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Transparent Quality Performance Monitoring in Batch Production

Master Thesis

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Graz, October 2012

Statutory Declaration

I declare that I have authored this thesis independently, that I have not used other than the declared sources/resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

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Abstract

For decades the concept of quality costs helped companies to calculate how much they spend on quality. Traditional quality costing has been discontinuous and served a pure reporting purpose. While this has been feasible to investigate the basic cost structure, it is of less use to control the firm in day-to-day business. Facing our today's increasingly volatile world, companies need to have access to timely and transparent information on their operational performance to become more agile and decrease reaction times. Therefore, a continuous monitoring of the operational performance including quality is required.

The study, conducted for the automotive supplier Kendrion Passenger Car Systems, suggests an extension of the existing pure quality cost reporting system to a bidirectional quality performance measurement system, that additionally provides traceability of costs back to their source. It makes use of modern IT systems that provide near real-time process data, while in the past most evaluation relied on longer-term and more intransparent accounting data. By following a new development methodology it was possible to create a concept that is both in line with the company's strategy and builds on existing systems and data, making it a very practical approach. As the core outcome a quality scorecard consisting of twelve specifically selected performance indicators in five dimensions was suggested. Detailed specifications provide a robust foundation for the subsequent implementation within the IT systems.

By applying the suggested concept, the company has constant access to information about their current quality performance. Reactive measures in case of quality problems can be accelerated; additionally, the timely and transparent information may facilitate the identification of trends and improvement potential already before quality problems occur. By utilising modern IT systems, the manual workload for quality performance information is decreased, generating further advantages in terms of costs.

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1. Introduction

Since the concept of quality costs was introduced by Juran (1951), it plays an important role in manufacturing and operations management. It helps analysing the costs that arise from providing quality products and services but also the costs in case of quality problems. While reporting of quality cost figures is often seen as the most important purpose of quality costing, the concept has more potential. Additional benefits include the identification of areas that need to be improved and the assistance in the operations and quality control (Yang, 2008).

Extensive reports on quality costing are provided in literature; especially quality cost structures are well documented. However, while the traditional concepts fulfil the reporting aspect, they lack in supporting the extended control tasks. In order to realise the additional benefits, a system design that provides transparency, traceability and continuous evaluation is required.

Many authors have explained why quality costing is useful, but pay less attention to the realisation of such a system. Superville (2001) claims that there is no correct quality cost model for a company due to the quality costs' dynamic nature. These issues may be reasons why, although considered as very important, quality costing is not widely applied in industry (Harry and Schroeder, 2000; Prickett and Rapley, 2001).

The presented study, conducted for the automotive supplier Kendrion Passenger Car Systems, approaches the problem in the following way: Starting from the existing limited failure cost reporting at Kendrion, the state of the art in measurement of operations performance was captured in a literature review. The problem was seen in a wider scope of a quality performance measurement system instead of a pure focus on quality cost reporting. In the presented study a new approach for developing such a system was introduced that helped to implicitly apply key recommendations for this task found in literature, namely strategy orientation and practicability through primarily using existing data.

1.1. Company Profile

The thesis was carried out at Kendrion Passenger Car Systems (PCS)[1], a division of the Kendrion N.V. group. With its product portfolio consisting of solenoids and other electromagnetic components (examples in Figure 1.1), Kendrion Passenger Car Systems acts as a supplier to the automotive industry. The company has five manufacturing locations in five countries: Austria, China, Czech Republic, Germany and the United States of America. Its headquarters are located in Villingen-Schwenningen (Germany).

In 2011, the Kendrion group achieved a total revenue of EUR 268 million and had 1,425 employees. The division Passenger Cars Systems employs in total approximately 600 persons and achieved a turnover of EUR 114 million in 2011, a 30% increase compared to the previous year. The site in Eibiswald (Austria) accounts for EUR 39 million of revenue and more than 135 employees. The division has been awarded ISO/TS 16949:2009 and ISO 14001:2009 certification.

[1] All business information on Kendrion N.V. from internal sources (mid-2012).

(a) Pressure-Control Valve (b) Electromagnetic Brake (c) Shiftlock Solenoid

Figure 1.1.: Examples of Kendrion Passenger Car System products. (Source: Kendrion N.V.)

The Passenger Car Systems business unit develops, designs and manufactures products in accordance with the customer's specific needs. The customers are typically Tier-1 suppliers to the automotive OEMs or in some cases the OEM itself. All five company sites are manufacturing locations. The sales and basic research functions for the Kendrion Passenger Car Systems division are centred at the headquarters in Villingen-Schwenningen. Application development for specific customer requirements is done at the locations such as Eibiswald as well.

The presented study was performed at the company location Eibiswald and at the headquarters in Villingen-Schwenningen. It was supervised by the Quality Manager of the Eibiswald plant in collaboration with the Head of Operations in Villingen-Schwenningen, who is responsible for operations and quality for the whole Passenger Car System division.

1.2. Problem Definition

The project was initiated by the operations and quality managers within Kendrion Passenger Car Systems. The initial definition of the problem, given in written form but also captured in narrative form through interviews, can be divided in four main areas.

Inconsistency: Up to now, a rudimentary quality cost evaluation was in place at the Kendrion Passenger Car Systems group which considered some failure costs. Although all locations reported quality costs to the division headquarters, the calculation differed between the locations, making the costs difficult to compare.

Relevance: Furthermore, a significant increase of the quality levels was achieved by Kendrion Passenger Car Systems in recent years. The currently calculated KPIs may not provide a comprehensive view on the company's performance in terms of quality.

Manual work: The current spreadsheet-based quality cost evaluation requires extensive manual work by the quality staff.

New IT systems: Upcoming new IT systems that are planned to be implemented may provide possibilities to improve the quality cost evaluation.

Considering those issues, the management identified the need for a revised measurement of operational performance in terms of quality. The listed issues built the foundation for the thesis project, which was meant to be targeted to all Passenger Car Systems locations, rather than specifically tailored to one of them. This adds a layer of complexity to the problem, since IT systems and processes vary between locations. Finding a solution as accurate and detailed as possible and at the same time as generic as necessary was an underlying challenge.

1.3. Thesis Aims and Objectives

Derived from the initial problem statement, aims and objectives were collaboratively defined with representatives from the Eibiswald and Villingen-Schwenningen sites (Figure 1.2). The main task, to develop an improved quality cost monitoring solution for the Passenger Car Systems group, was more specifically defined as provision of a continuous monitoring, providing improved transparency. The existing and upcoming data sources should be utilised and a focus put on the alignment with corporate objectives and the practicability of the system.

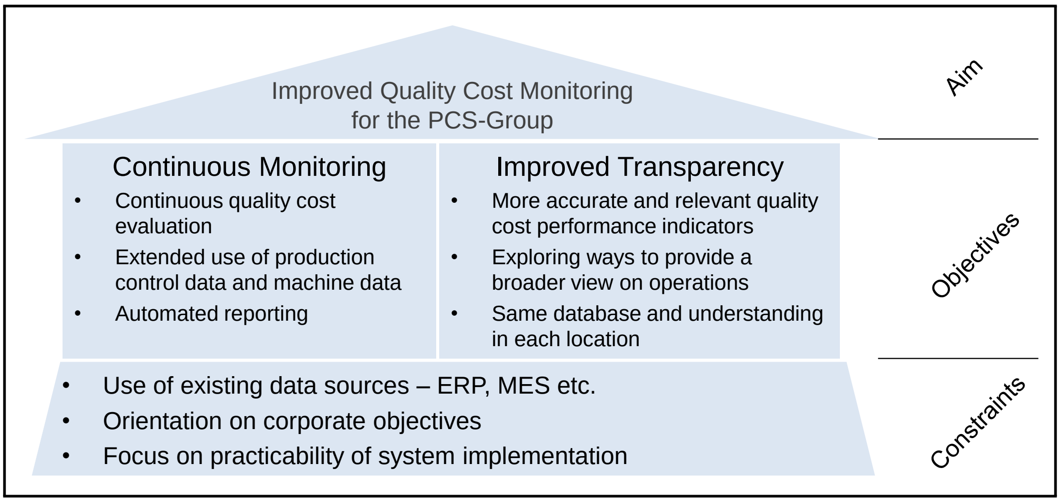

Figure 1.2.: Aims, objectives and constraints of the study. (Source: Author's illustration)

Together with the Head of Operations in Villingen-Schwenningen the decision of limiting the quality cost consideration to non-conformance costs was made. The rationale behind this decision is explained in section 3.1.1.

1.4. Methodological Approach

The study was divided into two high-level elements: Capturing the state of the art in quality cost management and the application of the findings on the real-life example at Kendrion Passenger Car Systems.

The case study element at Kendrion Passenger Car Systems followed a structured methodology that was developed according to recommendations from literature. Its main foundation was the scorecard PMS implementation methodology by Fernandes *et al.* (2006), which relies on suggestions by Kaplan and Norton (2001) and Papalexandris *et al.* (2004). Compared to those methodologies the presented one could build upon an existing corporate strategy and can therefore skip strategy definition steps suggested in the mentioned publications. The applied methodology (Figure 1.3) was divided in three main phases, the *Analysis Phase*, the *Development Phase* and the *Implementation Phase*. For all phases an important method for information gathering and continual validation were interviews with company representatives. The interviewees were staff in the departments for quality management, accounting, process engineering and shopfloor management in Eibiswald as well as operations support and project management in Villingen-Schwenningen. Additionally, initiation and validation meetings could be held with the managing director in Eibiswald and the Head of Operations in Villingen-Schwenningen. In total, more than 30 interviews were held in addition to continual informal discussions and conversations.

Analysis Phase For the first stage of the project a dedicated project initiation step was chosen. Due to the very strategic orientation of the project – a performance measurement system defines the way the company assesses performance and ultimately the success in the future – commitment from

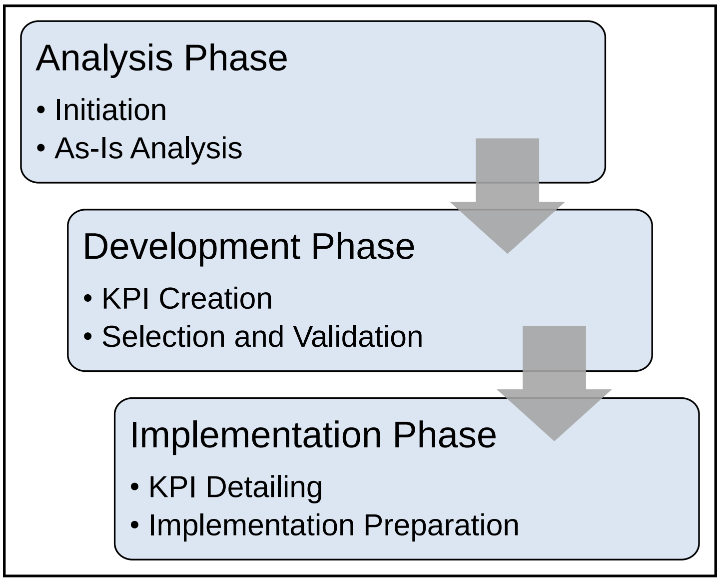

Figure 1.3.: Applied methodology. (Source: Author's illustration)

all involved parties was required. Especially management commitment is considered as a critical success factor, since a project of this type requires extensive access to information and a significant amount of working hours for development, implementation and deployment. In the discussed case management commitment was given throughout the project because it was initiated by the management who had high interest in an outcome that meets current and future needs. In the As-Is Analysis step, an in-depth evaluation of Kendrion's existing quality cost reporting processes was performed. Additionally, existing and upcoming IT systems that play a role in quality management were reviewed, since they are the key enablers of the desired system. Very limited documentation on detailed process flows and systems was present at the beginning of the study, so getting a basic understanding and mapping the processes and IT infrastructure was one key step in the beginning and represented also a first valuable outcome of the study for Kendrion.

