Development of a system of key performance indicators for quality monitoring

Diploma thesis

of

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In cooperation with:

SIEMENS

Siemens AG Austria

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Kurzfassung

Die Aufgabenstellung der Diplomarbeit war es ein optimiertes Kennzahlensystem zu erstellen zur Überwachung von Qualitätseigenschaften von Fertigungsprozessen. Es sollte ein Vergleich zu den bestehenden Systemen gezogen und daraus Empfehlungen für die Verbesserung bestehender Systeme und die Einführung eines neuen Systems abgeleitet werden. Als Untersuchungsbereich wurden der Fertigungsprozess und das Kunden-reklamationsmanagement von Siemens BG Graz gewählt.

Mit einer Analyse der Literatur zum Thema Kennzahlen wurden verschiedene Einflüsse und Grundlagen untersucht. Der Aufbau der Prozesse, für die die Kennzahl entwickelt werden soll, und deren Eigenschaften gelten als die Basis für das Design des Kennzahlensystems. Die Kennzahl sollte die bestehenden Datenmesssysteme zur Gewinnung der notwendigen Informationen nützen um die Entscheidungen des Managements zu unterstützen.

Die Kennzahl als Informationsprozess funktioniert ähnlich einem Feedback-Zyklus und kann je nach Aufbau unterschiedliche Informationen erfassen. Für das Qualitätsmanagement sind dabei Leistungsfakten ebenso wichtig wie eine Kostenbetrachtung um den Prozess bestmöglich beherrschen zu können.

Als weiterer wichtiger Einfluss sind die Qualitätsmanagement-Normen der ISO 9001:2008 und des spezifischen Eisenbahn-Industriestandards IRIS zu erwähnen. Sie schreiben vor die Gestaltung der Prozesse und aller Tätigkeiten vollständig zu dokumentieren. Außerdem muss in regelmäßigen Abständen die Leistung der Prozesse mit verschiedenen Kennzahlen überprüft werden. Damit haben die Normen erheblichen Einfluss auf die Erstellung von Kennzahlensystemen.

Die Zusammenfassung der in der Literatur vermerkten Erklärungen zu Kennzahlen hat zu der Ableitung eines Modells für einen Verbesserungsprozess für die Erstellung und Auswertung von Kennzahlensystemen geführt. Dieses Modell bündelt das erhobene Wissen in anschaulicher Weise.

Anhand eines Auswahlprozesses wurden aus einem umfassenden Verzeichnis von Kennzahlen, die für die Überwachung der Qualität des Produktionsprozesses relevantesten ausgewählt und einem detaillierten Bewertungsverfahren auf ihre Prozesszuordenbarkeit und Systemintegrierbarkeit hin unterzogen. Die am besten bewerteten Kennzahlen wurden ausführlich beschrieben und repräsentieren einen Vorschlag für ein optimiertes System.

Weiters wurden die bestehenden Systeme erfasst, beschrieben und anschließend mit denselben Bewertungskriterien analysiert. Ein Vergleich zwischen bestehendem System und dem vorgeschlagenen zeigt Verbesserungspotentiale und hebt Stärken der Systeme hervor. Bei den Empfehlungen findet sich die Einführung einer eigenen Scorecard für die Qualitätssicherung sowie eine Anregung die kontinuierliche Verbesserung strategisch zu stützen.

Abstract

The purpose of the thesis was to develop an optimised system of key performance indicators for the utilisation in quality assurance of the production quality. This system should be compared to the currently existing systems. The results of the comparison would be used to deduct recommendations for the improvement of used systems and the implementation of a new system. The scope of the analysis includes the production process and the customer complaint management of Siemens BG Graz.

The different influences and principles for KPIs and their system have been examined with the analysis of literature on this topic. The design of the processes, for which the KPI system is being developed, and its features are the foundation the system is built upon. The KPI should utilise existing data measurement systems for the extraction of the necessary information. This information should be provided to the managers for decision making.

The KPI as information process works similar to a feedback cycle and can gather varying information according to its design. It is important to acquire performance data as much as data on the costs occurring in the process to control this process at the best possible performance.

Other important influences are the standards for the requirements of quality management systems ISO 9001:2008 and the IRIS, a standard specifically used in the railway industry. They require the consistent documentation of the process design and all associated activities for certification. Furthermore the performance of the processes has to be reviewed with KPIs in different departments in frequent intervals. The standards have a considerable impact on the development of KPI systems.

The conclusions of the study of the literature have led to the deduction of a model for an improvement process for the development and assessment of KPI systems and the evaluation of the process performance with them. This model concentrates the acquired knowledge from the literature in a descriptive form.

The most relevant KPIs have been pre-selected from a comprehensive catalogue at the start of the selection phase. These KPIs have been evaluated using different criteria for the two basic attributes of a KPI, the ability for process assignment and system integratability. The KPIs that have achieved the best evaluations have been described in every detail and are recommended for an optimised system.

The currently existing systems have been described and analysed using the same evaluation criteria as has been mentioned above. A comparison between the existing systems and the recommended KPIs expresses some potential for improvement and emphasises the strengths of the used systems. The implementation of an specified scorecard for the demand of the quality assurance and a proposal to support the continuous improvement of the processes and systems are the recommendations.

Preface

First I want to show my gratitude and respect to Stefan Erlach from Siemens BG Graz for the possibility to make this thesis at the department for quality assurance. His constructive input and honest feedback helped me greatly with the thesis and the development of an effective system.

I want to thank Andreas Flanschger and Martin Marchner from the Institute of Business Economics and Industrial Sociology for the valuable feedback and the motivating support in the course of establishing this thesis.

My good friends, Christoph Wolfsgruber, Martin Führer and Philip Thaler, I want to thank for the great time we had during our studying together and for the many successes we could share in our works. It wouldn't have been possible for me to achieve such great results without this team.

I also want to thank my roommates Franz Plainer and Robert Dollinger for all the great time we spent together and the support that they have given me when I had difficult times ahead of me.

Last but not least, I want to thank my family, my brother Richard and my parents Hermann and Marianne, who supported me so greatly during my time of study. There had always been a comfortable place to come back for me. And they cheered me up when I had had troubles with the studying.

Graz, May 2012

Table of content

1 Introduction

This chapter will introduce the main purpose of the thesis and the initial situation. The description of assignments shows an overview of the tasks handled to achieve the goals of the thesis. The final sub-chapters introduce the company and the detailed scope of the analysis.

1.1 Purpose of the thesis

Siemens BG Graz develops and produces high-quality bogies for railway vehicles. The bogies are exposed to very high operational demands and therefore have to qualify for the highest safety standards, which in turn set high demands on the production quality.

The established system of key performance indicators for quality assurance provides means for securing, controlling and optimising the demanded production quality and process stability in the entire value-adding chain.

Data is collected for this at defined survey stations at the input or output of the process or in the process and administered in data bases, where it is used to derive the performance indicators. Operative decisions are prepared with the help of key performance indicators and their consequences are surveyed.

A new, optimised KPI system should be developed and compared to the established system by acquiring state-of-the-art knowledge of the available literature for KPIs. The main focus of the KPI system is the performance of the production process, its input and output and the feedback of the customers with the monitoring of the product quality.

In short the following goals should be completed with this thesis:

- Theoretical contemplation/literature study on the topic of key performance indicators for quality in the industrial supply chain from supplier to customer
- Definition of a theoretical model of KPIs using the literature study
- Description and analysis of the currently established system of key performance indicators for the specified processes in the value-adding chain of plant Graz Eggenberg
- Comparison of the theoretical model and the currently used system
- Deduction of recommendations for the optimisation of the currently used systems

The design of this thesis is in accordance with these goals. They are introduced in every necessary detail with supporting literature background and explanations.

1.2 Description of assignments

In this chapter the goals of the thesis are split into more detailed tasks and assignments. The very first is the development of theoretical basic knowledge on the topic of key performance indicators for quality assurance for mechanical engineering and vehicle construction industries. This should also include a research of quality standards and guidelines in mechanical engineering and especially rail way vehicle construction, i.e. ISO 9001 and IRIS. Additionally, a research should be performed on failure costs and efforts in industrial companies.

The acquired knowledge is applied for the definition of an evaluation system and criteria for key performance indicators. This evaluation system should be used for the definition of an optimised model of key performance indicators for quality assurance for processes and process steps in the value-adding chain. The evaluated KPIs are to be assigned to the processes. Then the necessary data gathering and preparation has to be deduced from the evaluated KPIs.

The next assignment was the description and analysis of the currently established KPI systems in the value-adding chain with previously developed tools. The usability of the measured data of the processes has to be examined.

The KPIs from the developed model should be compared to the established systems in the value-adding chain. The evaluation of the compared key performance indicators regarding optimisation is the next assignment.

Recommended procedures should be deduced from the comparison for the implementation of a new optimised KPI system.

1.3 Company Presentation Siemens AG Austria - Bogies Graz

The Siemens AG Austria, plant BG Graz Eggenbergerstraße 31 is part of Siemens Rail Systems division as world competence centre for research and production of high-tech bogies for railway vehicles for intercity and urban traffic. For example, Figure 1 shows the bogie model type Siemens SF 500. The bogies are constructed for use in commuter systems like metro vehicles, tram lines and light railways, and for use in mainline passenger systems like locomotives, passenger cars and motor train-sets[1]

Figure 1: Siemens SF 500 bogie[2]

Siemens BG Graz has a tradition of more than 150 years as competent partner in railway vehicle industry. At the beginning of 1990 SGP Verkehrstechnik GmbH was taken over step by step by Siemens. Between September 2001 and 2006 it's been a 100% subsidiary of Siemens AG Austria. From May 2006 till 2008 Siemens Transportation Systems Austria was a 100% subsidiary of Siemens Transportation Systems GmbH. In 2009 BG Graz was integrated into Siemens AG Austria.[3]

2011 after a new structuring of Siemens AG BG Graz was subordinated in the new Infrastructures & Cities sector. It is integrated in the business unit Locomotives and Components in the division Rail Systems.[4]

Currently, there are about 1,000 employees working in the plant. They produce in average 2,500 bogies per year. The industry type of BG Graz is mechanical engineering and vehicle manufacturing.[5]

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[1] Cf. Siemens Transportation Systems (2008), p. 4

[2] Siemens Transportation Systems (2008), p. 44

[3] Cf. Siemens Transportation Systems (2011), p. 12

[4] Cf. Siemens AG (2012)

[5] Cf. Siemens Transportation Systems (2011), p. 12

1.4 Scope of analysis

The scope of analysis includes specific processes of the value-adding chain, in more detail the production process with production disposition and production operations, as well as customer reclamations. The KPI system for quality monitoring had to be developed for these processes.

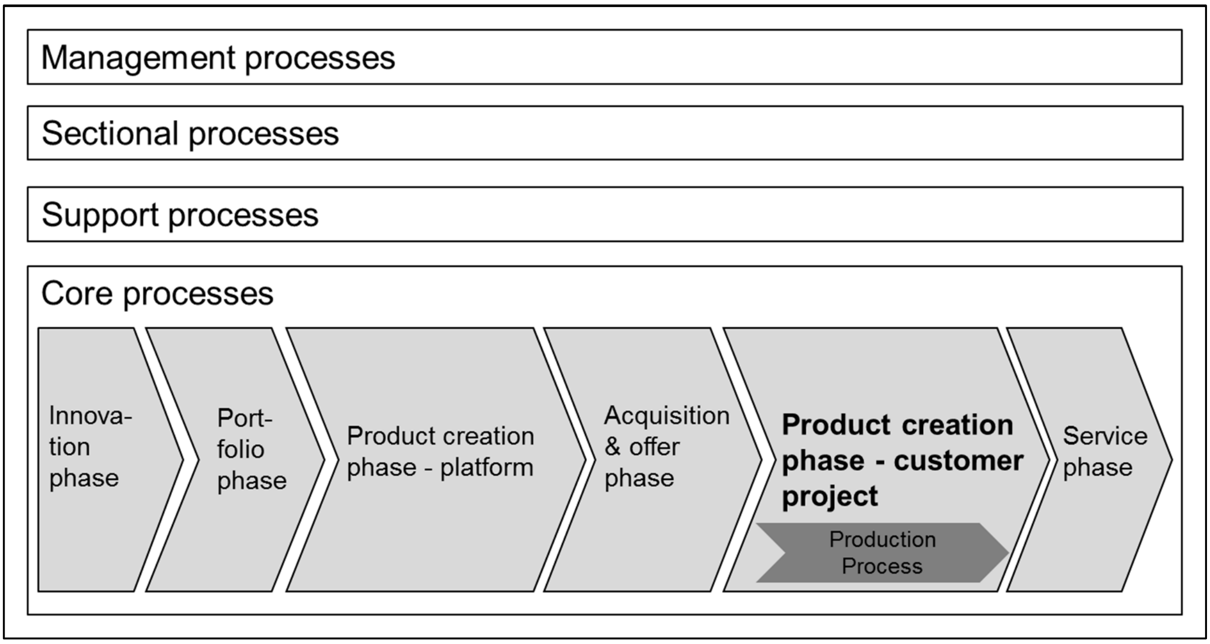

Figure 2: Process diagram: Processes of BG Graz with location of the production process[6]

Figure 2 shows the first level of the process organisation of BG Graz. The scope includes the production process, which is situated in the product creation phase for customer projects. This phase is one of the core processes that are supported and managed by the management, sectional and support processes.

The production process includes the sub-processes production disposition and the production operations which represent the value-adding processes.

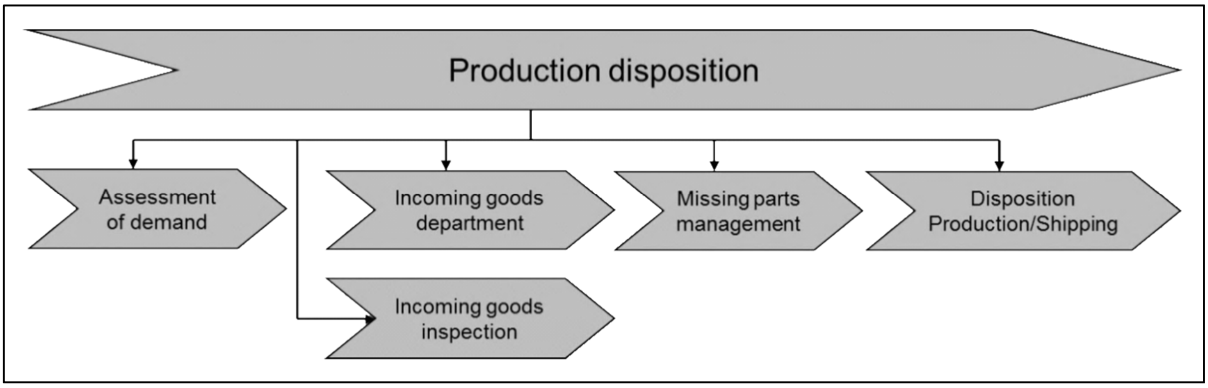

Figure 3: Process diagram: Production disposition - sub-process of Production process[7]

[6] Cf. Siemens BG QM (2012)

[7] Cf. ibidem

In Figure 3 the sub-processes of production disposition are displayed. The main activity of this process is to supply the production in time with the right parts. The incoming goods inspection is part of the scope of analysis.

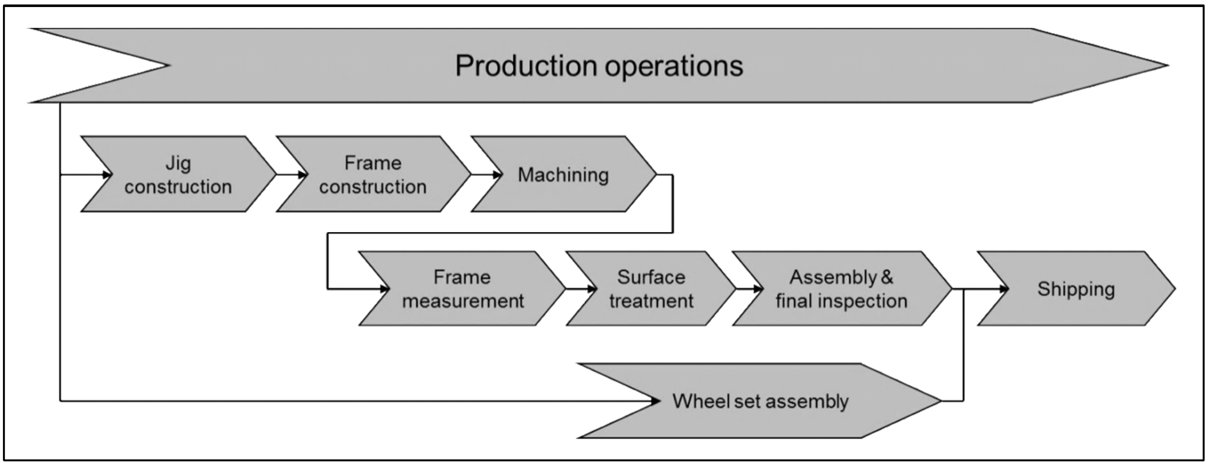

Figure 4: Process diagram: Production operations - sub-process of Production process[8]

Figure 4 displays the sub-processes of production operation. This entire process is part of the scope of analysis of this work. It displays the production sequence of bogies and the wheel set assembly process is included in it.

Not shown by these diagrams is the customer complaint management which is also included in the scope of analysis.

These processes are taken from the process house of Siemens BG Graz. The processes are designed using the ARIS process architecture concept. This concept is used for the analysis and planning of information systems. It integrates different description methods with varying conceptual aspects. On the process view level the used method is the event-driven process chain.[9]

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[8] Cf. Siemens BG QM (2012)

[9] Cf. VOLCK, S. (1997), pp. 87 ff.

2 Theory on quality and key performance indicators

This chapter introduces the necessary theoretical knowledge taken from state-of-the-art literature on the topics of quality in industrial companies and the key performance indicators and their systems. The findings of the literature study have been used to develop the improvement process model for KPI systems.

2.1 Quality

Quality is an important condition of products and processes in the modern industry. Maintaining and improving quality is an extensive task for the management. The following chapters include an introduction to the term quality and the systems used to implement them into modern processes, specifically the quality assurance.

2.1.1 Definition of quality

Quality as a concept is perceived differently throughout the industry when it comes to the detailed description. It mainly depends on the focus of business management. There are two different, important interpretations of quality:[10]

1. "Quality means those features of products which meet customer needs and thereby provide customer satisfaction. In this sense, the meaning of quality is oriented to income. The purpose of such higher quality is to provide greater customer satisfaction and, one hopes, to increase income. However, providing more and/or better quality features usually requires an investment and hence usually involves increases in costs. Higher quality in this sense usually "costs more"."
2. "Quality means freedom from deficiencies – freedom from errors that require doing work over again (rework) or that result in field failures, customer dissatisfaction, customer claims, and so on. In this sense, the meaning of quality is oriented to costs, and higher quality usually "costs less"."

2.1.2 Quality assurance

The main focus of this thesis is to develop a KPI system for quality assurance. According to literature this term has a few different meanings to different authors that are focused on in the following chapters.

2.1.2.1 Comparison of quality assurance to the Juran quality trilogy

The Juran Trilogy of Quality integrates the quality planning process, the quality control process and the quality improvement process into a single management concept. Managing for quality makes extensive use of these three processes. Each of the processes is a universal and follows an unvarying sequence of steps.[11]

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[10] JURAN, J.M. (2000), pp. 2.1 f.

[11] JURAN, J.M. (2000), p. 2.5

Quality Control and Quality Assurance are related by common procedures, as they evaluate performances, compare those to goals and act on the discrepancies. Yet there are also some differences. The primary purpose of quality control would be to maintain control. During operations the performance is evaluated and compared to goals. With the resulting information operators can act accordingly. The main purpose of quality assurance is the verification that the control of quality is being maintained. The evaluation of the performance is made after the operations and the resulting information can be used by the operators and other interested persons, like senior management etc.[12]

Primary focus of	
Quality management	Quality assurance
• Achievement of results for satisfaction of all quality requirements	• Demonstration of (probable) achievement of all quality requirements
• Motivation comes from internal stakeholders, mainly the management of the organisation	• Motivation comes from external stakeholders, mainly customers
• Satisfaction of all stakeholders is the goal	• Satisfaction of all customers is the goal
• The intended result is high effectiveness, efficiency and continuous improvement of overall quality-related performance	• The intended result is confidence in the products of the organisation
• All activities are covered by the scope of demonstration that affect the quality-related business results	• All activities are covered by the scope of demonstration that affect quality-related results of processes and products

Table 1: The primary focus of Quality Management and Quality Assurance[13]

The focus of quality management is compared to quality assurance in Table 1. Marquardt describes Quality assurance as a system which ensures that no defective output of the production reaches the customer and requires the feedback from the customers. The Quality management includes all the organisations entities.

2.1.2.2 Quality Assurance as part of the operative quality management

On the operative level of quality management there are four distinct functions:[14]

- Planning, design and development Quality planning
- Procurement, production and sales Quality control
- Assurance Quality assurance
- Improvement Quality improvement

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[12] JURAN, J.M.; GODFREY, A.B. (2000), pp. 4.3 f.

[13] MARQUARDT, D.W. (2000), p. 11.8

[14] Cf. SEGHEZZI, H.D. (1996), p. 53

Quality assurance is considered an independent function in this arrangement for operative quality management. The functions are assigned to the four phases of the Deming-wheel as seen in Figure 5. The Deming-wheel or PDCA-cycle is explained in chapter 2.1.3.1. J.M. Juran does not regard quality assurance as a distinctive function with his quality trilogy which has been mentioned in the previous chapter.[15]

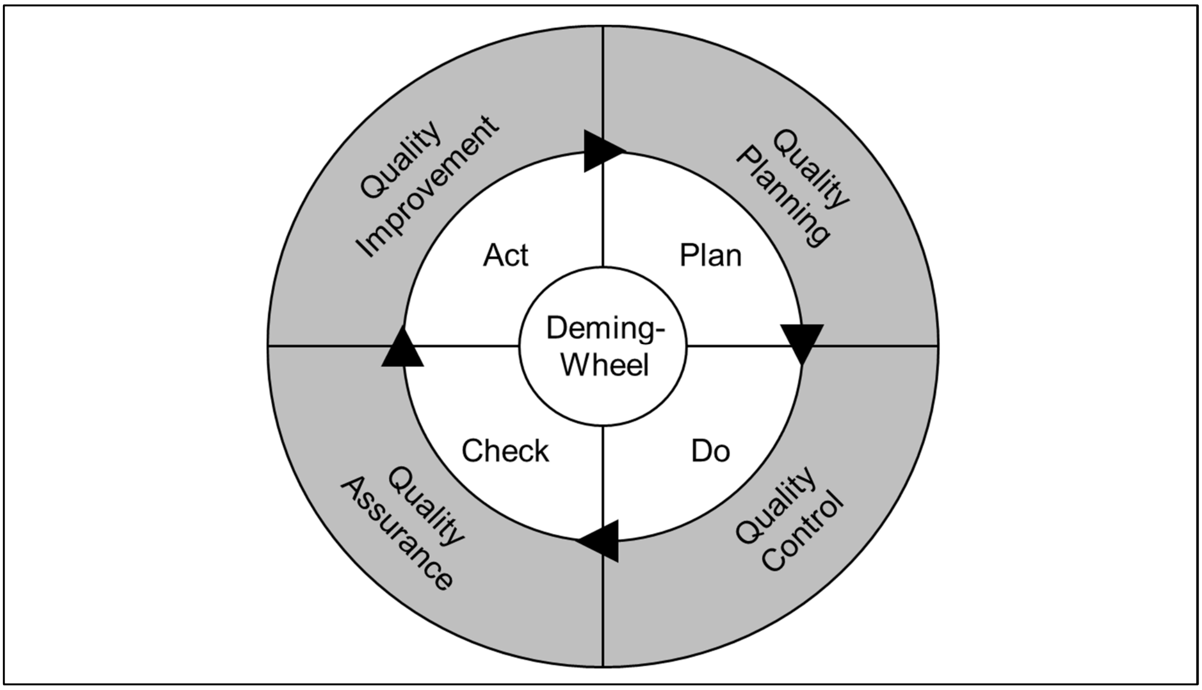

Figure 5: Arrangement of the operative tasks in the Deming wheel[16]

Quality assurance in this regard is defined as active risk management. Companies have risks with quality errors, like problems with deliveries, customers and users with defective products, and society with accidents due to such errors in the worst case. This type of quality assurance pursues two goals:[17]

1. A company should itself concern with the customers and society, because it has to ensure that offered services and products fulfil the requirements and have no errors. Customers and public society will earn trust in the qualitative capabilities of the company.
2. It should be guaranteed through quality assurance in internal processes that fulfilled quality requirements or errors can be discovered, corrected and managed with respect to their impact. The process owners, the leadership and co-workers will earn trust in the quality management of their company.

Methods for the application of all the four parts of operative quality management are introduced in chapter 2.2.2.

[15] Cf. SEGHEZZI, H.D. (1996), p. 53

[16] Cf. ibidem

[17] Cf. SEGHEZZI, H.D. (1996), pp. 96 f.

2.1.3 Quality assurance and Quality control in processes

Quality assurance and Quality control are quite similar functions of quality management. They require different methods and a systematic set-up for the implementation into the processes that are introduced in the next sub-chapters. They build the foundation of the KPI system.

2.1.3.1 PDCA-Cycle

The PDCA-cycle or Deming wheel applies four distinct phases to continuously improve the quality of a system or process over time, as is displayed in Figure 6. The application of these cycles in a process model for KPI systems makes the continuous improvement a requirement. See chapters 2.4.2.2 and 2.4.2.6 for more information.

