials to the assembly process.
    - **Missing**, parts are missing and not delivered to the process
    - **Wrong**, the wrong part is delivered to the process.
    - **Exposure**, the right part is delivered but to the wrong place of the assembly station, or if parts are located at a unsuitable position.
- **Product design**, the design of the part results in deviations due to difficulties to assemble.

Milieu, deviations connected to the environment in the assembly process.

- **Climate**, the work environment could affect the operators in their work and result in decreased quality performance.
    - **Physical environment**, the physical environmental factors, as for example temperature, lights and sound level.

4.4.3.1 Indicator structure

To enable fast measurement of the deviation and as simple use of the measurement system as possible, it is important for the user to have an overview of the indicators. A tree structure could be used to present the indicator hierarchy. Figure 19 and Figure 20 shows the indicator structure used for presenting the indicators and it is also suggested to be used as a basis for categorizing the indicators.

The reason for not having the same level for all the indicators is that the different categories demands for a different level of detail and in some cases the indicator treats a wider subject which demands more levels. The main indicators does in some cases need additional explanations. For this reason there might only be one sub indicator or lower level indicator. Categorizing a deviation should always be done at the lowest possible indicator, but if it is not possible an indicator at higher level should be used.

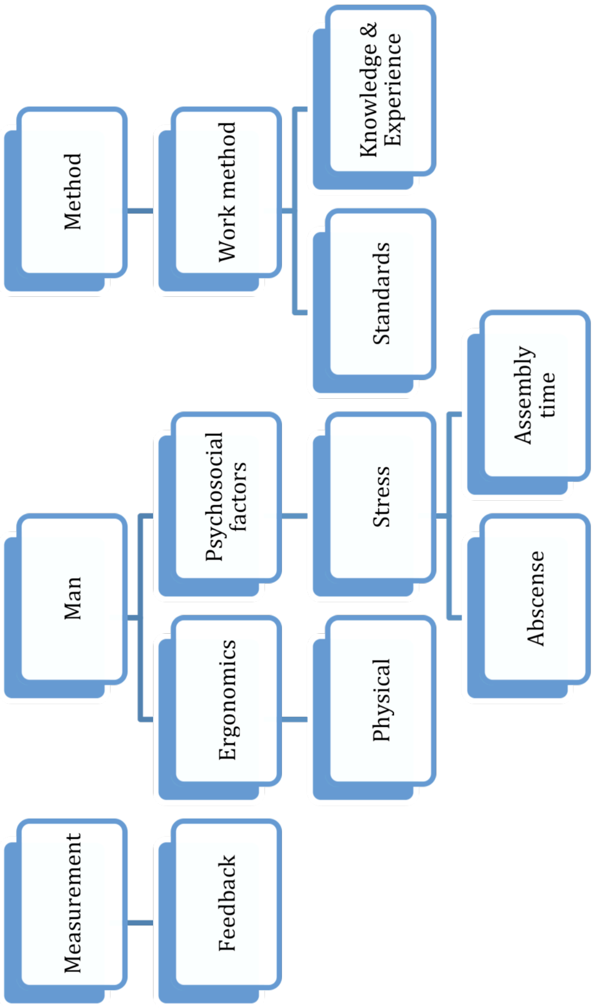

Figure 19 The first 3 main indicators with their sub-indicators

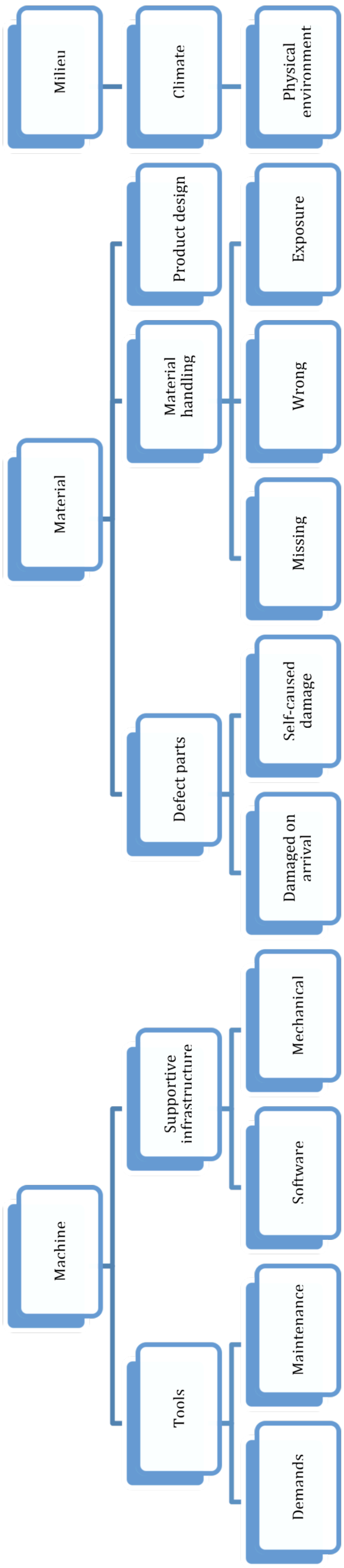

Figure 20 The last 3 main indicators with their sub-indicators

4.4.4 Data collection methods

The deviation categorization can be performed with different data collection methods. A paper with the printed indicator structure could be following the product. This is the simplest solution to implement but demands extensive aggregation procedures since the data needs to be handled manually. Using a personal digital assistant, PDA, where the operators enter the deviations through a touchscreen could be another method used. The PDA could be integrated with other quality systems allowing the data handling to be concentrated to one specific system. IT-integration could also allow accessibility for employees and personnel within the organization.

No matter of how the operators document the process quality measurements, the indicator structure could be the same since it is easily understood and intuitive. The person performing the documentation will make a mark for the corresponding category. These marks results in data that could be aggregated for users at different organization levels of the company.

Examples of how to use the quality performance measurement system

The following two examples explain how the measurement system can be used and how the documentation could be done. In both examples an andon person who is using a PDA to register the deviations performs the documentation. The andon person is supposed to assist the operators when deviations occur.

Example 1

In this example the operator finds two deviations at the own assembly station. The first deviation is that the wrong part has been delivered for the assembly and the second deviation is that the part delivered also is damaged. After the discoveries the operator pushes the andon button and the andon person comes to assist. The andon person helps to solve the deviations and reports them in the performance measurement system.

In this example there were two deviations and therefore the andon person should register two deviations. The deviations are documented according to the indicator structure in the PDA. The first deviation, the wrong part, is categorized according to the main indicator Material, sub indicator Material handling and the lower level indicator Wrong, see Figure 21*. Since the deviation could be evaluated to the lowest level of detail, the documentation should be performed at this level. The second deviation, damaged part, is categorized according to the main indicator Material, sub indicator Defect part and the lowest level indicator Damage on arrival, since it was not the* *operator who caused the damage. The second deviation is also shown in* Figure 21.

When these two deviations are aggregated into the main indicator Material, the sum of the deviations will be one, but still the lower indicators are marked as two deviations. The number of deviations is counted at lowest level where there is a mark.

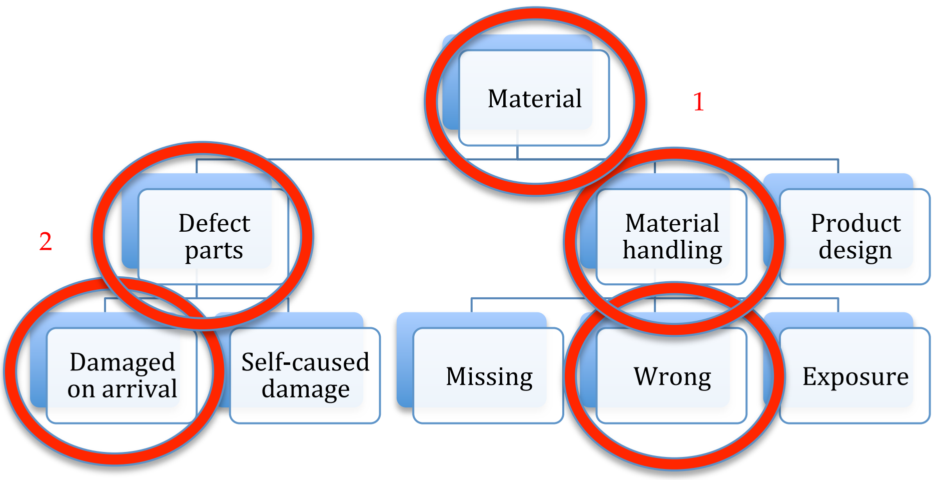

Figure 21 Categorization performed in example 1.

Example 2

In this example a deviation is found downstream along the assembly line. The deviation is that an already assembled part is damaged.

The operator finds that an assembled part is defect and calls for the andon person.

The andon person categorizes the deviation according to the main indicator Material, sub indicator Defect part. Since the deviation has been induced earlier there is no possibility to evaluate whether it concerns Damage on arrival or Self-caused damage of the part. This categorization can be changed after the root cause analysis has been performed, but it gives an indication of what area of the process that was concerned in the deviation. See Figure 22 *for how the categorization was performed.*

If the lower level indicators do not correspond with the deviation found it is possible to document the deviation according to the indicator that corresponds best, the importance is to get an indication of in what process area that the deviation occurred.

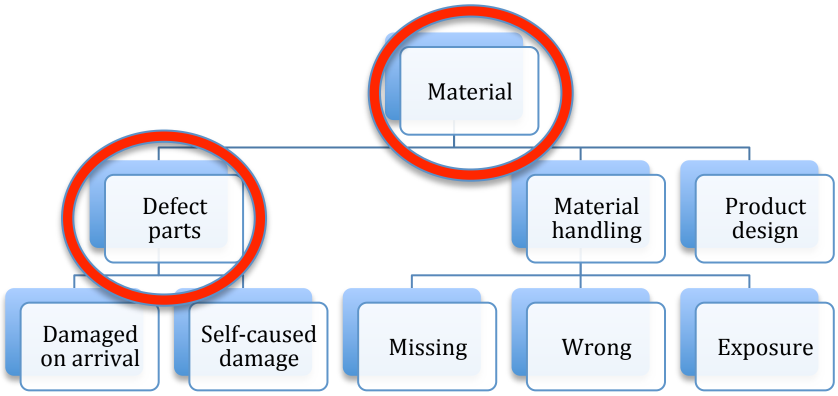

Figure 22 Categorization performed in example 2.