Development Phase In the development phase the focus was laid on a two-perspective approach. On the one hand practicability in terms of usage of existing systems and data, on the other hand a strong strategy orientation shall be ensured. This approach was developed to integrate the critical success factors for performance measurement that were found in literature into a structured methodology. It assists the executing persons in applying those suggestions in an easy way by following the structured process. Chapter 3 explains in detail how this aspiration could be realised and how, by applying the multiple step process, a quality performance scorecard was created.

Implementation Phase Within the scope of the study, to create a concept for improved quality performance measurement, the goal of the implementation phase was to provide a robust specification of the developed quality performance measurement system. The specification of the KPIs ensured that the actual implementation within the IT system had a robust definition to be built on. As outcome, specification tables for all KPIs and further explanations were given. In literature contradicting definitions were found for certain performance indicators, which were listed and discussed. Furthermore, additional ideas including literature references for possible next development steps were documented.

The study was started with capturing the theory of modern quality cost management approaches from scientific literature. Findings from this literature review are discussed in the following chapter, the application of those findings on Kendrion Passenger Car Systems is presented in chapter 3 on page 28.

2. State of the Art in Quality Cost Evaluation

Quality is often seen as one of the key factors with which a company can create customer value. It is therefore a foundation for lasting competitive advantage (Jaju *et al.*, 2009). Deming (1996) explains the importance of quality in the following way: He claims that improved quality leads to increased productivity, which results in long-term strength in the competitive business environment. If a company can improve quality levels, rework, mistakes, delays and wastage – in short costs – can be reduced, which leads to extended competitive advantage. As a result of better quality and lower costs and sales prices, the company can achieve a larger market share and stay in business in the long run.

This chapter provides a brief introduction to quality management from its origin to modern applications, discusses the costs associated with quality and finally explores how those costs can be reported and monitored in an effective way.

2.1. Quality Management

The foundation of modern quality management was laid centuries ago. It traces back to several inventions that were subsequently picked up by others and were further developed (Hoyle, 2007). One origin goes back to Eli Whitney who revolutionised mass production of weapons in the end of the 18^{th} century by introducing the concept of interchangeable parts (Folaron, 2003). His idea was to build muskets from components that can be randomly selected and interchanged. He achieved it by manufacturing parts of similar fit and function, or in other words: parts of similar quality. This concept allowed to produce in a more efficient and cost effective way, compared to the previously applied manufacturing of unique, specially fitted weapons. Other milestones in quality management were achieved by Henry Ford and the introduction of the moving assembly line (1910s), for which component consistency is an essential prerequisite; by Western Electric and its employees Joseph M. Juran, W. Edwards Deming and Walter A. Shewhart (1920s); and others. An important role in the evolution of quality management played Japanese companies, who took a leading position in the developments of quality management from the 1950s to the 1970s (Folaron, 2003). In 1987 the International Organization for Standardization (ISO) introduced its ISO 9000 standard, a set of quality management principles that are widely applied in industry (Folaron, 2003). At the same time Motorola became popular for its *Six Sigma* programme, which puts special attention on variances in manufacturing.

An interesting learning from the history of quality management, as it is seen today, is that it originated from different places and companies, but all originators were practising manufacturers. Only in later days academia picked up the quality practises from the work places and analysed them for generating universal management principles (Hoyle, 2007).

Throughout the development of quality management several definitions for the term *quality* were suggested. Hoyle (2007) lists some of them:

- A degree of excellence
- Conformance to requirements
- The totality of characteristics of an entity that bears on its ability to satisfy stated or implied needs
- Fitness for use
- Fitness for purpose
- Freedom from defects, imperfections or contamination
- Delighting customers

Especially noteworthy are the definitions by Crosby (1979), *"Conformance to requirements"* and another attempt, given by ISO 9000 (2005), *"Degree to which a set of inherent characteristics fulfills requirements."* since they provide a very practical definition for manufacturing practise.

In the field of managing quality, one popular concept was suggested by Joseph M. Juran. He shaped the term *Quality Trilogy*, by dividing the quality-related activities in three core processes *quality planning*, *quality control* and *quality improvement* (Juran, 1986, p.21):

1. **Quality Planning:** *"The process for preparing to meet quality goals."*
   The quality planning phase includes the identification of the external and internal customers as well as their needs. With respect to this needs, the features of the products or service are developed. Next, by having the target of lower overall costs in mind, quality goals for meeting the customer and supplier needs are set and a process for realising the product or service is developed. Finally, a prove of the process capability, that the process can produce the products or services under operating conditions, is done.

2. **Quality Control:** *"The process for meeting quality goals during operations."*
   The first step in quality control is the selection of the control subject. After deciding upon what to control, the units of the measure and the measurement itself is established. Next steps are the definition of a performance standard for the control subject and the actual performance. Occurring differences between standard and actual performance then need to be interpreted and actions on the difference need to be made.
3. **Quality improvement:** *"The process for breaking through to unprecedented levels of performance."*
   In quality improvement it is important to prove the need for optimisation, then to identify specific improvement projects. Subsequently, organisational actions for guiding the projects and the diagnosis are taken. After diagnosis and finding the causes, remedies are provided and their effectiveness under operating conditions are proved. Last step is to ensure that the gains can be controlled and as a result maintained.

One popular quality concept that combines various quality management streams and methods is Total Quality Management (TQM). It started as total quality assurance in the 1950s and was shaped in both the USA and Japan (Folaron, 2003). Martínez-Lorente *et al.* (1998) found that it is difficult to define the term TQM since authors use it in slightly different ways. They approached the definition by comparing the constructs or dimensions of TQM as reported by Ahire *et al.* (1996), Dale *et al.* (1994), Flynn *et al.* (1994) and Saraph *et al.* (1989), which are summarised in Table 2.1.

Table 2.1.: TQM constructs. (Source: Martínez-Lorente *et al.*, 1998)

	Dimension	Description
1	Top management support	Top management support is a fundamental success factor for TQM implementations. Top management needs to play a leading role in starting and driving the TQM initiatives.
2	Customer relationship	Fulfilling the customer needs is a key goal of quality management. Their needs must be understood and kept in mind by all employees. Customer relationship management also means to know their level of satisfaction.
3	Supplier relationship	Long-term relationship and collaboration with the suppliers is one factor for improving the product's quality. For the supplier selection, attention has to be paid on quality, which is more important than price.
4	Workforce management	The three core principles of workforce management are: training, empowerment of workers and teamwork. The management of personnel including recruitment and training needs to ensure that the employee takes part in the improvement process.
5	Employee attitudes and behaviour	Cross-functional work, focus on common goals or loyalty to the organisation are important factors for on-going success and therefore need to be promoted by the company.
6	Product design process	A cross-functional design process is recommended in order to collaborate on a design that fulfils the customer requirements within technical, technological and cost constraints of the company.

Continued on next page

Table 2.1 – *Continued from previous page*

	Dimension	Description
7	Process flow management	Different tools and methods have to be used in order to achieve mistake proof processes and to get processes under statistical control. The methods include the 5S methodology (sorting, straightening, systematic cleaning, standardising and sustaining), SPC (statistical process control) or self-inspection.
8	Quality data and reporting	Data and information on quality have to be available and part of the quality management system, which is visible for all employees. Records about cost of quality and other quality performance indicators have to be kept.
9	Role of the quality department	The quality department needs to have certain autonomy within the company and the chance to talk to the top management.
10	Benchmarking	Benchmarking for key processes should be undertaken.

From Table 2.1 it can be seen that TQM is a management approach with a wide area of influence. It does not only consist of product/service quality which is commonly linked to manufacturing performance and process management, but also looks at the relationship to supplier, the workforce and the employee's attitude as well as to the design of the product/service. Like other quality-related concepts it claims top management to be a key factor for success and identifies high relevance of quality data and information, on both internal performance as well as for comparison to others. This information includes the cost of quality, which is an important aspect for measuring and managing the impact and success of quality initiatives. The following chapter takes a closer look at cost of quality evaluations.

2.2. Quality Cost Models

Philip B. Crosby claims that *"Quality is free"* and refers to the importance of *"doing jobs right the first time"* (Crosby, 1979, p. 1). However, despite this striking statement there is consensus among many authors that producing quality products does cause costs. Several approaches towards the relationship between quality and costs can be found in quality management literature.

The concept of quality cost (or cost of quality) has its roots in reports by Juran (1951). Yang (2008) lists several definitions of quality costs and poor quality costs. One of them, cost associated with preventing, finding, and correcting defective work, was suggested by Mukhopadhyay (2004) and represents a practical and complete definition of the term. Bland *et al.* (1998) propose a definition of comparing actual operating costs to costs in a system where no failures of the operation's systems and no mistakes by staff occur. Most popular definitions have in common that they do not only include the costs of poor quality but also the costs associated with meeting the quality standards.

A number of approaches towards modelling quality costs were suggested; however, two models have gained highest popularity. The most widely accepted quality cost model (Plunkett and Dale, 1987) was suggested by Feigenbaum (1956) and consists of the three categories: prevention, appraisal, and failure costs (often referred to as P–A–F categories). A list by Wood (2007) provides an overview of the commonly used categorisation of quality costs according to the P–A–F model. He splits failure costs further and separates internal from external failure costs:

Prevention costs: Costs that arise from all activities that are intended to prevent poor quality. These costs include quality planning, supplier capability assessment, quality improvement activities and meeting, process capability evaluations and quality training and education.

Appraisal costs: Appraisal costs are associated with evaluating and measuring products to ensure conformity to defined quality standards; also auditing activities are normally seen as part of the appraisal costs. Further examples are incoming goods inspections, inspections during manufacturing, final inspections and calibrations of measurement equipment.

Internal failure costs: Failure costs that occur before the goods are shipped to the customer. Typical examples are scrap, rework, retesting and reinspection.

External failure costs: Failure costs occuring after delivery of the product to the customer, for example warranty, product recalls or customer complaint handling.