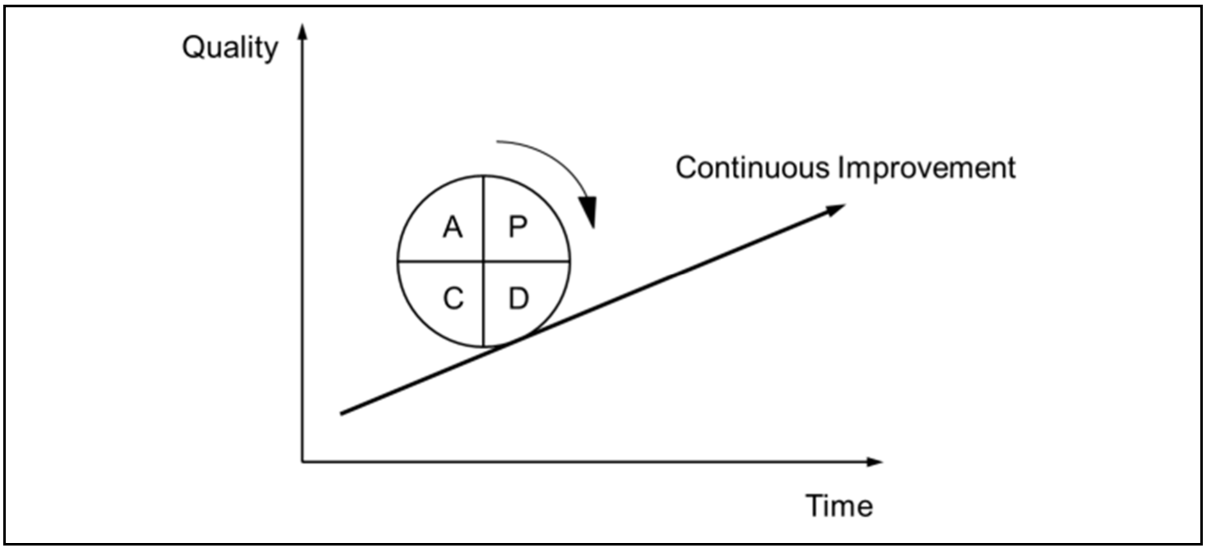

Figure 6: The PDCA-Cycle for Continuous Improvement[18]

The four phases of the PDCA cycle:[19]

- Plan

  An analysis of the current situation is performed with data investigation, analysis and evaluation in the first phase. An improvement plan is prepared with this data and realistic goals are defined.

- Do

  The responsible employees are introduced to the plan and have to execute the planned improvements.

- Check

  The necessary data is sampled as basis for the check on the goals. The actual data is compared to the targets of the planning phase.

[18] Cf. KOCH, S. (2011), p. 119

[19] Cf. KOCH, S. (2011), pp. 118 f.

- Act

  The accordance between set and actual values is checked in this phase. Either the results are being standardised for the processes, or the phases Planning and Doing are executed until it comes to accordance. There is a chance for old errors to reappear, when the standardisation is neglected.

2.1.3.2 The Feedback Loop

The PDCA-cycle in the previous chapter is an interpretation of the more generic feedback loop.[20]

The elements shown in Figure 7 are functions that are universal for every application. However, the responsibility for the execution of these functions varies with the application.[21]

One such application would be a key performance indicator, as can be seen in chapter 2.4.2.4.

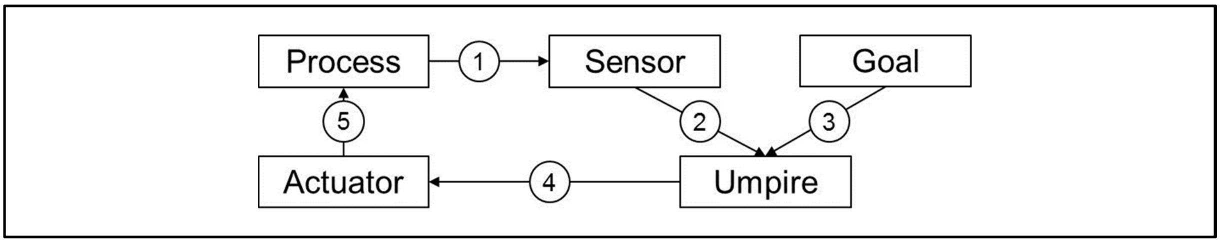

Figure 7: Generic feedback loop[22]

The following tasks are executed with the feedback loop:[23]

1. The sensor evaluates the actual quality of the product or process feature in question – the control subject.
2. The measured performance is relayed to the umpire.
3. The quality goal or standard provides the umpire with information.
4. The actual performance is then compared by the umpire. The actuator is used, if the difference is too great.
5. The actuator takes action on the process to restore the performance to the quality standards.
6. Conformance will be restored when the process responds.

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[20] JURAN, J.M.; GODFREY, A.B. (2000), p. 4.8

[21] JURAN, J.M.; GODFREY, A.B. (2000), p. 4.4

[22] ibidem

[23] JURAN, J.M.; GODFREY, A.B. (2000), pp. 4.3 f.

2.1.3.3 Pyramid of Control

The possibility to control every part of an organisation by the upper management is limited by the large number of managerial functions in a company. In order to maintain control over all aspects the division of the responsibility for control is a necessity. It is split into three areas: control by nonhuman means, control by the work force and control by the managerial hierarchy. The amount of responsibility for every level can be depicted as a pyramid as is shown in Figure 8.[24]

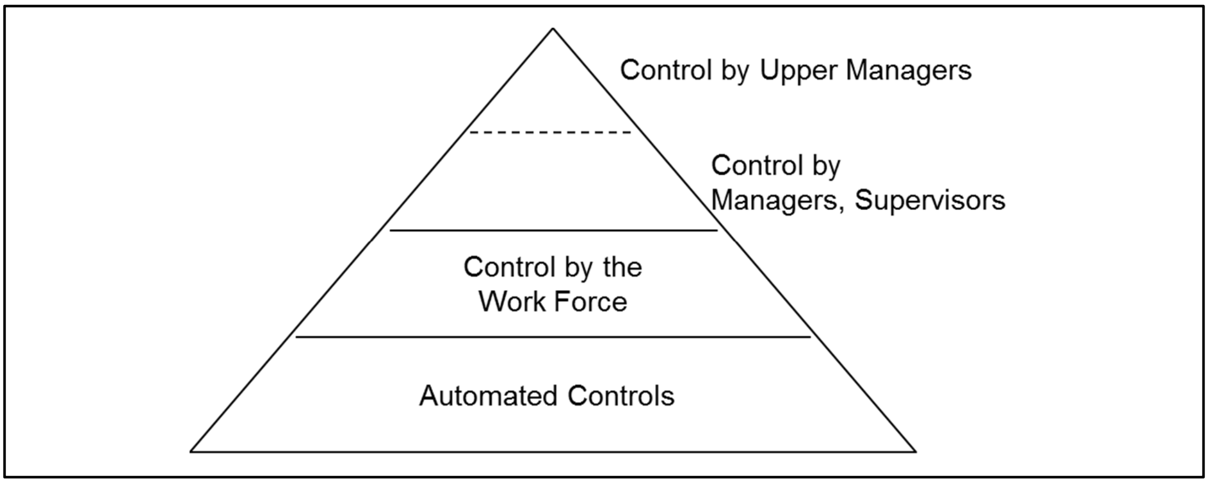

Figure 8: The Pyramid of Control[25]

Error-proofed processes and automated feedback loops construct the base of the pyramid. These operate without intervention by humans. They control the majority of control subjects. The control happens in real-time and on exclusively technological subjects.[26]

A feeling of process ownership and empowerment is carried to the work force by offering benefits in human relations by delegating responsibilities. Yet, it requires an increase in self-discipline in equal measures.[27]

Only the vital few control subjects are of interest to the peak of the pyramid. Quality control isn't the main task for the managers, only the most important decisions should be made.[28]

The control utilises the previously mentioned PDCA-cycle and generic feedback loop as management tools on all levels. Quality control processes mainly concentrate on automated systems and the control by the work force. Quality assurance systems on the other hand are used by the managers and supervisors and affect also the work force. More complex performance indicators are utilised in these systems. Cost of quality becomes more important for the higher hierarchies. See chapter 2.4.2.1 for further input.

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[24] JURAN, J.M.; GODFREY, A.B. (2000), pp. 4.8 f.

[25] JURAN, J.M.; GODFREY, A.B. (2000), p. 4.9

[26] ibidem

[27] JURAN, J.M.; GODFREY, A.B. (2000), p. 4.10

[28] ibidem

2.1.3.4 Measurement of processes

The feedback loop and PDCA-cycle require data measurement and evaluation for information acquisition. The reporting of this information is expressed in the pyramid of control in the previous chapter. Furthermore, the pyramid depicts the level of influence of decisions on the control parameters and data sampling systems.

QA is an information-gathering and decision-making process with the application of KPIs. The quality of information extracted from the available data makes decisions for changes in processes or products more sustainable and reliable. Better information can have any number of attributes, such as higher completeness, accuracy, relevancy, reliability of the source, precision, more appealing format for presentation, more up-to-date, etc.[29]

The possibilities for measuring with a sensor are at the end of a process the output (C), at the beginning the input (A) or in the process itself the parameters (B), for example Figure 9. Output results from the activities of the process which could be products to deliver or intermediary results in a process chain. The output of a task or process step can be the input for a follow-up task. The process or a task can be assessed by the output or the process parameters.[30]

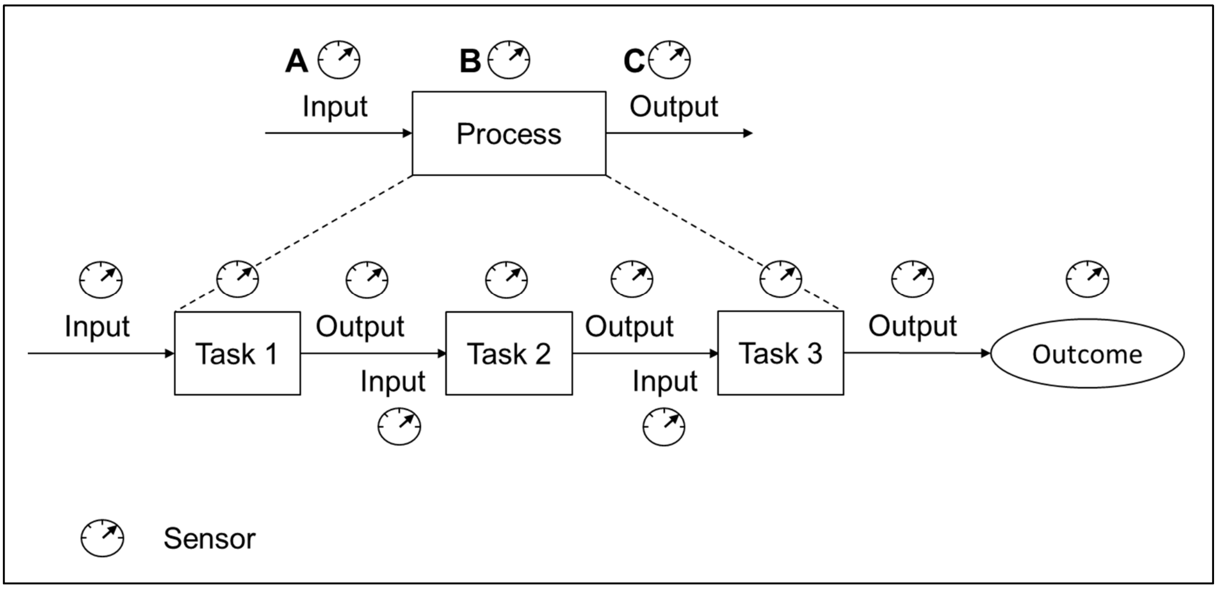

Figure 9: Measurement of processes, products (Input/Output) and outcome[31]

The main procedure in a KPI system for QA includes measurement of necessary data for the information and the analysis, synthesis and presentation of the information. Further parts of the system are the definition of the framework and the making and implementing the decision.[32]

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[29] REDMAN, T.C. (2000), p. 9.2

[30] Cf. SEGHEZZI, H.D. (1996), p. 33

[31] Cf. SEGHEZZI, H.D. (1996), p. 32

[32] ibidem

Sensors gather the data for different indicators. These indicators have specific requirements:[33]

- Measurability: An indicator must be able to be measured.
- Validity/Objectivity: An indicator should be characteristic for the analysed parameter and reproduce the reality
- Precision: More measurements have to lead to the same result.
- Sensitivity: An indicator should react accordingly to changes in the analysed parameter.
- Reliability: An indicator should not be easy to manipulate. This has to be regarded particularly when humans are used as sensors.
- Comprehensibility/Tangibility: Indicators and relations between measurements should be comprehensible and transparent for users.
- Influence: The user should be able to take action on the indicator.
- Reaction time: No considerable time delay should happen between changes of indicators and the display of the measured value.
- Measuring effort: The effort for measuring should be as small as possible.

These requirements are included in the requirements for the evaluation of KPIs concerning process assignment. The latter requirements are introduced in chapter 2.4.2.3.

[33] Cf. SEGHEZZI, H.D. (1996), p. 38

2.2 Quality errors and costs

Detection and correction of errors and avoidance of unnecessary quality costs are the main reasons quality assurance systems are implemented in the process structure of a company. The system should be capable of avoiding or at the very least detecting errors in the product quality and the processes and with that avoid these unnecessary costs. The following sub-chapters explain methods for the error detection and prevention and sources of quality costs. The KPI system has to integrate the information of the detection, correction and prevention systems and control the measures for improvement.

2.2.1 Quality errors

Definition:

> "An error is the condition of deviating from accuracy or correctness […]"[34]

Errors include many different deviations from the required condition and a reduction of the quality of a product or process by this definition. Quality management has to have systems and processes in place to deal with the errors accordingly. The systematic prevention of errors and improvement of the products and processes is explained in the following chapters.

2.2.2 Quality error management methods

Detection and correction of errors requires measurement of process parameters and product quality features with the quality control and quality assurance processes, such as the closed loop control and the correction cycle. The quality management should also tend to avoid errors in the first place by installing systems for error prevention. One of the most used methods for preventive error detection is the failure mode and effects analysis. The following methods are some of the most used from the operative quality management that has been introduced in chapter 2.1.2.

[34] http://www.thefreedictionary.com/ (22.04.2012)

2.2.2.1 Closed loop control

Closed loop control is implemented to achieve process control and a method of the quality control process. The implementation allows the processes to compensate for influencing disturbances of the environment, machines, workers, information, etc. In the control unit the measured variable of the output is compared to the set value. Deviations lead to adjustment in the process with the help of correcting values. The settings of the process are adjusted with the correcting value until the measured deviation disappears. Figure 10 displays the function of the closed loop control.[35]

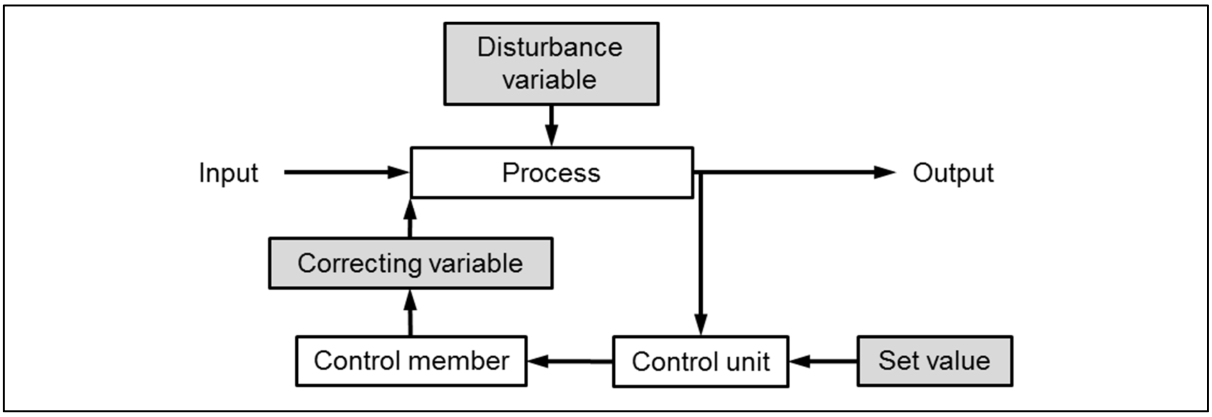

Figure 10: Closed loop control[36]

2.2.2.2 Correction cycle

The correction cycle is almost identical the closed loop control, yet it can detect and remove error sources. This cycle is an applicable method used in quality control and assurance processes. The error detection at the closed loop control leads to a compensation of the disturbance. It is not enough to recognise the errors with their symptoms in the correction cycle, but to look into the sources of these errors and remove them. This function leads to a sustainable correction of the process and minimizes the occurrence of disturbances. The function of the correction cycle is displayed in Figure 11.[37]

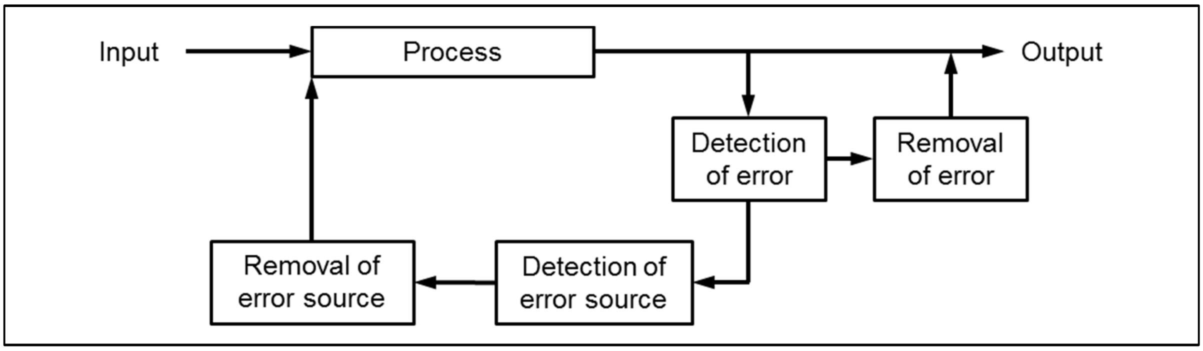

Figure 11: Correction cycle[38]

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[35] Cf. SEGHEZZI, H.D. (1996), pp. 84 f.

[36] Cf. SEGHEZZI, H.D. (1996), p. 85

[37] ibidem

[38] Cf. SEGHEZZI, H.D. (1996), p. 90

2.2.2.3 Failure Mode and Effects Analysis

The FMEA is a method for a reliability analysis to prevent errors and a method used in the quality planning process. A systematic approach is involved to analyse the function, failure modes, failure causes and failure consequences of products and processes. Thereby the analysis goes into detailed levels like the component level and analyses the corresponding failure consequences. It is possible with this to take measures to prevent failures from occurring.[39]

The process-FMEA can be used to evaluate the manufacturing process. Therefore malfunctions of products are studied and analysed. The goal is to analyse if the malfunction was caused by a disturbance in the manufacturing process. This can serve as basis for process improvement and the design of process control.[40]

The planning of the process-FMEA is similar to the design-FMEA in the product engineering phase. The application requires the definition and limitation of the system, the selection of the complexity level, the inspection of the functions of the systems and the components, the identification of possible failure modes and their consequences and the possibilities for failure detection. It should be possible after these analyses to judge on the severity of the failure and identify the dependencies between failures and their causes. Last but not least, the FMEA requires documentation of the analysis.[41]

2.2.2.4 Reduction of loss

The information acquired by the process-FMEA is further used for the improvement of the process. A systematic approach for that is available with the Six Sigma management concept for management of quality improvement. It applies a process with five phases for sustainable process improvement that is quite similar to the PDCA-cycle introduced in chapter 2.1.3.1. The five phases are the definition of the improvement goal, the measurement of the actual status, the analysis of the relevant causes, the improvement with developed solutions and the control of the implementation. These phases are abbreviated with DMAIC, define, measure, analyse, improve and control.[42]

The reduction of loss due to errors is one of the major concerns of the improvement processes. The Six Sigma management concept uses different methods to achieve an organisation wide reduction of losses. Fundamental to this are 8 basic concepts for quality engineering introduced by Genichi Taguchi:[43]

1. Minimisation of losses by ensuring uniformity around the preferred value

   In traditional quality thinking every product is accepted as equally good, if it is at least inside the boundaries of tolerances. Taguchi suggests a best point of quality at which

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[39] BERGMAN, B.; KLEFSJÖ, B. (1994), p. 125

[40] BERGMAN, B.; KLEFSJÖ, B. (1994), p. 126

[41] BERGMAN, B.; KLEFSJÖ, B. (1994), pp. 126 f.

[42] Cf. http://www.six-sigma-austria.com/ (04.05.2012)

[43] TRUSCOTT, W.T. (2003), pp. 109 ff.

the loss is at a minimum with the process performance deteriorating progressively as the values differ from the target.

2. Design of processes/products that produce uniform products economically

   The design of product and process has a strong influence on quality and costs. The improvement of product and process design should have the reduction of non-conformities and the need for stringent process control.

3. Exploitation of any non-linear effects of process parameters on performance characteristics

   Product/process performance variation can be reduced without tightening of manufacturing tolerances or process controls. The management has to take advantage of any non-linear relationship between the performance and product/process characteristics.

4. Cure of the effect and not of the cause

   Even though the Six Sigma concept instructs to seek out and remove causes for defects, often enough the removal of the cause is too costly. In this case it is better to deal with the effects, in other words with the defects.

5. Zero-defect standard is an inadequate goal

   Since almost every product/process has numerous quality characteristics the identification and measurement of the key characteristics is most important. Those are termed critical to quality. Improvement processes should focus on these critical attributes. Target specifications require tolerances about the preferred values.

6. Design of products/processes robust against operating conditions/use

7. Taguchi method is not essentially a problem-solving technique

   The method is a set of activities that should be integrated into the business processes. A key feature of the method is the shift from problem solving to activities of product and process design.

8. Exploitation of the three types of product/process parameters

   The parameter design establishes a system to influence the level or variability of the output by product/process parameters, so-called factors:

   - Control factors: affect the variability of the output
   - Signal factors: affect the level of the output
   - Null factors: do not materially affect the variability or level of the output

The implementation of such methods is to be controlled by a KPI system. Balanced Scorecards as mentioned in chapter 2.4.2.7 are capable of providing the framework for the control of process improvement. Quality control, assurance and improvement are parts of the same cycle and have been introduced in chapter 2.1.2.2.

2.2.3 Quality costs

Money is the basic language of the upper management. The communication of information is slower and less effective without the quality cost figures. The upper management requires the information on different areas of the company. The term quality costs can mean two different things similar to quality itself. In the first interpretation is the cost of "poor quality", meaning the prevention, detection and correction of defective work. The second is about the cost to attain a high level of quality as a product feature.[44]

2.2.3.1 Categories of quality costs

The composition of the costs for quality and their distribution over the amount of detected errors becomes apparent in Figure 12. The costs can be split between costs for correction of errors, the error costs, and the costs for testing and prevention of errors. Costs beyond the control of management are the outcome of having zero error detection and prevention activities planned as well as increasing the efforts for these activities to the point of zero-defect on all products. The sum of both error costs and error detection and prevention creates a parabolic curve as can be seen in the figure. The lowest point on this curve is the optimum for the costs where the organisation would have the lowest costs for error correction, detection and prevention.

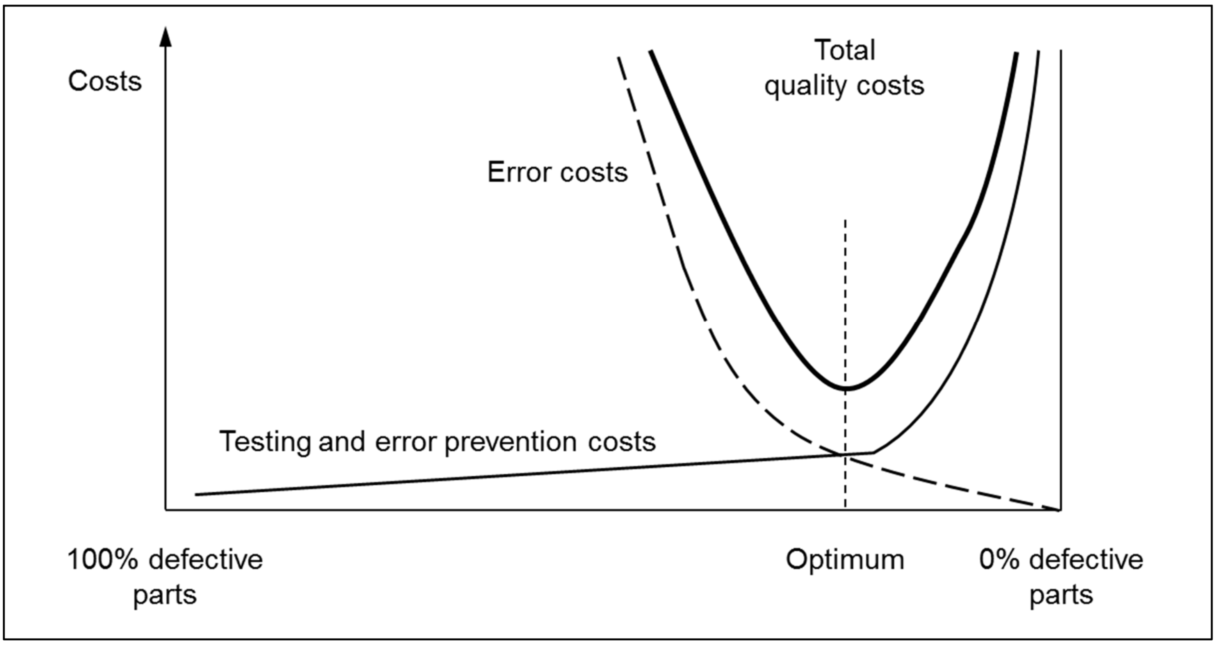

Figure 12: Diagram of quality costs for perfection[45]

[44] GRYNA, F.M. (2000), p. 8.2

[45] Cf. THEILIG, O. (2000), p. 59

Summarisation of costs of quality can be done basically in 4 different categories:[46]

Internal failure costs

In this category are costs included of deficiencies that are discovered before delivery of products. They are associated with failures, so-called nonconformities, to meet explicit requirements or implicit needs of external and internal customers. Included are process losses and inefficiencies that are avoidable and occur even when requirements are met.

- Failure to meet customer requirements and needs

  Exemplary subcategories: scrap, rework, lost or missing information, failure analysis, scrap and rework by the supplier, 100% sorting inspection, re-inspection, retest, changing of processes, redesign of hardware and software, scrapping of obsolete product, scrap in support opportunities, rework in internal support operations, downgrading

- Cost of inefficient processes

  Exemplary subcategories: variability of product characteristics, unplanned downtime of equipment, inventory shrinkage, variation of project characteristics from "best practice", non-value-added activities

External failure costs

These are the costs of deficiencies found after the product was received by the customer. They include lost opportunities for sales revenues as well.

- Failure to meet customer requirements and needs

  Exemplary subcategories: warranty charges, complaint adjustment, returned material, allowances, penalties due to poor quality, rework on support operations, revenue losses in support operations

- Lost opportunities for sales revenues

  Exemplary subcategories: customer defections, new customers lost because of quality, new customers lost because of lack of capability to meet customer needs

Appraisal costs

Those costs describe the efforts to determine the degree of conformance to quality requirements.