4.4.5 Data presentation

The data measured when using the proposed measurement system should be utilized to display graphs, showing the quality performance of the measured process area and assembly area. The data could be presented in a Pareto-diagram displaying the deviations according to frequency, based on indicators and measured assembly area. The graphs should be used to identify the assembly areas that have contributed to the received DOK value. The DOK value is received from measurements performed outside of this measurement system. By showing the connection between the DOK and the deviations it is possible to see which parts of the assembly processes that have contributed to the DOK. The graphs covering the different process areas could also be used, at different levels of the organization, to identify the different areas of the assembly process that are in need of improvements. When improving the process quality the DOK value should increase.

On station level the graphs should display within which indicators that the deviations occur and what the trends are. The data could be more detailed by presenting the measurement of the lower level indicators. This will enable the stations to know which assembly areas they need to improve in order to improve the quality performance of the assembly process.

On section level the graphs should display the same data as for the station level but with a more overarching view. The data displayed should be aggregation of the data from all the stations and assembly areas belonging to the section.

At line level the graphs should display the process areas where deviations occur but the focus should lie on the whole production line. At the highest level the focus should be at production site or line level; this will facilitate that a comparison can be made between different assembly lines or production sites.

A Pareto-diagram could enable the operators to see how they are performing according to the different categories. The graphs of the indicators are also useful aids in meetings, making it easier for the participants of the meetings to follow the data of the quality performance. This will help the different parts of the organization to know where to put extra focus.

By displaying the data at an information board by the assembly station all members will be able to see which these process areas are and work continuously to improve them.

4.4.6 Users of the measurement system

Users have been identified at different levels of the organization. The identified users are used to illustrate how the user is connected to the assembly process from an organizational point of view.

Figure 23 gives an illustration of which parts of the measurement system that the different users could use in their daily work. Middle managers communicate between all the levels of the system whilst top managers use the more general indicator and the users at operator level the more detailed.

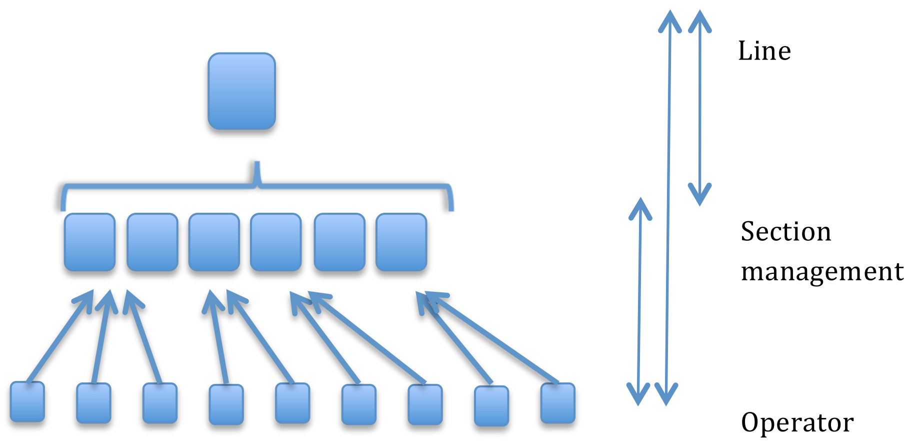

Figure 23 Users identified in the organization. The arrows represent the level of the indicators that the users could be interested in.

4.4.6.1 Operator level

The lowest level where the measurement system is used is at operator level. The results are followed up on daily basis as feedback by rolling down information about the previous quality performance. The data is used to inform about what process areas are in need of improvement.

It is important for the operators to know about their quality performance and the feedback should give indications of how the performance relates to the goals set for the process. The feedback should be provided as soon as possible after having performed the assembly, for example during morning meetings the day after the performed assembly. The data should also be available at the station at a board with process information. The data should be printed before the meetings and then presented and analyzed in the meeting with the operators.

Example

The group leader extracts data from the measurement system regarding the previous day's quality performance. This data is used and presented in the meetings held daily with the operators and covers which areas of the assembly process that had deviations. The data is used as a complement to other information provided at the meeting and could be used as a basis for a discussion with the operators to finds areas in the assembly process that are problematic.

The data that the group leader extracts from the measurement system should be in form of frequency diagrams, based on the structure of the indicators used to categorize deviations in the assembly process. The data could be structured covering the most reoccurring deviations within each category.

4.4.6.2 Section management

The section manager could use the data that has been rolled up from the measurement system to coordinate the operators he is responsible for. The results should be followed up regularly to be able to control the assembly processes according to the current quality performance. The measurement system could also be used to measure quality performance on a longer time span covering weeks or months to be able to identify trends by comparing previous data. This data could be used to determine what stations are in need of specific improvements, and through the data the section manager could coordinate the operators' problem solving focus according to the obtained data. The obtained data could be used to roll down information as operational feedback to the line, but could also be used by the manager in a strategic purpose to plan the process.

Example

The section manager extracts data regarding the quality performance for the previous day's before the daily meeting is held at the operator level. The information obtained from the measurement system can be used to point out process areas that are in need of improvements in the assembly process for each of the sections that the section manager is coordinating. The data extracted from the measurement system could be in form of frequency bars covering the deviations measured.

The section manager could also analyze weekly data to identify trends within the assembly quality performance. With this data the section manager could take actions to avoid big impacts on the assembly quality performance caused by negative trends. The data presented could be in form of charts on a more aggregated level of the indicators.

4.4.6.3 Line management level

The line manager is responsible for the assembly line operations and is managing the line section managers. The line manager follows up the data from the measurement system on a larger time scale, weekly and monthly. The aim is to obtain more overarching knowledge about the line or the section of the line and their quality performance, and from this knowledge be able to align the process according to quality goals. The data from the measurement system allows the line manager to identify process areas that are in need of improvements and evaluate plans for how the process could be improved in the future. The data can be used at managerial meetings as basis for discussion and for making decisions concerning the development of the assembly process.

Example

The line manager could for the weekly management meetings extract data about levels of the main indicators. Data could be extracted suiting the desired level of detail. More aggregated data could be extracted as basis for strategic decision making and data on a shorter time period for more operative decision making.

5 Discussion

In this section the results obtained are discussed followed by a general discussion about the thesis.

5.1 Discussion of the suggested measurement system

The measurement system is intended to measure the quality performance of the assembly processes at VTC and should support VTC in developing stable processes. As discussed previously, a capable process always has to be stable, and therefore developing the process into becoming stable is a natural step towards making the processes capable. To make a process stable it is important that there is knowledge about the assembly process regarding what makes it unstable, and to use this knowledge for improving the system with permanent solutions. The suggested measurement system can be used as a tool to obtain knowledge about which areas of the assembly processes that are in need of improvements. This knowledge is obtained by measuring all deviations and the measurements are performed after having evaluated which process area that caused the deviations.

The measurement system allows feedback to be created covering process performance based on assembly process quality. Process quality is one of the two quality measures discussed in the theory chapter. The process quality feedback is regarded to be missing at VTC and therefore the suggested measurement system complements the feedback information already used at Volvo.

Since the measurement system gives the frequencies of deviations occurred and do not provide suggestions of what process areas to improve, it is necessary to evaluate the results obtained from the measurement system. Since the data from the measurement system can be aggregated for users at different levels in the organization, it is possible to coordinate different types of improvement actions. The feedback provided at operator level could be used to coordinate continuous improvement actions. The continuous improvements could be performed by letting the operators focus on the process areas with the most deviations and let them suggest improvements. For users higher up in the organization the obtained data could not only be used to coordinate continuous improvement actions, but also to identify process areas where focused workshops are necessary. In these workshops, the process could be analyzed in more detail.

One problem with starting to register all deviations is that the measures could show a very negative picture of the operations. It is important to remember that the results should be used to permanently improve the system in the long run, and therefore it is necessary to obtain the data. To handle this, target levels of the measures could first be set to a more generous level and with time be tightened as the assembly process improves.

When comparing different parts of the line or different production sites it does not matter if the comparison is performed with low values as long as all measures are created in the same way.

The suggested measurement system can be used for two purposes that were identified in the theory chapter. These purposes concerns managing the process and improving it. The managing purpose is fulfilled since the feedback from the measurement system could be aggregated in a way to make it useful for mangers in their work with controlling the assembly process quality performance. It will also help managers to make decisions based on facts from the actual quality performance. The purpose of improving the process is achieved in that the measurement system provides data concerning actual deviations, and could be used for coordinating improvement efforts. Since the measurement is intended to be based on the same indicators and performed in the same way throughout the whole VTC, it will allow for comparison between units within the production site and between production sites.

The explanations above support three of the four levels of process management proposed by Bond (1999). Process improvement, process reengineering and process stabilization are all reached. Process improvement, since the measurement system allows for detection of process areas in need of improvements. Process reengineering, since specific actions could be directed towards the assembly areas with most number of deviations. And process stabilization, since the indicators proposed are appropriate for measuring process quality performance, and to continuously improve and reengineer the different assembly areas will stabilize the process.

How does the proposed measurement system connect to ISA95?

The measurement system suggested is overlapping levels 2,1,0 and 3 in the ISA95 standard, see Figure 24. This because the users identified are at production site management level down to operator level in the process.

Since the data can be aggregated for users from process level up to production site management level and there by overlapping the different levels of ISA95, the measurement system can be regarded as a communication channel in the organization. The communication channel is obtained by measuring the indicators in the process, and by aggregating data according to the users that are receiving the data.

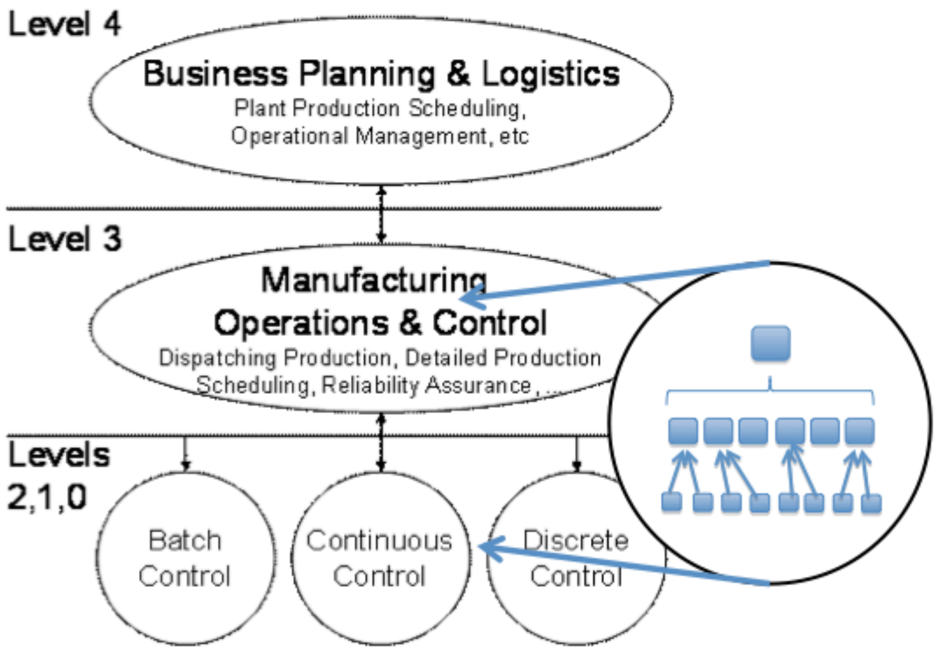

Figure 24 The measurement system aligned according to ISA95.