The P–A–F scheme is often used in industry and academia for a basic categorisation of different quality cost types. However, there are various drawbacks associated with this model. Tsai (1998) explains some points of criticism:

- Differentiation of prevention cost is generally difficult. Most activities in a well-managed firm are somehow associated with prevention of failures.
- This leads to the fact that in companies many prevention activities are done which may never be part of the quality costs.
- Unique allocation of costs into the P–A–F categories is often difficult.
- The classic P–A–F definitions do not include intangible cost types. If included, the definitions of cost types such as "loss of customer goodwill" are vague.

- The quality cost model draws the attention on the costs and the quality-related cost reduction and ignores the potential of increased price and attractiveness leading to increased sales by better quality levels.
- The traditional quality cost evaluations which try to achieve a certain quality level for highest cost reduction do not reflect the philosophy of continuous improvement found for example in TQM.
- Major focus in TQM is on process improvement. Many quality initiatives that look on a process are cross-functional and therefore difficult to allocate in prevention, appraisal, internal failure or external failure costs.

Authors also point out that levelling the different quality cost categories can be difficult. A certain balance is important for maintaining a decent overview of the relevance of the calculated costs. As an example, one issue here is the allocation of overheads in the quality costs. Some companies add them to the direct labour which adds to failure costs as rework and scrap. In this case, *"rework and scrap costs become grossly inflated compared with prevention and appraisal costs"* (Dale and Plunkett, 1991, p. 45).

The rise of more process-oriented quality management approaches like TQM and the mentioned criticisms concerning the P–A–F model lead to the development of the second popular quality cost model. The so-called process cost approach was introduced by Porter and Rayner (1992) who defined it as the sum of the costs of conformance (COC) and the costs of non-conformance (CONC) for a process. COC are the costs of producing products or services to the process' required standards. CONC are the failure costs when the process is not operated to the required and specified standard. A graphical representation of the relations between the traditional P–A–F and the process cost model is given in Figure 2.1.

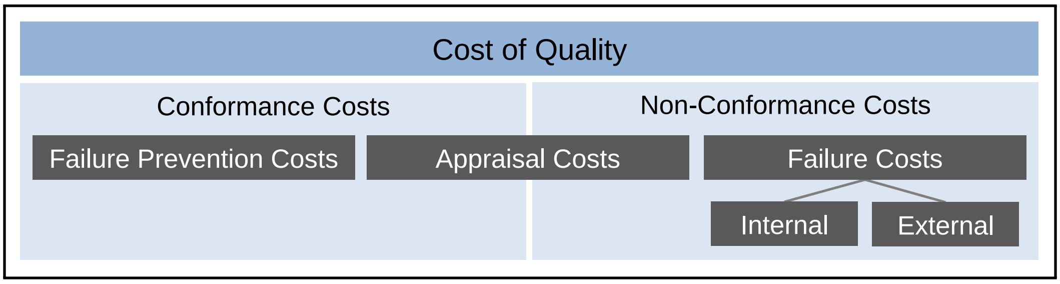

Figure 2.1.: Comparison P-A-F and process quality cost model. (Source: Author's illustration)

When putting the quality costs for a product into relation to revenue, quality cost shares ranging from 10 to 30% were found and reported in academic publications (Berry and Parasuraman, 1992). Since quality costs, especially non-conformance costs, directly influence the profitability of a company, quality cost optimisations plays an important role in the manufacturing business.

A key question is about the return of quality expenses, when quality improvement initiatives are seen as investment. For example companies like Motorola or General Electric were able to lower the quality costs from 30 to 2% of their revenue while at the same time improving their product quality (Superville *et al.*, 2003). Desai (2008) reports that for manufacturing companies the cost of poor quality (rework and scrap) ranges from 5 to 35% of the sales revenue. However, Wasserman and Lindland (1997) warn that the cost of quality is determined by the used quality measurement, therefore the numbers should only be seen as a rough approximation.

Two main hypotheses for the relation between quality levels (0% quality to a virtual 100% quality) and total quality costs exist. While older literature (Juran, 1962; and others) speaks about a certain quality level below 100% where the sum of all quality costs has a minimum, newer literature (Kume, 1985; Schneiderman, 1986; Wolf and Bechert, 1994) suggests that highest quality levels result in lowest overall quality costs. Figure 2.2 illustrates those two models. Ittner (1996) claims that internal failure costs are the most expensive part and prevention is the least expensive part of the occuring costs for in quality management. This would support the latter hypothesis.

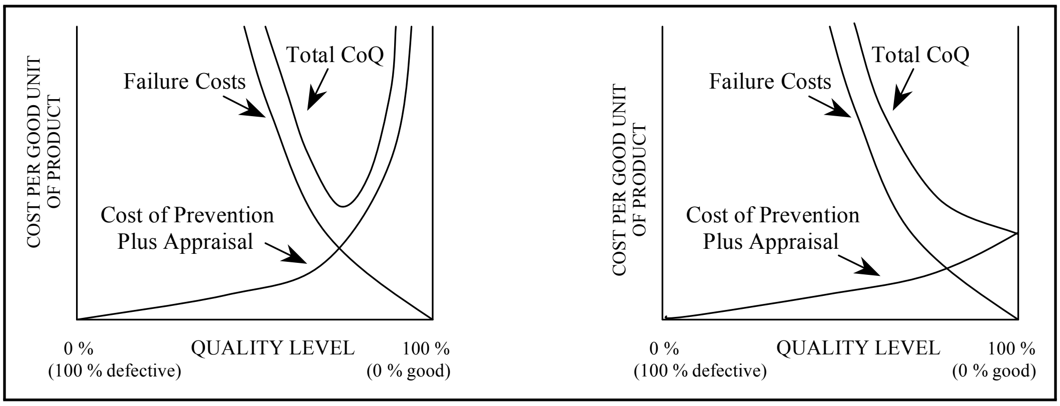

Figure 2.2.: Classical (left) and modern view (right) on total cost of quality. (Source: Schiffauerova and Thomson, 2006)

There is a general consensus that spending in failure prevention is the quality investment with the highest return, followed by spending in the categories appraisal and failure costs. In reality, the amount of spending is the other way round; companies spend just 0.5 to 5% of their total quality expenses on prevention, 10 to 50% on appraisal and 50 to 90% on internal and external failure costs (Superville and Gupta, 2001).

As discussed, prevention of failures has shown to be the most effective way of meeting quality standards with lowest costs. In case a quality issue cannot be prevented, the appraisal processes should facilitate an early detection. An interesting relationship between quality costs and the time of defect detection can be observed. The earlier a quality problem is found, the less expensive it is.

Roth and Morse (1983, p.227) quote a general manager from Hewlett-Packard, who explains the possible resulting costs from a defective two-cent resistor:

> *"If you catch a two cent resistor before you use it and throw it away, you lose two cents. If you don't find it until it has been soldered into a computer component, it may cost USD 10 to repair the part. If you don't catch the component until it is in the computer user's hands, the repair will cost hundreds of dollars. Indeed, if a USD 5,000 computer has to be repaired in the field, the expense may exceed the manufacturing cost."*

This progression of failure costs over is often expressed by the *"1-10-100 rule"* (Stasiowski and Burstein, 1993; Omachonu and Ross, 2004): USD 1 spent on prevention activities will save USD 10 dollars in failure correction in-house or USD 100 on failure costs for problems discovered by contractors or clients. An illustration of the rule is given in Figure 2.3.

The automotive industry is especially aware of the severity of late detection of quality issues. In the case of major quality problems the car manufacturer may need to start a recall to get already sold and shipped units back to their dealers for inspection and repair. Examples in history have shown that those product recalls have severe consequences for the manufacturer. In 1996, Ford had to call back 8.7 million vehicles which created cost of estimated USD 2 billion (Inman and Gonsalvez, 1998). In 2010, Toyota performed a recall of about 436,000 vehicles for brake defects, after recalling eight million units due to accelerator and floormat problems (BBC, 2010). According to Sorge (1996), some car manufacturers spend up to USD 1000 per vehicle on warranty repairs. However, the damage to the company may not stop at direct expenses for repairs. Further indirect financial burden from lost customer satisfaction, damaged brand image and value or re-

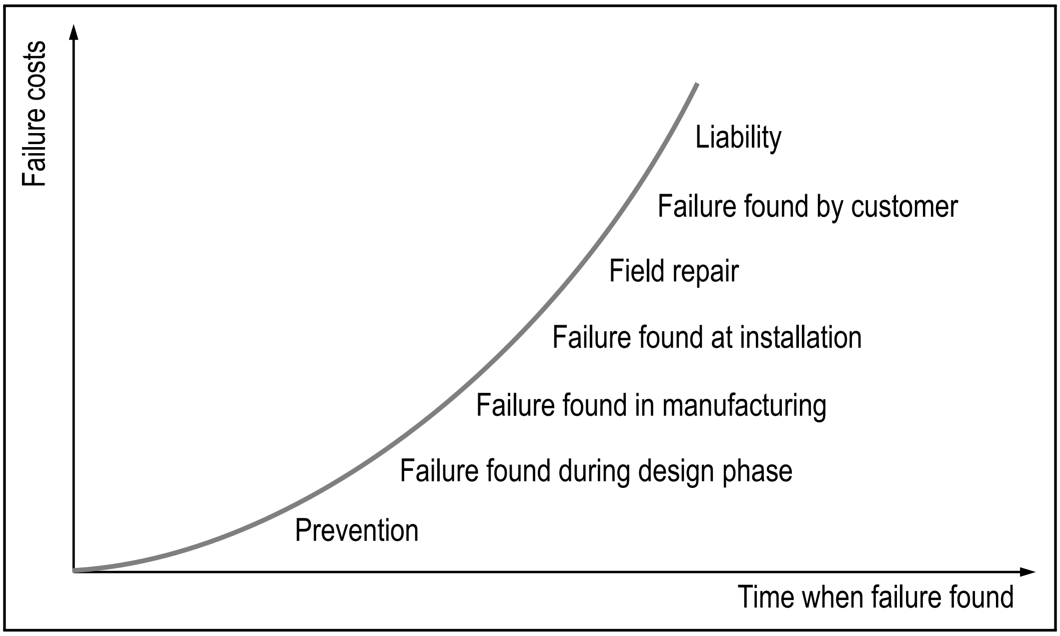

Figure 2.3.: Illustration of the *"1-10-100 rule"*, the failure cost progression following delayed detection. (Source: Author's illustration adapted from Sameh, 2010)

duced stock price may occur. For example, due to a recall, Audi's USA sales dropped from about 74,000 in 1985 to 21,225 in 1990. Therefore, managing quality throughout the supply chain in order to prevent quality problems in the first place or, if not successful, to detect failures in early stages is a main goal in automotive quality management.

From the presented findings it can be seen that quality-related costs play an important role in quality management. In general, quality cost information helps expressing quality related activities in the language of management (Dale and Plunkett, 1991; Superville and Gupta, 2001; Desai, 2008). Although it is recognised that quality cost information can be useful in various ways (Omachonu and Ross, 2004, p.213), research shows that it is not widely applied in industry (Williams *et al.*, 1999; Cheah *et al.*, 2011).