Exemplary subcategories: Incoming inspection and test, in-process inspection and test, final inspection and test, document review, balancing, product quality audits, maintaining accuracy of test equipment, inspection materials and services, evaluation of stocks

Prevention costs

Failure and appraisal costs should be kept to a minimum with this cost category.

Exemplary subcategories: Quality planning, new-products review, process planning, process control, quality audits, supplier quality evaluation, training

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[46] GRYNA, F.M. (2000), pp. 8.4 ff.

Hidden costs

The costs of poor quality may be not accurate enough because of costs that are difficult to estimate. Some hidden costs might occur. Here are some examples:

- Potential lost sales
- Costs of redesign of products due to poor quality
- Costs of changing processes due to the inability to meet requirements
- Costs of downtime of equipment
- Scarp and errors not reported
- Extra process costs due to excessive product variability
- Costs of errors made in support operations

2.2.3.2 Objectives of evaluation for KPI systems

The KPI system for quality assurance should supply the necessary information for the upper management in terms of costs for the establishment of primary objectives for sustainable improvement.

The objectives main purpose is the increase of product and process output value. This should enhance the customer satisfaction. The primary objectives for evaluating the quality and their related costs are the quantification of quality problems in information usable by the upper management, the identification of major opportunities for reduction in cost of bad quality within all activities of the organisation and customer dissatisfaction and associated threats to sales revenues. Further objectives are the provision of means to measurement of the result of implemented quality improvement activities for achievement of aforementioned objectives and the alignment of the quality goals with the goals of the organisation.[47]

2.2.3.3 Quality costs of modern industry

The quality-related costs range for most companies between 10 to 30% of sales and 25 to 40% of the operating expenses. In the chapters before is shown that some of these costs are visible and some are hidden.[48]

When all costs are included the Cost of Quality can range between 30 to 35% of gross sales for profit-oriented organisations and 40 to 60% for not-for-profit organisations, e.g. hospitals, charities, government. Cost of Quality is a measurement to assess the waste and losses of processes. These costs have been mentioned in chapter 2.2.3.1.[49]

[47] GRYNA, F.M. (2000), pp. 8.3 f.

[48] GRYNA, F.M. (2000), p. 8.2

[49] http://www.pqa.net/ (04.05.2012a)

Sigma level	Share of good quality in %	PPM/DPMO	COQ in % of Sales
2	95.45	45,500	Over 40%
3	99.73	2,700	25 - 40%
4	99.9937	63	15 - 25%
5	99.999943	0.57	5 - 15%
6	99.9999998	0.002	Less than 1%

Table 2: Sigma quality level and related Cost of Quality[50]

Table 2 shows the relation between the quality levels of the Six Sigma concept and the average Costs of Quality. The levels can be understood as mathematical multipliers for standard deviations. The level will get higher if the process output deviations are small and more standard deviations lie within the tolerance limits. Six Sigma strives for operational excellence with 6 standard deviations inside the tolerance limits and almost perfectly controlled processes. The share of good quality presents the acceptable or good quality output in relation to the entire output. Other comparable ratios are the parts per million or deficiencies per million opportunities. They express the amount of defective parts in a million produced parts. If the level is low and a lot of the output is deficient, it will mean high costs of quality, as is displayed in the table.

The percentage of defective units will drop, if a company spends more on prevention and appraisal activities. The results are lower costs for internally and externally detected errors. The company can effectively reduce the total costs of quality when it focuses its efforts on prevention and appraisal. The savings on total costs from the reduction of defects normally outbalance the additional efforts.[51]

	Year 1		Year 2	
	Amount [$]	% of Sales	Amount [$]	% of Sales
Prevention Costs	650,000	1.3 %	1,000,000	2 %
Appraisal Costs	1,200,000	2.4 %	1,500,000	3 %
Internal Failure Costs	2,000,000	4 %	3,000,000	6 %
External Failure Costs	5,150,000	10.3 %	2,000,000	4 %
Total Quality Costs	9,000,000	18 %	7,500,000	15 %

Table 3: Example of total quality cost reduction from Ventura Company[52]

[50] http://www.pqa.net/ (04.05.2012b)

[51] http://www.accountingformanagement.com/ (04.05.2012)

[52] ibidem

An example of the Ventura Company shows the reduction of the total quality costs before and after the shift of quality management focus in Table 3. Year 1 represents the year before the shift, year 2 represents after it. As can be seen, the costs for prevention and appraisal increase, which in turn decreases the external failure costs drastically by more than a half. The internal failure costs increase as well, which is due to the higher effort in appraisal and the improved in-house detection. In total the costs are reduced by 1.5 million $ and the low external failure costs will have a positive impact on customer satisfaction.

A similar example would be General Electric after the implementation of a Six Sigma concept in 1995. The data on revenue, investment in Six Sigma and the savings for GE is displayed in Table 4 for the years 1996 till 1999. The investment in Six Sigma has steadily increased, on the other side the savings have topped these investments by far. In 1999 savings are more than three times bigger than the investment.

Year	Revenue [$B]	Invested [$B]	% Revenue invested	Savings [$B]	% Revenue Savings
1996	79.2	0.2	0.3	0.2	0.2
1997	90.8	0.4	0.4	1	1.1
1998	100.5	0.5	0.4	1.3	1.2
1999	111.6	0.6	0.5	2	1.8
1996-1999	382.1	1.6	0.4	4.4	1.2

Table 4: Six Sigma Cost and Savings by GE[53]

[53] http://www.isixsigma.com/ (04.05.2012)

2.3 Quality standards

The following introduction to quality standards should give an overview of the applied standards for Siemens BG Graz and the requirements for the system of KPIs as listed by those standards. As a railway vehicle manufacturer Siemens BG Graz is certified by the international quality standard ISO 9001:2008 and more specifically for this industry type the IRIS - International Railway Industry Standard.

2.3.1 ISO 9001 - Requirements for quality management systems

The ISO 9001:2008 is the latest version of an international standard concerning requirements for quality management systems. It is an expansion to the ISO 9000:2005 that defines the fundamentals and basic vocabulary of quality management systems. [54]

ISO 9001 is the most comprehensive standard for the requirements of quality assurance of the ISO 9000 standards family. The across-the-board applicability to all organisational structures is one of the most important benefits of the ISO 9001 standard. The requirements are equally relevant to all scales of the supplier organisation.[55]

2.3.2 IRIS - International Railway Industry Standard

The International Railway Industry Standard IRIS is a globally accepted standard for the railway industry to evaluate quality management systems. The area of application for IRIS includes the requirements of QM systems in railway industries.[56]

IRIS is a specific industrial standard based on the ISO 9001:2008. By definition, it is process oriented, meaning that every process mentioned in the standard has to be well documented. All requirements of the ISO 9001:2008 have to be applied in total plus the specific requirements for the railway industry.[57]

2.3.3 Requirements of quality standards

The following explanations on requirements are taken from ISO 9001:2008 and in additions to those the IRIS explanations for further information on the requirements specific for the railway industry. Both have to be implemented for certification.

2.3.3.1 General requirements

The general requirements have to be met by all quality management systems if a certification for the ISO 9001:2008 is to be achieved. Those requirements include the determination of all processes that are concerned with the quality management system, their sequence and interaction with each other and the criteria and methods to ensure the effective operation and control. High availability of resources and information that are necessary for operations and

[54] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), pp. 12 ff.

[55] MARQUARDT, D.W. (2000), pp. 11.5 f.

[56] Cf. UNIFE - IRIS Management Centre (2009), p. 8

[57] Cf. UNIFE - IRIS Management Centre (2009), p. 24

monitoring support is also required. The processes are required to be monitored, measured and analysed. And it is required to implement actions for the achievement of planned results and continuous improvement.[58]

There has to be a documented method for the outsourcing of processes or parts of it within the progress of a project. This has to include: [59]

- Feasibility study
- Risk analysis
- Planning
- Communication with customer
- Initial sample testing

2.3.3.2 Documentation requirements

Documentation means to record the concerned task or process in readable form. Examples for documents are overall quality manuals, system procedures, work instructions for specific jobs, etc.[60]

The documentation requirements according to ISO 9001 include a clear statement concerning the quality policy and quality objectives, a complete quality manual, the documentation of all required procedures and records, as well as documents and records that are necessary for effective planning, operation and control of the processes.[61]

Further requirements would be the documentation of technical safety policy and safety goals, the documented requirements by supervisory authority in charge of inspecting the quality management system and open access for personnel, customers and responsible inspectors to the documentation of the management system.[62]

2.3.3.3 Requirements for management review

The managers have to review the quality management system in planned intervals. Criteria are suitability, adequacy and effectiveness. The review should include the assessment of opportunities for improvement and needed changes. The intervals for review have to be maximum 12 months.[63]

Input for the review:[64]

- Audit results
- Feedback from customers
- Performance measurements of processes and conformity of products

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[58] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), pp. 14 f.

[59] Cf. UNIFE - IRIS Management Centre (2009), p. 27

[60] MARQUARDT, D.W. (2000), p. 11.6

[61] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), p. 16

[62] Cf. UNIFE - IRIS Management Centre (2009), p. 27

[63] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), pp. 22 f.

[64] ibidem

- Status of actions for prevention and correction
- Follow-up activities from previous management reviews
- Changes to the quality management system
- Improvement recommendations

Further input for the review should be important aspects from previous project evaluations, conclusions from these previous evaluations and an analysis of occurring and potential failures and their influence on safety or environment. For this matter IRIS specifies or at least recommends several KPIs, mentioned in chapter 2.3.4.[65]

Output of the review should be decisions and actions for the improvement of the effectiveness of the system and the processes, the improvement of product features required by customers and the needed resources.[66]

Further output of the review should be decisions and actions on plans for improvement on the integration of processes, on the performance of business goals and on customer satisfaction.[67]

2.3.3.4 Requirements for product realisation

The processes of product realisation should be planned and developed by the organisation and this should be consistent with other process requirements.[68] The organisation has to determine, implement and control key processes that are connected to product realisation and customer satisfaction.[69]

The requirements for product realisation include aspects for policy, objectives and planning for which processes will be required. This can be understood as resource management and includes a series of processes and sub-processes for measurement, analysis and improvement for those processes.[70]

2.3.3.5 Purchasing - Verification of purchased product

To verify that a purchased product meets with all specified requirements, the organisation should establish and implement the necessary inspection. Should the organisation have intentions to perform verification at the supplier, it should state the verification arrangements and product release method in the purchasing information.[71]

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[65] Cf. UNIFE - IRIS Management Centre (2009), pp. 30 f.

[66] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), p. 23

[67] Cf. UNIFE - IRIS Management Centre (2009), p. 31

[68] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), pp. 25 f.

[69] Cf. UNIFE - IRIS Management Centre (2009), p. 33

[70] HOYLE, D. (2001), p. 353

[71] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), p. 34

Activities for verification according to IRIS:[72]

- Obtaining documented evidence of quality conformity
- Evaluation of necessary documentation
- Testing of delivered parts in incoming goods department

2.3.3.6 Control of production

The production has to be carried out under controlled conditions. There has to be a process to control reworking and scrapping. This includes the availability of information on product characteristics and work instructions, the utilisation of suitable equipment, the availability and utilisation of monitoring and measuring equipment and the implementation of monitoring and measurement mentioned in the following chapter and the implementation of activities after production for products.[73]

Further requirements include the controlled conditions for the responsibility for all products in production and documented evidence for production and testing activities according to process planning.[74]

2.3.3.7 Requirements for monitoring and measurement

The organisation is required to implement processes for monitoring, measurement, analysis and improvement for the demonstration of conformity to product requirements, of the quality management system and the continuous improvement of the effectiveness of said system.[75]

One important measurement is the customer perception as to whether the organisation has met the requirements given by the customer, in other the customer satisfaction. The methods to obtain and use this information have to be determined.[76]

The monitoring process for customer satisfaction has to be defined and executed. External data sources and statutory requirements have to be included. This is recommended to be measured with a KPI. See also chapter 2.3.4.[77]

Internal audits should be done at regular intervals to conform the compliance of the quality management system to the planned arrangements and the effective implementation and maintenance of the International Standard.[78]

A process for data acquisition for the audits has to be defined and implemented. The organisation must audit all processes of the management system.[79]

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[72] Cf. UNIFE - IRIS Management Centre (2009), p. 39

[73] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), p. 35

[74] Cf. UNIFE - IRIS Management Centre (2009), p. 40

[75] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), p. 39

[76] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), p. 40

[77] Cf. UNIFE - IRIS Management Centre (2009), p. 47

[78] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), p. 40

[79] Cf. UNIFE - IRIS Management Centre (2009), p. 47

Methods for monitoring and measurement have to be applied for all processes of the quality management systems. Goal is the demonstration of the ability of the processes to achieve the planned results. When the deviation of the process goal is apparent, corrective actions have to be taken.[80]

Key performance indicators have to be defined to measure and control the process.[81]

Methods have to be implemented to monitor and measure the quality characteristics of the product and verify that the requirements have been met. The evidence of positively confirmed products has to be maintained.[82]

The specifications for testing of products have to be documented. Documentation of the test has to show the actual test results and the explanation for approval or restriction of the tested product.[83]

2.3.3.8 Requirements on the analysis of data

Appropriate data should be determined, collected and analysed with the KPI systems for the demonstration of the suitability and effectiveness of the quality management system. This could also be used to assess where continual improvement of the effectiveness can be made.[84]

Information should be provided for customer satisfaction, conformity to product requirements, characteristics and trends of processes and products, opportunities for preventive action and suppliers.[85]

The process performance has to be measured by key performance indicators. Additional requirements are the analyses of external field reports of products and of product safety.[86]

2.3.4 Key performance indicators required by IRIS

The industry specific standard IRIS lists a few KPIs for detailed measurements and processes. Some KPIs can be designed by the company's own accord.

Obligatory KPIs:[87]

- Customer reaction concerning delivery on time
- Nonconformities reported by the customers
- For open competitive bidding management
- For research and development

[80] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), p. 41

[81] Cf. UNIFE - IRIS Management Centre (2009), p. 47

[82] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), p. 42

[83] Cf. UNIFE - IRIS Management Centre (2009), p. 48

[84] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), p. 43

[85] Cf. Normenausschuss Qualitätsmanagement, Statistik und Zertifizierungsgrundlagen (2008), p. 44

[86] Cf. UNIFE - IRIS Management Centre (2009), p. 49

[87] Cf. UNIFE - IRIS Management Centre (2009), pp. 58 ff.

- For procurement process
- For project management
- For cost management

Recommended KPIs:[88]

- Internally or from supplier caused nonconformities
- Supplier performance concerning delivery on time
- Reaction time on nonconformities reported by the customers
- Error costs
- Evaluation of fulfilment of product requirements
- For initial sampling testing
- For customer satisfaction
- For data analyses

Not all of these KPIs are part of quality assurance for production processes. The obligatory KPIs are used in the QM Scorecard described in chapter 4.1.1. The standards build the legal framework with the mentioned requirements for the KPI systems. The requirements include the measurement of the quality in processes and products, customer feedback and they specify regular intervals for analysing the quality. This is needed for the KPI system.

2.3.5 Standards in Siemens BG Graz

Siemens BG Graz had been certified according to both standards, ISO 9001:2008 and IRIS 2009:Rev.2. All processes in the company are documented in detail. Each task in the process steps is supported by documents describing all requirements and activities. The Quality Management department introduced several key performance indicators to monitor the output of different departments as is required by IRIS. Those KPIs are checked in regular intervals.

[88] Cf. UNIFE - IRIS Management Centre (2009), pp. 58 ff.

2.4 Key performance indicators and systems of KPIs

Key performance indicators are the tools for evaluation of products and processes. They gather measured data in the respective processes and on products and deduce the information intended with the implementation. In this chapter the definition of KPIs is presented as well as the developed improvement process model.

2.4.1 Definition of key performance indicator

Key performance indicators are figures that offer information to facts of business processes. The value creating and value adding processes are regarded as control objects. The information they offer is defined as the goal oriented knowledge concerning specified objectives and tasks.[89]

A KPI can be regarded as business process model due to its properties. Four different types of models can be discerned: report, detection, forecasting and decision models. It is not possible to describe a business process in all its details completely. A KPI can describe one or more of the process steps quantitatively.[90]

KPIs can be classified by different characteristics. Classification by statistical-methodical characteristics can differentiate between absolute numbers, i.e. sole numbers, sums, differences and average values, and ratios, i.e. reference numbers, quotas and index numbers. More classifications are about the quantitative structure (e.g., based numbers, chronological structures), the reference to point in or span of time, the structure with regards to content, amounts or values and can be concerning the area of application, the data sources and planning concerns.[91]

Key performance indicators for quality

A quality key performance indicator is defined as quantitative measurement and information gathering tool for a quality feature applicable to business processes within quality management.

The ideal quality KPI has to be understandable, allows making decisions on an agreed basis, supports consistent data interpretation, is economically applicable and can be derived from currently used data sources. These features are used for the definitions of the criteria for process assignment in chapter 2.4.2.3.[92]

[89] Cf. MEYER, C. (1994), pp. 1 f.

[90] Cf. MEYER, C. (1994), pp. 5 f.

[91] Cf. MEYER, C. (1994), p. 6

[92] Cf. EARLY, J.F.; COLETTI, O.J. (2000), pp. 3.22 f.

2.4.2 Improvement process model for KPI systems

The following Figure 13 shows an exemplary process of how to use a system of KPIs, including the development of such a system and important inputs and outputs. The process and its parts have been deduced from multiple sources and are integrated into a single model that can be used for the improvement of processes and their adjacent KPI systems. The entities of this model are explained in the following sub-chapters.

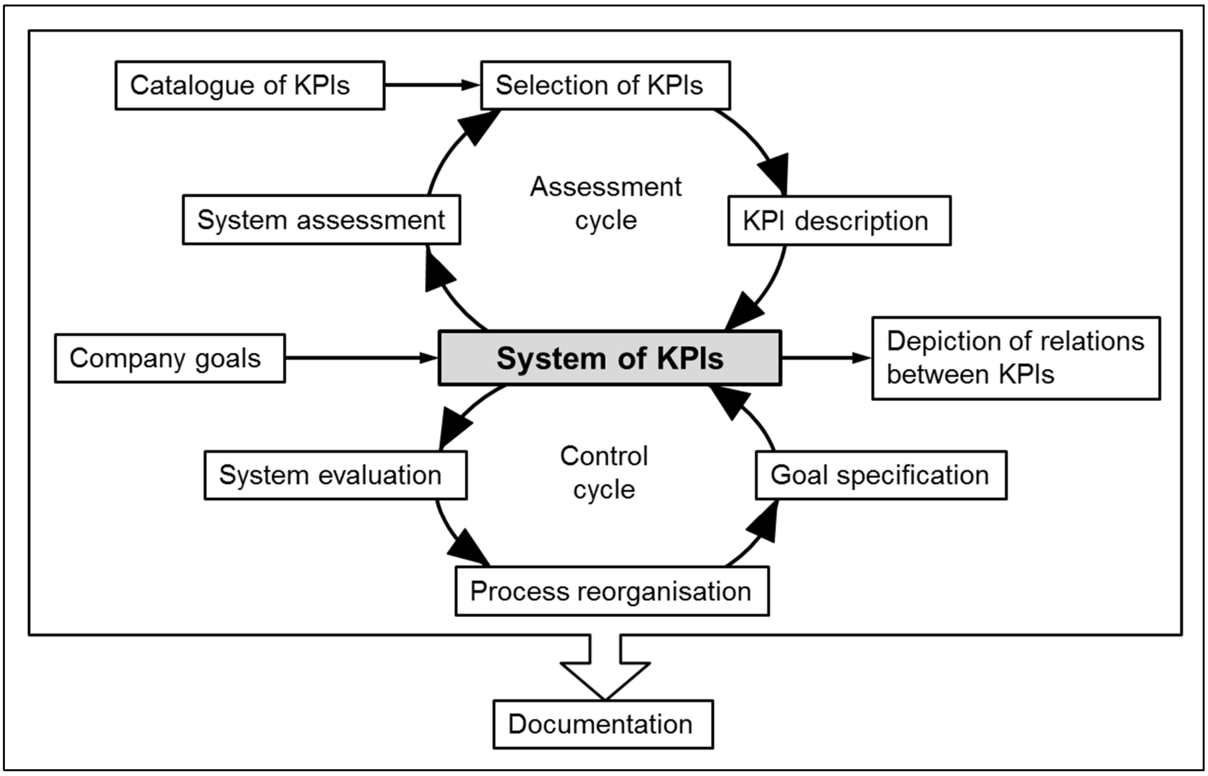

Figure 13: Depiction of a process model for KPI systems

2.4.2.1 System of KPIs

A system of KPIs encompasses two or more KPIs with mathematical or systematic connection and delivers information for one or more facts of business processes. Systems of KPIs can be classified by mathematical connection or systematic relation of the KPIs into calculation or classification systems. The system can be developed through induction or deduction.[93]

The relations between KPIs themselves can be classified into logical, empirical and hierarchical relations.[94]

The system gathers information on facts of business processes. It is in the central part of the model where all the business processes are measured with the use of KPIs. All processes have to be well documented for the effective use of a KPI system which is required by the standards as well (see 2.3.3 Requirements of quality standards). Sensors are attached to the processes where they gather data on parameters. The KPIs extract information with the

[93] Cf. MEYER, C. (1994), pp. 10 f.

[94] Cf. KÜPPER, H. (2005), p. 361

analysis of the available data. The demand of information for the management determines the assignment of the KPI to one or more process.

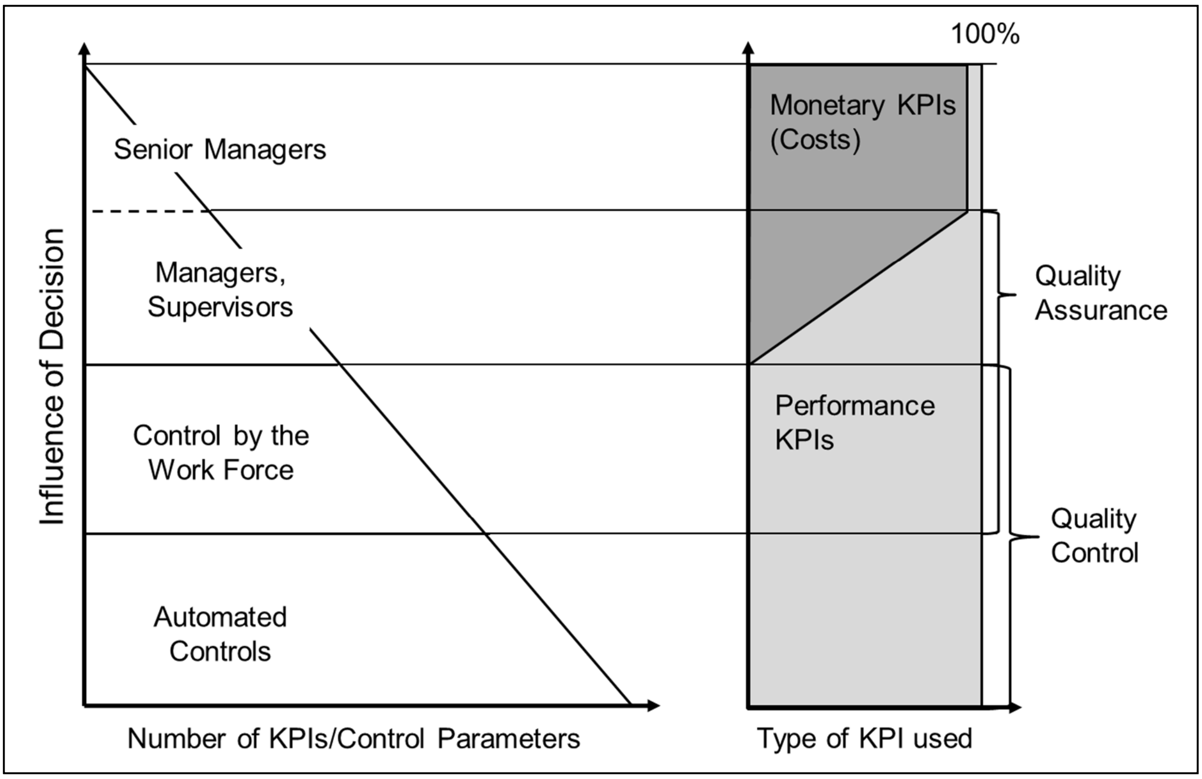

Figure 14: Example of basic design of KPI systems

Figure 14 displays an example of a basic design of a system of KPIs. The left part of the diagram is an adaptation of the Pyramid of Control (see 2.1.3.3), showing the number of KPIs/Control parameters used by the different levels of the company hierarchy. The right part shows the composition of the types of KPIs used. Monetary KPIs become more important for the management and they are the basic information needed by the senior managers. More on the quality costs in chapter 2.2.3.

2.4.2.2 Assessment Cycle

The assessment cycle is one of two feedback cycles involved in the process model. With this cycle the system of KPIs itself is analysed and assessed. The four main parts of the cycle, which can be understood as phases of the PDCA-cycle, are the “KPI description” as PLAN, the “System of KPIs” as DO, the “System assessment” as CHECK and the “Selection of KPIs” as ACT-phase. This cycle improves the system of KPIs in the sense of continuous process improvement. This cycle has a strategic focus and should be executed at least once per year. The phases of the PDCA-cycle are explained in chapter 2.1.3.1.

2.4.2.3 Selection of KPIs

The definition of the objectives and of the KPIs for controlling these objectives is required for the development or improvement of an effective planning and control system. Systems of KPIs are mainly pictured as hierarchical structures such as trees or pyramids with a top KPI being deduced logically from several other related KPIs (e.g., ROI/DuPont-Scheme). However, logical and hierarchical relations will become more complex, if more processes are included in the system and detailed information is demanded. Therefore the relations become harder to describe and even more so to understand. Describing those relations is only possible with high effort. Because of these unknown structures in empirical systems of somewhat related KPIs, it's better to regard them as nets of KPIs. This in turn makes it more complicated to choose the right KPI for the system. The requirements in Table 5 can support the selection of a KPI for a system.[95]

Integrity	Every necessary KPI for monitoring of the concerned processes is chosen.
Intersubjectivity	Every responsible person should be convenient with the selection of the KPI.
Clarity	Requirement on systematic, uniform and transparent structure of the system.
Multicausality	The relations between the KPIs are also a requirement.
Goal orientation	The overall company goals are regarded as determining factor.
Participation	The selection process is influenced at defined steps by managers.