5.1.1 Discussion of data aggregation

The data aggregation can be adapted to suit the needs and requirements for a specific user. This is possible since the deviations are measured as frequencies and since the data is based on a common structure in form of the indicators.

Since the data is based on the indicators it allows for traceability of the measures. Traceability is obtained by identifying the assembly and process areas that are contributing to the obtained results from the measurement. This allows the users to find which assembly areas that are affecting the quality performance of the assembly process, and use this data to coordinate improvement actions.

To construct the data obtained on a common structure improves the communication in the organization, both horizontally and vertically. Horizontally since it would be easier for users at the same organizational level to communicate about their quality performance and exchange knowledge and experience. Vertically since the operator could more easily communicate with their managers about their quality performance, and managers could discuss the production quality performance with the operators. Since the communication could be based on the same data and feedback constructed in the same way, the communication is improved.

When a data is aggregated and fed back it is important to adapt the depth of the feedback from the deviation according to different organizational levels. For example if a part is missed in the assembly the feedback to the operator could be that he forgot to assemble the part. At assembly manager level, the scope of the deviation should be lifted to handle the standards and the reason for why the standards were not followed. In this way the assembly manager will not drown in detailed operational information.

5.1.2 Discussion of indicators to measure

It is important to remember that the chosen indicators can change over time because of the internal and external dynamic environment. Some indicators will change more often than others, for this reason continuous work for verification of the relevance of the indicators is necessary, and if this is not done properly the indicators can provide a miss-guiding result. The importance is that the chosen indicators is providing data about the assembly processes quality and is providing the user with relevant data about the performance. The measurement system should also be simple enough to be implemented without disturbing the assembly process. The simplicity is vital since the measures should be easy to perform and not disturb the operators to the extent that the measurement system is ignored.

There could be a need to adjust the indicators over time if new process areas are identified and are not covered by the chosen indicators. This would demand that the new indicators are explained for the operators performing the categorization and for implementing a new sub indicator to administrate.

5.1.3 Discussion of data collection method

Using a PDA would eliminate the need of papers as measuring media and to transfer the results into the computer, since this could be integrated in the PDA. It could also make the deviation registration more effective but would still require time for entering the registrations. To reduce the problem with time consuming registration, there is need to allow time for the routines connected to the measurement. To have an organization where the focus is to improve the processes, it is necessary that the management supports the routines associated with the quality performance measurement system and allows the operators to perform the measures.

The person doing the documentation will need to be educated about how the deviations should be measured and how to handle the equipment used for documenting the deviations. It is also necessary to inform the operators how the measurement system is intended to be used and why it should be used. There could be benefits by having a dedicated person doing the documentation, since it would decrease the need of extensive education and less time could be spent on reporting the deviations. If the documenting person is the andon person, it is important that the andon person gets informed about all deviation that has occurred, since it is necessary to bring all deviation to surface and document them. The lack of communication between the andon person and the operators may cause deviations to be undocumented and the amount of deviations documented is also affected if the andon person is busy with other obligations.

5.1.4 Discussion of data presentation

By presenting data in form of Pareto-diagrams, users at different levels of the organization could obtain feedback concerning the quality performance according to the indicators. Data in Pareto-diagrams shows the process area deviations based on frequency of occurrence. This is a simple way of presenting the data and is easy to understand, and therefore it will also be easier to communicate and understand the information obtained.

The data obtained from the measurement system is easy to connect to the existing quality performance measures used at VTC. If the amount of deviations decreases the DOK will increase. This will be valid as long as the majority of deviations are documented and will facilitate a comparison between assembly lines and productions sites. The relationship between the measures is important since it creates an understanding of the assembly process quality performance and what affects it.

5.1.5 Discussion of users of the measurement system

The users suggested and discussed illustrates at which level of the organization the users could be located in. This does not mean that there could not be any other users of the measurement system. The general user of the data is a user who has interest in improving the assembly process.

The suggested users have a connection to the assembly quality performance. It is necessary that the operators who work in the measured process get feedback on their quality performance, since measures create motivation for improvements. Feedback from the measurement system could be used by managers to communicate with the operators about the quality performance and to improve the assembly process. Experiences from the pilot showed that the operators are feeling that what they measure is not used to improve the system.

5.2 Internal validity

To confirm the internal validity of the proposed measurement system and indicator structure a pilot was performed. It was executed at the end of a section of the line at the Tuve production site by letting the andon person and a product quality controller register the process deviations. The andon person and the product quality controller performed the deviation measured and mediated the information to the authors. The authors, who participated throughout the entire pilot, made the marks on a paper that illustrated tree structure of the indicators. A thorough explanation of the pilot execution can be seen in Appendix D.

Evaluating questions regarding the quality performance measurement system were given to the participants of the pilot. These were identified as key-questions during planning of the pilot are presented below. The general feeling among the participants is that the measurement system and the indicators are simple to use and valuable for indicating deviation areas in the assembly process. They thought that a simple and quick measurement system would be to prefer since it would remove some of the time pressure and at the same time enable them to measure all deviations.

How easy is it to understand the indicators?

The indicators were in most cases logical to understand and intuitive to use for measuring deviations. The indicator that was found not to be intuitive and that was found most confusing was "Measurement" with the sub indicator "feedback". This indicator had to be explained in more detail for the participating operators after having started the pilot. All the indicators were found to be understandable after having answered the questions.

How intuitive are the indicators?

The operator's saw most of the indicators as straightforward and intuitive. In some cases the measurements could be difficult since these were performed on a more general level. The general level of feedback demanded the operator to evaluate the situation to why the deviation actually occurred and to use this for measurements. The ability of the operators to categorize was observed to improve as the pilot proceeded. The reason is that the operator got used to analyze the situation and also got more familiar with the measurement report.

How easy is it to measure the deviations?

Overall, the deviations were easy to measure. In the beginning of the pilot however, it was more difficult. This was ascribed to that it was hard for the operator to find the indicators on the measurement report. Another problem that arose during the pilot was that the deviations, which were found downstream in the assembly process, were hard to measure. To make the judgment of why these deviations were induced created problems and to handle them in the best way additional education of the operators would be required.

Are the indicators covering the deviations that arose?

The deviations that occurred during the pilot could all be measured with the suggested indicators. Some opinions from the operators regarding measurements were discussed and used for improving the measurement report making it more straightforward. The improved measurement report was used during the second day of the pilot and was experienced as better and clearer for the operators performing the pilot.

Questions concerning the suggested quality performance measurement system

How easy is it to understand what the measurement system is used for?

The conversations with operators show that there is an understanding for the purpose of the measurement system. The operators received an explanation of how the measurement system is supposed to be used, and what it would provide for the operators and the quality of the assembly process. According to the operators, the measurement system proposed for measuring the assembly process could be very useful to emphasize deviations and obtaining data on their occurrence. Benefits were also seen in using the data from the system as basis for improvements, since there are no actions taken unless there is data on why the deviation occurred.

What are the operators opinions regarding the measurement system?

The operators consider that the measurement system could be very useful if implemented in the right way. The data obtained from the measurement system is seen as very useful when identifying deviation areas in the assembly process and to use this as a basis for improvements. Most of the improvement actions today are taken to improve the product, since the current measurement system for reporting deviations is based on deviations with the product and not the process. Operators' thoughts and improvement suggestions are not regarded unless the deviations have been documented in the IT-system used for feedback from the assembly.

How is it to perform the measurements on paper?

According to operators performing the measurements on a paper is not the best possible way. It is seen as too time consuming in an already stressed production environment. Adding papers would also increase the need of paper handling and create a need of transferring the content on the paper into an IT-system.

The operators thought that performing the process reporting on a portable device could simplify the reporting procedure. In the current assembly process the operator acting as andon person is using a PDA for receiving andon-calls. A similar PDA could be used for entering the process feedback. Using a PDA could also allow to present the tree-structure in a more effective way and by this make the process reporting more effective.

How is the measurement system inflicting on current quality reporting routines and the assembly process?

According to the operators, they would like to have the opportunity to provide management with process feedback but do not consider that time is given to do this. As the situations is today, all deviations are not reported since there is a lack of time to feed back information, and the time that could be available is most often used to correct product deviations.

5.3 General discussion

There was not much literature found covering how to measure assembly process quality in detail, this made it difficult to verify the suggested indicators. Therefore, more benchmarks of companies measuring assembly process quality could have been made to simplify the development and suggestion of the process quality measurement system.

The indicators were identified with the QMPMS method and had to be verified by conducting a pilot. The pilot showed that the process quality indicators were covering the process deviations that occurred during the assembly process. The result from the pilot implies that using the QMPMS method is a good way of identifying what possible process areas that could be necessary to measure when measuring assembly process quality.

The results from the benchmarks provided the authors knowledge about how different production sites, both within and outside VTC, work with process quality measurements. Since the benchmarks were performed over a large time period, the results from them could have different quality levels, this because the authors obtained more knowledge over time and became more aware of what to study. To increase the quality and objectivity of the benchmarks outside VTC, it would have been necessary to meet and interview more persons.

5.4 Research contribution and further work

This thesis can be regarded as a complement to existing literature covering quality performance measures of assembly processes. Suggesting what to measure and how to quantify the process quality performance in more detail complements the existing literature. The result has been focused to cover quality performance of the manual assembly process and therefore the performance of automated assembly has not been regarded. Even though the focus has not been to cover automated assembly, the results could be applied with some modification. To cover automated assembly processes, the suggested indicators need to be reviewed and process areas that are of interest need to be identified.

To develop the result of this thesis, the recommendation is to perform further research of what process areas that could cause deviations of the assembly process quality, and evaluate how these deviations affect the process quality. The purpose of this would be to evaluate the deviations and to identify how these contribute to the quality performance of the assembly process. To do this it would require thorough research and effort to generalize the deviations making them applicable for any manual assembly process.

A more detailed evaluation of how the data should be handled after having performed the process deviation measurements and used to aggregate the data for users at different levels of the organization, would further improve the result. How the measurement data could be used to improve the quality of the assembly process could be further evaluated and developed.