Tsai (1998) finds that there is a lot of literature explaining why quality cost measurement is important and what should be included in such a system, but seldom reports how to actually measure quality costs. Plunkett and Dale (1988) think that quality cost categories depend on the company of interest, so it is a good idea to develop a cost approach specifically adjusted for the company's needs (Schiffauerova and Thomson, 2006; Jaju *et al.*, 2009). According to Dale and Plunkett (1991, p. 38) *"the collection and synthesis of quality costs is very much a matter of searching and shifting through data which have been gathered for other purposes"*. Oakland (1993, p. 210) points out that quality costs should not be absorbed into overheads, for Omachonu and Ross (2004, p. 213) it is central to identify where costs are caused, rather than incurred of allocated. Therefore, traceability and visibility is an important aspect of a quality cost evaluation system. However, Tsai (1998) finds that there is no adequate method to trace quality costs to their source. Sesma (2000) confirms that in beyond theory the cost transparency is a big issue and claims that in industry practice a large portion of non-conformance costs is hidden, which is illustrated in the iceberg model in Figure 2.4.

Most quality cost literature explores the topic on a very generic level, more specific publications normally discuss one-time cost structure analyses with longer-term data (Schmahl *et al.*, 1997; Desai, 2008; Jaju *et al.*, 2009). Jaju *et al.* (2009) suggests to measure quality costs regularly, but in literature little information on constant IT-supported quality cost monitoring, using (near) real-time production and process data, exists. Available sources like Pursglove (1996) and Desai (2008) provide analyses in a narrow scope and achieve limited success, Brad *et al.* (2006) and Fang *et al.* (2008) focuses mainly on the technical implementation and programming aspect of the problem.

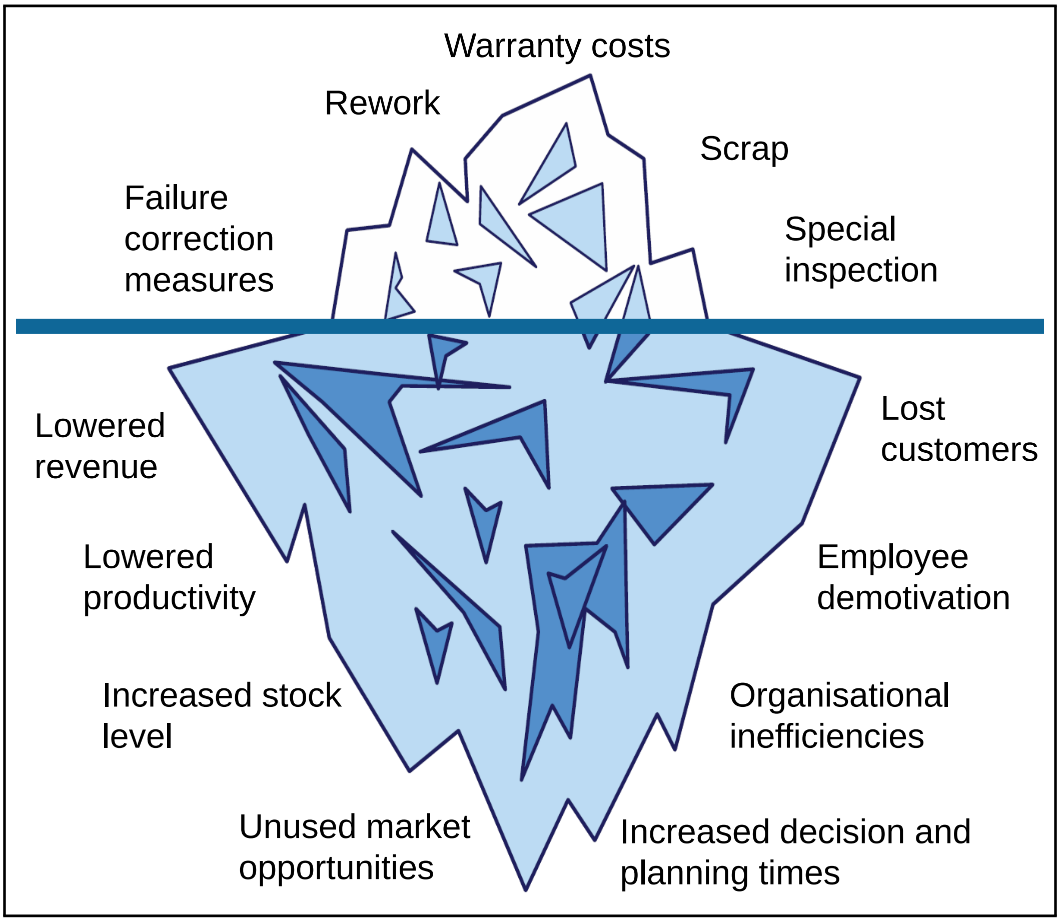

Figure 2.4.: "Iceberg of diseconomies". (Source: Author's illustration adapted from Sesma, 2004)

2.3. Quality Performance Measurement

Traditional cost of quality evaluation has several limitations. Malone and Sinnett (2005) report that traditional metrics do not facilitate the identification of the root causes of problems. Furthermore, traditional accounting-oriented metrics fall short on decisions for longer-term, strategic actions (Kaplan and Norton, 2005).

Following those inadequacies, newer literature suggests an extension of the traditional quality costing towards a performance measurement systems (PMS). Neely *et al.* (2005, p.1229) defines it as *"a set of metrics used to quantify both the efficiency and effectiveness of actions"*. One popular example is the balanced scorecard, *"a set of measures that give top managers a fast but comprehensive view of the business"* (Kaplan and Norton, 1992, p.71), which led to increasing interest in holistic performance measurements including both financial and non-financial key performance indicators (KPIs) (Bahsin, 2008). The initial balanced scorecard has four dimension: Financial, Customer, Internal Business Processes and Learning and Growth. Kaplan and Norton designed their model as a practical management tool, which should capture a balanced view on the performance by answering the core questions described in Table 2.2. Kaplan and Norton (2001) further suggest that a scorecard shall reflect the organisational strategy, in order to make it a powerful tool for evaluating the success in achieving the strategic goals.

Implementation methodologies and the impact of scorecard PMS were reported by Kaplan and Norton (2001), Ittner and Larcker (2003), Papalexandris *et al.* (2004), Doolen *et al.* (2006), Fernandes *et al.* (2006) and Tung *et al.* (2011). Rigby (2001) and Malmi (2001) analysed a number of scorecard implementations and confirmed their success.

Table 2.2.: Original balanced scorecard dimensions. (Source: Kaplan and Norton, 1996, p.4)

Dimension	Key Question
Learning and Growth	"To achieve our vision, how will we sustain our ability to change and improve?"
Internal Processes	"To satisfy our shareholders and customers, what business processes must we excel at?"
Customer	"To achieve our vision, how should we appear to our customers?"
Financial	"To succeed financially how should we appear to our stakeholders?"

2.4. IT Systems in Operations Management

An essential prerequisite for a performance measurement system is a robust data foundation. In an typical manufacturing environment various IT systems are used which can provide the required data. Two common IT systems in production are Enterprise Resource Planning (ERP) systems and Manufacturing Execution Systems (MES).

According to Shehab *et al.* (2004), ERP is a business management system for managing all business functions within an organisation. Designed as integrated sets of software the solutions includes functionalities in the areas of financial and cost accounting, sales and distribution, materials management, human resource, production planning and computer integrated manufacturing, supply chain and customer information. Due to the orientation on business management, ERP systems normally do not provide manufacturing control functionality. Its data does not provide the required depth and information granularity required for effective control, additionally they lack in provision of timely data. The gap between the physical manufacturing layer and the business management layer is filled by MES as shown in Figure 2.5.

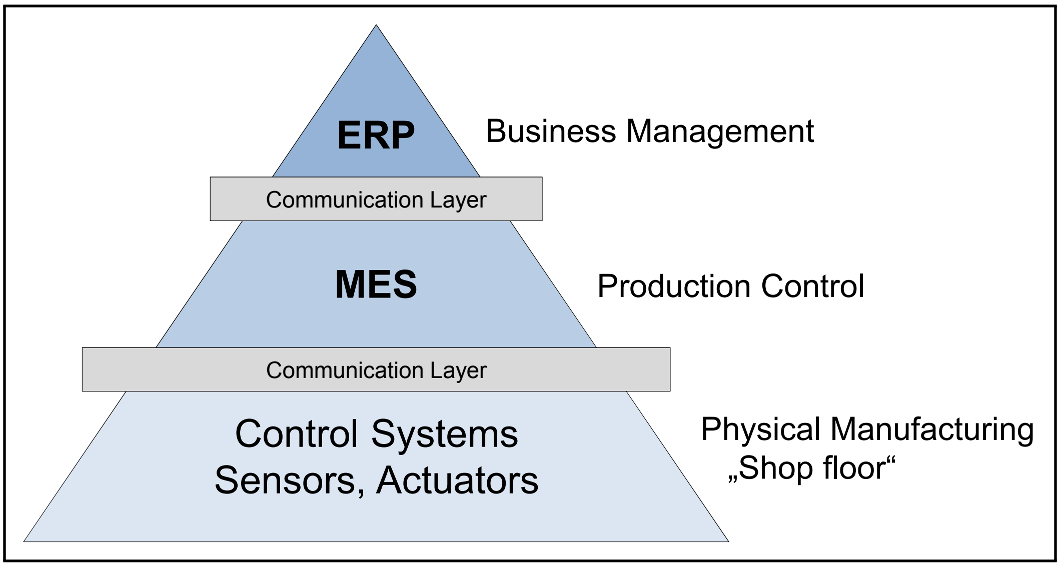

Figure 2.5.: Automation pyramid. (Sources: Author's illustration adapted from Zuehlke, 2010, and Engell and Harjunkoski, 2012)

MES systems typically provide the following functionalities (Kletti, 2007, p. 22):

- Detailed production planning and scheduling control
- Operations resource management
- Materials management
- Personnel management
- Data acquisition and processing
- Interface management
- Quality management
- Information management
- Performance analysis

Considering the listed tasks of MES as well as the system architecture, a major strength of MES lies in the access to real-time production data and the timely processing and analysis of the generated information.

2.5. Conclusion of Literature Findings

The review of quality management literature revealed that quality at a manufacturing company should be seen as cross-functional attitude, rather than a set of tools within the production. Total Quality Management involves different functions within the organisation and extends the view up- and downstream of the supply chain to form a holistic quality approach.

The traditional quality cost concepts are well established, but have certain limitations. Quality costing is traditionally discontinuous and based on longer-term data. Commonly set up as pure reporting system, it does not provide the important traceability of failures to their source. Hence, while it is useful to get to know the basic quality cost structure, it is of little value for controlling the quality-related operations. Performance measurement systems (PMS), as a comprehensive performance evaluation approach that uses financial and non-financial performance indicators, have demonstrated their potential to overcome those limitations. Although the general PMS concepts are well-documented, little information is available on continuous IT-based monitoring. Due to the automation system architecture the MES system promises to be the link between the traditional accounting-type quality cost calculation and the actual manufacturing process that can enable the desired traceable PMS set-up.