Table 5: Requirements on the selection of KPIs for the system[96]

The requirements mentioned in Table 5 do not regard the process orientation of the KPIs for quality assurance. The definition of KPIs for quality in chapter 2.4.1 supports other requirements as well for the selection as can be seen in Table 6.

Comprehensibility	This requirement is similar to the before mentioned requirement intersubjectivity. A KPI has to be formulated comprehensible for every participant. Furthermore there should be no misinterpretation and an agreed basis for decision making.
Efficiency	The application of the KPI has to be economically maintainable.
Compatibility	The information of the KPI can be derived from currently used data sources.

Table 6: Requirements on the selection of KPIs for quality monitoring[97]

The requirements mentioned in Table 6 consider the process characteristics and are more process-oriented than the requirements in Table 5. They include the requirements for indicators mentioned in chapter 2.1.3.4. The requirement comprehensibility can supplement the requirement intersubjectivity. A KPI that should be implemented into a KPI system can be evaluated with these requirements. These requirements are transformed into evaluation criteria for KPIs and utilised in chapter 3.2.3.

[95] Cf. RÖGLINGER, M.; REINWALD, D.; MEIER, C.M. (2009), pp. 1 f.

[96] Cf. RÖGLINGER, M.; REINWALD, D.; MEIER, C.M. (2009), p. 2

[97] Cf. EARLY, J.F.; COLETTI, O.J. (2000), pp. 3.22 f.

2.4.2.4 KPI description

The main task of a KPI is to offer necessary information for the management. A KPI can be regarded as part of an adaption of the feedback cycle. The KPI includes the steps 1 and 2 displayed in Figure 15. It is a tool for the reporter to prepare the information.

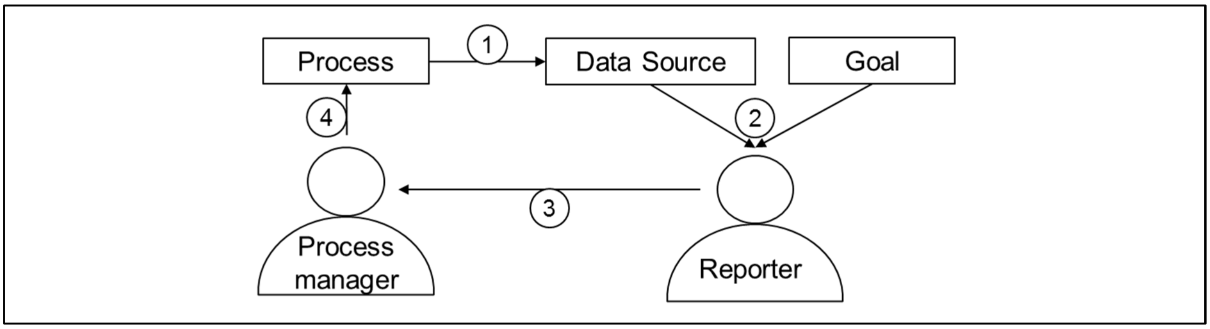

Figure 15: KPI as part of an adapted feedback cycle

Figure 15 shows an adapted feedback loop which works similar to its generic counterpart. See chapter 2.1.3.2 for further information on the feedback loop. The umpire and actuator in this cycle are real persons. Actions in this cycle are:

1. Data from different process parameters is gathered in dedicated databases.
2. Data is extracted and refined with the KPI to calculate the necessary information. The reporter compares the information offered by KPIs to defined goals for the process performance.
3. The reporter gives the acquired feedback to the process manager.
4. The process manager decides on necessary actions to bring the process back on the intended course.
5. Conformance will be restored when the process responds.

A KPI has to be fully described and documented for this feedback cycle to work. Some necessary parts of the description are:[98]

1. Name

   The name is a short identification form that should give an appropriate idea of what this KPI is about.

2. Description

   The description explains in short on how the KPI works and how it is calculated.

3. Process description

   A KPI always gathers information to a process characteristic. This process has to be identified and documented transparently in accord to the process documentation required by the standard for quality management.

[98] Cf. Siemens BG QM (2010)

4. Process owner

   The process owner is responsible for each aspect of the process including improvement actions.

5. Formula/Calculation

   The calculation of the KPI is explained in this part, if necessary even with a formula.

6. Unit

   The unit is the mathematical description of the calculated value, e.g. hours, EUR.

7. Reference value

   A reference value is used to compare the current value or trend development of the KPI to another performance indicator. This can help assess the value of the KPI in more detail during its development. Another reason is to deduce appropriate measures in relation to this development.

8. Evaluation period

   This period defines the duration of data collection and periodic reporting. The period depends on the definition of the KPI. Commonly used periods are months and quarters.

9. Data source

   The system that offers the necessary data for the calculation of the KPI is documented in this part.

10. Target value/Goal

    A target value is necessary for the comparison of the actual value of a KPI and to deduce actions on correction. This value has a high strategic importance and defines the reaction on deviations. Sometimes the target value is fixed by the definition of the KPI, e.g. zero accidents.

11. Tolerance limits

    The target value is basically idealistic and the actual value rarely meets the goal. Smaller deviations are not as drastic as greater deviations. An appropriate warning mechanism has to be implemented for tolerance of these different deviations. The tolerances are as important as the target value and have an impact on the improvement actions.

12. Reporter

    The reporter is the person responsible for calculation and comparison of the KPI to the goals, as well as reporting this value to the responsible managers. Probably this person has to execute more detailed analyses of disturbances occurring during the evaluation of the system.

13. Receiver

    The persons and organisations interested in the information of the KPI are listed as the receivers. The reporter gives feedback to these receivers.

14. Display format

    The display format describes the design of the information. For instance, which kind of diagram is used to report the information.

15. Preparation effort

    A short notification is documented in this part on the effort of the information preparation to help in planning.

16. Deficits/Limitations

    This is also an important part of the description. The notations on deficits and limitations of the KPI document weaknesses to be considered when evaluating the KPI. These deficits have to be regarded also when the KPI system itself is assessed.

17. Relations to other KPIs

    Possible relations to other KPIs are documented in this part.

The offered information can be directed and evaluated accordingly with the detailed description of a KPI. Influences on the system can be easier identified and actions can be deduced more appropriate to achieve the desired results.

2.4.2.5 System assessment

The system assessment should be capable of determining the performance of the KPI system. Some of the tasks to be implemented are:

- Identify areas not covered by the KPI system

  This could mean that additional information of a characteristic of the processes has to be acquired or some weaknesses of the processes are not covered at all.

- Identify deficiencies and limitations of the KPIs

  This means that KPIs may have not the capability to perform the task it was introduced for. Such deficiencies should at least be documented in the description of the KPI.

- Identify exceptionally good performance of KPIs

  A KPI is introduced for the monitoring of a process characteristic. However, it should be documented when the performance of a KPI is exceptionally well. An example could be that the information of the KPI is also important for other non-intended areas.

Problems and weaknesses of the KPIs might become apparent during evaluation period and should be documented. This documentation can help with the system assessment.

The St.Galler management concept offers a model for the assessment of the used system for quality assurance. This model assesses the system in four different criteria with two opposing extreme cases as reference points. One criterion for the assessment is the responsibility for quality assurance. It lies somewhere between the principle of self-inspection and the principle of external control. Another is the arrangement of quality assurance. The actual arrangement lies somewhere between the reaction and prevention of errors and risks in products. The inspection mode also should be assessed. The current mode lies somewhere between process-isolated inspection with a centralised control process and process integrated inspection with control within the production processes. Last but not least the assessment checks the methodical support. The used methods apply either spontaneous, reactive application or systematic appropriation of methods in the quality assurance system.[99]

2.4.2.6 Control cycle

The control cycle is also a feedback cycle and presents the actual evaluation and improvement of the business processes with the information offered by the KPI system. The main four parts of the cycle, which can be understood as PDCA-cycle similar to the assessment cycle mentioned in chapter 2.4.2.2, are the "Goal specification" as PLAN, the "System of KPIs" again as DO, the "System evaluation" as CHECK and the "Process reformation" as ACT-phase. This cycle has an operative focus and is executed as regularly as deemed necessary during a business year. The phases of the PDCA-cycle are explained in chapter 2.1.3.1.

2.4.2.7 System evaluation

Purpose of the system evaluation is the comparison of the actual process performance to the performance targets. KPIs are one of the most prominent tools for this task as they deliver the necessary information. Other tools are needed to gather the information of an entire system of KPIs and display the regular performance evaluation in an organised manner. One of the most popular for modern management is the use of scorecards.

The Balanced Scorecard provides a management system for organisations in general with the means to adapt a company's strategy into a coherent set of performance indicators. The scorecard can be understood as a language to communicate mission and strategy of a company. It informs employees by the use of measurement about the drivers of success.[100]

The scorecard is split into four different perspectives of the organisation. The perspectives are financial, customer, internal business process and learning and growth, as displayed in Figure 16. This split allows for balance between objectives in short- and long-term, between outcomes, the desired ones and their performance drivers, and between objective and more subjective measures.[101]

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[99] Cf. SEGHEZZI, H.D. (1996), pp. 108 ff.

[100] KAPLAN, R.S.; NORTON, D.P. (1996), pp. 24 f.

[101] KAPLAN, R.S.; NORTON, D.P. (1996), p. 25

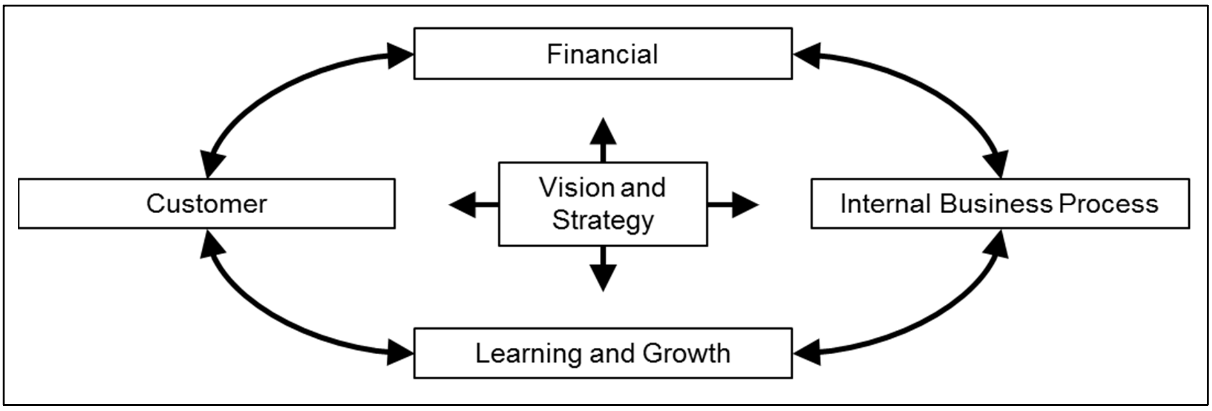

Figure 16: Perspectives of the Balanced Scorecard management system[102]

Financial perspective:[103]

Financial measures are of value in the summary of measurable economic consequences of actions taken. These measures indicate the contribution to a company's improvement by its strategy, implementation and execution.

Customer perspective:[104]

The installed measurements in this perspective should help identify and evaluate the customers and market segments the business unit wants to compete in. Core outcome measures in this perspective are the customer satisfaction, customer retention, acquisition of new customers, customer profitability, as well as market share in the segments. Some generic measures should also be included like measures of the value propositions delivered to customers.

Internal-Business-Process perspective:[105]

With this perspective the critical processes in an organisation are identified. The organisation has to excel in these processes. Goals of these processes are the delivery of value propositions to attract and retain customers and the satisfaction of expectations of shareholders on financial returns.

Another approach of this perspective is the introduction of continuous innovation as a long-term process for sustainable value creation.

Learning and Growth perspective:[106]

Long-term growth and improvement for an organisation are two prime success factors to be ensured by the management. With this perspective the necessary infrastructure for these factors are identified.

Organisational growth comes principally from people, systems and organisational procedures. The organisation has to take care of qualifying and training people,

[102] Cf. KAPLAN, R.S.; NORTON, D.P. (1996), p. 9

[103] KAPLAN, R.S.; NORTON, D.P. (1996), p. 25

[104] KAPLAN, R.S.; NORTON, D.P. (1996), p. 26

[105] KAPLAN, R.S.; NORTON, D.P. (1996), pp. 26 f.

[106] KAPLAN, R.S.; NORTON, D.P. (1996), pp. 28 f.

implementing state-of-the-art information technologies and systems and restructure organisational procedures and routines to close gaps in the capabilities of people, systems and procedures.

KPIs for quality assurance are mainly associated with internal processes. A Balanced Scorecard provides a framework for a management tool to assess the entire organisation. An adjusted scorecard for assessing the quality features of processes is recommended as the four perspectives of the Balanced Scorecard wouldn't be balanced with a focus on quality.

2.4.2.8 Process reorganisation

The business processes controlled by the KPIs will be adjusted to achieve the strategically defined targets in this part of the process model. The Balanced Scorecard goes beyond a simple analysis tool just with the KPIs represented in it. The scorecard integrates initiatives to implement the company's vision and strategy and to help achieve the strategic goals.

The set targets in the Balanced Scorecard require the strategic initiatives. Those initiatives have to be explicitly linked to the targets. Ways to create the initiative:[107]

- "Missing Measurement" program

  If it becomes apparent in the design phase of the Balanced Scorecard that some planned measurement would need data not available at the moment, necessary initiatives for the management of those "blind spots" need to be implemented. It is no problem of data measurement, more likely the management of the process in question is inadequate and needs to be reformed.

- Continuous improvement programs linked to rate-of-change metrics

  The decision has to be made between continuous or discontinuous improvement in regard to the strategic targets. A rate-of-improvement metric should be installed to check that near-term efforts are able to achieve the long-term target, if a continuous improvement approach is decided upon.

- Strategic initiatives, such as reengineering and transformation programs, linked to radical improvement in key performance drivers

  If the strategic goal cannot be achieved by means of continuous improvement over a long period, new ways to accomplish these process goals will have to be developed and deployed. In this case the scorecard provides the justification for process reengineering and transformation.

Other applicable process for continuous improvement is presented in chapter 2.2.2.4.

2.4.2.9 Goal specification

Short-term, operative goals for the process measures have to be implemented to achieve the set strategic targets of the company goals mentioned in chapter 2.4.2.11. These goals are introduced into the KPI system and later compared with the actual process performance in the system evaluation. The goals should be considered as milestones on the way to achievement of the strategy. They have to be oriented on the initiatives for process

[107] KAPLAN, R.S.; NORTON, D.P. (1996), pp. 230 ff.

reorganisation and support the control of changes in the improvement phase. It is important to choose those goals with respect to the evaluation period as they should have a realistic, achievable target value. If goals are set to high and unattainable stricter changes to the processes will have to be executed. If the goals are set to low fewer changes in the processes will occur.

2.4.2.10 Inputs

The inputs describe influences and sources to the system of KPIs. The represented inputs are the “Company goals” and the “Catalogue of KPIs” in this model.

2.4.2.11 Company Goals

The company goals include the aforementioned strategy and vision. Strategic goals define the organisations processes and therefore have a major impact on the KPI system. This also implies the need for organisational change and improvement. Managers establish targets to communicate this need more effectively with a span of three to five years. The goals should represent a discontinuity in the performance of the business unit and achieve a transformation in the company.[108]

The introduction of a Balanced Scorecard provides acceptance for aggressive targets since it links related measures to achieve outstanding performance. It does not just improve performance in isolated measures which is the problem with most other stretch-targeting systems like best-in-class benchmarking. These methods make an effort to define the process performance of other organisations as target of their own performance and develop a program to achieve this performance. Benchmarking might not always achieve this target due to its isolated process reorganisation.[109]

2.4.2.12 Catalogue of KPIs

This catalogue is an information source for the KPI system. Literature has lots of basic and more sophisticated KPIs to offer. The catalogue should bundle the literature sources for the KPIs and offer a simple directory with some basic information. Helpful for pre-selection is an attribution of the entered KPIs to different departments of the company. With this attribution comes the need for a unique identification of the KPI with adequate codes to make retrieval easier.[110]

The catalogue should also document a short explanation and the calculation method used for the KPIs. The explanation helps with the pre-selection as the name of the KPI might not be significant and self-explanatory enough. A few words of explanation on the meaning and use of the KPIs are sufficient. The calculation method should leave no room for misunderstanding and misinterpretation of the KPI. It also should explain which kind of data is needed to calculate the information and give a clue on what kind of unit the value of the KPI is expressed in. The latter matters for the display format the most.

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[108] KAPLAN, R.S.; NORTON, D.P. (1996), pp. 226 f.

[109] KAPLAN, R.S.; NORTON, D.P. (1996), p. 227

[110] Cf. Siemens BG QM (2011a)

Standard-KPIs could be used to create more adapted KPIs for more specific information on processes. This allows adjusting the system to reflect more on the actual processes and the data gathered by the sensors. See also chapter 2.1.3.4. The utilisation of the catalogue is described in chapter 3.2.1.

2.4.2.13 Outputs

The outputs are defined by the results of the two cycles. The “System of KPIs” can be considered an output of the planning phases of both cycles. Further outputs are “Depiction of relations between KPIs” and more importantly “Documentation”.

2.4.2.14 Depiction of relations between KPIs

If there are relations between KPIs those should be expressed for better understanding of the interdependencies of the system. Relations between KPIs can be classified in logical, empirical and hierarchical relations.

Logical relations are either definitional or mathematical. Definitional type means KPIs relating to each other by conceptual delimitation. Mathematical relations form at the application of mathematical rules for transformation.[111]

Conditions of reality form empirical relations. General relations are decisive for KPI systems to describe mostly universally valid connections. The existence of such relations is claimed in hypotheses or theoretical claims; they have to be validated in reality. When they are proven empirically, their existence can be approved. Empirical relations can be further classified into deterministic and stochastic relations.[112]

Hierarchical relations originate in rankings of KPIs. They are an important basis for the creation of hierarchically structured KPI systems. Those relations can be distinguished between factually hierarchical and subjectively evaluating relations. The first classification refers to factually caused rankings between facts based upon conditions of reality.[113]

2.4.2.15 Documentation

One of the most important requirements of the standards mentioned in chapter 2.3 is documentation of everything the organisation concerning. It had proven very useful to document the progress in detail during the development of the KPI system. This helps with the review of decisions, correction of flaws and presentation of results to co-workers.

To be more precise, the system of KPIs has to be documented for the duration of the process data sampling and interpretation. The selection has to be documented for review purposes and comparison in the system assessment after evaluation period. The KPI description in itself is documentation. The system assessment has to document the analysis of strengths and weaknesses of the system.

[111] Cf. KÜPPER, H. (2005), 361 f.

[112] ibidem

[113] ibidem

At the system evaluation the comparison between set and actual value needs documentation with an according analysis of the deviations. The process reorganisation needs to be documented with all the initiatives and measures to be implemented and executed for further feedback. The goal specification is the next step for the process reorganisation and the documentation is necessary for the following evaluation period.

3 Development of a KPI system

This main chapter’s purpose is to introduce the reader to the application of the acquired theoretical knowledge on quality and KPIs of the previous chapters on the development of a KPI system for quality assurance. It starts by a description of the type of processes implemented in the production of bogies and wheel sets and the requirements they have on KPIs. The second sub-chapter deals with the selection of theoretically optimal KPIs for a measurement system for these processes. The selected KPIs are described and attributed to the processes in the third chapter.

3.1 Description of processes and requirements

In the following sub-chapters the processes of the scope of analysis are described by interpreting the internal process documentation of the ARIS and the data measurement systems. The description includes the types of processes used for the incoming goods inspection, the jig construction, the frame construction, the machining and frame measurement, the surface treatment, the wheel set montage, the montage and final inspection, the shipping processes and the customer complaint management.

In the end of this chapter the requirements for the KPIs are presented as they have been deduced in the progress of the thesis.

3.1.1 Types of utilised processes

The production processes of Siemens BG Graz are set up for the manufacturing sequence for bogies and wheel sets. The sequences have been introduced in chapter 1.4. It is necessary to have different types of work-steps for the production. These different types of work require varying measurements because some assigned KPIs might not be applicable for other process-steps. It is important to know how the processes are aligned and how they function.

The basic measurement of process parameters with KPIs has already been introduced in chapter 2.1.3.4. The measurement positions and sensors of the process parameters are displayed in Figure 17. The performance of a process can either be assessed by the direct measurement of the process (B) or a characteristic of the output (C). A measurement of the input (A) can detect deficiencies that would decrease the process performance or cause poor quality in the output. Requirements for these measurements have been introduced with the standards for quality management in chapter 2.3.

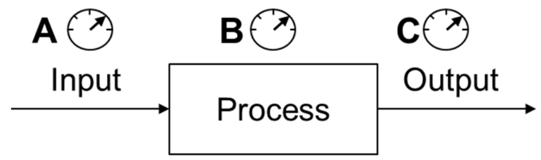

Figure 17: Measurement of processes[114]

The following explanations will present a description of the types of processes introduced in chapter 1.4.

The input of the production process is controlled with the incoming goods inspection. Each delivered good is inspected with the utilisation of specific inspection instructions. The components are either approved or restricted before being used in the production process.

Processes and process-steps can be differentiated by the amount of automation utilised for the manufacturing. Quality of highly automated processes is usually depending on the utilised machines and tools. The influences on the quality in these processes are well known and adjustable so that the quality output can be easier controlled. Some processes and process-steps would allow the ideal opportunity for the application of Statistical Process Control mechanisms.

SPCs purpose is the finding and elimination of as many sources of variations of results as possible. There are often many various causes of these variations in each situation. It can be difficult to identify the contribution of the individual causes. Causes are either assignable, when they contribute an identifiable amount of variation, or they are common, when they contribute to the general noise in variations.[115] The machining and frame measurement afterwards is a highly automated process with programmable, automatic manufacturing and measurement equipment that would fit in such a process category.

The quality is depending on the qualifications and working environment of the human workforce in processes with high share of manual work. Human error is an influence to be managed by means of education and training. The inspection of the product quality characteristics is done by specific inspection methods. The methods are applied with an inspection plan for each type of product. Those inspection plans are developed with the product and its requirements on quality by the engineering department. A good example for such processes is the frame construction.

The frames are the main component of a bogie and they are welded either manually or with the use of automatic, programmable robots. The welding seams have high requirements on the quality of the material as their position might be in zones of mechanical strain and stress. Another example is the surface treatment. The frames and other components are painted in this process. The painting requires qualified personnel to achieve the required product quality. The inspections are done manually.

[114] Cf. SEGHEZZI, H.D. (1996), p. 32

[115] BERGMAN, B.; KLEFSJÖ, B. (1994), p. 179

All assembly processes are highly dependent on the product quality of the input material and the qualifications of the assemblers. Sub-components and single parts are assembled and inspected after completion. These processes require the strict adherence to product quality requirements in the preceding processes in order to achieve good quality output themselves. The value-adding effect in production processes also increases the value of an error, meaning the repair of poor quality will cost more in processes at the end of the manufacturing sequence. Time for error correction will delay the delivery of a bogie to the customer. In this category are included all wheel set assembly sub-processes and the assembly and final inspection. After an approved final inspection the bogies are shipped to the customers.

The construction of jigs is another process to be considered different from the aforementioned. It is a process which has the goal to construct tools for the following processes. The quality of the tools definitely affects the quality of the products which means that the jigs have to be inspected on all possibilities for error occurrence. A product-FMEA as introduced in chapter 2.2.2.3 helps with the introduction of specifically assigned inspection methods as each jig is different and has different requirements on dimensional accuracy and material conditions.

In the scope of analysis included is the management of customer complaints. Those complaints are the feedback of customers on poor quality output of the production. Complaints can have very different reasons and need to be analysed for appropriate repair and process improvement to eradicate the causes of the errors. A company has to have processes for the management of customer complaints at the ready as is required by quality management standards. See chapter 2.3.3 for further information.

The quality measurement and analysis in the processes is explained in chapter 4.

3.1.2 Requirements for KPIs

An important requirement for KPIs in this thesis is the process orientation. The described types of processes in the previous chapter need effective control. Actual data measurement is highly effective and offers a lot of process feedback as can be seen in chapter 4. KPIs have to utilise this data purposefully and transform it into information later to be applied for process control. Deviations in process performance from the set goals should be compensated with initiatives directed with the information. Short-term initiatives are outcome of the quality control function and the long-term initiatives are the outcome of the quality improvement function, both introduced in chapter 2.1.2.

Many of the KPIs will change their output after an evaluation period which leads to the possibility for trend analyses. The weakness of these trend analyses however lies in dependence on other reference indicators in the production. The creation of specified quotas and ratios is not the optimal solution for this problem. A parallel review of a performance indicator of the production, like the sum of productive hours, and the preferred quality KPI is more adequate.

The comparison of the number of quality reports to the number of bogies produced in a certain time period is a good example to show the effect of the trend analysis and comparison of a KPI to a reference indicator. If the number of quality reports is stable in an evaluation period, it will be regarded in a positive way when the number of bogies produced is increasing in the same period. This comparison makes it obvious that reference indicators are useful or even necessary for some KPIs, mainly ones with absolute values.

Another important thing to note is the right selection of the evaluation period. A KPI always analyses one or more process features and these have to be checked in regular intervals according to the sensitivity for disturbances and process stability. Some KPIs also require a certain amount of time to acquire enough data for meaningful evaluations. The effort for the calculation of a KPI is also a criterion for the evaluation period.

Just a handful of the most necessary and therefore optimal KPIs should remain to guarantee a transparent system at the end of the selection process. That was a goal of this thesis.

3.2 Selection of KPIs with evaluations

The selection of KPIs follows the assessment cycle introduced in chapter 2.4.2.2. The principal sequence of process steps is shown in Figure 18. It starts with a pre-selection of the KPIs in the catalogue, then goes on to the selection with evaluation in different important criteria. Afterwards, the selected KPIs are fully described and finally introduced to the KPI system. The following sub-chapters will explain the process in more detail.