6 Conclusions

The purpose of the thesis was to develop a performance measurement system measuring assembly process quality, which could be used by VTC to make the assembly processes stable in their strive for making them capable. The suggested measurement system measures process quality deviations by registering deviations in the assembly process according to suggested process indicators that covers important process areas. The suggested measurement system provides data about the assembly process that is considered as important and is missing at VTC. With the data from the measurement system, improvement opportunities can be suggested to make the processes stable, which would affect both the quality of the process but also the assembly environment where the operators work.

The conclusion of the thesis is evaluated according to how well the result fulfills the research question stated in the Problem definition. These research questions and the concluding remarks are presented below.

What potential deviations could be identified that affects the quality performance of an assembly process?

The quality performance indicators that were suggested for the measurement system were based on 6 of the 7 Ms, these were Measurement, Man, Method, Machine, Material and Milieu. For every M, lower level indicators were identified since the Ms were considered as to general and not providing the level of detail necessary for obtaining useful data about the quality performance of the assembly process.

The measurement system and the indicators are considered to be sufficient to provide data of the assembly process in order to make the assembly process stable. The coverage of the indicators was verified by performing pilot study where the suggested indicators were used to evaluate deviations that occurred in the assembly process. The results showed that the indicators could be used to measure the deviations that occurred.

How should a quality performance measurement system be designed so that it captures the actual performance?

The measurement system was constructed and suggested to be used to register all deviations that occurred in the assembly process. By registering all occurring process quality deviations, the actual quality performance of the assembly process in terms of process quality can be obtained. To obtain data on actual quality performance it is important that the measurement system is easy to use and that the management supports the measurements. To be able to perform the measurements, the operators need the time to evaluate the deviation and to perform the registration. If these prerequisites are not given, the measurements will not be performed.

How could the suggested quality performance measurement system allow for traceability in the assembly process and in the organization?

By aggregating the data obtained from the measures for the different assembly areas of the production line traceability can be enabled. The traceability is regarded as the ability of the users to find what process area of the production line has influenced the quality performance of the assembly process. The traceability is achieved since the performance measures and feedback are all based on a common structure in form of the suggested indicators, and due to that the measures are only performed at process level.

Since the data can be aggregated to users at different hierarchal levels of the organization it is possible to compare the quality performance of different parts of the assembly line, different assembly lines within in a production site or different production sites to each other.

General conclusions

The systems that are used today for process quality performance feedback at VTC provides feedback data about the product and very general feedback about the assembly process quality, by using DOK. The measuring system suggested in this thesis complements this product feedback with assembly process feedback. This process feedback is important to obtain knowledge of the assembly process, which then could be used both to improve the process making them more stable. An important part of delivering feedback is to feed back the right data to the right user. To improve an assembly process it is important that the operators who perform the assembly operations obtain feedback on their quality performance to be able to improve the assembly process in the desired direction.

Data on quality performance gives a foundation for different types of improvement actions. The data can both be used to coordinate continuous improvement actions and to identify process areas where focused workshops should be appointed. The knowledge from the measurement system can therefore be used to improve the assembly process, in the strive for making the assembly process quality stable.

7 Recommendations to Volvo Trucks

After having performed the thesis, the authors can state some final recommendations for VTC. These recommendations are based on the experiences obtained from the VTC organization and on the knowledge obtained regarding process quality measurements. The recommendations are summarized below.

Measure process quality in more detail

To stabilize the assembly processes at VTC, it is required that the current process quality measure is complemented with additional data. This data should be obtained by measuring the frequency of the assembly process deviations. It is necessary to measure assembly process quality deviations, as a complement to product quality deviations, since the assembly process quality measures give data that can be used to stabilize the assembly process.

Use data obtained from the measurements

An experience obtained from the pilot showed that the operators perform measurements during assembly, but data obtained do not come to use, which results in that the operators loose the will to perform the measurements. This implies that it is important to make use of the measured data and make the operators aware that the measurements are useful and necessary.

Feedback on a common structure

To organize the feedback in the organization on a common structure enables traceability of the measures within the organization. Data provided on a common structure also makes communication within the organization easier since all feedback receivers could more easily relate to the connection between their and the organization's performance.

Consistent feedback of process quality to the right receiver

Feedback of the process quality performance should be provided to the right receiver continuously. This implies that the receiver can relate the current performance to the previous performance, and use this knowledge for improvement.

An organization that supports process quality measurements

The quality performance measurement system has to be supported by the organization through allowing the operators the time that is required to perform the measurements. The operators need to support the measurement system by having the will to perform the measurements.

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Appendix A

Question to be answered from benchmarks and interviews

- What is measured in the production?
    - What KPIs are used?
    - What is measured on different level? (group, section, line)
    - Who decides what to measure? (Local measures or global?)
- When is it measured?
    - Continuously or at planned occasions? (Every day, every week?)
- Where is it measured?
    - Continuously or in specific places? (Continuously at assembly operations or in control zones, product revision etc.?)
- How is it measured?
    - What systems are used? (IT systems, product control cards?)
    - Who performs the measures? (Operator, group leader etc.?)
- How are the results used?
    - How are the results from the measurements followed up? (Meetings, display boards, IT-systems?)
    - How are the measurements used to improve the assembly process?
    - How are the changes followed up? (Are changes followed up in the future to verify permanent improvement?)
- How are the process deviations documented?
    - How is the information available in the future?
    - What systems are used to document deviations?
- How does the current system function?
    - Shortages? Advantages? Discussion about possible future improvements

Appendix B

Process stability

A capable assembly process is always stable. An unstable process is never capable and therefore process stability needs to be achieved before a process is capable. Capability is a measure of the process performance under stable conditions (Juran & Godfrey, 1998) (Bergman & Klefsjö, 2010). According to Juran & Godfrey (1998) stability of a process is achieved when the variations in the performance is only due to random causes and no assignable causes. The criterion for a stable process is that the performance plotted and interpreted on a Shewhart control chart should be in statistical control (Juran & Godfrey, 1998). According to Wu *et al.* (2009) capability indices cannot be used unless the process is in statistical control and it would be useless to perform a capability evaluation if stability is not verified.

The Shewhart control charts have several criterions to how the process is defined to be in statistical control. Generally the majority of the process measure samples should be aligned within the control limits of the Shewhart control chart. In Figure 25, where samples of process measure's distributions are plotted, the left monitoring sequence is not stable since several of the distributions are aligned outside the control limits. In the monitoring sequence to the right all distributions are aligned inside the control limits which implies that the process tends to be in statistical control.

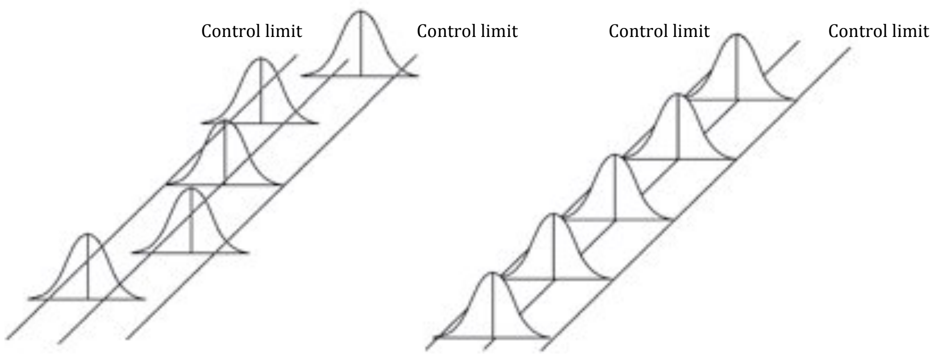

Figure 25 To the left, an unstable process and to the right, a stable process.

When the process is stable it is possible to predict future behavior within the specification limits of the process control chart (Juran & Godfrey, 1998). The limits are determined and set according to the natural variation of the process, which allows the user to identify when assignable causes occur.

Appendix C

Definition of a capable process

The capability of a process is the measure of the reproducibility of the product produced by the process (Juran & Godfrey, 1998). This means that a capable process is predictable, at least within the specification limits defined. Statistical distributions of process samples are compared to the specification limits of the process. This allows a capability index to be computed, which is a measure of how far away from the specification limits the process is performing (Juran & Godfrey, 1998) (Bergman & Klefsjö, 2010). According to the definition, a capable process is always stable; if it is not stable it can never be capable (Juran & Godfrey, 1998). This implies that process stability is a necessary precondition before the process can become capable.

Capability can be explained with Figure 26. In this figure the process sample's distributions are plotted according to the specification limits of the process. In the process sample to the left, some of the distributions are aligned outside of the specification limits; hence the process is regarded as not stable and therefore not capable. The process samples in the middle shows that the process is stable, but the samples are distributed outside the specification limits which mean that the process is not capable. In the sample distribution to the right, all the process samples and their distributions are aligned inside the specification limits and show a stable behavior, which makes the process capable.

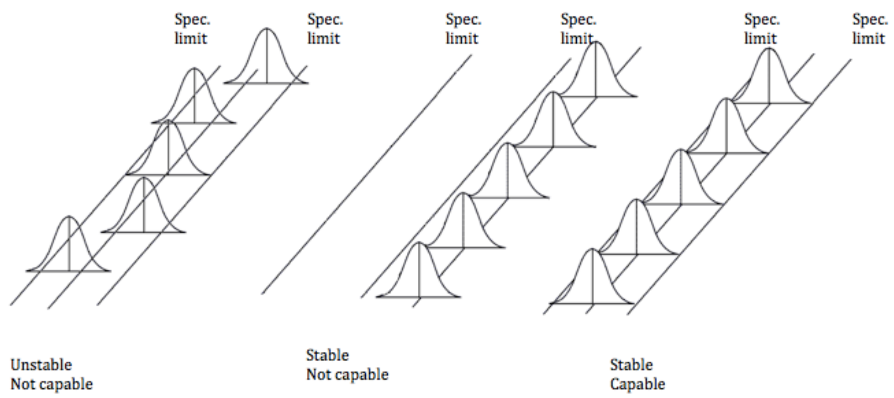

Figure 26 Process samples compared to process specification limits

From the example above, it is made clear that a stable process is not necessarily capable. This is illustrated by another example of a dartboard, visualized in Figure 27. Arrows have been thrown on a dartboard with different results, which could illustrate a process behavior. The edge of the dartboard illustrates the specification limits of the process. The process in the top-left shows an example of a stable process which is very capable. The top-right result shows a process that is stable but less capable compared then the top-left, since the darts have ended up focused on the board but away from the aim. The bottom-left board shows an unstable process since a couple of darts have ended up outside the specification limit, the edge on the board. The bottom-right board shows a stable process since the darts are inside the edge of the board and the darts are spread all around the board it is less capable then the board to the top-left.