Combining the application of the concept of quality costing within a comprehensive scorecard PMS and a continuous IT-based evaluation seems to be a promising way to achieve the aim and objectives set in this study.

3. Extended Quality Performance Measurement for Kendrion PCS

The application of the literature findings at Kendrion Passenger Car Systems is described in the following chapter. In accordance with the goal of developing a monitoring system for continuous measurement and more transparent quality performance, a concept for a tailored quality performance measurement system was designed.

3.1. Analysis Phase: Existing Quality Cost Management

The following discussion of the analysis phase covers the situation found at the beginning of the study. It provides an overview of Kendrion's basic manufacturing process and the implications for quality management. At that time the implementation of new IT systems for business and manufacturing management was planned. Although those systems were intended to be the foundation of the extended performance measurement system, an analysis of the existing IT systems in production management and the quality cost calculation were conducted. As a result of this analysis, an understanding of Kendrion's prerequisites and needs was achieved. By capturing the changes the new system would cause, the starting point for the development phase could be defined.

3.1.1. Production System

Kendrion Passenger Car Systems manufactures a variety of electromagnetic components including solenoids and valves for the automotive industry. It operates as Tier-1 or Tier-2 supplier and is therefore an intermediate part of automotive supply chains. Production at Kendrion is driven by high requirements for quality and efficiency, causing special manufacturing practices which are discussed in more detail below.

Description and Characteristics

The production at Kendrion Passenger Car Systems consists of three core processes: (1) coil winding, which is considered as a core competence of the company; (2) assembling and (3) automated end-of-line inspection, which is performed as 100% testing. Besides those core processes, Kendrion follows a strict outsourcing strategy; all components are purchased from suppliers.

Although the assembly lines range from fully automated cleanroom lines to semi-automated and manual lines, the underlying manufacturing process (Figure 3.1) is universal. It is worth mentioning that the incoming goods inspection was completely eliminated in recent years due to cost reasons. This implies that the supplier quality need to meet high standards, since defective parts are detected when they have already reached assembling. In case non-conforming supplied parts are detected, it normally requires at least a temporary stop of the assembly line.

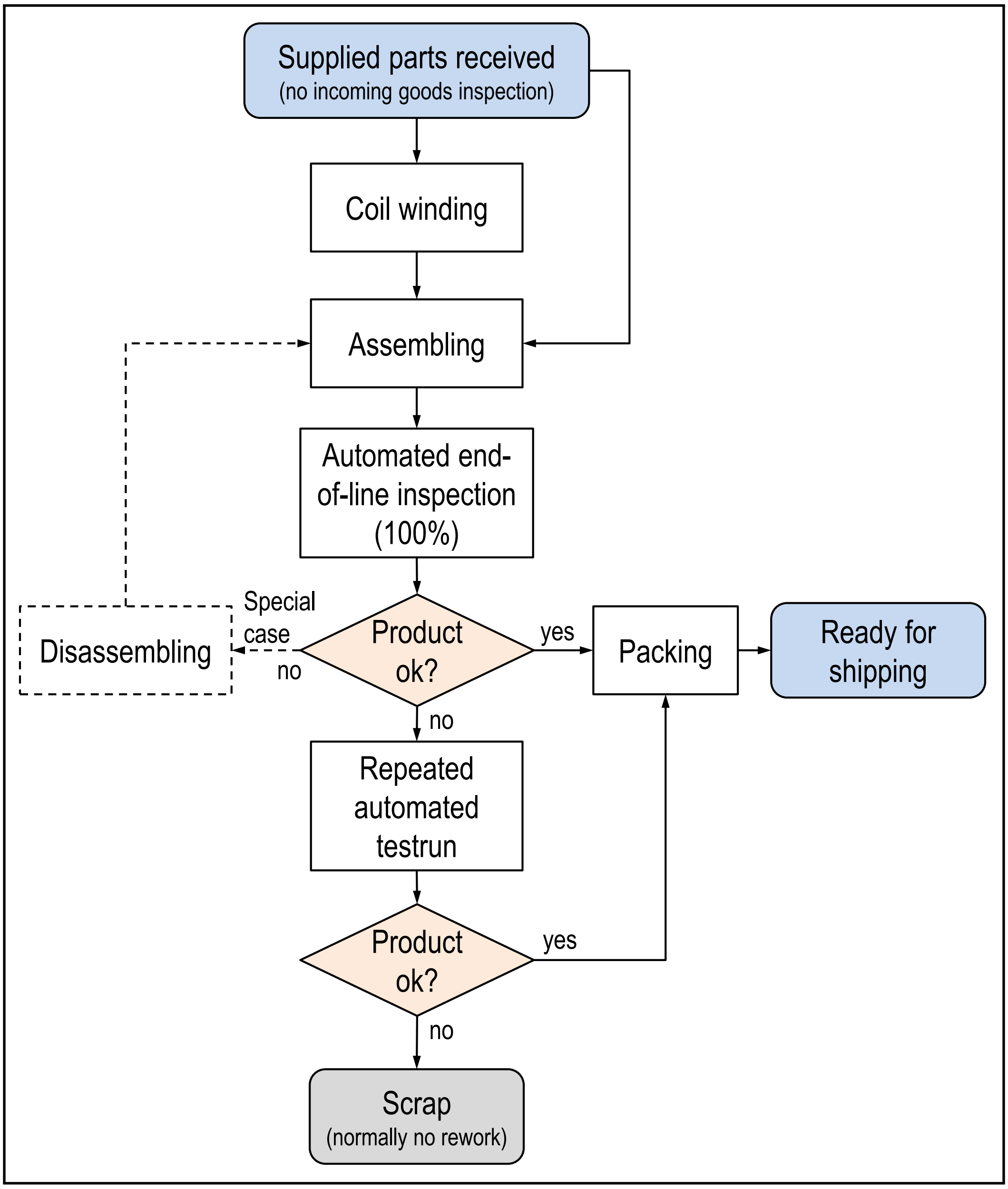

Figure 3.1.: High level view on the manufacturing process. (Source: Author's illustration)

As seen in Figure 3.1, the 100% end-of-line (EOL) inspection is performed in the following way: If a product fails in the first inspection it is retested in a second run. If it fails in the second test run as well, it is scrapped. If it conforms in the first or the second test it proceeds to packing. Dependent on the product, the EOL test consists of up to five single inspections, as seen in Table 3.1. All tests are fully automated, except the visual inspection.

Table 3.1.: End-of-line inspection.

Performed for all products	Performed for selected products
• Force-stroke measurement	• Optical geometry measurement (camera)
• Proof voltage testing	• Impulse voltage testing
• Visual inspection at packing	• Reed-switch testing

Implications for Quality Management

Suppliers to the automotive industry face strict performance requirements given by their customers. External failures, that are failures after delivery to the customer, are one of the most critical aspects in quality management since they can result in very high costs. Hence, a major goal of Kendrion Passenger Car Systems is to keep this external failure rate as low as possible. Besides other measures, it is achieved by applying the 100% testing and a strict scrapping policy. As a result, the low external failure rate is achieved on the expense of higher testing costs and high internal scrap rates.

When looking closer at the quality costs over time, significant differences between the cost categories can be seen (see Figure 3.2 for a qualitative illustration). While failure prevention and appraisal costs can be considered as relatively constant over time, the failure costs show more volatility. Internal failures occur unsteadily but normally result in manageable costs.

Critical are external failures, which occur rarely but can cause considerable costs, for example due to exchange, recall or penalties. In severe cases external failures can put the company as a whole financially at risk, especially in case of major incidents or product recalls. As a result of those cost characteristics, at Kendrion failure prevention and appraisal cost are not monitored in detail; special focus is on internal and external failure costs.

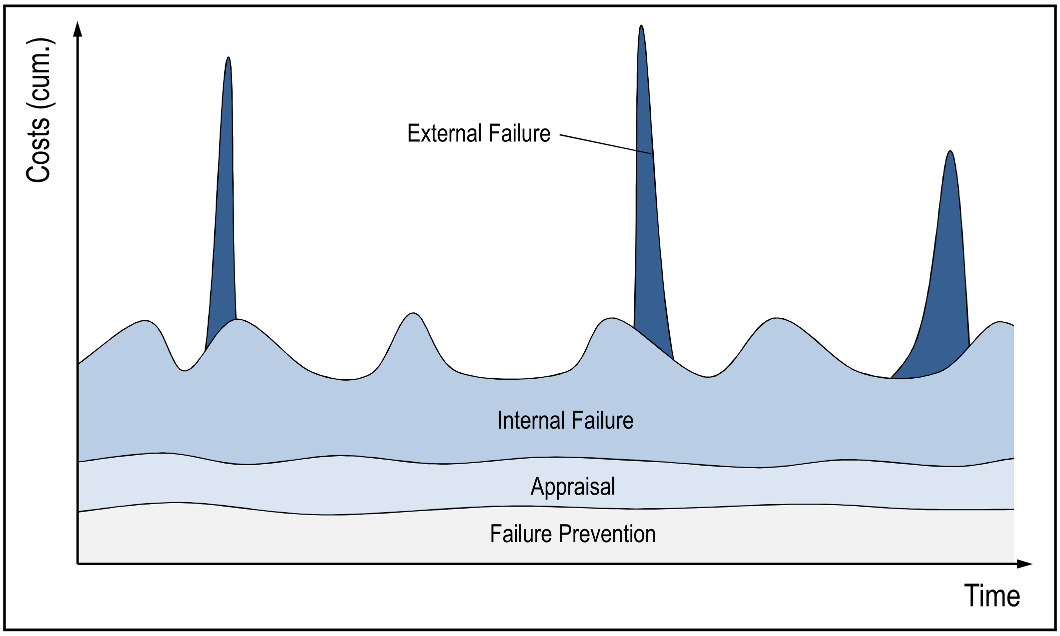

Figure 3.2.: Quality costs over time (qualitative illustration). (Source: Author's illustration according to discussions with the Head of Operations, Kendrion Villingen-Schwenningen)

When comparing the considered quality cost categories at Kendrion with the list of possible quality cost categories for manufacturing and assembling processes by Yang (2008), it can be seen that only a few were evaluated by the company. The full list in Appendix B reveals that 11 of 82 Yang's listed types are covered in Kendrion's quality cost calculation. In coordination with the Head of Operations the policy of limiting the quality costs measurements to non-conformance costs was also kept in the presented study.

3.1.2. IT Systems for Production Management

At the time of the study, the company used a number of separate stand-alone IT systems in the field of process and quality management. One of the first steps of the study was to map the existing IT systems. Figure 3.3 gives an overview of systems that are used for quality cost evaluation at the Eibiswald site.