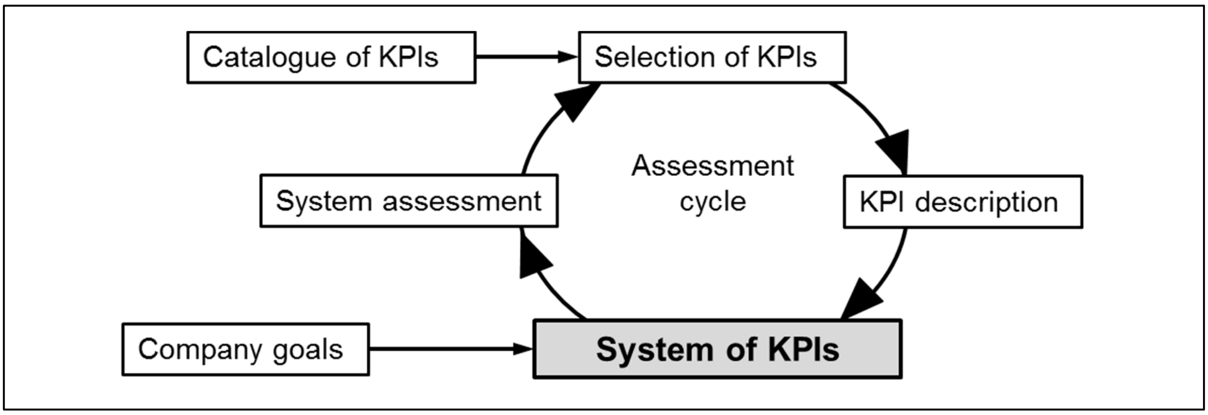

Figure 18: Assessment cycle for KPI selection

3.2.1 Pre-selection of KPIs

Relevant KPIs are extracted from a source with the pre-selection. In this case a catalogue of many KPIs supplied by Siemens QM department serves as the source.[116] The KPIs in this catalogue are assigned to different industrial departments. Many performance indicators are assigned to more than one department.

Available departments:

- Procurement
- Controlling and Finances
- Research & Development, Engineering
- Maintenance
- Logistics, Warehousing
- Human resources management
- Production, Manufacturing
- Process management
- Quality management
- Sales, Customer service, Marketing

A short description and formula or calculation method is implemented for almost all of the KPIs in the catalogue. For further information see chapter 2.4.2.12.

[116] Cf. Siemens BG QM (2011a)

The pre-selection is defined by the relevance of the KPI for the assignment to a process or the system. The description of the indicator is compared to this assignment. The outcome is a simple yes or no decision. Performance indicators that are quality related have a much higher relevance than others for a KPI system for quality assurance purposes. For instance, KPIs from human resources management were not at all relevant for product and process quality topics in production. KPIs that are attributed to the departments Production and Quality management in the previous list have the highest relevance. KPIs from the Procurement department can be used for the measurement of the incoming goods inspection. KPIs of the Controlling department are mostly concerned with costs. Some of those are quality related and therefore more relevant.

The next step was the assignment to processes, when the relevance of the performance indicator was evaluated positively. The ability of a KPI to be used for the control of one or more process features is essential for its attribution to the process. As an example, KPIs of the procurement department are more appropriate for the process incoming goods inspection than KPIs of the maintenance department.

When there are a sufficient number of performance indicators for every process these KPIs will be introduced to an evaluation matrix and a more detailed selection procedure is performed. Sufficient means in this case that all necessary information of the process will be gathered by the KPIs.

3.2.2 Numeration of the KPIs

A numeration with reference to the source is performed to make retracing and attribution of the KPI as easy as possible.

3.2.2.1 Catalogue number for reference to source

The first number of the KPI relates to the source in the catalogue. This number is a composition of an abbreviation for the department, which the performance indicator is assigned with, shown in Table 7, and a continuing number, which is attributed to the alphabetical arrangement of the KPIs. The abbreviations in Table 7 are for the German translations of the departments. Have a look at the list of abbreviations at the end of this thesis for the exact meaning of the words.

Procurement	B
Controlling and Finances	C
Research & Development, Engineering	F&E
Maintenance	IH
Logistics, Warehousing	L
Human resources management	Pers
Production, Manufacturing	P
Process management	PM
Quality management	QM
Sales, Customer service, Marketing	V

Table 7: Abbreviations of the departments for the catalogue number[117]

If some of the KPIs are associated to more than just one department, the respective numbers would be inscribed together and separated by a slash “/”. This will enable a direct allocation inside the catalogue.

3.2.2.2 KPI number for process assignment

The second number of the KPIs relates to the assigned processes. This one is also composed of an abbreviation for the respective process and a continuing number attributed to the alphabetic order in the evaluation matrix.

General assignment applies to KPIs that cannot be assigned to a process directly and are either assigned to the production process in general or they can only be assigned to process steps or machines.

Both numbers are documented in their respective columns in the evaluation matrix and serve as cross references. They are copied to the different documents later-on to help with retracing them to their sources.

[117] Siemens BG QM (2011a)

3.2.3 Evaluation of KPIs with criteria

The following sub-chapters describe the utilisation of the selection phase introduced in chapter 2.4.2.3. A detailed analysis of every performance indicator is performed in the evaluation of the KPIs with the goal to filter the most optimal of them. The most optimal KPIs are used to have not an unnecessary number of KPIs and consequential unjustifiable efforts. Eight different criteria of a KPI are evaluated for this purpose with the expected result of a few remaining KPIs with preferred capabilities.

There are two basic features for KPIs that have to be fulfilled to a certain degree. The first feature to be analysed is the process assignment. A performance indicator that is not really able to be assigned to a process is not recommended for further utilisation. The second feature is the evaluation of the system integratability. The KPI in question should be able to integrate into a system of other existing KPIs.

Both features, the process assignment and system integratability, have subordinate criteria for which the actual evaluation commences with the awarding of points. The criteria have been introduced as requirements in chapter 2.4.2.3. It is important to achieve the highest possible objectivity for the evaluation and to award the criteria with points to the best of one’s knowledge. The documentation of each evaluation in the criteria can support the decision and enable an easier retracing.

3.2.3.1 Criteria of process assignment

The criteria of process assignment are

- Comprehensibility,
- Efficiency
- and Compatibility.

An accumulation of the results of the evaluation of every criterion produce the effectiveness of the KPI. The effective assignment of a performance indicator to the respective process is expressed quantitatively with this result.

The evaluation is strongly focused on the process and disregards the integratability of the KPI into the system.

3.2.3.2 Criteria of system integratability

The criteria of system integratability are

- Integrity,
- Clarity,
- Relations,
- Goal orientation
- and Participation.

The criterion Relations stands for the requirement of multicausality. An accumulation of the results of the evaluation of every criterion produce the integratability of the KPI. The ability of a KPI to be integrated into a newly to create or actually established KPI system is expressed quantitatively with the integratability.

The evaluation is focused on the KPI directly and doesn't regard details of the assigned processes.

3.2.3.3 Selection of the preferred KPIs

The accumulation of effectiveness and the integratability is performed at the end of the evaluation. Some of the evaluated performance indicators have a greater difference to the most preferred KPIs and so they will fall out of further review. If the pre-selection was done well with hindsight to the fulfilment of the purpose of the KPI system, many of the relevant KPIs will stand at the top positions.

The final goal is to have a limited number of key performance indicators for the system to be created or improved. A boundary value is applied to use the quantified results of the evaluations. The sum of the evaluations has to at least be equal to this boundary value or better exceed it to achieve an advantage in the selection. The number of KPIs that the system should later integrate is the decisive factor for the boundary value. If this value is close to the highest achievable sum of the evaluations just a few of the performance indicators achieve the advantage. These KPIs are the most optimal.

Special case:

It might happen that some KPIs would have a high rating in process assignment, however they lack system integratability. This can happen, when the process manager has a special interest in the implementation of a specific KPI, even though it should not be integrated into the system for reasons of the definition or the purpose of the system. In this case the selection with the boundary value is ignored and the effectiveness as result of the ability for process assignment is the main decision value for selection.

The supportive function of the evaluation with the criteria becomes obvious in this case. That means a closer review of the properties of a performance indicator might be helping, yet at the final selection always a subjective decision of the responsible managers determines the application of the KPI.

Subsequently to the evaluation phase the selected KPIs will be fully described and presented to the decision committee. The committee consists of the process owner and manager and employees of the quality assurance or quality management department. The committee has the final word on the application of the KPIs.

3.2.3.4 Integrity

It refers mainly to the necessity for the system of the performance indicator to be evaluated as criterion of the system integratability. A fundamental characteristic of the system is the complete description of the process features with all necessary KPIs. Standards and company guidelines are very important for this criterion, as they prescribe the data to be gathered and the information to be extracted. The quality standards mentioned in chapter 2.3

need to be considered for an evaluation with this criterion. Table 8 shows the rating of the KPI in the evaluation matrix for this criterion.

Ultimate goal of the criterion for the system:

Global and complete coverage of all necessary process parameters with key performance indicators

Points	Cause for rating
1	Performance indicator is not necessary and has no additional use
2	Performance indicator is not necessary, but at least has additional use
3	Performance indicator is necessary according to standards, possibly has additional use

Table 8: Rating with points for Integrity

Additional use offers a not really necessary addition to the system with further information helpful in the decision finding.

3.2.3.5 Clarity

A systematic, transparent and consistent structure with an easy ascertainable number of KPIs is required for the system. The integration of another KPI should support this requirement as best as possible. Accordingly this criterion of the system integratability refers to the clear arrangement of the system. This means in other words, when the evaluated KPI offers the same information according to its definition than another performance indicator and is able to control other process features as well, this superior KPI receives an advantage with more awarded points. Table 9 shows the rating of the KPI in the evaluation matrix for this criterion.

Ultimate goal of the criterion for the system:

Smallest possible number of KPIs in transparent structure and least complexity for information gathering on the most important features

Points	Cause for rating
1	Performance indicator has no use in the system and raises complexity level
2	Performance indicator offers beneficial information, yet it can be replaced by another KPI
3	Performance indicator offers more beneficial information and can replace other KPIs

Table 9: Rating with points for Clarity

3.2.3.6 Relations

The quality and quantity of connections and relations between the KPIs is evaluated with this criterion of the system integratability. Hierarchical, empirical and logical relations of the performance indicators are therefore important for the analysis. The better these relations are identified, the better consequences of changes in the system can be predicted. Table 10 shows the rating of the KPI in the evaluation matrix for this criterion.

Ultimate goal of the criterion for the system:

All KPIs are connected or related and the type of relation is completely identified.

Points	Cause for rating
1	Performance indicator is isolated and has no relations to other KPIs
2	Performance indicator has some minor relations to other KPIs or these relations are hard to identify
3	Performance indicator is strongly related to other KPIs

Table 10: Rating with points for Relations

A high rating in this criterion could give some clue to a possibly existing redundancy of the KPI. This is to be analysed.

3.2.3.7 Goal orientation

This criterion of the system integratability selects the strategic company goals and strategies as foundation for the evaluation. Goals set by department or for specific processes are also to be considered. These goals are the framework for every system and each of the performance indicators to be evaluated. A consideration of guidelines and strategies for this criterion is recommended. Table 11 shows the rating of the KPI in the evaluation matrix for this criterion.

Ultimate goal of the criterion for the system:

Company goals and strategies are being transformed to KPIs and the system supports the completion of the goals.

Points	Cause for rating
1	Application of the performance indicator cannot be justified
2	Application of the performance indicator is conditionally justified
3	Application of the performance indicator is fully justified

Table 11: Rating with points for Goal orientation

Exclusion of the criterion:

This criterion was excluded for the evaluation of the performance indicators with this system. This is due to the fact that Siemens BG Graz has not set any distinctive specification for the KPI system, neither clearly specified is the gathering of information with the KPIs. It was agreed that the application of each performance indicator is basically justified for the optimisation of the KPI system. This was also due to the task assignment of finding KPIs in the related literature without any kind of obstacles.

3.2.3.8 Participation

Responsible managers give a subjective evaluation for the application of the KPI in the system in this criterion of the system integratability. Table 12 shows the rating of the KPI in the evaluation matrix for this criterion.

Points	Cause for rating
1	Worst possible rating
3	Best possible rating

Table 12: Rating with points for Participation

This criterion is to be differentiated with the criterion comprehensibility mentioned in chapter 3.2.3.12, because the latter evaluates the process assignment of the KPI objectively. The KPI to be evaluated can get an advantage with the participation of the responsible managers.

Exclusion of the criterion:

Purpose of the thesis was to create recommendations for the optimisation of a KPI system. The subjective decision of a committee on the application and optimisation of a KPI system could not have been waited for.

3.2.3.9 Recommendation for the evaluation of system integratability

It is recommended to document the evaluation of the previously described criteria in one file to check upon the rating later when questioned. It is better to create one file per KPI and add a full description to it. The relations can be analysed and evaluated best with a graphical depiction of the relations in the system. Every KPI is entered for this into one interface and the relation is made apparent by adding connecting arrows like the images in Appendix 1. For example, the data of one KPI is used in another KPI which marks a direct, logical connection.

3.2.3.10 Compatibility

This criterion of process assignment evaluates the utilisation of existing data gathering systems for the calculation of the performance indicator. The necessary data for the evaluated KPI are compared to the actually gathered data of the process for the evaluation. If these lists are mostly in accord with each other, the rating will be higher. Table 13 shows the rating of the KPI in the evaluation matrix for this criterion.

Points	Cause for rating
1	Data gathering has to be newly designed
2	Data is gathered in many areas and has to be extracted from different sources
3	Data for calculation can be acquired directly from one source

Table 13: Rating with points for Compatibility

3.2.3.11 Efficiency

This criterion of process assignment evaluates the effort in comparison to the benefit of the performance indicator. The main focus for evaluation lies on the effort. This is due to the fact that at the pre-selection the performance indicators with the fitting benefits were deemed relevant. Not useful performance indicators drop out at pre-selection.

To regard are following different efforts:

- Compilation effort
- Calculation effort
- Assessment effort

When the compilation effort of the KPI is not known in the evaluation phase, proper estimates have to be performed. It is necessary for an estimate to regard the definition of the performance indicator, the process and the data gathering. Table 14 shows the rating of the KPI in the evaluation matrix for this criterion.

Points	Cause for rating
1	Effort is not justified
2	Effort is high, yet justified
3	Effort is low, so the utilisation is strongly recommended

Table 14: Rating with points for Efficiency

3.2.3.12 Comprehensibility

This criterion of process assignment is important in reference to the comprehension of the benefit and the utilisation of the performance indicator to be evaluated by every employee related to the process or the data evaluation, for instance process owners and quality employees. A rating of this criterion can only be performed in discussion with those employees. Table 15 shows the rating of the KPI in the evaluation matrix for this criterion.

Points	Cause for rating
1	Application of KPI is not comprehensible
2	Application of KPI is partly understandable
3	Application of KPI is totally understandable

Table 15: Rating with points for Comprehensibility

3.2.3.13 Recommendation for evaluation of process assignment

The evaluation of the previously described criteria should be documented for each process individually, meaning there has to be one document per process. In this document every KPI assigned to the process is included. KPIs that are assigned to more than just one process should have their own documentation when it comes to the evaluation of comprehensibility. This reduces the overall effort for documentation a little.

The documentation of the ratings can be linked with hyperlinks in the Excel-file of the evaluation matrix to enable faster access.

3.2.3.14 Exemplary evaluation of preferred KPI: Number of quality reports

This KPI describes the accumulated number all quality reports for the evaluation period in a specified process.[118]

This evaluation is done for the assignment to the process Assembly and Final inspection. Table 16 shows the evaluation of this KPI. The ratings are explained in the following text.

Integratability		
	Integrity	3
	Clarity	3
	Relations	3
	Sum = Integrity + Clarity + Relations	9
Effectiveness		
	Compatibility	3
	Efficiency	3
	Comprehensibility	3
	Sum = Compatibility + Efficiency + Comprehensibility	9
Evaluation sum = Effectiveness + Integratability		18

Table 16: Exemplary evaluation of Number of quality reports

This KPI is highly suitable to evaluate the process with simple methods on its qualitative output. An investigation is recommended if not necessary, making 3 points for integrity.

This simple KPI can potentially replace many other KPIs, because it describes the number of problems with quality in a process. It offers advantages to the clear arrangement of the system. More detailed information are offered by other performance indicators, however this is not important for the rating in the criterion clarity, making it 3 points.

This KPI has a connection to Non-conformance costs as its data source with the documentation of error correction costs. Directly related is the Number of customer complaints, they are a special form of quality reports. The quality reports are also a data source for the Duration of error correction. The strong connections make evaluation with 3 points possible in the criterion relations.

This means for integratability a result of 9 from 9 points.

[118] Cf. Siemens BG QM (2011a)

Quality reports for the process Assembly and Final inspection are documented in SAP systems. This means the necessary data is already available and makes 3 points for the criterion compatibility.

The calculation of this KPI is rather effortless, merely the accumulation of the documented quality reports in SAP. The option to limit the calculation for a specific time period is available as well which makes 3 points for efficiency.

The entry of the Number of quality reports supplies the responsible managers with interesting information and overview to existing complications with the process quality. This makes the application understandable and makes for 3 points for comprehensibility.

This means for effectiveness a result of 9 from 9 points. The sum of integratability and effectiveness results in a sum of 18 from 18 points for the evaluation. The application of the KPI for this process is highly recommended.

3.2.3.15 Exemplary evaluation of rejected KPI: Costs for repeated inspection

This KPI is a monetary assessment of the expenditures for repeated inspection of products. They are a part of the Non-conformance costs and are related to Error detection costs. This type of costs only applies to products that have been repaired.[119]

This evaluation is done for the assignment to the process Frame construction. Table 16 shows the evaluation of this KPI. The ratings are explained in the following text.

Integratability		
	Integrity	3
	Clarity	2
	Relations	2
	Sum = Integrity + Clarity + Relations	7
Effectiveness		
	Compatibility	2
	Efficiency	2
	Comprehensibility	2
	Sum = Compatibility + Efficiency + Comprehensibility	6
Evaluation sum = Effectiveness + Integratability		13

Table 17: Exemplary evaluation of Costs for repeated inspection

[119] Cf. Siemens BG QM (2011a)

A recording of these costs is necessary for the production according to the Non-conformance costs-guideline of Siemens BG Graz which makes it 3 points for integrity.

The KPI supplies the reporter with an overview to a small part of the error correction costs. However this information raises the complexity level, because these costs are included in the Non-conformance costs. It makes only 2 points for the criterion clarity.

These costs are part of the error correction costs and therefore Non-conformance costs. There is just one strong hierarchical and a weak empirical connection which has been awarded 2 points for criterion relations.

This means for integratability a result of 7 from 9 points.

The costs for rework and adherent to that the costs for repeated inspection of repaired products are documented according to the Non-conformance costs-guideline, however a detailed documentation is not always available which makes only 2 points for compatibility.

Costs are always more difficult to compile than other performance parameters like time. The benefit of having the costs for repeated inspection extracted is not fully justified and this is awarded with 2 points for the criterion efficiency.

The application of the KPI is not really reasonable. The only application possible is for the repeated inspection of repaired, important welding seams, when the costs in this process step are increasing. That makes for 2 points in comprehensibility.

The evaluations in these criteria accumulate to a result for effectiveness of 6 from 9 points. The sum of integratability and effectiveness results in a sum of 13 from 18 points for the evaluation. The application of the KPI for the frame construction is not recommended.

3.2.3.16 Graphical depiction of evaluation

The evaluations of both examples have been included into a spider's web diagram to display the apparent difference. Figure 19 displays the diagram. The six axles of the diagram are the aforementioned criteria. For all criteria would have been maximum 3 points achievable. The KPI Number of quality reports succeeded in the fulfilment of all criteria to the maximum and is therefore highly recommended for integration into of the KPI system for quality assurance. The KPI Repeated inspection costs had a significantly lower evaluation sum which can be seen in the diagram as well. It is therefore not recommended for the integration in the KPI system for quality assurance.

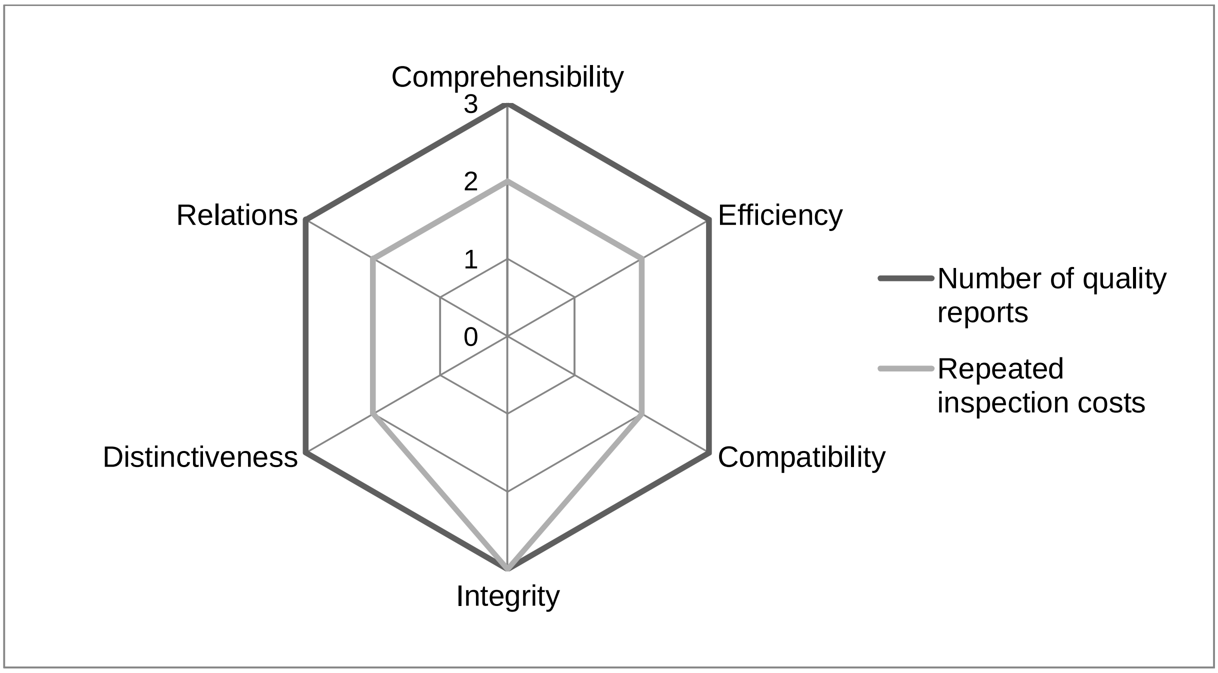

Figure 19: Graphical illustration of exemplary evaluation

3.2.4 Conclusion of the evaluation phase

The KPI catalogue had a broad amount of KPIs for every necessity of control parameters in industrial and other organisations. The pre-selection phase has deemed 31 different KPIs as relevant for a KPI system for quality assurance purposes. The two examples were included in those.

After the assignment of the KPIs to the processes a total of 147 KPIs have been introduced in the evaluation matrix. This matrix is an MS Excel-file and includes columns for the number of each KPI for the retracing of its source and process assignment, the name of the KPI and columns for the criteria and the accumulation of the points similar to the before mentioned example. The integration of the hyperlinks to the documentation allows for fast access of said files. An explanation for the evaluation with points and the meaning of abbreviations in the matrix has been included into the headline of the matrix.

9 different processes have been assigned with the KPIs making an average of 16.3 KPIs per process. This number is too high and so the selection with the evaluation criteria had its purpose. 31 of the total 147 KPIs have been selected because they achieved a higher

evaluation sum than the boundary value or their strong ability for process assignment made them preferable. See chapter 3.2.3.3 for further information on the selection. In the end 3.4 KPIs remained in average per process. Just 12 different types of KPIs have been selected and are described in the next chapter. Figure 20 displays the statistics with a column diagram.

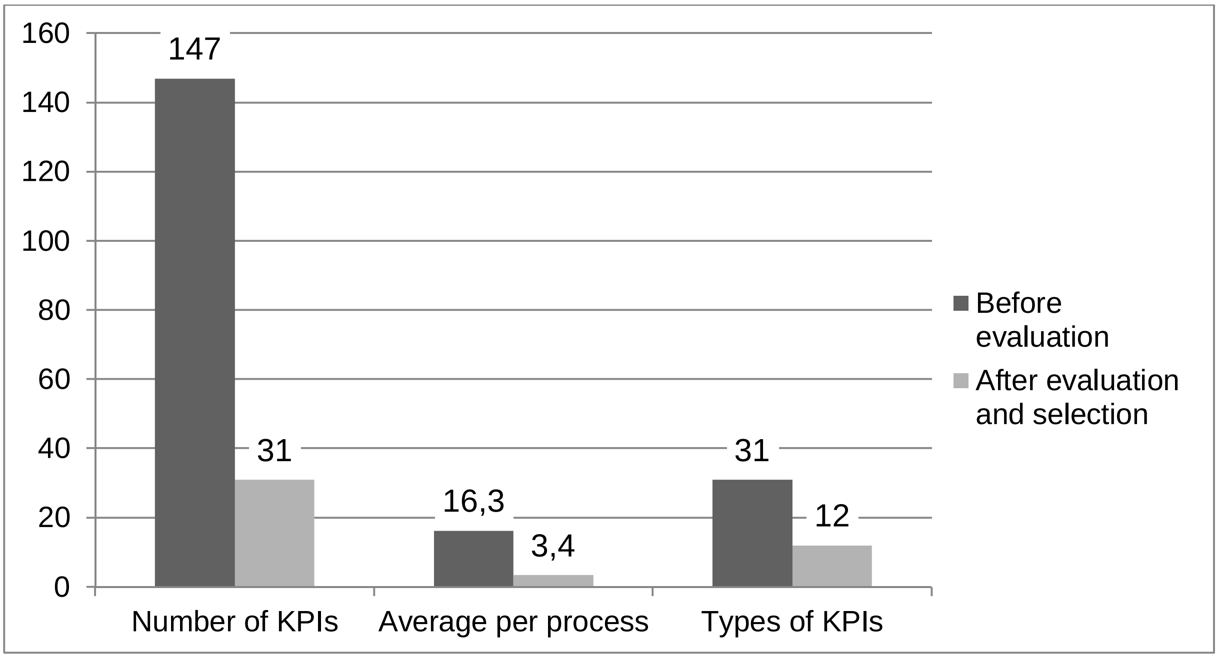

Figure 20: Statistics on the evaluation phase

The specifically developed reference indicators and indicators for additional information are not included in this statistic.

3.3 Description of selected KPIs

All selected KPIs are described with the necessary details in the following sub-chapters. The parts of the description are taken from the list introduced in chapter 2.4.2.4. Some KPIs are assigned to more than one process. However, there are some slight differences on how they are implemented in the processes and which data they collect. The KPIs are differentiated by their source. KPIs for quality assurance have been taken from the KPI catalogue and have been evaluated as has been explained in chapter 3.2. Reference indicators and indicators for additional information have been created specifically for this thesis and have not been evaluated due to their significance for the system. See chapter 3.1.2 for further information.