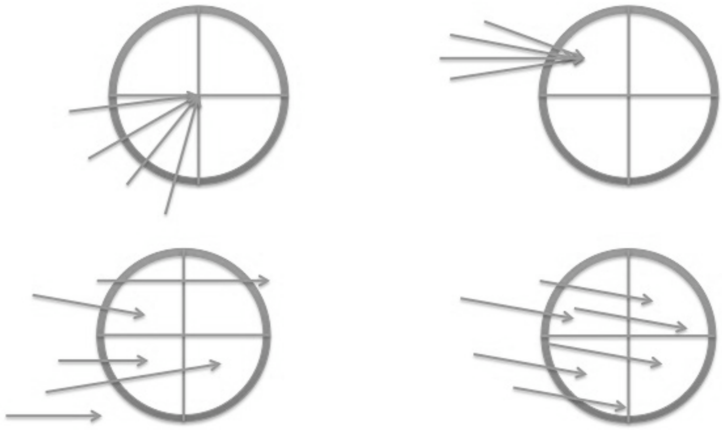

Figure 27 Illustration of stability on dartboard.

To illustrate the miss-aims of the example above into an assembly process environment, the top-left shows a predictive behavior with very small deviations, meaning that products are assembled in the same way most times, with very small deviations. The top-right could illustrate an assembly that is predictive but some deviations are always affecting it. For example when a tool is malfunctioning or when a parts has inferior quality. The bottom-left shows an assembly with a lot of variations that are not derivable from natural causes. This could be illustrated by late deliveries, parts that are damaged and need to be replaced etc. The bottom-right shows an assembly process that is more predictive compared to the bottom-left, but there are many deviations of a smaller character. This could be illustrated by un-even material quality, but still good enough to not reject the part; late deliveries, but not affecting the assembly resulting in more severe problems etc.

Appendix D

Pilot execution

The pilot was carried out at line 21, section 3, and station 20 at the production site in Tuve during two days. For the pilot to be executed in the best possible way the measurement system and the indicators was introduced for the Production Leader, PL, responsible for section 3, before the pilot start. The PL agreed with how and when the pilot was supposed to be performed and proposed two operators that were suitable to follow during the two days. One of the operators conducting the pilot was the andon person of the section and the second was the group leader, GL. At the beginning of the first day a short introduction was held at the section where the pilot was performed and a more detailed explanation of how and why to perform the measurements was given to the two operators that were supposed to participate in the pilot.

When the pilot started it proved to be hard to follow the GL since he had other responsibilities except for assembling trucks. The quality controller for section three turned out to be a suitable replacement for the GL, providing good information about deviations that had occurred upstream in the assembly process. Other operators' reported to the andon person and to the controller about parts that was not assembled as they should or when deviations were found. The deviations that were reported were from regular controls and from spontaneous comments or complaints regarding the assembly process. The andon person and the controller were then reporting what the deviation was and the possible cause of the deviation to the authors. When the possible cause was evaluated focus laid on the first *why question* in the *five why* analysis.

To categorize the indicators, a paper with the suggested indicator-structure was printed. Printing the indicators on a paper was considered sufficient since the pilot was aimed at evaluating the measurement system and the indicator structure, and not how to perform the categorization in the most suitable way.

The first intention was to let the andon person and GL do the marks on the measurement report by themselves. After a short period it was discovered that the most efficient way was to let the authors do the marks and to let the operators make the decision of which indicator to mark.

During the pilot there was an ongoing discussion with the participants about the indicators and about how and why the measurement system should be used. Personal opinions have been documented and the climate between the authors and the operators was open.

Appendix E

Benchmarks

Tuve

The benchmark of the Tuve production site was performed over a long time period since it was where the authors were positioned during the thesis. The study of Tuve was conducted by following the meeting structure for reporting assembly process performance from the line up through the organization together with a production leader. In the study of Tuve interviews and meetings were held with employees from different functions, among others the quality manager and the responsible for the quality reporting system QULIS. QULIS is used for distributing information about deviations identified in the processes.

Reporting of production performance

In the daily OMS-meeting that the authors followed, the information focused on assembly performance in terms quantity but also as performance in terms of final assembly quality. At the meetings, problems that had been identified were informed about and planned actions were presented and discussed. If any problem had caused line-stops, stop time was presented and the cause of the stop discussed. Line stop evaluation is prioritized at the meetings.

The assembly process is controlled strategically by long-term goals set according to the strategic goals of the company. The goals are broken down into STM-plans, Steps To Milestone, and deployed throughout the organization. These goals are broken down and concretized for every employee and the progress in meeting these goals is presented at the line where the operator works.

The STM-plans do not cover any hands-on process goals that are derived from the business goals. The goals set in the STM-plan are more concerned with development of the operators' educational process. STM goals are reported at meetings with the operator and the production leader regularly on longer time intervals.

Quantification and reporting of quality performance measures

Assembly throughput is calculated as the amount of trucks assembled and finished from the line and from every section of the line. The assembly quality is measured at the end of the line and is a product measurement of whether the product has been successfully assembled or not, the measure is refereed to as DOK. A product is OK if the control card following the chassis is not containing any deviations when the truck reaches the end of the line. A

DOK-measure is calculated as the number of product that are OK directly off the line divided with the total amount of assembled products. DOK is used as a measure of processing quality. This KPI is measured and evaluated on daily basis.

To distribute information about process deviation, Volvo Tuve uses a globally supported IT-software called QULIS. Identified deviations are registered into QULIS and categorized according to where in the process it was found. Deviations that are identified after the station where the deviation was induced, but still before the product has been handed over to the end customer, are categorized as customer reported deviations. The deviations that are identified in the own process are reported as self-reported. Deviations can also be reported through audits, which are random controls of approximately 2% of the produced trucks. These deviations are registered as audit-defects and are classified according to severity of the deviation according to the customers point-of-view. Deviations that are not identified in the process or audits but are identified by the end customer are registered as field-claims in the QULIS system. At the lines there is personnel dedicated to perform product checks. These personnel have the responsibility of entering the deviations into QULIS. When deviations have occurred but are not solved in the process, they are registered on a control card following the truck chassis. Less severe deviations and deviations that have occurred and have been solved by the andon person are never reported into QULIS or the deviation card.

Table 3 The different deviation categories used in Tuve

Customer reported	Deviations identified in the process
Self-reported	Deviations identified in the own work at the station
Audit	Random product controls, approximately 2% of the production
Field claim	Deviations reported by the end customer

Meeting structure for reporting production performance

The structure of the meetings held at the production site has been predefined concerning what process functions should participate and very roughly what the content of the meeting should be. The meeting structure and the participants are schematically presented in Figure 28 below. The group leader holds the first meeting with the operators in the group and then reports upwards to the production leader. These two meetings are held at the line. The next step in the meeting structure is that the production leaders report together with different line functions up to the assembly line manager. In this meeting production performance from the day before is reported. The next step in the meeting structure is that the assembly line manager reports up to the production site management.

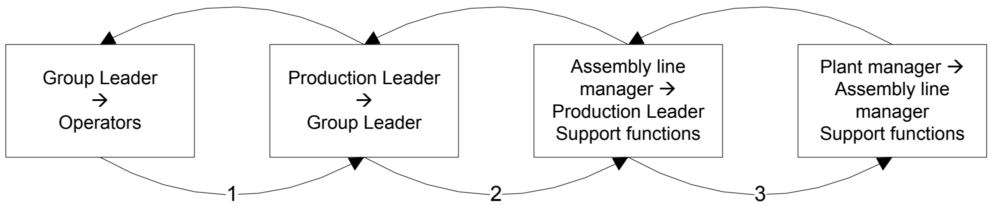

Figure 28 OMS structure in Tuve

At the daily meetings held, the information reported is presented on whiteboards located at a dedicated place beside the assembly line. During the meetings, KPIs are reported but also deviations that have occurred are handled. The KPIs and their measures are found on the whiteboard and the deviations found are presented and delegated to the problem owner through QULIS. The deviations are reported based on the product and not according to the process, which means that the deviation report concerns what is wrong with the product but not what in the process that has caused the deviation. Information about what in the process has caused the deviation is normally obtained after further deviation research and evaluation. Deviation description and information is obtained through QULIS.

What KPIs are reported at the production performance meetings?

At the OMS-meetings, production output from the lines and from the stations are reported together with an end-of-line DOK. The KPIs are presented visually on the whiteboard that is placed at the dedicated meeting place. The KPIs and their quantities are presented on daily basis on the whiteboard and are recorded together with data for the current production week.

How is the information from the meetings made accessible in the company?

In QULIS the information can be customized since it allows filtering according to predetermined options. Since the software is managed and supported by VTC it is possible to adapt the software, allowing new filtering options. Where in the processing chain the deviations were found are categorized according to Table 3 above and they should be described in a standardized way. Deviations are forwarded to the process owner which usually is the section where the deviation was introduced. The sections of the line receive data concerning their performance, by obtaining data about deviations that have been found downstream in the process through QULIS. The KPIs cover the overall line performance of the line and is reported on daily and monthly basis.

Umeå

The benchmark of the Umeå production site was performed during a two-day visit where the reference person from Umeå had arranged meetings and the possibility to participate in the daily OMS-meetings. During the benchmark, one of the section leaders helped the authors showing the assembly process and the process tables as well as answering the author's questions. QULIS is used for distributing information regarding deviations identified in the process and as source of data for creating KPIs used.

Reporting of production quality performance

The assembly process quality performance measures used in Umeå are connected to work environment, milieu, quality of the product, and material quality. Measures that are used concerning product quality are number of deviations in total and the amount of deviations on every product, stop time of the line and DOK on line segments.

Weekly and daily reports about the process quality performance are displayed at a process board close to each section. The performance data concerns the most frequent problems, stop time and number of problem occurrences.

Quantification and reporting of performance measures

For handling the information and data the IT-system QULIS is used. In QULIS all deviations are documented. The deviations found at line are documented on a paper following the chassis and is transferred into QULIS at the end of each section. By transferring the information to QULIS it is easier to distribute the information to other parts of the organization so they can use the information for improvement work.

The paper following the product is a quality control-paper and consists of one part where the team members confirm with their employment numbers that a specific task has been done. These tasks concern either parts that has to do with safety on the cab or reoccurring deviations that need to be checked. The second part is used to document deviations. Deviations are documented by the group that have caused the deviation or by groups that find a deviation downstream in the process. By verifying critical tasks the operators can ensure that the product has passed the critical points. The deviation documentation provides data about what corrective actions need to be taken. All the deviations or marks on these papers are transferred into QULIS at end of the line, and not after each section compared to other deviation registration.

If any deviations are found in the product audits they are classified according to severity when entered into QULIS. The goal is to make an audit on 2% of the cab produced. The data from the audits are entered into QULIS. Generally the deviations found are categorized according severity or frequency.