The different solutions are grouped into the categories *Process and Production*, *Complaint Management*, *Working Time* and *Quality Cost Evaluation*, which can be described in the following way:

Process and Production: This group contained the largest number of different systems in three categories. The systems within the first category performed documentation tasks for process approval, which is done normally once a day, after setup, or after three hours downtime, according to the quality control plan. The second category consisted of the process data logging systems that used on-line databases. The third category that was responsible for production control consisted of the ERP and the production control system PDCA.

Complaint Management: The complaint management documentation was done purely based on spreadsheets, one for supplier complaints and one for customer complaints. The documentation of the 8D reports ("Eight Disciplines Problem Solving", a problem-solving technique introduced by Ford, see Bhote and Bhote, 2000) was also done based on industry-standard spreadsheet forms.

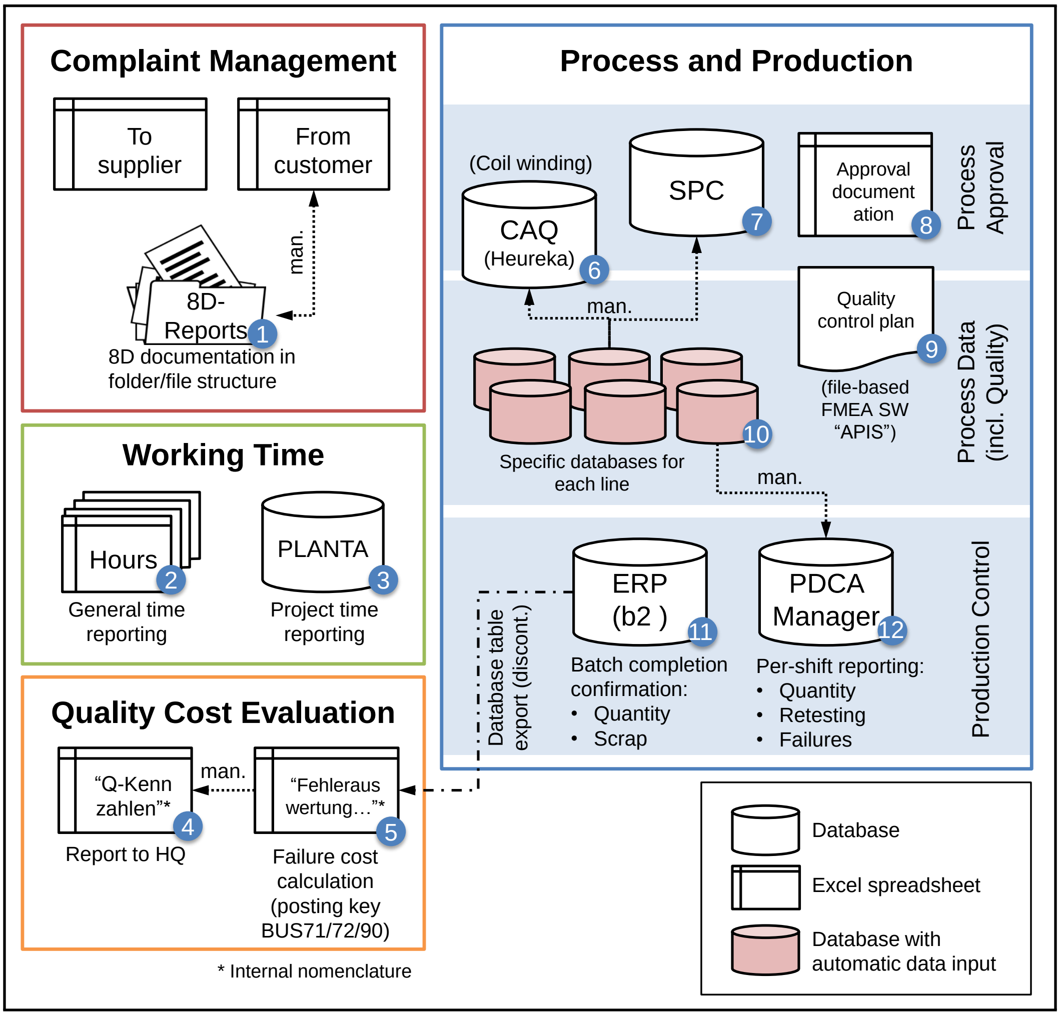

Figure 3.3.: Existing IT systems relevant for quality cost evaluation at the Eibiswald site. (Source: Author's illustration)

Working Time: Working time of the salaried employees was captured in two places. The total working time was charged against lines or projects and reported via spreadsheet to the management accounting department. Time spent on projects was additionally reported to the project management system PLANTA.

Quality Cost Evaluation: Finally, quality cost evaluation was based on a spreadsheet. The results were reported using another spreadsheet to the headquarters.

Table 3.2 provides more detailed explanations on the different systems, the responsible department and indicates if the system was planned to be replaced by new ones. The numbers in the first column correspond with the numbers in Figure 3.3.

Table 3.2.: TQM constructs. (Source: Martínez-Lorente *et al.*, 1998)

Nr.	Dimension	Resp.	Replaced
1	◇ contains 8D documentation in Excel, PDF, image format and email format	QM	⊗
2	◇ filled into Excel ◇ sent to controlling staff, who manually transfers the data into their calculation ◇ per-day reporting of hours spent on work for specific line	Acc.	
3	Computer aided project management ◇ for project time reporting ◇ database based system for project management	Acc.	
4	◇ standard Excel sheet for failure cost reporting to headquarters (HQ) in Villingen-Schwenningen ◇ covers failure costs, blocked stock value, supplier complaint revenues, additional transport costs (directly charged)	QM	⊗

Continued on next page

Table 3.2 – *Continued from previous page*

Nr.	Dimension	Resp.	Replaced
5	⋄ imported Excel sheet list of preselected data from b2 ⋄ once a month ⋄ synthesis of total failure costs ⋄ graphical representation of highest failure cost parts	QM	⊗
6	Computer aided quality documentation ⋄ process approval and process data for coil winding machines	PE	
7	Computer aided quality documentation ⋄ pure process approval information for several production lines (no actual statistical process control data) ⋄ filled in manually 1x a day, after setup, or after 3hrs downtime	PE	
8	⋄ separate Excel based process approval documentation	PE	⊗
9	⋄ quality control plan for each product ⋄ defines process approval and continuous testing ⋄ according to VDE standard	PE	⊗
10	⋄ databases for inspection chart data (automated testing) ⋄ stored/mirrored in central SQL database	PE	
11	⋄ ERP system, used for material management and production completion confirmation ⋄ line manager fills in production completion including produced units and scrap ⋄ accounting department exports table with posting key BUS71/72/90 data for quality cost evaluation monthly	(-)	(new system: IFS)

Continued on next page

Table 3.2 – *Continued from previous page*

Nr.	Dimension	Resp.	Replaced
12	◇ database for per-shift reporting of produced units and failure (divided by failure code) ◇ filled in by workers after shift ◇ simple reporting tools and export to Excel	PE	⊗
	QM . . . Quality Management *Acc. . . . (Management) Accounting* *PE . . . Process Engineering*		

The system architecture developed over time, therefore legacy systems were used and the full functionality of an modern integrated software solution was not provided. A main issue of the used IT systems was the isolation of all systems from each other, no automated data transfer was possible. This required data entry in multiple systems and made simple continuous data exchange impossible. Another problem for an automated data evaluation were various functions that relied on spreadsheets for manual data collection, processing, visualisation and reporting. Without having databases where data is stored in a structured and accessible way, utilising those data sets is difficult. Furthermore, there were major inconsistencies between company locations. Some systems were used in other locations as well (b2, PLANTA), others were locally developed (PDCA manager) and only deployed in certain locations. However, IT projects aimed to harmonise those IT systems by implementing standard software solutions for the core activities and processes (see chapter 3.1.5).

3.1.3. Quality Cost Calculation

Up to the time of the study, a manual quality cost calculation was carried out by using the available data in the existing IT systems. The evaluation process can be seen in Figure 3.4.

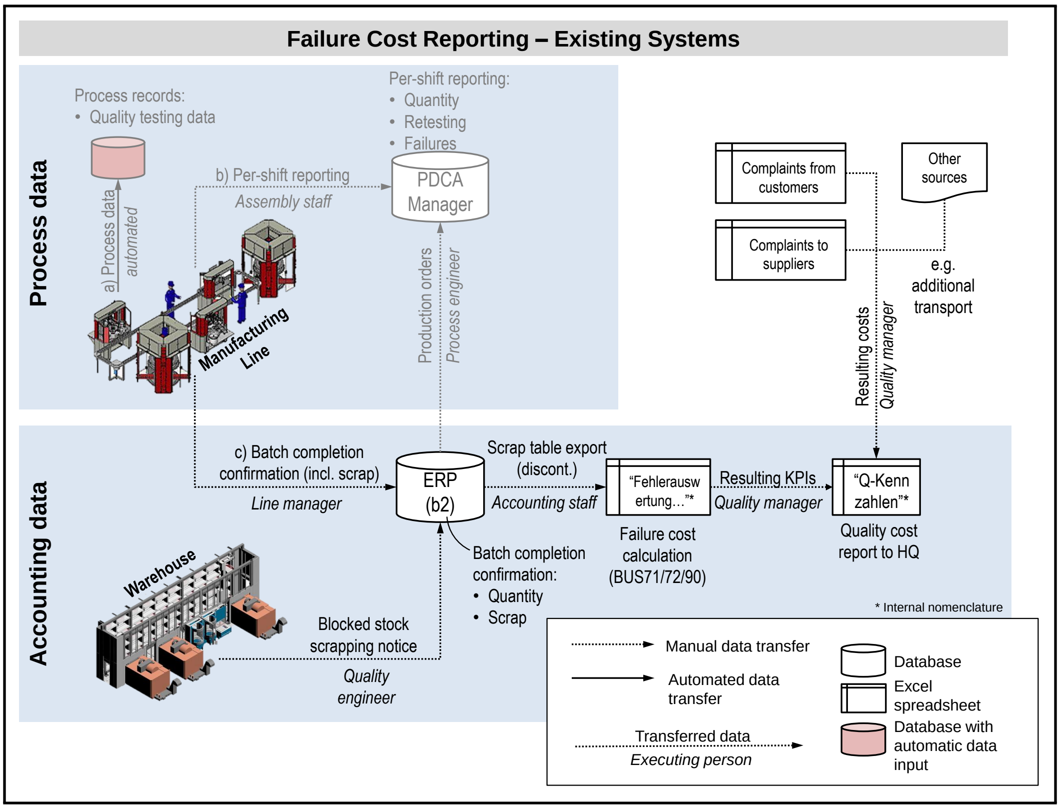

Figure 3.4.: Existing failure cost reporting at the time of the study. (Source: Author's illustration)

Basically, there were three data streams originating from the manufacturing line. There was (a) the process data which is automatically recorded by the manufacturing line. Those datasets consisting of inspection results and other operations data were stored in a local database. After each shift an assembly worker reported the (b) produced quantity, retesting and failures to the PDCA Manager production control system, which compared it with the targets in the production order. The failures were reported with considerable details such as failure mode and the corresponding frequency. After batches or orders were completed, the line manager reported the (c) batch confirmation including produced quantity and total scrap to the ERP system. In case any (blocked) stock needed to be scrapped, the responsible quality engineer reported it to ERP as well. In the monthly (sometimes weekly) quality cost evaluation an accounting staff member exported a scrap report table from the ERP system to a spreadsheet calculation. The quality manager manually processed this accounting-type data to analyse failure cost groups, added complaint information and information from other sources (e.g. special transport costs) and reported via spreadsheet to the division headquarters.