3.3.1 KPIs for quality assurance

The selected KPIs for quality assurance purposes have been pre-selected from the catalogue of KPIs and assigned to different processes. Some have been adapted for specified use in the processes however all of them stay true to their basic definitions. They will be explained in the following sub-chapters.

3.3.1.1 Share of defective products

This KPI measures the share of defective wheel sets or bogies in all produced. Defective products have to be repaired or scrapped.[120] Table 18 shows the detailed description of the KPI.

Formulae:	
	$$\frac{Number\ of\ defective\ wheel\ sets}{Number\ of\ produced\ wheel\ sets} * 100\% \quad (1)$$ $$\frac{Number\ of\ defective\ bogies}{Number\ of\ produced\ bogies} * 100\% \quad (2)$$
Unit:	%
Evaluation period:	Month/Quarter
Data source:	Quality reports
Display format:	Signal light diagram / Line or Bar chart

Table 18: Description of Share of defective products

This KPI makes it possible to review the defective output of the wheel set and bogie assembly over a long period. This includes every bogie and wheel set that caused an error report during manufacturing.

[120] Cf. OSSOLA-HARING, C. (2006), p. 318

It could also be recommended to use the “Share of non-defective bogies/wheel sets” as counterpart to this KPI, because it has a more positive connotation to it, which would be comparable to the “Zero-defect-bogie”. See chapter 4.1.3.1 for information on this KPI.

3.3.1.2 Number of errors per product

This KPI allows the documentation of the numbers of errors detected during the non-destructive testing per frame or wheel set. A differentiation between the varying test methods is also possible.[121] See 4.1.5.2 for further information. Table 19 shows the detailed description of the KPI.

Formulae:	
$$\frac{Number\ of\ detected\ errors(per\ test\ method)}{Number\ of\ tested\ wheel\ sets} \quad (3)$$ $$\frac{Number\ of\ detected\ errors(per\ test\ method)}{Number\ of\ tested\ frames} \quad (4)$$	
Unit:	Errors/Frame; Errors/Wheel set
Evaluation period:	Month/Quarter
Data source:	Database for QM
Display format:	Line or Bar chart

Table 19: Description of Number of errors per product

This KPI controls the proneness to errors of frames and wheel sets during manufacturing. It is also suited for the application to control specific process steps and/or machines, to check the process capability of these. Differentiation of the inspection methods allows for comparison if the methods with less effort have the same rate of error detection than methods with more effort and random sampling testing.

[121] Cf. Siemens BG QM (2011a)

3.3.1.3 Number of quality reports

This KPI describes the accumulated number all quality reports for the evaluation period in a specified process.[122] Table 20 shows the detailed description of the KPI.

Calculation:	Accumulation of every quality report for the department
Unit:	Number
Evaluation period:	Month/Quarter
Data source:	SAP
Display format:	Line or Bar chart

Table 20: Description of Number of quality reports

A quality report is the complaint about a defective quality feature of a product. A distinction is made about errors caused by external suppliers or errors caused by internal departments.

This KPI enables for a good overview on the occurred complications in a process and the handling of these complications. A quality report is also a comprehensive documentation of a complaint and provides data for more detailed analyses.

3.3.1.4 Duration for error correction

The duration documents the time period between the detection of an error and preparation of a quality report till its completion and conclusion. Either average values or an accumulation of the time should be used for this KPI.[123] Table 21 shows the detailed description of the KPI.

Calculation:	Accumulation of time spans between preparation and conclusion of a quality report
Formulae:	
	$$\frac{Sum\ of\ the\ durations\ for\ error\ correction}{Number\ of\ quality\ reports} \quad (5)$$
Unit:	Hours/Days
Evaluation period:	Month/Quarter
Data source:	Quality reports
Display format:	Line or Bar chart

Table 21: Description of Duration for error correction

[122] Cf. Siemens BG QM (2011a)

[123] Cf. Siemens BG QM (2011a)

The time duration for error correction and its documentation with the quality reports is especially interesting for the control of measures to improve the quality at the supplier or the internal processes. The necessary time for repair delays delivery dates and has an influence on the planning of capacities.

The duration of error correction in case of customer complaints is also measured with this KPI. A measurement is absolutely required to analyse the reaction time for customer complaints.

It is recommended to analyse the trend development of this KPI in more detail. The calculation of the first derivation/gradient of an approximated function on the trend allows for conclusions regarding the impact of improvement initiatives in the processes. A negative gradient would be connected to an improvement.

3.3.1.5 Non-conformance costs

This KPI accumulates all occurring costs that are related to lacking quality, e.g. error correction.[124] Look in chapter 2.2.3 for further information. Or look in chapter 4.1.4 for more specific explanations for the production process. Table 22 shows the detailed description of the KPI.

Calculation:	Accumulation of costs of non-conforming quality
Unit:	EUR
Evaluation period:	Month/Quarter
Data source:	Quality reports; Complaints
Display format:	Line or Bar chart

Table 22: Description of Non-conformance costs

A compilation of the Non-conformance costs offers a good overview on the expenditures with defective products and processes, as these costs are documented in complaints and quality reports. Costs should always be regarded by the management. This has been shown in chapter 2.4.2.1.

[124] http://www.qfinance.com/ (23.04.2012)

3.3.1.6 Process Capability

The process capability is the ability of a process to achieve the set goals. The arithmetical mean of measured values μ, the upper and lower tolerance limit UTL or LTL and the standard deviation σ are required data for the calculation. Calculated are two different process capability indices.[125] Table 23 shows the detailed description of the KPI.

Calculation:	The C_{pk}-value is defined as the smallest distance between the arithmetic mean and the tolerance limits divided by three times the standard deviation. The C_p-value is the distance between the tolerance limits divided by six times the standard deviation.
Formulae:	
	$$Cpk = \frac{min(\mu - LTL; UTL - \mu)}{3\sigma} \quad (6)$$ $$Cp = \frac{UTL - LTL}{6\sigma} \quad (7)$$
Unit:	-
Target values:[126]	The C_{pK}-value has to be at least 1.33 to guarantee process stability that equals 4 standard deviations distance between mean value and tolerance limits. In the Six Sigma concept the C_p-value is required to be 2.00, equaling a width of the tolerance field of ± 6 standard deviations. The C_{pK}-value is required for Six Sigma to be 1.5, equaling a distance of at least 4.5 standard deviations between mean value and tolerance limits.
Evaluation period:	Day/Week/Month/Quarter
Data source:	Measurement protocols
Display format:	Signal light diagram / Line or Bar chart

Table 23: Description of Process capability

In Statistical Process Control the Process Capability is one of the most used tools for long-term analysis. Statistically gathered variables are the basis for it. The great advantage of this KPI lies in its scalability and usability in different, repetitive processes.

[125] TAGHIZADEGAN, S. (2006), pp. 138 ff.

[126] ibidem

3.3.1.7 Overall Equipment Effectiveness

The Overall Equipment Effectiveness is a product of the Availability, Performance and Quality factors. The Availability factor is a measure for the losses due to unscheduled downtimes of machines. The Performance factor is a measure for the losses due to deviations of the planned production rate, smaller losses and idling cycles. The Quality factor is a measure for the loss due to defective products that have to be repaired.[127] Table 24 shows the detailed description of the KPI.

Formulae:	
$OEE = Availability\ factor * Performance\ factor * Quality\ factor * 100\%$ (8) $Availability\ factor = \frac{Uptime}{Uptime + Downtime}$ (9) $Performance\ factor = \frac{Production\ time}{Uptime} * \frac{Actual\ processing\ rate}{Theoretical\ processing\ rate}$ (10) $Quality\ factor = \frac{Approved\ product\ output}{Actual\ product\ output}$ (11)	
Unit:	%
Evaluation period:	Quarter
Display format:	Signal light diagram / Line or Bar chart

Table 24: Description of Overall Equipment Effectiveness

This KPI is able to control machines and processes on their most important features and parameters. Much information is provided for this control function. It is applied for uncovering bottlenecks in capacities or processes which do not produce the required quality output.

[127] Cf. MUTHIAH, K.M.N.; HUANG, S.H.; MAHADEVAN, S. (2008), p. 1

3.3.1.8 Supplier quality constancy

The compliance of the delivered quantity by the suppliers with the ordered amounts and the quality of the delivery when it meets the requirements are integrated and calculated with this KPI. If need be, the adherence to schedules can be integrated as well.[128] Table 25 shows the detailed description of the KPI.

Formulae:	
	$\frac{Number\ of\ positions - Number\ of\ defective\ positions}{Number\ of\ all\ incoming\ goods\ positions} * 100\%$ (12) $Adherence\ to\ schedule = \frac{Number\ of\ deliveries\ on\ time}{Number\ of\ all\ deliveries} * 100\%$ (13)
Unit:	%
Evaluation period:	Month/Quarter
Data source:	Quality reports
Display format:	Signal light diagram

Table 25: Description of Supplier quality constancy

This KPI is adapted to control the compliance of amount, punctuality and quality of delivered goods. A detailed documentation offers a lot of information for all concerns relevant to the incoming goods department.

3.3.1.9 Number of repaired jigs

This KPI accumulates the number of jigs that have been repaired due to mechanical wear and preventive maintenance.[129] Table 26 shows the detailed description of the KPI.

Calculation:	Accumulation of all repaired jigs
Unit:	Number
Evaluation period:	Month/Quarter
Data source:	Photo-documentation on the jigs
Display format:	Line or Bar chart

Table 26: Description of Number of repaired jigs

[128] Cf. GLADEN, W. (2011), p. 273

[129] Cf. GLADEN, W. (2011), p. 280

This KPI controls indirectly the expenditures for repairs on jigs. This information is useful in determining the average wear in dependence of the utilisation of the jigs.

3.3.1.10 Number of customer complaints

This KPI reviews the number of all unfinished customer complaints that can be assigned to errors in the manufacturing or suppliers.[130] Table 27 shows the detailed description of the KPI.

Calculation:	Accumulation of the documented complaints
Unit:	Number
Evaluation period:	Month/Quarter
Data source:	SAP or database for QM
Display format:	Line or Bar chart

Table 27: Description of Number of customer complaints

A complaint is a special type of quality reports. It is the complaint on a quality feature of an already delivered bogie or wheel set.

This KPI provides a good overview on the occurred complications in the production. In complaints a comprehensive documentation of the error is available and makes more detailed analyses possible.

3.3.1.11 Reclamation quota

This KPI is a quota of the number of customer reclamations and the number of delivered bogies and wheel sets. In other words, it measures the share of products that have to be taken back because of customer complaints, even though they have passed the final inspection.[131] Table 28 shows the detailed description of the KPI.

[130] Cf. OSSOLA-HARING, C. (2006), p. 322

[131] Cf. PREIßLER, P.R. (2008), p. 286

Formulae:	
$$\frac{Number\ of\ reclamations}{Number\ of\ delivered\ bogies(wheel\ sets)} * 100\% \quad (14)$$	
Unit:	%
Evaluation period:	Month/Quarter
Data source:	Complaints
Display format:	Signal light diagram / Line or Bar chart

Table 28: Description of Reclamation quota

The application of this KPI allows for documentation of the delivered, defective bogies and wheel sets in comparison to the entire output of the production.

The calculation of this KPI enables taking measures concerning the process stability and flexibility. A high reclamation quota of a project or product series shows a great weakness in the production process. Complaints that are related to complications at the process set-up point out weaknesses in process flexibility and the refitting of the processes.

3.3.1.12 First-Time-Fix-Quota

This Quota calculates the share of successful product and project starts with zero-defects on all product starts.[132] Table 29 shows the detailed description of the KPI.

Formulae:	
$$\frac{Number\ of\ successful\ product\ starts}{Number\ of\ all\ product\ starts} * 100\% \quad (15)$$	
Unit:	%
Evaluation period:	Year
Data source:	Complaints
Display format:	Signal light diagram / Line or Bar chart

Table 29: Description of First-Time-Fix-Quota

This KPI has a positive connotation to it and offers potential motivation. It is possible with it to check the flexibility of internal processes and suppliers with a new product series and if there are some complications with the refitting of processes.

[132] Cf. http://www.tuv.com/ (23.04.2012)

3.3.2 Reference indicators and indicators for additional information

These kinds of indicators are used in addition to the aforementioned KPIs for reasons of comparison for trend analysis or to gain some additional information input on the processes. The following sub-chapters describe these indicators.

3.3.2.1 Amount of productive hours

This indicator accumulates the amount of actual productive hours in the evaluation period.[133] Table 30 shows the detailed description of the KPI.

Calculation:	Accumulation of productive hours
Unit:	Hours
Evaluation period:	Month/Quarter
Data source:	Production reports
Display format:	Line or Bar chart

Table 30: Description of Amount of productive hours

This performance indicator will be used as a reference indicator for other KPIs. This helps with the trend analysis of these KPIs as their development over time is compared to an indicator of the production.

3.3.2.2 Number of bogies/wheel sets produced

The indicator returns the accumulated number of bogies or wheel sets produced in the evaluation period.[134] Table 31 shows the detailed description of the KPI.

Calculation:	Accumulation of all produced bogies or wheel sets
Unit:	Number
Evaluation period:	Month/Quarter
Data source:	Production reports
Display format:	Line or Bar chart

Table 31: Description of Number of bogies/wheel sets produced

This performance indicator will be used as a reference indicator for other KPIs similar to the previously introduced indicator. This helps with the trend analysis of these KPIs as there development over time is compared to a performance indicator of the production.

[133] Cf. GLADEN, W. (2011), p. 281

[134] Cf. GLADEN, W. (2011), p. 280

3.3.2.3 Amount of delivered parts

The indicator returns the accumulated number of delivered parts. Table 32 shows the detailed description of the KPI.

Calculation:	Accumulation of the amounts of all delivered goods
Unit:	Number
Evaluation period:	Week/Month/Quarter
Data source:	Delivery receipt
Display format:	Line or Bar chart

Table 32: Description of Amount of delivered parts

This performance indicator will be used as a reference indicator and as data source for the calculation for other KPIs. This helps with the trend analysis of these KPIs as there development over time is compared to an indicator of the production.

3.3.2.4 Quota samples per delivered parts

This KPI compares the number of random samples taken in the incoming goods inspection to the number of delivered parts. Table 33 shows the detailed description of the KPI.

Formulae:	
$$\frac{Number\ of\ samples}{Number\ of\ delivered\ parts} \quad (16)$$	
Unit:	Samples/Parts
Evaluation period:	Week/Month/Quarter
Data source:	Inspection protocols, delivery receipts
Display format:	Line charts

Table 33: Description of Quota samples per delivered parts

This KPI is used for additional information to control the expenditures of inspection.

3.3.2.5 Number of existing jigs

The current number of jigs in the company is documented with this KPI. A differentiation between jigs in use, jigs in inventory and jigs in production is possible. Table 34 shows the detailed description of the KPI.

Calculation:	Accumulation of existing jigs and/or jigs in production
Unit:	Number
Evaluation period:	Month/Quarter
Data source:	SAP
Display format:	Line or Bar chart

Table 34: Description of Number of existing jigs

This KPI offers an overview to the existing stock of jigs. This information is useful for the manufacturing processes.

3.3.2.6 Number of measurement points per test method and frame

With this KPI the accumulated number of points for measurement in the varying non-destructive test methods per frame is controlled. Table 35 shows the detailed description of the KPI.

Calculation:	Accumulation of the number of measurement point per test method and frame
Unit:	Number
Evaluation period:	Week/Month/Quarter
Data source:	Database for QM
Display format:	Line or Bar chart

Table 35: Description of Number of measurement points per test method and frame

This KPI is able to control the efforts for testing with the different methods per frame. Since the necessary data is already available, it is easy to calculate this KPI. It can be used as reference indicator for other KPIs like Number of errors per product.

3.3.2.7 Share of deliveries on schedule

This KPI compares the number of outgoing bogies and wheel sets on schedule to the number of delivered bogies and wheel sets for the evaluation period.[135] Table 36 shows the detailed description of the KPI.

Formulae:	
	$$\frac{Number\ of\ outgoing\ bogies\ on\ schedule}{Number\ of\ delivered\ bogies} * 100\% \quad (17)$$ $$\frac{Number\ of\ outgoing\ wheel\ sets\ on\ schedule}{Number\ of\ delivered\ wheel\ sets} * 100\% \quad (18)$$
Unit:	%
Evaluation period:	Month/Quarter
Data source:	Shipping documents, Delivery schedule
Display format:	Signal light diagram / Line or Bar chart

Table 36: Description of Share of deliveries on schedule

This KPI controls the number of delivered bogies and wheel sets plus the timing of the deliveries.

[135] Cf. GLADEN, W. (2011), p. 393

4 Description and comparison of used KPI systems

The actually used systems for data gathering and evaluation with KPIs are described and analysed in the following chapter. The next chapter compares the theoretically optimal KPIs described in the previous chapter and the actually used systems and KPIs with each other.

4.1 Description and analysis of the currently established system

Currently there are 4 different major systems in use for Siemens BG Graz. The first system would be the BG Quality management scorecard as the top hierarchical reporting tool for all quality related functions of BG Graz. The second system in use is the Balanced Scorecard of the manufacturing department for the reporting of several KPIs. The third and most important system for this thesis is the database for quality management. The fourth system is the documentation of errors and their correction with quality reports. The systems will be analysed in the final sub-chapter with respect to the evaluation criteria mentioned in chapter 3.2.3 and the purpose of this thesis.

4.1.1 BG Quality Management Scorecard

Some KPIs must be checked in regular intervals quarterly or monthly according to standard requirements and they must be reported to the upper management. The Quality Management Scorecard for BG Graz documents those KPIs which are required or at least recommended by the ISO 9001:2008 and IRIS standards as mentioned in chapter 2.3.3. There are currently 13 KPIs in the scorecard, which are assigned to different departments, including project management, engineering and production.[136]

The KPIs have a target value with two tolerance limits. If the actual value lies within the first tolerance, it’s declared positive with green colour markings. If the value lies within the second tolerance area, it’s declared a warning with yellow colour. If it lies outside of the tolerance areas, it is declared negative and marked with red. Display of these ratings happens with signal light diagrams. A trend marker to the value of the previous evaluation period shows the development of the KPI with an arrow sign that is either pointing upwards or downwards for changes in the evaluation.

4.1.2 Balanced Scorecard of the manufacturing department

The second important system is the Balanced Scorecard of the manufacturing department. It lists several KPIs which are evaluated once a month for the manufacturing departments. These KPIs gather information of the four perspectives of the Balanced Scorecard: Internal Business Process, Customers, Finances and Employees.[137]

[136] Cf. Siemens BG QM (2010)

[137] Cf. Siemens BG MF-GRZ (2011)

This Balanced Scorecard was developed and implemented to help control the implementation of strategies into the production process.[138]

Just a few of the utilised KPIs can be used for the control of the production quality, mainly those of the customer perspective.

4.1.3 Database for quality management

The database for QM is the major concentration point for the gathering of all data from product inspection in the production and service processes. The data is inserted in specific interfaces and can be analysed whenever the user needs information. Additionally to the data gathering it is also sampling of all existing inspection and measurement protocols, which can be accessed for a more detailed error analysis. All data sampling is attributed to the specific projects because the production of bogies and wheel sets is project-related. The data can later be analysed for the projects as primary keys.[139]

Some KPIs for direct analysis are available within the database. There is the possibility to extract all the gathered data in Excel-lists for a selected quality feature from one or more projects. The user can perform manual analyses to acquire the needed information in these extracted lists.[140]

There is an additional user-oriented analysis-program available that has full access to the data stored in the database. This assembly line analysis tool integrates pre-fabricated analyses to all the quality gates of the production processes. It enables the graphical illustration of the used KPI for the selected time period. In these analyses the description of the selected project, the necessary data and the calculation of the KPI is shown as well. The illustration is always a bar chart that includes the tolerance limits and a marking of the bars with the signal colours for easier identification.[141]

The illustration includes a smaller depiction of the development over time of the KPI in previous periods for further information. This allows for an intuitive estimation of the trends. The Share of defective products is the KPI most used for these illustrations.[142]

The illustration does not express the exact kind of error that has occurred in the quality gates. However, it is possible to analyse these errors in more detail with specific program interfaces and it also provides a link to the error documentation.[143]

The database stores the data of the inspections for the quality gates in manufacturing directly to the assigned product. Such data includes the manufacturing ID and date of the inspected product, the type of bogie it is used for. The different types can be trailer bogie, swivel bolster carrier, motor bogie, cross beam, bogie bolster or components. Other data included is the

[138] Cf. PSILINAKIS, P. (2000), p. 56

[139] Cf. Siemens BG QM (2011b)

[140] ibidem

[141] ibidem

[142] ibidem

[143] ibidem

material, the order ID and the measurement method which is different for every quality gate. The activities for correction of occurred errors are included in this data. More information will be in chapter 4.1.5.[144]

Inspection protocols are stored as electronic documents to every product and can be accessed with the database. Data recorded in the protocols are the order ID, the inspection data, including specification, testing equipment, standards, technical data, the result of inspection, the responsible tester with date of inspection and signature and in case of error detection, documentation of measured values out of tolerance. Some documents will have additional information and documentation as the inspection method might demand. Those will be introduced in chapter 4.1.5.[145]

4.1.3.1 KPIs of the assembly line analysis

Share of defective products:[146]

A bar chart is displaying the share of defective products for the selected project and time period in each quality gate of the production process. A quality gate is an inspection in the process that can put a hold on a product, frame or bogie, and take it out of the ordinary production, when a critical error has been detected. The product is restricted until the error has been corrected.

Quality gates are:[147]

- Non-destructive inspection in the Frame construction
- 3D-measurement after Machining
- Pressure test stand after Assembly
- Final inspection in goods issuing department

Zero-defect bogie:[148]

This important KPI is used in the Balanced Scorecard of the manufacturing department and the Quality Management Scorecard. It is defined by the ratio of the number of non-defective bogies during the entire production to the number of all produced bogies.

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[144] Cf. Siemens BG QM (2011b)

[145] ibidem

[146] ibidem

[147] ibidem

[148] ibidem

4.1.4 Non-conformance costs and documentation with quality reports

Non-conformance costs include many different types of costs for BG Graz and are documented in quality reports and disturbance analyses. Non-conformance costs are always additional costs for all the non-planned activities in a project. They include costs for defective output that can be attributed to occurred errors and defects including their cause and detection.[149]

A distinction has to be made for costs before and after the delivery of products. The first include costs for externally caused costs. This type includes all deviations caused by the suppliers that have influence on the on-going production of products and therefore cause additional non-conformance costs in the production process of BG Graz. The documentation includes every deviation, quality and random sampling inspection, as well as controls of the number of units. They mainly occur during the incoming goods inspection, yet also sometimes in the production process until the delivery to the customer.[150]

The costs for internally caused errors are part of the NCC before the delivery. This type includes all deviations caused by internal departments that have an influence on the on-going production of products and therefore cause additional non-conformance costs in the production process of BG Graz. The scrapping costs occur for not repairable products. Either can be attributed to projects or not, which influences the accounting of these costs.[151]

Warranty costs are included in costs after the delivery to the customer. Siemens warrants that deliveries and services are state-of-the-art at the time of issuing an individual order. It also warrants that the products adhere to the latest safety restrictions and contractual specifications and that they comply with the effective statutory and regulatory clauses, as well as respective industry standards limited to the specified countries as documented in the specifications sheet at the time of the individual order.[152]

The warranty period starts with the transfer of perils and ends by default 24 months after delivery to the final customer. In some cases it ends after 36 months when the customer accepts a delivery with missing parts. The period is interrupted if a defect is introduced to Siemens BG. In case of corrections and subsequent deliveries the warranty period for this specific part is at least till the end of the ordinary warranty period and maximum 24 months. Warranty includes all deviations and expenditures that occur after delivery and acceptance by customer within the contractual warranty period.[153]

Costs for goodwill include all expenditures for deliveries and services that are not accounted to the customer out of superior commercial reasons. A difference is made on expenditures for the correction of deviations or reparation services after the expiration of the warranty period and expenditures that occur during the processing of orders out of reasons that are

[149] Cf. Siemens AG Austria (2009), p. 9

[150] Cf. Siemens AG Austria (2009), p. 8

[151] ibidem

[152] Cf. Siemens AG Austria (2009), pp. 8 f.

[153] Cf. Siemens AG Austria (2009), p. 9

due to customer wishes, like change-orders, changes in the delivery and service extent, or damages from installed materials and components.[154]

Costs for penalties include all expenditures that occur because of violations of agreed delivery and service specifications after the delivery of the product.[155]

4.1.4.1 Information documented in an error report

The necessary data is documented for the error management at Siemens BG Graz in an error report, either quality report, disturbance analysis or change management. The data includes the description of the affected project, the material number with index and description. A description of the error is also part of the documentation. This includes the cause and consequence of the error and the department where the error was detected. Included are the documentation of the type of error, the error correction measures and the duration of the disturbance or error correction as well as the responsible person.[156]

4.1.4.2 Documentation and reporting

There are three different methods of documentation and reporting of errors. The first would be the already mentioned quality report. It is used for major complications with quality features when the costs for error correction or the duration of the correction measures is above a specified limit. The process for documentation with quality reports is the Complaint management.[157]

The second method is the disturbance analysis. It is used for minor complications with quality features that do not meet the before mentioned criteria for quality reports. The respective manager in the department is responsible for the smooth and efficient process of documentation with disturbance analyses. If it is necessary to perform some training of the employees on the documentation of those analyses, the manager will organise them instantly. The documentation of the filled disturbance matrix posters has to be performed by a selected person of each department.[158]

After a break of six months since the completion of a disturbance analysis the department has to perform a new disturbance analysis for the duration of four weeks. The process starts anew with the same progression. This repetition of the analysis helps with an effectiveness inspection of the set corrective measures. In general every department of BG Graz is required to perform a disturbance analysis or disturbance matrix plus repetition once a year for the duration of four weeks.[159]

The possibility of documentation with the change management of inventory exists aside from the error documentation with quality reports or disturbance analysis. The process for this kind

[154] Cf. Siemens AG Austria (2009), p. 9

[155] ibidem

[156] Cf. Siemens AG Austria (2009), pp. 5 f.

[157] Cf. Siemens AG Austria (2009), p. 6

[158] ibidem

[159] ibidem

of documentation is the "change management". The documentation is for changes and rework on the inventory.[160]

Either method can be used as data sources for a KPI system which is especially necessary for some recommended KPIs. The disturbance analysis would be suited for data sampling for improvement processes.

4.1.5 Data sampling and documentation in inspections

Almost every detected error gets documented with one of the aforementioned methods. Sometimes repairs are executed without the error documentation. However, all inspection data from the production processes will be documented not just the errors. The database for QM is the used system for this. See chapter 4.1.3 for further information. The introduced data could be used for the calculation of specific KPIs.