Meeting structure for reporting production performance

The daily meetings in Umeå start with a meeting between the operators and the production leaders of the sections at the line. This meeting is held 06:48 every day. The next meeting at 06:52 is a meeting where all the production leaders meet and report their resource status. Operator shortages and surplus are presented and the operator staffing is leveled in the best possible way. At 07:15 there is a meeting with the production leaders and the production leader who have the chef responsible for the operations and the cab trim. This position is referred to as production leader "8020". The operations leader-position is rotating between the production leaders on a weekly basis. At 07:15 a meeting is held to discuss the production performance from the day before. At the next meeting 07:45, the production leaders, segment leaders and the technology department have a meeting focusing on quality deviations that occurred in production the day before. The meeting structure is illustrated in Figure 29 OMS structure Umeå

The quality deviations brought up are further discussed at the 09:00 meeting, which is held by the 8020-production leader together with the process support functions such as material, quality etc. In this meeting, deviations that were identified the day before are discussed. All segments of the line report their performance and deviations from the day before one by one. The deviations that are handled are discussed together in the cross functional-meeting.

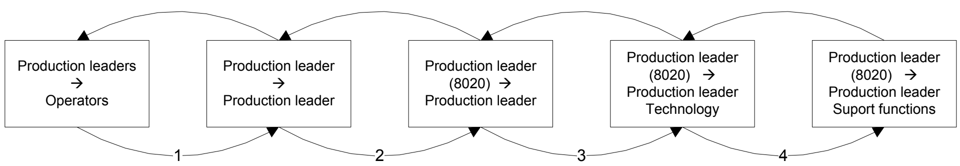

Figure 29 OMS structure Umeå

What KPIs are reported at the production quality performance meetings?

The KPIs reported and deviations discussed vary between the different OMS-meetings. Depending on the meeting held, the information distributed in the meetings changes from the different meetings. The further up in the organization the meeting is held the more overarching the information becomes.

In the first meetings held, available resources and production status are the first reporting subjects. In these meetings the available resources are a reporting KPI and these are compared to a target level required for normal production. This information is used to determine if it is possible or not to start the production or if the pace of the line needs to be decreased.

As the meetings move upwards in organization the focus changes and becomes more concerned with the product and the processes. The KPIs reported are work environment, quality of the product, material quality, number of product deviations, stop time of the line and DOK. The KPI values are explained by additional information from the meeting participants. The deviations that have caused a decreased DOK are presented and explained. This gives both overarching quality performance data which can be broken down in more detailed information. The data obtained from these KPIs is fed back to the groups and even to individuals once week. The feedback concerns the process performance, severe deviations that have occurred and frequent deviations.

At the meetings, the sum of deviations are presented and regarded for all sections. The sum of deviation occurrences is reported as a KPI for the assembly processes. In the meetings the DOK is reported as a KPI for all the section at the line. The sections are also reporting stop time of the line as a KPI. Additionally to the stop time, the cause of the stop is reported.

How is the information from the meetings made accessible in the company?

In Umeå the software QULIS is used to document deviations and to spread the data about process performance. This software is globally supported and used by VTC, which means that the information can be spread easily between the different production sites. The documented deviations can be categorized in QULIS according to frequency, chassis number and to, by the user, specified parts. There is also a possibility to sort the data according to the sections of the line where deviations have been reported. To sort the data according to work group or at operator level is not possible unless the user himself has knowledge of who performs what in the section.

The information from QULIS is used at the meetings as basis for the process reports and for discussions concerning improvement actions. Before the meetings, the reported KPI values are collected and based on data from QULIS and entered into an Excel-sheet clarifying the data. This data is printed after the meetings and posted on the process boards at each line-section with the purpose of informing the operators. The papers contain the same basic data as reported at the meetings concerning the sections DOK, graphs displaying quality performance, the most frequent deviations, stop time and number of deviations.

Gent

The benchmark in Gent was conducted by visiting the cab-trim factory and by following the OMS meetings. During the visit interviews were also performed with employees from process functions. One employee from the quality department and a continuous improvement coordinator were interviewed. The data at the meetings is based on reports from the IT-system Quality. At all meetings the KPIs are constructed by data from Quality.

Reporting of production performance

The performance indicators indicators measured in Gent are frequency, cost, impact to the line, safety, number of product deviations, efficiency and quality as direct runners. The impact to the line is an evaluation of how big impact a deviation has on the line and direct runners is a measure of the fraction of products that passes through the production unit without any deviations.

Short term goals, line performance, stop time of the line and the teams' contribution to the overall performance of the production site are presented so that operators and teams can take part of the results. Informing the teams about their performance and the current state is normally done at regular meetings held with the operators.

Quantification and reporting of performance measures

At the production site in Gent, the information and data handling for process information is done with an IT-system called Quality. Most of the process data is entered in Quality, except for the documentation that the operators perform at the line. The operators document deviations and process remarks on team papers and control cards following the chassis. The data from Quality is used as a basis for information regarded in the different meetings held.

The team paper consists of one part where the team member verifies the product quality by stamping the paper with the employment numbers that a specific task has been done. The tasks that are checked concern either parts that has to do with truck safety or deviations that are reoccurring. The process checks are done at the team or at the end of line. The second part of the team paper is used to document operator related deviations. At this paper the operator documents deviations that occur during the process.

The product has a control card that is connected to the product by the chassis number to which product is built to. The control card also consists of checkpoints that need to be verified with an employee's stamp since many of them are connected to safety deviations. This paper consists of a part where product deviations are documented. The groups that caused the deviation or identified it register the deviation on the control paper so that operators downstream in the process can correct the deviations. All the deviations or remarks from the control papers are documented into the Quality IT-system together with the deviations found in audits. The deviations found in the audits are graded according to the severity of the deviation.

Meeting structure for reporting production performance

The daily and weekly meetings held in Gent follow the OMS structure used within VTC. The content that is discussed and regarded at these meetings is a predetermined content structure. Important questions that are treated and regarded at all meetings are connected to safety, occurred deviations, efficiency and quality. In the meetings there is a clear distinction between the topics and they are handled one-by-one.

The meetings in Gent start with a meeting between the operators and the team leaders. Short-term goals, line performance and the teams' contribution to the overall performance are presented and discussed. From the Quality software there is a possibility for the teams to receive data about the DOK for the line or DOK for their part of the line. Every second week the group receives data about the company's long-term goals and performance according to them. The meetings are held at the line where a process table in form of a square pillar is used for posting the important information for each team. Two sides of the pillar cover quality performance on short-term goals and the other two sides concerns the long-term goals.

The next meeting in the structure is a cross-functional meeting where functions as quality, material and logistics participate together with the team leaders from one of the lines. The assembly line manager is chairman of the meeting and makes sure that all functions are participating and are active in the reporting. Deviations are discussed and the departments and group leaders report about their current state. The assembly line manager presents quality performance in form of DOK.

In the third level of the OMS structure the production site assembly manager holds a meeting where all the assembly line managers together with the supporting functions attend. The content of this meeting is the same as the previously described, but the data has a more general character. A fourth meeting is held once a week with the production site assembly managers together with the production site manager where the top management receives generalized reports concerning the performance.

The way to perform meetings is structured and the content within the different meetings are the same with the exception of where the focus is put. The feedback from the meetings is not as structured as the meetings and some of the work might for that reason be lost. A semantic picture of the OMS structure used in Ghent can be seen in Figure 30 below.

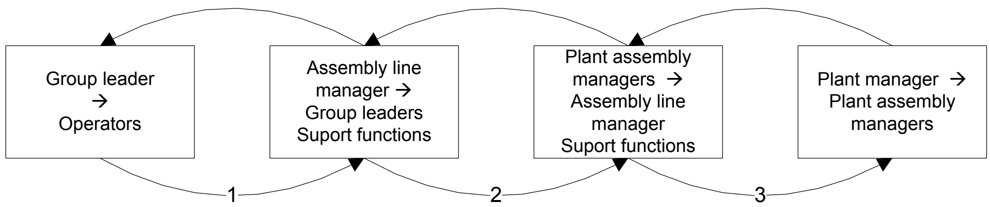

Figure 30 OMS structure Gent

What KPIs are reported at the production quality performance meetings?

The process performance indicators covered during the meetings of the OMS structure are the same for the different levels. The data character is changing between the meetings. The further up in the organizational hierarchy the meetings are held, the more general the data becomes.

The deviations documented can be sorted according to different priorities which are frequency, cost, and impact to the line. This data is also used to create data for KPIs used concerning the product. Process related KPIs are safety deviations that have occurred, amount of deviations, efficiency and quality in terms of direct runners. The KPIs are updated and reported on a daily basis.

How is the information from the meetings made accessible in the company?

The Quality IT-system used for documentation of deviations and performance is a local program used only in Gent, similarities exists between other systems used within VTC but some applications differ. This system is not only used to document deviations but also for following the improvement work and to document KPIs.

All the data that is used concerning the assembly processes is saved in Quality. At the OMS meetings the data that is reported is extracted from Quality. This data is displayed in both text with digits but also visualized with graphs. The performance data is also used to create data that is supplied as feedback to the operators which concerns their part of the line.

Team leaders also use the system to gather data about their part of the line. A selection can be made in order to see which assembly areas along the line that belongs to the group that has caused the most deviations. This data is displayed at team level together with the goals that the group should meet. The Quality system gives the user the possibility to customize the desired data.

Toyota material handling

The benchmark of Toyota Material Handling was performed together with a representative from the company that showed the authors around in the production process. The representative guided the authors through the meeting structure of the company and answered questions about the organization. The authors had the possibility to contact the representative afterwards to complement the data that was obtained during the study.

Reporting of production quality performance

At the line, the deviations that have resulted in stops of the assembly process are presented as a KPI and are followed up on daily basis. The KPI is showing the sum of occurrences at line which resulted in a line stop. This KPI is followed up on both daily and monthly basis. The monthly is constructed by just aggregating the daily data into the monthly. This KPI is available for every station at the assembly line since all stations are measuring the line stop occurrences.

All deviations at Toyota Material Handlings are documented on a control card following the product. The deviations that created line stops are registered and explained on a physical paper available at the station and the sum of the line stops is used to quantify the KPI. Deviations that occurred but did not result in a stop are registered into an IT-system where they are explained and the data is stored, these deviations are not included in the KPI.

Quantification and reporting of quality performance measures

The KPI that is used for reporting quality performance of the line is measured at the every station. The operators calculate the KPI by themselves and keep track of it on diagrams were the operators print the data manually with a pen. There are two different quality performance diagrams; the first covering daily performance and the second covers the monthly performance, the team leader is responsible for keeping track of both diagrams.