It can be seen that the process data streams (a) and (b) were not further considered for the quality cost evaluation process, only the accounting-type data (c) from the ERP system was used to perform the reporting calculation.

3.1.4. Limitations of the Existing System

The study revealed that the existing quality costing at Kendrion Passenger Car Systems had several limitations and deficiencies. Following the analysis above and the comparison to literature findings (Martínez-Lorente *et al.*, 1998; Tsai, 1998; Omachonu and Ross, 2004; Jaju *et al.*, 2009; and others), seven main issues could be found.

I. Quality cost approach

1. Quality cost calculation was limited to some failure costs (mainly scrap, directly charged expenses).
2. Failure prevention, appraisal and other failure costs were disregarded, expenses charged as overheads.
3. Quality cost evaluation was discontinuous; typically monthly, in case of special occurrences weekly.
4. Quality cost calculation only used accounting-type data, not utilising available production data.
5. Spreadsheet-based failure cost calculation required significant manual work, even for repetitive tasks.

II. Supporting IT systems

6. Different isolated systems and missing interfaces required multiple manual data input.
7. Several legacy systems and file based data management made automated data access and exchange difficult.

As seen from the analysis above, the focus on failure costs disregarded most conformance costs, but was a practical approach according to the industry-specific challenges. A more severe issue was the limitation to accounting-type data. The quality cost calculation completely disregarded the more production-oriented data sets of the PDCA Manager production control system, which would provide much richer and more process-oriented data. By using process data, the system would provide traceability of failure costs back to their source, enabling the identification of weak areas in the production that need improvement. Furthermore the reports would provide more transparency in terms of production control issues such as rework frequency or scrap rates. In comparison, the ERP system in general is aimed for accounting purposes, providing data types for which failures are already transformed to financial expenses, which are charged against cost centres. In this transformation, transparency is lost and tracing back failures to their source was made impossible without further information.

The IT-specific problems are mostly addressed by the upcoming IT systems. Those new systems can be an enabler to overcome many of the discussed limitations and deficiencies of the quality cost evaluation.

3.1.5. Plans for Upcoming ERP and MES Systems

Two projects, which were performed in parallel to the presented study, had the goals to gradually replace the existing ERP and production management software at Kendrion's production sites.

First, at the time of the study the ERP software b2 was planned to be retired. In the whole Kendrion group, including the Passenger Car Systems division, the software IFS shall be used as common ERP solution. The IFS project was meant to standardise not only the basic hardware and software infrastructure but also to harmonise business processes. It was already implemented at the headquarters in Villingen-Schwenningen, the implementation at the Eibiswald plant was scheduled. IFS was intended to be used for a variety of tasks including human resource management, finance and accounting, sales management, procurement management and inventory management.

Second, Kendrion realised that the process control capabilities of IFS are insufficient for their needs. Therefore the decision to implement the standalone MES/CAQ (Computer-Aided Quality Assurance) solution SynCOS was made. The functionality would include an operating and machine data logging, production control panel, statistical process control (SPC) and the complaint management in deployment phase one and audit management, initial sampling and selected logistic tasks in deployment phase two. At the time of the study the MES system was evaluated in a field test at the production site in Villingen-Schwenningen. Afterwards is was intented to be rolled out throughout the Kendrion Passenger Cars group. However, due to problems in the initial implementation the further roll-out was postponed.

In the final setup an automated data exchange between ERP and MES through software interfaces was planned. The data streams between the systems is shown in Figure 3.5.

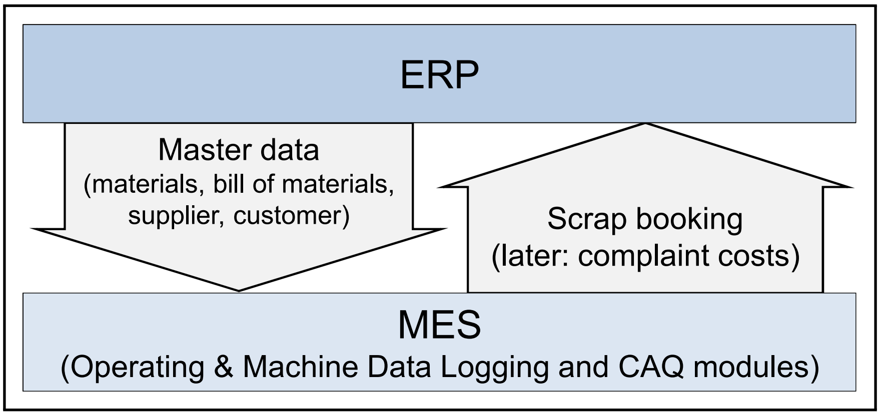

Figure 3.5.: Data exchange between ERP and MES. (Source: Author's illustration according to Kendrion internal project documentation)

The ERP acts as the leading system and provides the MES with master data including bills of materials, the corresponding materials and information on suppliers and customers. In the other direction, information on scrap is automatically booked in the ERP by the MES. In a later stage the complaint costs which are captured within the CAQ module will be transferred automatically. The booking of the good parts will remain manual in the first step in order to allow validation checks before entering the recorded figures into the IT system.

According to the deployment roadmap, the final MES/CAQ system at Kendrion Passenger Car Systems will have the following functionality:

Machine data logging:
: Interface to the machines for gathering real-time data from the actual production process.

Operating data logging:
: Handles process management information such as orders and batches or personnel allocation.

Production control panel:
: Processes manufacturing control information and provides a visual overview of the production management.

Quality control data logging, SPC:
: Capturing and documenting quality data, including SPC (Statistical Process Control) data.

Complain management:
: Integrated management and documentation of internal, supplier and customer complaint cases.

Initial sampling:
: Managing initial sample documentation.

Audit management:
: Assists in performing and documenting audits.

Minor logistics functionality:
: Minor logistics tasks, main logistics management is done in the ERP system.

3.2. Development Phase: New Quality Performance Measurement System

Following the aim of providing a continuous monitoring system with increased transparency, a new quality cost concept was developed. It combines the findings from the analysis of Kendrion's current quality cost reporting, the possibilities of the upcoming IT systems and is guided by suggestions and recommendations from literature.

3.2.1. Conceptual Considerations

As discussed earlier, literature suggests to see quality costing as part of a more comprehensive quality performance measurement system. A modern quality performance shall provide a holistic view on the operations, therefore it should not be limited purely to financial performance indicators, but should contain non-financial indicators as well. The used data must allow traceability from resulting failure costs back to their origin. Following those considerations, the conceptual setup of the system for Kendrion Passenger Car Systems was developed.

Figure 3.6 illustrates one of the underlying considerations for setting up the quality performance measurement. The previously used pure cost reporting was designed to act as an unidirectional system, which transformed failures into costs, condensed them to a few indicators which could be reported to the headquarters (path A). Compared to this unidirectional quality cost reporting system, the new quality performance measurement system aims to be bidirectional. Not only it generates reporting performance indicators, it additionally provides feedback on where improvement is necessary, since the resulting costs can be traced back to the actual failures

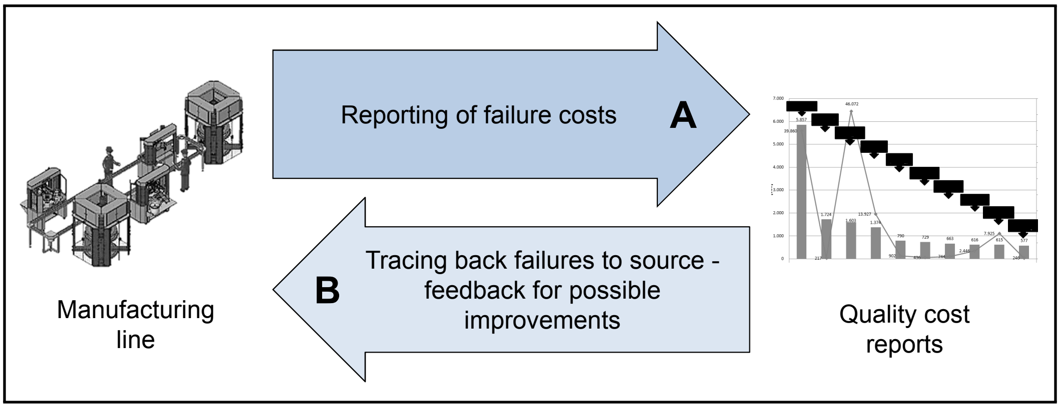

Figure 3.6.: Quality performance measurement as a bidirectional system. (Source: Author's illustration)

(paths A and B). This setup is a fundamental step towards a more comprehensive performance measurement system that provides the required transparency of quality performance.

Strategy of Kendrion Passenger Car Systems

Before developing a robust performance measurement, the purpose of such a system has to be understood. It becomes clearer when looking at the bigger picture of the business: Ultimate goal of every company is to fulfill its vision by meeting its corporate strategy. Derived from the strategy, objectives are defined. In order to measure its success in fulfilling those objectives, the company needs measurements and quantified indicators. Providing those very specific indicator is the purpose of a performance measurement system. Accordingly, the system has to be aligned with the strategy to provide the right, company specific measurements. Figure 3.7 shows the relationship between the corporate vision, strategy, objectives and the derived performance management.

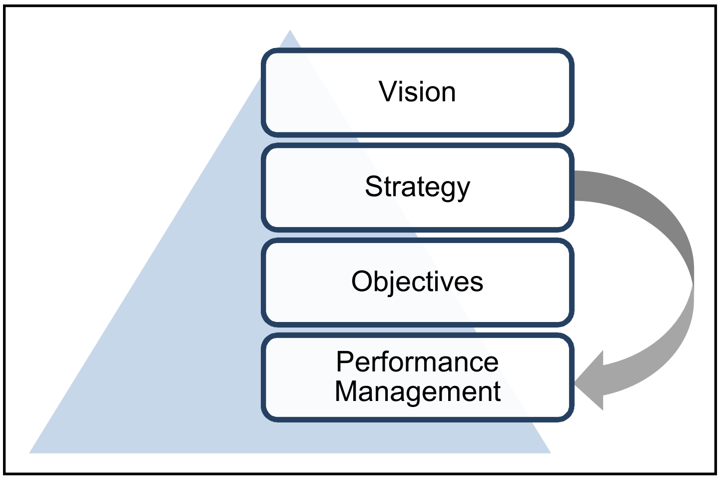

Figure 3.7.: Relationship between strategy, objectives and performance management. (Source: Author's illustration)

Ittner and Larcker (2003) analysed the success of performance measurement systems and listed a missing link between measures and strategy as the number one PMS mistake. Therefore, in order to generate the required outcome, the developed quality performance measurement system needs to be in line with Kendrion's strategic objectives. As part of the analysis phase the corporate strategy of Kendrion Passenger Car Systems was evaluated. The overall strategy, which is available in the corporate quality management system, was filtered according to relevance for quality management. The resulting strategic objectives are provided in Table 3.3. The column *Ref.* links to the Table 3.4 on page 52.