4.1.5.1 Inspections in the production process

The following explanations are descriptions of the protocols and interfaces from the database for quality management:[161]

- Inspection of incoming goods

  Incoming goods are tested for the fulfilment of quality requirements. If the requirements are not fulfilled an individual quality report is established per defective position in the delivered parts. The quality report includes the data mentioned in chapter 4.1.4.1.

- Documentation of jigs

  Documentation for jigs is available in the jig database. Documentation with pictures exists for every jig which includes the repairs and damages. A proper failure analysis would be possible with this documentation if an error has occurred.

- Inspection of the paint job

  Visual inspections are made for the condition of the paint job by qualified personnel. An inspection of the lamination strength of the paint job is performed at specific measuring points. The repair of detected errors of the paint is not always documented, when the establishment of a quality report is not required. The database offers access to the inspection protocols.

- Electrical inspection

  A number of attributes of the electrics of bogies are inspected and documented with protocols of the electrical inspections. The data includes measurements for environmental conditions (air pressure, temperature and humidity), electrical resistance, electrical grounding, insulation resistance, resistance of the magnetic rails brake and results for the inspection of shielded connectors on the motor casing, wiring, impermeability and freedom of movement.

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[160] Cf. Siemens AG Austria (2009), p. 6

[161] Cf. Siemens BG QM (2011b)

4.1.5.2 Quality gate Non-destructive material inspection

The first important quality gate in manufacturing is the non-destructive material inspection of the produced frames. The welding seams of the frames are important to be inspected. The use of quality gates means that a frame could be restricted for further manufacturing due to some critical defects. This restriction is held up until the point of complete correction and repeated inspection.

Non-destructive material inspection methods include different methods to measure the quality of products on the condition of the material at the surface or on the inside without damaging or changing the test object permanently.[162]

The engineering department defines critical points of measurement for each type of frames that have to be inspected with specific inspection methods and eventually documented. These measurement points are located mainly at the most critical points of stresses for the frames.

The following methods are applied in this process:[163]

- *Visual testing VT*

  An employee with the required qualifications controls the welding seams with different measurement tools like welding-seam gauges and for visual defects on the surface.

- *Magnetic powder testing MT*

  Internal fractures disturb the magnetic flow in ferromagnetic materials and divert the force lines to the surface of the work piece. Magnetic powder that is dissolved in oil on the surface shows the location of the fracture.

- *X-radiation testing RT with random samples*

  The electromagnetic oscillations wander in straight lines through the material. They react differently on the passage through the material. If internal fractures exist the x-rays will not be weakened as much. The exiting radiation shows differences in intensity that is analysed optically, on monitor, photographically for documentation and displayed by measurement instruments.

- *Ultrasonic testing UT*

  Sonic waves wander in metals through mechanical vibrations in straight lines with high speed. They are reflected at boundary layers and the on-moving sound is weakened. The weakening or reflection of the sound waves is used to detect internal fractures.

- *Colour penetration testing PT*

  Surface fractures can absorb the dampening liquids with capillary action. After cleaning the surface some rest liquids stay in the fracture. Colour markings appear at the fracture exit with the application of a reactor liquid.

The data stored in the database includes the applied methods for inspection, the number of measurement points and the number of detected errors.[164]

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[162] Cf. http://www.xpertgate.de/ (22.04.2012)

[163] Cf. WEIßBACH, W. (2010), pp. 397 ff.

[164] Cf. Siemens BG QM (2011b)

4.1.5.3 Quality gate 3D-measurement

The next quality gate in the production process is the 3D- coordinates measuring machine for the measurement of all welded and machined frames. Every frame has to go through this quality gate, including externally manufactured ones.

The measuring machine has a specific measurement program for each type of frame with several measuring points. It works fully automatic and establishes a protocol. In the protocol the required dimensions plus their tolerance limits are noted aside the actual value. The comparison shows the deviation and the difference for each value.[165]

The rule also applies for this quality gate that a frame is being restricted for the production process when a critical error is detected. An approval and continued production follow after complete correction of the error.

4.1.5.4 Quality gate Pressure test stand

The pressure test stand is one of the most important inspections and adjustment procedures in the production of bogies and performs a complete inspection of the bogies. It is also one of the quality gates in the production process which means it can restrict a bogie in case of a detected error from going further in the process until the error is corrected.

The right height and the springing behaviour of the bogies are adjusted in this process. The calculation of shims for the height adjustment is a major result of the procedure. The adjustment balances the entire tolerance chain of the single components of the bogie. In some cases the calculation would cause an error detection, which is not documented with a quality report as the disturbances are varying too much. It is possible that the procedure requires a stiffness assessment of all spring components and the frames to calculate the appropriate amount of shims.

The calculation protocols include the theoretical corner loads of the vehicle, the test loads of the vehicle, the calculation of the theoretical primary spring force, the theoretical wheel load of the vehicle, the determination of the balancing shims for the primary and secondary level and the measured results with comparison to tolerances. Furthermore, the protocols would document the total weight of bogie, the impermeability inspection of wheel disc brake system, the adjustment of the rail guard and the wheel flange lubrication and the oil level in the gearbox.[166]

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[165] Cf. Siemens BG QM (2011b)

[166] Cf. Siemens BG QM (2011b)

4.1.5.5 Quality gate Final inspection

The final inspection is the last quality gate in the production process and inspects the total condition of the bogie with the inspection lists. The protocols include the inspection of the documentation of the bogie, the missing parts and quality reports and last but not least the shipping status. The documentation in the database includes a description of repairs when an error has been detected with the type of issued complaint. Examples for the complaints are a damaged axle, an incomplete documentation, a missing certificate for the wheel set or incorrect labelling.[167]

A source for errors in this inspection might be a deficient protocol or document. Other errors can be missing and dummy parts at delivery. Missing parts are parts that have been included in the configuration of the bogie, yet they have not been mounted due to complications in the supply. Normally, those will be delivered and mounted after delivery of the bogie. Dummy parts are parts that have been mounted to the bogie, but they do not have an approval for the series, which means that the customer has to approve those parts in an approval proceeding.

Bogies can be delivered with unfinished quality reports, if the customer agrees to accept the defective bogie. The correction of the quality report is then done at the customers, for instance with missing parts.

The entire configuration of the bogie is documented in the data lists, which are stored in the database. Not every bogie of the same type has the same specifications in the projects. The differences must be documented with the configuration data lists for all components of the bogie.[168]

4.1.5.6 Data feedback and analysis of customer complaints

Complaints are a special form of quality reports. These customer complaints occur after a bogie or a component has been delivered. Complaints are documented with much detail similar to the quality reports and are intensively maintained until their completion. Each complaint is available in the database for quality management and can be analysed at will.

The data documentation of complaints includes product and customer data, an error description of the defective part and consequences of the error and its cause. One part of the complaint is the information about the warranty period with the number of delivered and defective bogies. Another section includes the responsibilities for the complaint, the responsible managers as in project manager, warranty manager, engineering technician, a description to the error classification and consequences and the setting of priorities. An important part in the documentation is the solution finding with the comparison of planned and actual dates and the responsible manager for these solutions. The complaint includes the documentation of the final report and the synergy effects in Lessons Learned, the error code definition and the initiation of measures. It further includes the important part of costs

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[167] Cf. Siemens BG QM (2011b)

[168] ibidem

with a comparison of the actual and budgeted costs. The chronology of the complaint notes the frequency of errors, if it is an individual or serial case.[169]

Analyses of customer complaints:[170]

It is possible to analyse and evaluate the complaints on this data with different methods. The analysis can be made in the database. A pre-selection to limit the amount of the analysed data is made with the business year or the months, the product type or the status, which is differentiated in all complaints, complaints in progress, finished, finished justified or finished unjustified.

Analyses of complaints can be made for the costs of the complaints which will create a table with the Project IDs, Assembly description, Complaint manager, Project manager, Warranty manager and the Costs for the complaint. The table can be extracted into an Excel-file.

The analysis of the number of complaints displays a table with the total amount of complaints. These complaints are differentiated according to their status in total number justified, finished justified, in progress, or declined, and according to their date of establishment in before or after delivery to the final customer, or after the end of the warranty period.

The analysis of the duration of complaints will create a table that shows the duration of all complaints with their date of establishment and reporting and their completion date. The average duration of the pre-selected complaints is shown as well.

The analysis of the error code results in a comprehensive table with data on projects, error description and classifications und a specific attribution to the affected part with the responsible managers and costs.

The number of projects analysis creates a table that shows the number of complaints per project.

All data about the origin of the complaint and error are listed in the origin analysis. The created table depicts all the error analyses with their evaluation grade - with feedback or in progress. In the evaluation grade is the difference between completed, incomplete and not evaluated complaints. Probable origins might be e.g. procurement, production/frame construction, R&D, engineering departments.

A reaction analysis inspects the fulfilment of the levels of strictness. The first level should be completed within the first 24 hours, the second within 10 days. The number of complaints that have exceeded or have fallen short on the deadlines is shown with the reaction analysis.

In the meeting analysis the number of meetings for the selected complaints is displayed and how many of those have been successful.

The analysis of the number of unfinished deadlines shows a table with each user of the database who has an unfinished deadline for the domains of error analysis, initiatives, claim measures and technical solutions

[169] Cf. Siemens BG QM (2011b)

[170] ibidem

The created table with the analysis for unfinished deadlines in detail offers more information to the unfinished deadlines for initiatives. The available information includes project designation, a short description, the description of initiatives, the planned date, the responsible manager and the delay.

4.1.6 Analyses of established systems

The following analysis is about the previously introduced KPI and data gathering systems and deals with their strengths and weaknesses regarding the purpose of this thesis. The ability for process assignment and the integrity of the systems is evaluated with this analysis.

4.1.6.1 Analysis of the BG QM Scorecard

This scorecard is used to inform the management board of BG Graz and their superiors in the Siemens AG about the most important quality concerns. The system is based on the requirements of the ISO 9001:2008 and IRIS standards and has to be updated constantly for certification reasons. This is one of the greatest strengths of this system, as it supports the senior managers in frequent intervals with necessary information for their decisions. This system has been improved and adjusted for the actual needs over the years and is very effective by now.

The weakness of this system with respect to the purpose of this thesis is the fact that it does not offer enough information for the control of the value-adding chain and its production process. Many of its KPIs are not able to be scaled down on the level of sub-processes of the production. This means no weakness in itself, yet it is not purposeful for this thesis.

The KPIs are able to support the process overview as is necessary for the senior managers. The amount of information included in these performance indicators requires the sampling and deduction of much process data from different departments. Improvement initiatives that are conducted because of the information of these KPIs have a sizeable impact on many departments of the plant. The zero-defect bogie as one of its KPIs is presented as a motivational indicator in the production departments.

The process assignment of the KPIs in this system is rather difficult and requires a decisive deal of background knowledge and overview on the functionality of each KPI. The system is well developed and adjusted to the task of a reporting tool for the quality management to the upper management.

4.1.6.2 Analysis of the Balanced Scorecard of the manufacturing department

This balanced scorecard sticks with the basic definition in the literature and offers necessary information with its included KPIs on the four perspectives of Internal Business Processes, Finances, Employees and Customers.

The great strength of this system is the complete coverage of the important perspectives with sufficient information. Some of the included KPIs are escalated to the QM Scorecard, specifically those of the Customers perspective. This Balanced Scorecard is first and foremost a reporting tool for each process manager and the plant management.

The weakness of this system is the partially not useful information for quality assurance purposes. Many KPIs are relevant as reference indicators like the output of frame construction or the output of the montage. Other KPIs like the warranty costs and adherence to delivery schedule are more relevant for the quality assurance in production. Eventually this means that just KPIs of the Customer area are of interest to this thesis. The remaining areas offer no information on quality topics.

The production process assignment of the KPIs is much higher than that of the QM Scorecard KPIs. This scorecard as an independent system is well developed and arranged to be a helpful tool for decision making of the receivers of the information. The Balanced Scorecard is mostly inapplicable however for this thesis.

4.1.6.3 Analysis of the database for QM and quality reports

The database for quality management in Siemens BG Graz is the central concentration point for all data that is acquired in all the different product inspection processes in the plant. The documentation with quality reports has similar features when it comes to this analysis though they only document errors.

The evaluation of each data set is performed manually and demand-oriented with the assembly line analysis tool for control of projects or continuously for the control of processes. The process performance is analysed by the accumulation of output from different projects for a selected evaluation period. It is also possible to extract information with the calculation of individually generated KPIs from the existing data. The possibilities for evaluation of the data are manifold and the opportunity to analyse the development of the process performance over time is open to each user.

The strength of the system lies in the possibility that each person with authorisation has full access to the data of the product inspection and can cover their demand for information easily and fast. The assembly line analysis tool with its user interfaces enables a good overview over occurred complications in the quality gates or the outstanding performance of the zero-defect bogie. A more detailed error analysis can be performed by the user with the selection of the stored inspection and measurement protocols.

The weakness of the system is the great amount of stored inspection protocols for different methods which might not always be available for every product of a series. The sampling of data for a specific KPI can become difficult under the said conditions. A more detailed error analysis requires the manual evaluation of different protocols.

The database is optimal for the process assignment, since it allows for direct access on the gathered data of each process. The integrity of the system is good. Since its introduction the system has grown persistently and is constantly fed with more actual data. It provides a consistent documentation of all data necessary for the quality in the production process.

4.2 Comparison of the key performance indicators

The recommended KPIs for quality assurance described in chapter 3.3.1 are compared to the used KPIs and system in this chapter. The comparison should determine the weaknesses of the established systems and balance it with the recommended KPIs. Furthermore it should be shown that some of the currently used KPIs approve of the recommended KPIs for a process. This requires that the established system with the currently used KPIs displays a high effectiveness.

Share of defective products

This KPI measures the share of defective wheel sets or bogies in all produced. Defective products have to be repaired or scrapped. It is introduced in chapter 3.3.1.1.

It is already being used for each quality gate of the production process that has been shown in chapter 4.1.3.1. And it is comparable to the zero-defect bogie KPI. The recommendation is therefore approved. The regular control of this KPI for other inspections is not implemented yet.

Number of errors per product

This KPI allows the documentation of the numbers of errors detected during the non-destructive testing per frame or wheel set. A differentiation between the varying test methods is also possible. It is introduced in chapter 3.3.1.2.

It can be extracted manually from the data stored in the database for quality management, namely those of quality gates. The calculation for other inspections would require the analysis of single inspection protocols which is bound to high efforts.

Number of quality reports

This KPI describes the accumulated number all quality reports for the evaluation period in a specified process. It is introduced in chapter 3.3.1.3.

The quality reports are stored in a single system and that means an easy calculation of this KPI. It is already calculated monthly for the quality assurance.

Duration for error correction

The duration documents the time period between the detection of an error and preparation of a quality report till its completion and conclusion. Either average values or an accumulation of the time should be used for this KPI. It is introduced in chapter 3.3.1.4.

This KPI can currently be calculated for the analysis of customer complaints. Some KPIs of the QM Scorecard that has been introduced in chapter 4.1.1 are comparable to this KPI. A calculation with data from the quality reports can be done manually.

Non-conformance costs

This KPI accumulates all occurring costs that are related to lacking quality, e.g. error correction. It is introduced in chapter 3.3.1.5.

Currently this KPI is not measured on a regular basis. The quality reports are the data source for the calculation. The costs could be extracted manually. A comparable KPI are the warranty costs, which are being used in the company's scorecards.

Process Capability

The process capability is the ability of a process to achieve the set goals. The arithmetical mean of measured values μ, the upper and lower tolerance limit UTL or LTL and the standard deviation σ are required data for the calculation. Calculated are two different process capability indices. It is introduced in chapter 3.3.1.6.

This KPI is currently not in use, yet it would be properly applicable in processes with the opportunity for statistical process control. The data for the calculation is already being collected in the inspections.

Overall Equipment Effectiveness

The Overall Equipment Effectiveness is a product of the Availability, Performance and Quality factors. The Availability factor is a measure for the losses due to unscheduled downtimes of machines. The Performance factor is a measure for the losses due to deviations of the planned production rate, smaller losses and idling cycles. The Quality factor is a measure for the loss due to defective products that have to be repaired. It is introduced in chapter 3.3.1.7.

This KPI is not used in the current systems. It is recommended to apply the KPI for the planning of capacities and process analysis. It is capable of providing a lot of information for the process control and quality assurance.

Supplier quality constancy

The compliance of the delivered quantity by the suppliers with the ordered amounts and the quality of the delivery when it meets the requirements are integrated and calculated with this KPI. If need be, the adherence to schedules can be integrated as well. It is introduced in chapter 3.3.1.8.

Currently there are some similar KPIs in use which are integrated in the QM Scorecard or extractable from the quality reports for supplier claims. The application of this adapted form is recommended because it offers some necessary information for the incoming goods inspection.

Number of repaired jigs

This KPI accumulates the number of jigs that have been repaired due to mechanical wear and preventive maintenance. It is introduced in chapter 3.3.1.9.

There are currently no KPIs for the control of jigs in use. It is recommended to apply this KPI for the control of the maintenance of the jigs. Picture documentations of the jigs are the data source for this KPI.

Number of customer complaints

This KPI reviews the number of all unfinished customer complaints that can be assigned to errors in the manufacturing or suppliers. It is introduced in chapter 3.3.1.10.

It can be extracted directly from the database for quality management and is used frequently.

Reclamation quota

This KPI is a quota of the number of customer reclamations and the number of delivered bogies and wheel sets. In other words it measures the share of products that have to be taken back because of customer complaints, even though they have passed the final inspection. It is introduced in chapter 3.3.1.11.

A similar KPI is used in the QM Scorecard for the complaint about delivered products. Quality assurance could make use of it in the sub-processes of the production process for the control of effective inspection.

First-Time-Fix-Quota

This quota calculates the share of successful product and project starts with zero-defects on all product starts. It is introduced in chapter 3.3.1.12.

It is not used in any system currently however it is somewhat comparable to the zero-defect bogie. The data for calculation is available in the database for quality management.

5 Conclusion and perspectives

This chapter gives a conclusion with the recommendation for the implementation of the described KPIs. It will introduce the recommendation for the establishment of a quality assurance scorecard. Further recommendation will include the continuous improvement of the KPI system, the upgrade of the KPI catalogue and the documentation in general. The last sub-chapters include a summary and the perspectives for further scientific analysis.

5.1 Recommendation for the implementation of KPIs

Chapter 3.3 Description of selected KPIs introduces the most appropriate key performance indicators for the purpose of the development of a KPI system for quality assurance. The selection phase has provided a comprehensible evaluation of the KPIs taken from different literature sources. They have been selected because of preferable abilities for process assignment and system integratability. They interact in a documented relation with each other and the processes as can be seen in Appendix 1. Therefore they are recommended to be integrated in a new or already existing system.

The comparison with the KPIs of the existing system has pointed out that some of the indicators are already being used with the same or a slightly differing definition for extracting the necessary information for process control. The existing systems have a high coverage of data sampling and preparation for the customer complaint management process. The database for quality management is a system that samples all the quality related data of the production processes in one system and provides the user with an easy-to-use analysis tool to extract all the demanded information. An evaluation of process data with frequent intervals is recommended for this system.

The KPIs Duration for error correction and Non-conformance costs are special in this context. The necessary data for those KPIs is available in the database, however aside from the customer complaint management process this data is not used in any regular inspection for any other process. A focus on the costs of bad quality is recommended to identify the causes of these costs and acquire the information to set action against the causes. The application of the KPI Duration for error correction is advisable because it can offer quite necessary information for more effective capacity planning and delivery scheduling.

The implementation of KPIs with general process assignment is recommended. They have the ability to not just control entire processes but go more into detail at the process and working step level, or even machine level. The first one of these would be the Process Capability as it is commonly used in the Statistical Process Control. It is possible to have long-term control of repetitive processes with this KPI and to analyse the trend development of a quality feature. Another KPI capable of such a detailed process view is the Overall Equipment Effectiveness. This one is most commonly used for the identification of losses and bottlenecks in the production processes at machine level. It can identify quality features of the control object as well as performance and availability.

The reference indicators and indicators for additional information are presented to complete the recommendations on KPIs. These reference indicators have a supporting function and the purpose to provide a better overview about the process while having a simple definition. KPIs of the quality assurance can be put into a more coherent perspective with these indicators. This decreases the risk of a one-sided review and leaves no room for the wrong decision. The additional information provided by the indictors helps with the measurement of some basic process parameters.

5.2 Establishment of a scorecard for quality assurance

The previous recommendation on KPIs leads to the establishment of a scorecard for the utilisation in the quality assurance. Selected, important KPIs should be provided on a regular schedule for the managers of the manufacturing processes and quality assurance with this scorecard. This would balance the weaknesses with regard to the goals of quality assurance of the other existing KPI systems.

The weakness of the QM Scorecard is the difficulty to use the provided information for specific control of the production processes. It would still require more detailed analyses to find the actual cause of bad performances which could be easier done with appropriately designed KPIs. And it offers no room for evaluating good performance of single processes. See chapter 4.1.1 for more information.

The Balanced Scorecard of the manufacturing department is more oriented towards the production processes its KPIs however have not much information on production quality features as has been mentioned in chapter 4.1.2.

The database for quality management provides for the evaluation of data from each quality inspection of the products. An analysis tool is in place to control the qualitative output of the production processes and the quality gates. The utilisation of this tool however is demand-oriented or not used with careful regularity. Furthermore only comparatively small amounts of data are evaluated with KPIs even though there is a lot of data available. Look up chapter 4.1.3 for more information.

A scorecard for the quality assurance offers the best advantage of a better process orientation and a systematic approach for the review of quality features for each process. Another advantage is the required, regular evaluation of the processes with the selected KPIs in the scorecard. A better discipline with the evaluation would be the consequence with this scorecard. It is easier to follow the development of the selected KPIs and the processes over time.

The KPIs to be included into this scorecard have been described in chapter 3.3.

5.3 Continuous improvement with the Assessment Cycle

A frequent analysis and continuous improvement of the KPI system would be enabled with the repetition of the assessment cycle introduced in chapter 2.4.2.2. These systems have to be persistently adjusted to the processes, which they have to control, to support decision making with the necessary information. The KPIs or the system should react accordingly, when the focus of the management shifts from one feature of the processes to another. Similar things can be said about newly structured processes that have had adjustments to their data gathering systems which have compulsory effects on the KPI systems. Furthermore the weaknesses of the existing systems or other occurrences have to be identified and balanced with the system assessment.

KPIs and KPI systems are tools of the improvement process per definition, yet this does not mean that the tools themselves don't require improvement. Once a year the system should be analysed and adjusted to new circumstances.

5.4 Upgrade the catalogue

A lot of KPIs exist and one can establish a new one when the demand for specific information occurs. Informative sources and catalogues for KPIs are helpful for a more effective improvement of the KPI systems. The existing catalogue should be kept up-to-date with current description and calculation formulae. The integration of different sources can help with this purpose.

5.5 Documentation

An important task during the development of a KPI system is the detailed documentation not just of the KPIs themselves but also the derivation of the decision that has led to the integration in the new system. This makes retracing the decision much easier during the assessment of the system. The KPI is analysed in every detail with the description of the evaluation in criteria and this helps with the integration and presentation of the new system.

It is advised to document detected strengths and weaknesses of the KPIs and the system during the evaluation period to make the assessment more appropriate. The gathered information is for the following improvement phase essential.

Specifications in written form are required, if the quality would be negatively affected when documents are missing.[171]

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[171] Cf. WAGNER, K.W. (2006), p. 133

5.6 Summary

The purpose was to develop a theoretical KPI system for the monitoring of the production quality on the basis of a literature study, compare those with the existing systems and deduct recommendations for the improvement and optimisation of the currently used systems. The ultimate goal is to achieve the best process control with the least amount of defective product output for an optimum of the total quality costs.

The scope of the analysis was to focus on a system for the quality monitoring in the manufacturing department and customer complaint management, respectively called the value-adding chain. The KPI system should analyse the processes in the value-adding chain and extract as much data as needed for the evaluation of the process information. The KPIs of the system were optimised for the task at hand and evaluated for a reproducible selection. Another additional task was to determine the expenditures for quality in modern industries which are about 20-40 % of the sales. This can be improved to the point of operational excellence.

The first important task was to determine the influencing parameters of a KPI system to get to the most appropriate result. A KPI system is developed in accordance to the design of the processes, the implemented quality inspections of the products and the data sampling tools plus the description of the available data. I deducted the basic needs of the processes from this and which KPIs could be relevant to cover these needs.

The next step was to determine the influence of the applied standards in this industry environment. The requirements of the ISO 9001:2008 and IRIS were decisive for the currently used systems and had influence in the development of a new system with their requirements. The standards have an impact on all the process design and all surrounding documentation. Furthermore they require the analysis and review of process data with the application of KPIs.

The literature study was concluded with the generation of the process model. It integrates all the necessary steps on the way for the optimisation or development of a KPI system and how it is used with the processes. The centre of the model is the KPI system with some requirements on the KPIs including a cost focus for the management. The system itself is used for control of the continuous improvement of processes which requires updates and improvement with the use of feedback cycles for this function. The assessment cycle is applied to improve the KPI system. It pre-selects KPIs from a source starting at the top. The source for all KPIs is a catalogue taken from state-of-the-art literature. The system evaluates the KPIs with important criteria on the ability for process assignment and system integratability in the selection phase. The KPIs with the best evaluations are selected and described for the application in the system.

The currently used systems were analysed with regard to the evaluation criteria of the theoretical system. BG Graz utilises different KPI systems at each hierarchical level of the company structure. At the top is the QM Scorecard for reporting of important quality features for some departments to the senior management. This system is required by the implementation of the standards for quality management. The Balanced Scorecard of the manufacturing system helps with the control of many process parameters in the production process. It has little information on production quality. The database for quality management is the data sampling tool for the inspection of quality and the most applied system for quality control. The evaluation of data with KPIs is demand-oriented and leaves room for the use of more frequent applied KPIs.

The recommendations for the KPI systems are based on a comparison of the currently used systems and the selected KPIs that have been optimised for the fulfilment of requirements for a KPI system for quality assurance. The implementation of the KPIs is to be done by the managers of the processes and the quality assurance department from Siemens. In the sense of continuous improvement the assessment of the KPI system should be done annually.

5.7 Perspectives

The process model expresses the need for continuous improvement of the KPI system to be up-to-date with the requirements of the processes it controls. While this thesis mentions some examples for the assessment of the KPI system there might be some other methods available for this task.