Deviations are registered on a standardized control card following the product through the assembly process. This control card is adapted to the long-term goals of the company. Currently the focus is to implement work standards everywhere in the process. Therefore all deviations are evaluated according to if there is a standard or not, and if the standards has been followed or not when the deviations occurred.

Deviations that are identified at Toyota Material Handlings in the own process are categorized as “A” deviations. The deviations found downstream in the process are also reported on the control card following the product. These deviations are categorized as a “B” deviation. At Toyota Material Handlings all products produced are controlled in a CVI, Complete Vehicle Inspection, process. These deviations are registered on the control card and then reported into the IT-system as “C” deviations”. Deviations that are not identified in the assembly process or by the CVI but are experienced by the end customer are reported as “D” deviations in the IT-system. Deviations are only categorized according to these categories. They are not categorized and weighed according to severity for the assembly process. The categories are presented in Table 4.

Table 4 Deviation categorization at Toyota Material handling.

A	Deviations identified by the own process
B	Deviations identified outside the own process
C	CVI-identified deviations
D	Field claims

All feedback at Toyota Material Handling is available in paper format. All the papers concerned with the process quality performance are located at meeting place called Asaichi. The company has all data available in paper format at the Asaichi place, but they still use IT-systems to provide information to the organization. The data that is gathered at the production line is available at the Asaichi place. Feedback can be provided on operator level if desired since all processes have standards and it is clear who is responsible for what.

Meeting structure for reporting production performance

All content of the Asaichi meetings have first been reported to the quality department, which are also the ones leading the meetings. All teams on the line first report their data to the quality department, which in turn presents the data at the meetings. The meetings are conducted with the only purpose to inform, therefore no discussions about deviation solutions should be held. All the data given should also be available in paper format at the Asaichi place and be based on a standardized format before the meeting starts.

The meeting structure of the company is presented schematically in the Figure 31 below. The place from where information is spread throughout the company is called an “Asaichi”-place. In the Asaichi place, data about production site quality performance is made accessible for all employees and is made visible in performance diagrams. The first step in the meeting structure is when a team leader reports deviations that the operators have discovered during the assembly process. The reports are made to the quality department; they are also the ones leading the meeting that follows a specific agenda and consists of a specific content. The data provided from the team leader is reported by the quality department at the Asaichi meetings together with deviations discovered later in the process. At the Asaichi meetings team leaders and representatives from other departments in the company are present. The content in the meetings is used as feedback to the team leader that brings back the information to where the deviation occurred. The team leader discusses short-term and long-term solutions with the coworkers and reports this back at an upcoming Asaichi meeting.

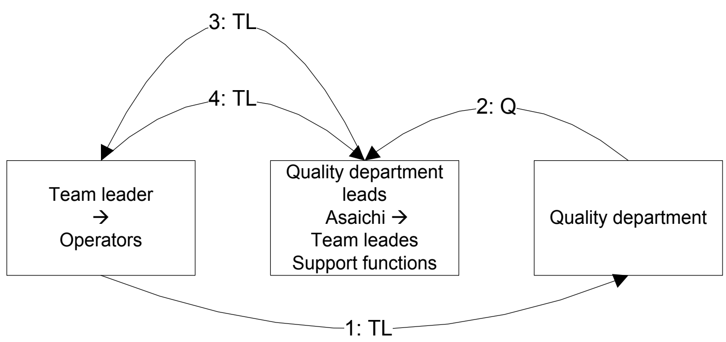

Figure 31 Meeting structure Toyota Material handling

What KPIs are reported at the production quality performance meetings?

At the Asaichi meetings, stop occasions of the line and their time duration are reported. The stop occasions are presented for every day and presented on a paper covering data for the current production week. The data concerning line stops is aggregated in different ways making it available on daily, weekly and monthly basis at the Asaichi place.

How is the information from the meetings made accessible in the company?

The data presented at the meetings is registered on a standardized paper where the deviations are described. At the stations along the line, the team leader reports the line quality performance according to the KPIs in a manually created diagram. This data together with deviation information is then presented at the Asaichi meetings. The data and information reported at the Asaichi meetings are documented in a standardized way. The data from the manually created diagrams are entered into an IT-system that is used to present data which is more difficult to present manually.

Toyota Material Handling do not use a global IT-system to document deviations occurred previously in the production site or deviations occurred at other production sites. The data obtained from production in form of sum of line stops is continuously compared to target levels for the KPI. The quality performance of the line is displayed at the stations by the manually created diagrams and the data is continuously updated.

Autoliv

Autoliv produces products that are simpler to assemble compared to the other companies visited during the benchmarks. They are simpler in the sense that they consist of fewer parts and that the product variants are not that many at a production line. The responsibilities at the production site are broken down according to product type and the production site is also divided physically according to these responsibility areas. Since the responsibility areas are smaller they are easier to overview and understand. The areas have fewer levels in their organization, compared to the other companies that were investigated, which enables a more efficient and faster information flow.

The benchmark at Autoliv was performed after the pilot was conducted, which means that it did not contribute to the final result to the same extent as the other benchmarks. The insight from the visit can however be used to evaluate the final result.

Reporting of production performance

All the indicators measured and reported at Autoliv follow the QCDSM structure, which stands for Quality, Cost, Delivery, Safety and Management. The data reported in the company is adapted to the organization level at where the data is used. Higher in the organization the level of detail is decreased and the data becomes more general. The data reported upwards is aggregated from the lowest level in the organization. By aggregating the KPIs all employees within the organization uses the same KPIs. The data aggregation allows for traceability within the system that enables the users to find the cause to why the KPI values were obtained.

Quality of the assembly process is measured as the amount of defects per million units, DPMU. As process feedback, micro-interferences are counted at the assembly stations. In the micro-interferences any deviations or occurrences that disturbed the production are counted. The cost-indicator is calculated by dividing the cost for assembling the products with the amount of products produced and is reported as CPU, cost per unit. Cost is also measured by the mean time used to produce a unit, which is the total time used to assemble the product divided by the products, and by measuring according to the cost for down-time, material shortages and machine failure, which are also treated in the cost-KPI. Delivery is measured as the level of delivery precision from the line to the local storage and from the storage to the end customer. Safety is the injuries or the incidents that have occurred. Management is measured as the number if improvements suggestions received, both from operator but also from management.

Quantification and reporting of quality performance measures

The data measurements for the KPIs are done in two ways. The first is that every part used is automatically scanned during the assembly process by scanners in the fixtures used. If any part is deviating from specification the assembly process stops and the part is removed. All data from the scanning process is stored into a computer system. The second way is measuring of the micro-interferences. This is done by letting the operators push a button on a counter every time they are disturbed in the assembly process. A micro-interference could for example be that a washer is dropped on the floor or that tools are malfunctioning. The number of micro-interferences is recalculated into a time factor, which illustrates a more realistic view of the measure. There is a possibility to analyze the KPIs with a Pareto diagram to visualize the quality performance. This could be used to evaluate which processes to prioritize when conducting improvement actions.

To be able to calculate some of the indicators, the operators need to obtain data from a computer system and then fill in the quality performance data on a process board connected to the assembly area. This forces the operator to take part of the feedback and provides knowledge of the process performance. The data aggregation from the production lines is conducted through that the production leader visits every line and reads from the process table and use the data to construct own process feedback. These data-gathering activities are performed daily.

Meeting structure for reporting production performance

At the part of Autoliv studied, there are daily meetings held in a cross functional group consisting of four employees. The group is responsible for one part of the production site and it consists of 17 assembly lines. The meetings are held every morning and the duration is approximately five minutes. During the meetings KPI highlights, which are the most critical KPI values, are discussed. The KPIs are evaluated for the complete QCDSM structure. The data is based on the production from the previous day.

In addition to this daily meeting, there are other weekly meetings. Mondays there is a weekly report about the current status and the upcoming production. This meeting also follows the QCDSM structure and the data for the different KPIs is aggregated to handle the entire assembly area of which the group is responsible for. Tuesdays there is a meeting with the management responsible for all the assembly areas together with the shift leaders. Wednesdays are used for line revision and assembly line checks. The purpose of the line revision is to make sure that the assembly process performs and operates as supposed to. During Thursdays planning and re-planning of the ongoing projects is made and during Fridays a two-week plan for the project is laid out.

What KPIs are reported at the production performance meetings?

All the meetings follow the QCDSM structure but the focus at the different meetings differs. Higher up in organizational hierarchy the focus is on a longer time period and the more general production performance is handled. For each production line specified target levels for the KPIs are established. An assembly line that satisfies the targets is marked as passed with a green mark in the KPI indicator. If the target levels are not satisfied the KPI indicator is marked with a red mark. For the management level all production lines in the assembly area should have passed to allow the management KPI indicator to be green.

The KPIs that are regarded in the meetings are based on QCDSM. These KPIs have been globally determined and defined and are used at all organizational levels within Autoliv. At the meetings deviations as micro-interferences, cost in number of defects per million unit and downtime, material shortages, delivery, safety deviations and the number of improvements suggestions are the normal KPIs discussed.

How is the information from the meetings made accessible in the company?

Data is saved in a computer system and the operators withdraw the information in order to fill in the data at the process boards in connection to the process. Managers gather data from the assembly lines manually and do also aggregate the data manually for the production areas.

Most of the data handling concerning process feedback is done on a physical paper and computer systems are intended to save results from projects and improvement effort for future use. Documentation about the ongoing projects is posted on the wall in the office of the cross functional group. This creates a good overview of the ongoing work and this it also easily handled by the group members.

Appendix F

Potential deviations

Potential deviations in an assembly process were identified through literature studies and by following the QMPMS-method, combined with the 7Ms. The deviations were categorized on general level, according to the Ms, since the measuring system is aimed to provide general data based on the quality performance of the assembly process.

The potential deviations are presented in Table 5.

Table 5 Presentation of deviation categories

M	Description of the M	Possible deviation areas
Management	The influence of the organization and production control on assembly quality performance.	Organization, Supply chain, Production planning.
Man	The operator's effect on quality performance.	Psychosocial factors, Knowledge & Experience, Ergonomics.
Method	Methods for performing the assembly process.	Standards
Measurement	Performance measures and their feedback.	Feedback
Machine	The effect of the process infrastructure and tools used on quality performance.	System layout, Equipment, Maintenance.
Material	The influence of the parts assembled and the delivery of these to the assembly process.	Material handling, Product design, Delivered material quality.
Milieu	The environment in the assembly, both physical and psychological.	Physical environment, Culture, Coworker climate

Management

The managerial functions in an assembly process coordinate the resources and improves the preconditions to enable the process to perform according to the strategic plans. Managerial processes are concerned with making strategic decisions and aligning the performance of resources to the strategy (Bitici, Carrie, & McDevitt, 1997) (Daniel & Reitsperger, 1991).

Organization

The organization is a supportive infrastructure of the assembly processes. Having an effective organization limits the decision space of individuals, which increases the probability of the company to reach its goals (Daniel & Reitsperger, 1991). The effectiveness of the organization demands for qualitative communication and information sharing. A vital part of managing a company is to provide the different levels of the company with the right information, so that managers of the different levels can control and align the company in the best way. The information should be used as an input to strategy and strategy alignment (Bitici, Mendibil, Martinez, & Albores, 2005). It is important to identify the needs of the information receiver since providing too much information can have a negative effect on the performance. (Daniel & Reitsperger, 1991). An ineffective information system would increase the risk of disturbances, since updated knowledge about the assembly is necessary.

From an operators perspective the managerial structure is important with respect to decentralized responsibilities. The meaning of decentralized responsibilities is that employees are involved and empowered to contribute by allowing them to think by themselves and make their own decisions (Liker, 2004). According to Rubenowitz (2004), to have control over one's own work is a sign of a good psychosocial work environment. Which is important since it affects the operators and their work performance.

Supply chain

An assembling company needs to have parts delivered to perform the assembly. The parts need to be delivered with the right quality, in the right time and in the right amount. This demands for a supply chain that connects all the participating companies and enables them to interact with each other. Having an ineffective supply chain will make planning very difficult and it will therefore be harder to manage the company (Bergman & Klefsjö, 2010). When deviations and variations in the supply chain occur it is important that it is flexible. One of the important parts of managing an assembly process is concerned with reducing the variations and their effect to the assembly process.

Production planning

Planning a assembly process is about ensuring abilities and the right preconditions for production, both in short- and long term perspective (Freivalds & Niebel, 2009). In the short term perspective planning can be associated with ensuring materials, resources and scheduling the production. Long term planning treats long-term relations with suppliers, in order to make the relations as efficient and reliable as possible to ensure deliveries.

Production scheduling is a function connected to production planning. In the production scheduling, the production sequence is determined. A production sequence that is leveled and smoothened will increase the quality, which means that large variations between the products will introduce uneven use of the resources but also introduce deviations of different types. (Liker, 2004). Therefore the production scheduling is an important part of the quality of the assembly processes.

Man

In this M, the human as a part of the assembly process is considered. The operator is one of the most important parts of an assembly process since the operator is performing direct work on the product. They also hold knowledge about the interaction between the product and the assembly process.

Psychosocial factors

According to Rubenowitz (2004) there is a connection between low work satisfaction and low productivity. This implies that the satisfaction of the employees has an effect on the assembly process. Employees that feel dissatisfied with their work or working conditions will not perform their best or improve the system they are operating in. If the operators are satisfied with their work and their working condition it will have a positive effect on the quality of the assembly process. Having employees that feel as a part of something bigger and meaningful will also perform better (Liker, 2004) (Rubenowitz, 2004).

Having a goal to strive towards creates motivation for an employee. From a learning perspective, motivation is one of the most important factors enabling a learning process. Without motivation there will be no learning (Rubenowitz, 2004). Therefore the motivation of the employees is important since it is fundamental for the employee's development and will to improve the assembly process.

Stress

Stress can be regarded as the negative consequences from too high demands from work, small decision space and insufficient social support (Prevent, 2008). There are different levels of stress. The stress-level that is often referred to and spoken about is the lack of time. Real stress is the consequences of individual overloading and the effects are physical, psychological or social. The latter type of stress is harmful for humans and can results in sick leave (Prevent, 2008).

Stress, in terms of lack of time, can affect the operator in such way that the operator misses parts of the assembly process. This may result in deviations introduced in the assembly process. Stressful situations can occur due to several different interruptions for example when a tool breaks or when the scheduling is un-leveled.

Knowledge & Experience

Knowledge is important for performing work task in the right way. Without knowledge of how to perform the work it is hard to control the work procedures and the results from the work. If there are established standards it is important that information of how to follow the standards is provided to the employees. Without this knowledge, there will be deviations induced in the assembly process that could have been avoided.

Knowledge gives a foundation for understanding the processes and therefore a basis for improvements. Knowledge together with a holistic view of the assembly process is important for avoiding sub-optimization and when performing improvements.

Experience is another important source of knowledge and is obtained by practicing the work and by learning from previous occurrences. It can be exchanged between operators as knowledge and therefore it is also an important basis of understanding a system. Experience normally implies a deeper knowledge and understanding of the assembly process.

Flexibility

In an assembly process it is important to have flexibility. The flexibility could be expressed as the ability of the operators to perform many different tasks and by this be able to cope with variations that occur during the processes. Since everything comes with variation it is important to have flexibility to cope with the variations.

Ergonomics

Ergonomics in a work place is important since it has a big influence on the process quality performance (Freivalds & Niebel, 2009). A workplace with improper ergonomic conditions will wear the operator and decrease their ability of process quality performance. This may result in quality deviations that will be induced in the process. Examples of bad ergonomics could be when assembly surfaces are hard to reach, heavy parts need to be moved or operations that demand abnormal body angles.

Method

A standard should be set according to the current best way of performing a task (Liker, 2004). The standards are important because it is from this best practice the work should be planned and improved. Improving the standard will also improve the current best way of performing the assembly, resulting in continuous improvement (Liker, 2004). From a planning point of view, a standardized process is easier to predict which implies an easier planning process.

Measurement

Information obtained from measurements or any other process information is necessary for managing the processes performance. With this information the process could be managed to perform in the best possible way according to the new conditions. It is important that the right information is delivered to the right user at the right time (Bitici, Carrie, & McDevitt, 1997); otherwise the receiver might perform in an unsuitable way. An example of a bad situation is when the operators keep performing the task in the same way even after deviations have been identified downstream in the process.

An effective feedback system can act as an early alarm, diagnostic system and pointer of what corrective actions should be taken (Bond, 1999). A system providing feedback about the measured system quality performance, is necessary since it would be useless to have a control system without using the information it is providing (Bourne, Mills, Wilcox, Neely, & Platts, 2000)

Machine

Machines used in assembly environments are aimed at supporting the operator in the assembly process and can be tools used by the operator or equipment supporting the assembly process. In order to have an effective assembly process it is important that the layout is supporting the assembly processes. It is also important that the equipment and tools are reliable and sufficient for giving the operator the possibility to reach the desired result.

System layout

Different system layouts allow for more or less flexibility. In line production it is important to have a flexible system in order to cope with variations, since deviations at one station could cause deviations at other station and eventually stop the line (Baudin, 2002). These deviations can induce large consequences on the output. The layout of the assembly process has big impact on line quality performance (Inman, Blumenfield, Huang, & Li, 2003), an example is when there are no buffers and a product cannot be sent to the next station, this creates disturbances for the next station since they do not have any product to work on.

Equipment

Equipment in a production environment could be used to perform the work or to support the processes (Baudin, 2002). The tools used by the operators could be wrenches or riveting tools. Supportive equipment can be regarded as mechanical for example fixtures, motor driving the line or non-mechanical for example software used in automated equipment. To enable high quality performance of the assembly process it is important that equipment and tools are reliable. Unreliable tools can easily induce deviations.

Maintenance

Maintenance is necessary to ensure that equipment is functioning and running when needed. Equipment disturbances can affect the processing quality in different ways, tools can cause deviations in the process or supportive equipment can malfunction. The risk of malfunctioning can be reduced through maintenance. There are two different types of maintenance that are often discussed, reactive and proactive. Reactive is applied when the deviation already have caused a deviation, similar to firefighting. The aim of proactive maintenance is to reduce the risk for equipment malfunction by maintaining it before it breaks.

Material

The materials used in production affects the assembly process in several ways. It needs to be handled and exposed in a manner that helps the operators to perform their work. The design of parts and products should encourage an intuitive assembly and quality of the parts delivered from suppliers should meet the specifications.

Material handling

The more parts products consist of the larger is the probability of picking errors, which is according to Baudin (2002) one of the primary causes of defects in today's manufacturing. The material handling before the assembly process consists of several different and important steps. The materials need to be packed in such way that they are easily accessible by the operators; the exposure should allow the operators to easily find the parts and the parts should be supplied to the assembly station.

Product design

The product design is important since superior quality design could reduce several deviations in the assembly process. Designed-in-quality could for example be choosing materials, dimensions, tolerances and procedures, striving for minimizing the probability of a non-conforming product (Baudin, 2004). The product design can reduce process deviations that can arise due to assembly limitations or fitting of parts.

Delivered material quality

The materials delivered to an assembly line need to conform to the demands set by the material specification. To assure a proper quality level, inspections of the material are needed. Having a close cooperation and relationship with the supplier can also affect the quality level. Deviations connected to the parts used are often subject to six different deviations. These are: wrong part, damaged part assembled, part missing, incorrect assembled part, dirt or contamination, or part defect caused by the part mating action (Baudin, 2004).

Milieu

This M describes how the milieu surrounding the assembly process affects the operators. Milieu in this context means both the physical work environment consisting of lighting, temperature, noise etc., and the psychosocial work environment consisting of coworker- and management climate. The company culture also has an important role affecting the employees and their quality performance. How physical work environment affects tools and materials used is not regarded.

Coworker climate

The coworker climate is affecting the assembly process through the operators. Depending on how the operators experience the group constellation, it has different effects on the operators. According to Liker (2004), the best team spirit is achieved by putting a group together where the members have similar interests. Experience has shown that when constructing operator groups in production environments with high demands on work pace it is more important that the operators are functioning well together from the beginning (Rubenowitz, 2004). In order for a group of operators to perform effectively it could be necessary to determine and establish rules for how the members of the groups should act and behave (Rubenowitz, 2004).

Culture

What the company culture is and how it affects the assembly process is hard to explain. According to a definition by Edgar Schein, which have been quoted by Liker (2004), culture is

"The pattern of basic assumptions that a given group has invented, discovered, or developed in learning to cope with its problem of external adaption and internal integration, and that have worked well enough to be considered valid,

and, therefore, to be taught to new members as the correct way to perceive, think and feel in relation to those problems" (Liker, 2004).

This quote implies that the company culture is very vast. But basically is concerns the behavior of a specific group of humans. This could for example be how deviations are handled when they are handled at a production line. Is the culture allowing that deviations are passed by without any corrective actions or is the culture associated with pride of having superior quality?

Physical environment

The physical part of the work climate consists of factors that are easy to measure and to control. Physical climate is to a large degree connected to ergonomics (Prevent, 2008) since it affects the operators through the environment they are acting in. Physical factors could for example be temperature, lights, noise etc. These factors can be disturbing for the operators and through this induce deviations in the process.