Furthermore it is very time-consuming to find relevant KPIs in the catalogue and evaluate them with the criteria. This process requires also good background knowledge of the KPI and the process it should be used for. In words this means that only qualified people are able to assess the potential of a KPI and use it for the system. It would be good to have some automatic system available for the process model. This automatic system could be designed as a database that has on the one side the complete description of the KPIs stored and on the other side includes the processes and data measuring systems. The user introduces a few key parameters necessary for the task or information they want to acquire with KPIs to an interface and the database recommends him automatically with the most appropriate KPIs it has stored. This would decrease the effort for the improvement of the system immensely and help with the set-up of a new system.

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List of abbreviations

AG	Aktiengesellschaft
ARIS	Architecture of Integrated Information Systems
B	Beschaffung
BG	Siemens Bogies department
C	Controlling
$C_{pk,}$ C_p	Process capability indices
DMAIC	Define, Measure, Analyse, Improve, Control
e.g.	exempli gratia
etc.	et cetera
EUR	Euro
F&E	Forschung und Entwicklung
FMEA	Failure Mode and Effects Analysis
GmbH	Gesellschaft mit beschränkter Haftung
i.e.	id est
IH	Instandhaltung
IRIS	International Railway Industry Standard
ISO	International Organization for Standardization
KPI	Key performance indicator
L	Logistik
NCC	Non-conformance costs
P	Produktion
Pers	Personalmanagement
PM	Prozessmanagement
QA	Quality assurance
QM	Quality management
RaSMo	Radsatzmontage
SAP	System der Systemanalyse und Programmentwicklung AG
SGP	Simmering-Graz-Pauker AG
SPC	Statistical Process Control
V	Vertrieb

Appendix

Appendix 1: Depiction of recommended KPIs

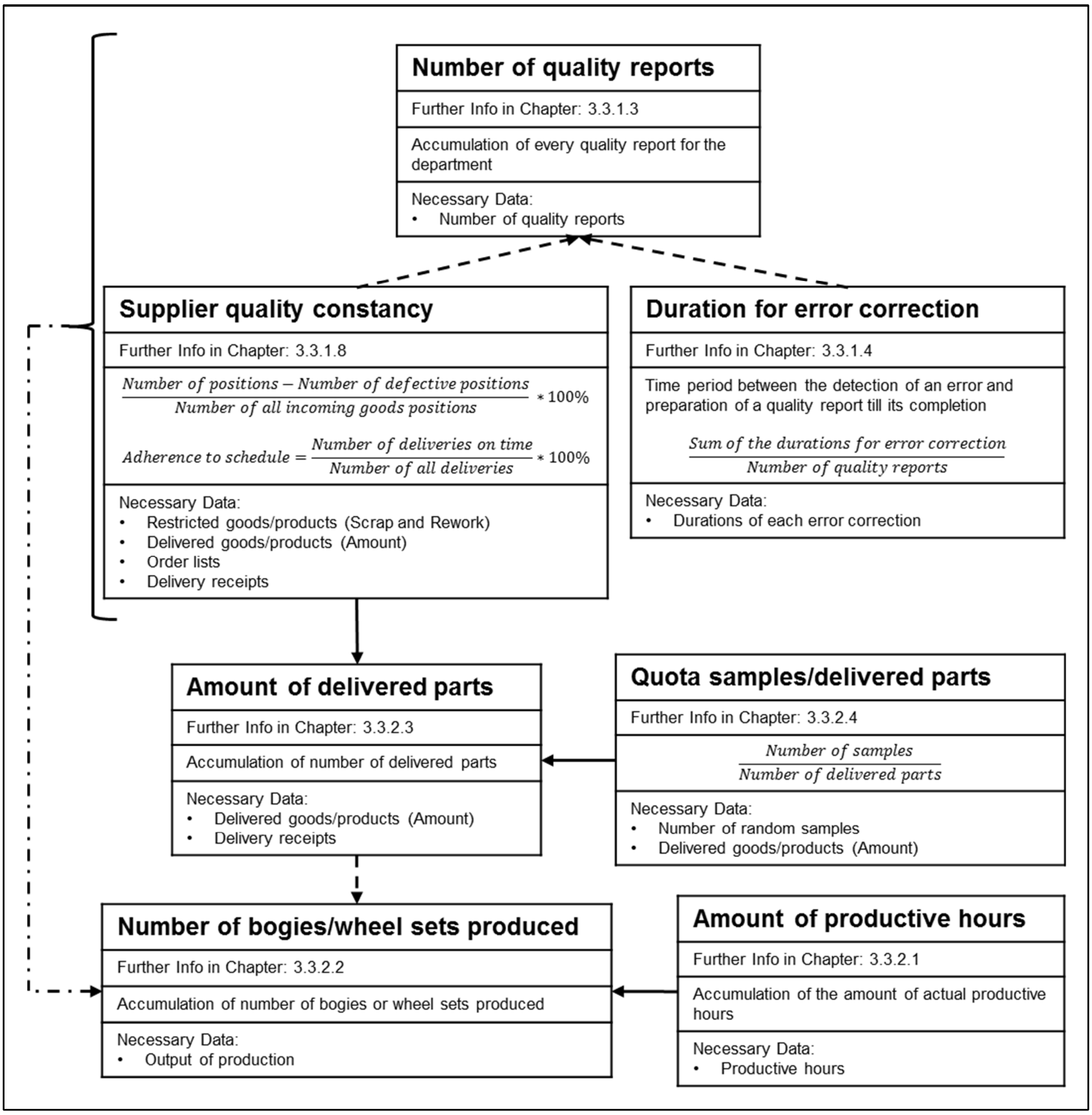
For further information on relations see Chapter: 2.4.2.14

Legend:

- Logical connection ←——
- Hierarchical relation ← – – –
- Empirical relation ← · – · ·

Data source in direction of the arrow

Incoming goods inspection



Jig construction

Number of repaired jigs

Further Info in Chapter: 3.3.1.9

Accumulation of the number of jigs that have been repaired due to mechanical wear and preventive maintenance

Necessary Data:
- Photo-documentation of jigs

Number of existing jigs

Further Info in Chapter: 3.3.2.5

Accumulation of the number of jigs in use, jigs in inventory and jigs in production

Necessary Data:
- Photo-documentation
- Number of jigs in SAP

Number of bogies/wheel sets produced

Further Info in Chapter: 3.3.2.2

Accumulation of number of bogies or wheel sets produced

Necessary Data:
- Output of production

Amount of productive hours

Further Info in Chapter: 3.3.2.1

Accumulation of the amount of actual productive hours

Necessary Data:
- Productive hours

Shipping

Share of deliveries on schedule

Further Info in Chapter: 3.3.2.7

$$\frac{Number\ of\ outgoing\ bogies\ on\ schedule}{Number\ of\ delivered\ bogies} * 100\%$$

$$\frac{Number\ of\ outgoing\ wheel\ sets\ on\ schedule}{Number\ of\ delivered\ wheel\ sets} * 100\%$$

Necessary Data:
- Number of production output
- Delivery schedules

Production Process

Overall Equipment Effectiveness

Further Info in Chapter: 3.3.1.7

$$OEE = Availability\ factor * Performance\ factor * Quality\ factor * 100\%$$

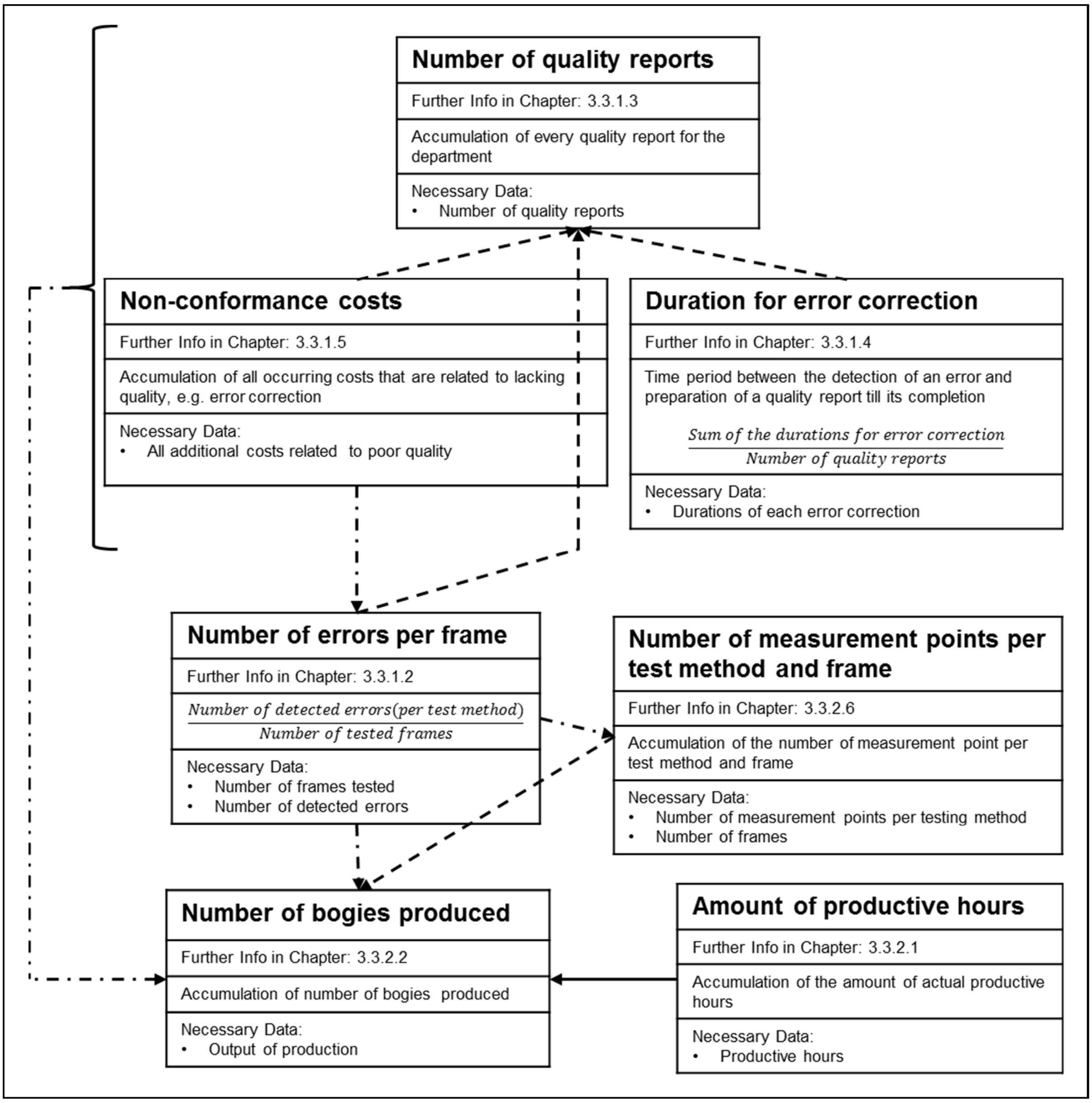
$$Availability\ factor = \frac{Uptime}{Uptime + Downtime}$$

$$Performance\ factor = \frac{Production\ time}{Uptime} * \frac{Actual\ processing\ rate}{Theoretical\ processing\ rate}$$

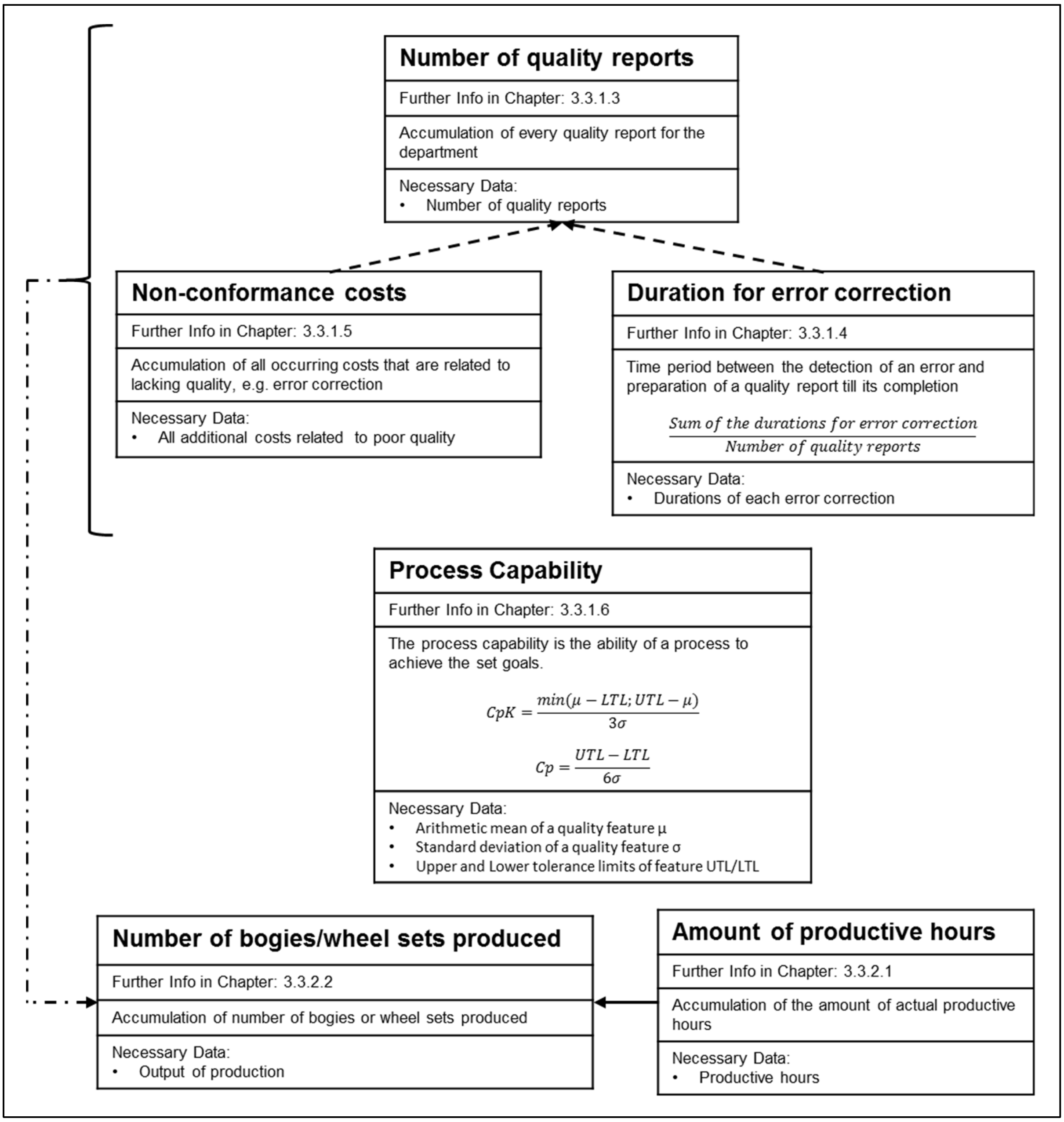
$$Quality\ factor = \frac{Approved\ product\ output}{Actual\ product\ output}$$

Necessary Data:
- Uptimes
- Downtimes
- Production times
- Processing rates
- Product output; approved and restricted

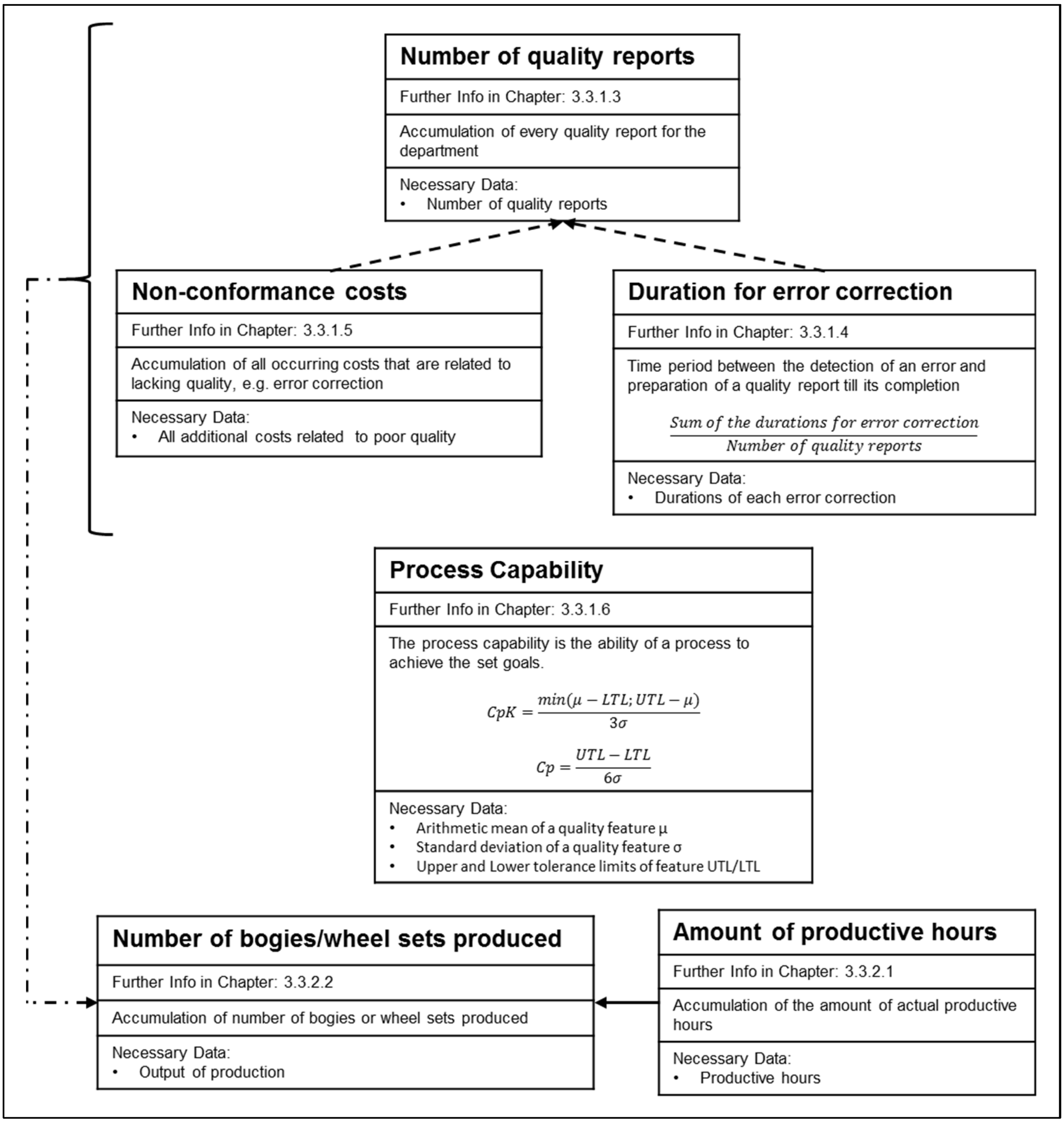
Frame construction



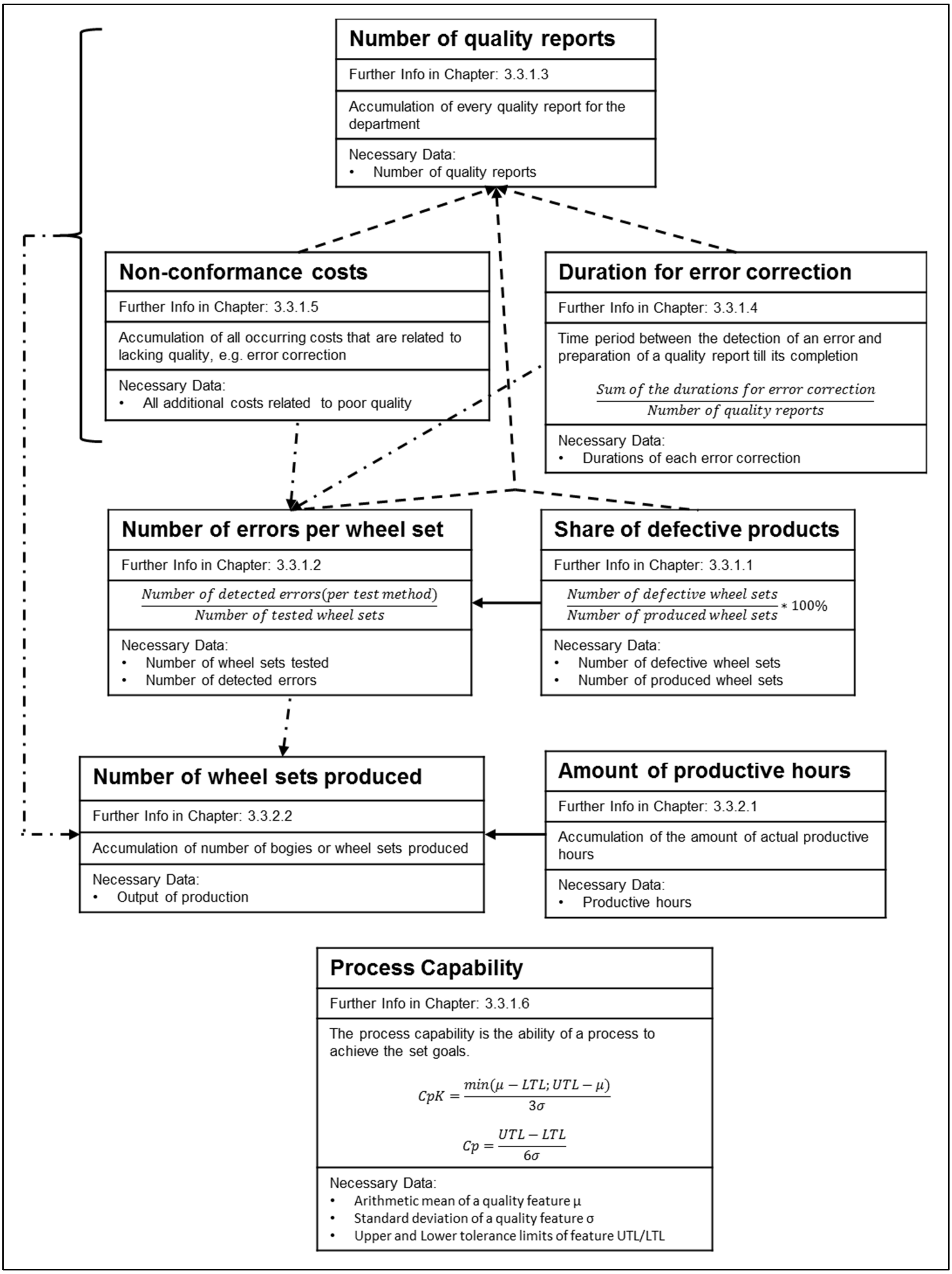
Machining and Frame measurement



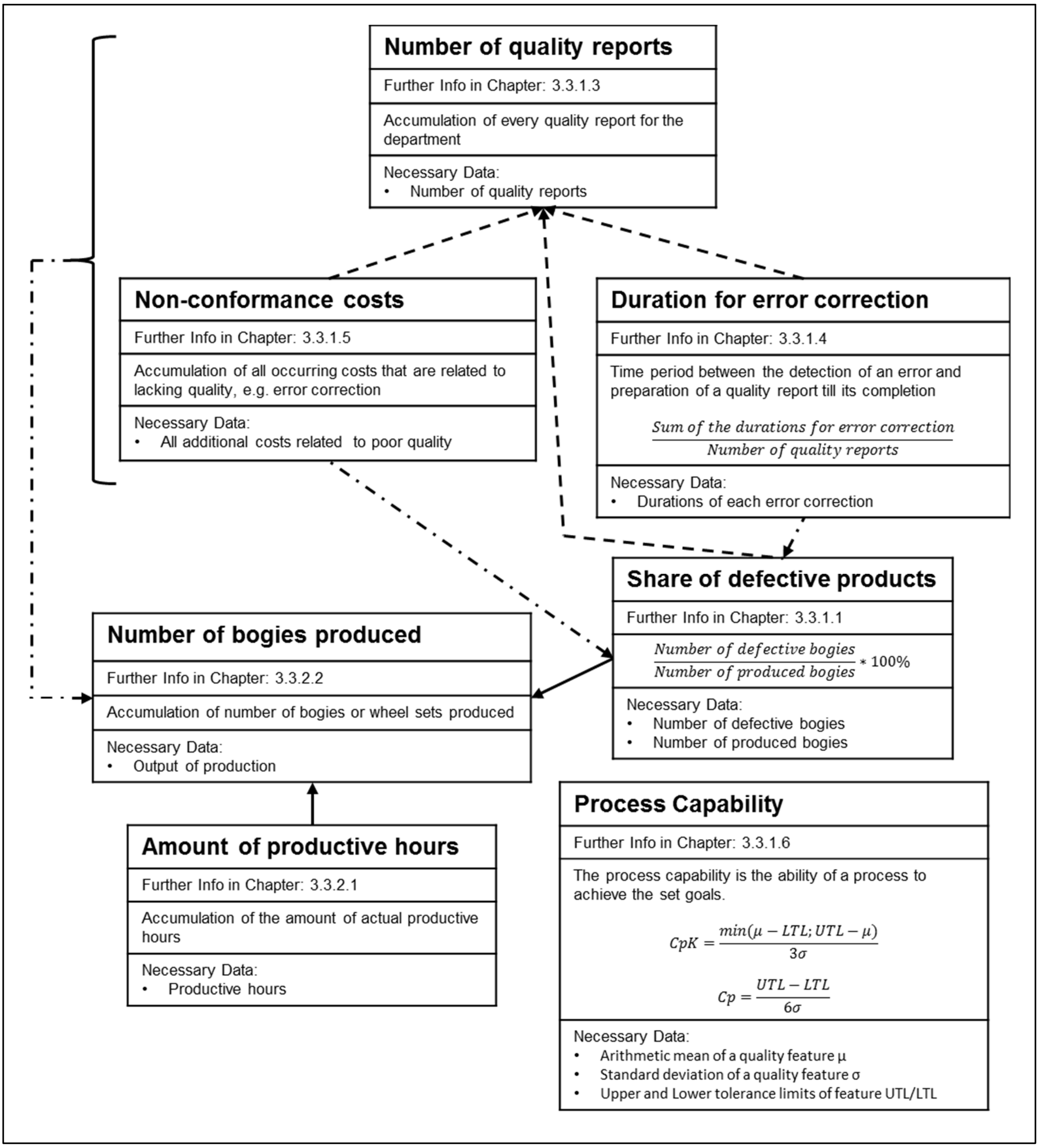
Surface treatment



Wheel set assembly



Assembly and Final inspection



Customer complaint management