It can be seen that a focus is on internal process optimisation (O1), IT integration (O2) and improvement in quality and quality costs (O3 to O5). The found objectives subsequently act as guidelines for the development. According to those major objectives at Kendrion Passenger Car Systems, the conducted study is very much in line with the corporate strategy.

Table 3.3.: Corporate strategy filtered according to relevance for quality management.

Improvement area	Strategic objective	Ref.
Business Development	Speed-up of internal processes.	O1
	Further development of information management and expansion of the ERP-system to the complete Kendrion Passenger Car Systems (PCS) Group.	O2
Quality	Decrease the quality costs per plant in the PCS-Group (linear <[redacted].[redacted]% till 2013)*.	O3
	Decrease internal ppm rates (>10 %); Stabilisation of the external ppm rates.	O4
Organisational Development	Implementation of strict cost management at all locations.	O5

** Numbers are blackened out due to confidentiality reasons*

3.2.2. Performance Measurement System Development Process

For the development of the PMS a new approach was applied. It was inspired by several implementation methodology suggestions for (scorecard) PMS found in literature (Kaplan and Norton, 2001; Fernandes *et al.*, 2006; and others). The approach combines the recommended strategy orientation in a PMS development with a strong consideration of existing data, which makes it practical for a medium-sized company. The development method uses a process approach (Figure 3.8) from available data within Kendrion's systems to processing of this data and finally to the resulting set of performance indicators. Furthermore two separate views on this process are applied, which is a distinctive feature of the methodology.

The *Realisation view* on the left side tries to answer the question: *"Which indicators can be calculated by using the available data?"*. It therefore acts as the bottom-up view within the development process. For the *Strategy view* on the other side the leading question is: *"Which indicators are needed to measure the success in achieving the strategic goals?"*. This top-down view ensures that indicators are chosen that facilitate measuring the success in achieving the strategic goals. By bringing the two views together, a comprehensive system could be developed.

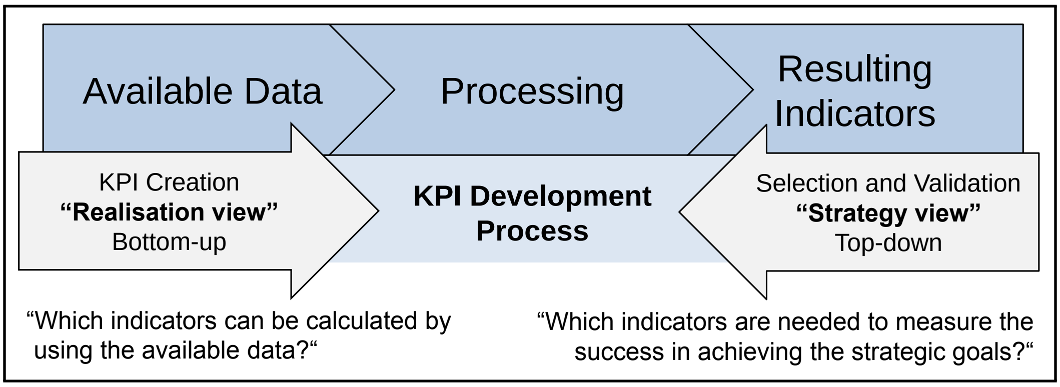

Figure 3.8.: Development phase: process view. (Source: Author's illustration)

In the first development stage (*Realisation view*, on the following page) a variety of potential indicators was found with respect to existing data and KPI suggestions from academic literature and other sources. In the second development stage (*Strategy view*, on page 50) the strategy-relevant indicators were selected. The selection was done in form of individual assessment on the one hand and with discussion with department representatives on the other hand. The conversations with company representatives were held in the following way: After (1) recalling the strategic objectives and (2) deriving their implications for production and quality management, (3) the required measurements that fit best to the objectives could be selected.

KPI Creation – "Realisation View"

In this stage more than 100 KPIs from various sources could be collected. The research method included in the first step an extensive literature review. Subsequently, discussions with process engineering staff ensured that feasible KPIs in the field of manufacturing and quality management were found, however, little further selection was done at this step to avoid limiting the view too early. Selection and validation was meant to be the subsequent step.

For finding potential KPIs the following four types of sources were investigated.

1. **Research publications:** Scientific publications (Ahmad and Dhafr, 2002; Doolen *et al.*, 2006; Fernandes *et al.*, 2006; Bhasin, 2008; Wudhikarn, 2012; and others) were reviewed. Although those papers mainly deal with PMS on corporate level, they acted as a valuable guideline. Taking journal paper recommendations into account ensured that proven indicators are considered that already withstood scientific review.
2. **ISO recommendations:** At the time of the study an ISO standard draft (ISO/DIS 22400-2 Draft, 2011) was available which aimed to standardise performance indicators in an automation and MES environment. The suggested KPIs were therefore especially relevant; by using an industry standard as a guidance, later benchmarking with other companies would be facilitated.

3. **Reference documents from industry:** Additional source of KPIs were documents and whitepapers by automation and IT providers as well as industry associations.
4. **Internal company-specific investigations and developments:** An important part of this development stage were internal investigations within the company. Following the preceding analysis, company-specific indicators were developed that are in line with the special requirements and the existing data and information at Kendrion.

The resulting set of KPIs were then visualised as mind map. This has proven to be an effective way to present the large number of indicators and facilitated structured conversation on the indicators with company representatives. Appendix B shows the found indicators as a mind map and provides a complete list of all KPIs categorised by source.

KPI Selection and Validation – "Strategy View"

The described selection, performed in discussions with company representatives, resulted in a set of indicators that were considered as most relevant for Kendrion Passenger Car Systems. As described the, selection was conducted in group activities with staff from different departments in the first step. In a second step they were presented to the managing director of Kendrion Eibiswald who gave remarks that were considered in a revised version. Table 3.4 provides the final set of 12 indicators that were taken to the next phase, their specific source and the link to the strategic goal (compare Table 3.3) the indicator is associated with.

Table 3.4.: KPI Overview.

KPI	Description	Source	Linked to strategic goal
Realised CIP ideas	Number of continual improvement process (CIP) ideas that are implemented.	Internal investigations	O1, O2
Knowledge sharing	Success of knowledge sharing activities.	Internal investigations	O2
Supplier PPM	Number of non-conforming pieces delivered by suppliers per 10^6 (parts per million, ppm) delivered pieces (accepted complaints).	Doolen *et al.* (2006)	O4
Number of supplier complaints	Absolute number of complaint cases to supplier for non-conforming pieces.	German Society for Quality (2008), internal investigations	O4
Average time for supplier complaint processing	Time needed from opening to closing a supplier complaint case.	Internal investigations, Doolen *et al.* (2006)	O1
Internal PPM	Number of scrapped pieces per 10^6 pieces started.	Ahmad and Dhafr (2002), ISO/DIS 22400-2 draft (2011)	O5

Continued on next page

Table 3.4 – *Continued from previous page*

KPI	Description	Source	Linked to strategic goal
First pass yield	Percentage of pieces that is produced without rework or retesting.	Wudhikarn (2012), ISO/DIS 22400-2 draft (2011)	O1
Overall Equipment Effectiveness OEE	Metric how effectively a manufacturing facility performs considering availability, cycle time performance and quality rate.	Ahmad and Dhafr (2002), Wudhikarn (2012), ISO/DIS 22400-2 draft (2011)	O1
External PPM	Number of non-conforming pieces rejected by customer per 10^6 delivered pieces (accepted complaints).	Ahmad and Dhafr (2002)	O4
Number of customer complaints	Absolute number of complaint cases from customer for non-conforming pieces.	Ahmad and Dhafr (2002), German Society for Quality (2008)	O4
Average time for customer complaint processing	Time needed from opening to closing a customer complaint case.	Internal investigation	O1
Total non-conformance costs (% of production value)	Sum of all (selected) non-conformance costs in a period, compared to production output (value) of the period.	Based on Yang (2008) and internal investigation	O3

Discussion was needed in two main aspects. First, about which indicators are most feasible when choosing between several options. Here a simple but powerful rule was found to be helpful: What needs to be improved must guide the question of what is actually measured. As an example, the number of submitted continual improvement process (CIP) ideas is less feasible for measuring the impact than the number of realised CIP ideas. The goal is not to submit a high number of suggestions but to deploy the best ideas in order to improve performance – that is what should be measured as well. Second, each KPI selection results in a compromise between accuracy and calculation effort. While certain indicators could be found that provide very precise measurement of operational performance, they were not chosen due to a relatively high evaluation effort and especially demand of manual work. In general a focus was put on KPIs that could be automatically calculated by the IT system without considerable further manual work. It was found that absolute precision is of less value for operations control than indication of trends and tendencies.

3.2.3. Quality Performance Scorecard

After finding the KPIs that fit best to Kendrion's requirements, they were placed onto a balanced scorecard as suggested by Kaplan and Norton (1992), according to the key questions that shape its four dimensions (Table 2.2). The resulting scorecard has already visually indicated that it provides a comprehensive picture of the operations since all dimensions were populated by KPIs. However, it was found that the general design of the balanced scorecard had severe deficiencies in terms of capturing supplier performance. The original design with Internal Processes and Customer only covers a part of the production supply chain. The supplier performance is completely missing in the measurement approach. Due to Kendrion's high dependency on suppliers a fifth scorecard dimension, Supplier, was introduced. It replicates the existing Customer dimension and uses similar indicators.

The final five dimensions of the developed quality performance scorecard can be described as follows:

Learning/Growth: Indicators for successful improvement and creation of new knowledge, which later contributes to better internal performance, customer satisfaction and finally financial success.

Supplier: For Kendrion Passenger Car System, as a company that is very dependent on suppliers, the monitoring of supplier performance is critical. The dedicated Supplier dimension accounts for the importance of supplier performance.

Internal Processes: Indicators in the Internal Processes dimension focus on the process quality that is achieved in the production at Kendrion. Implicitly they also cover product quality as factors of the calculations.

Customer: The question of how the company is seen by the customer has high priority. Not only easily quantifiable measurements are considered, but also "softer" factors that play a role in the customer's perception. The Customer dimension can be seen as the opposite of the Supplier dimension, relying on the same performance indicators as used for supplier performance assessment.

Financial: The Financial dimension provides a condensed view on the monetarily quantified performance that results from performance in the other dimensions.

Figure 3.9 shows the final scorecard, consisting of twelve KPIs in five dimensions. When looking at the dimensions, different types can be identified. The dimensions Supplier, Internal Processes and Customer describe a

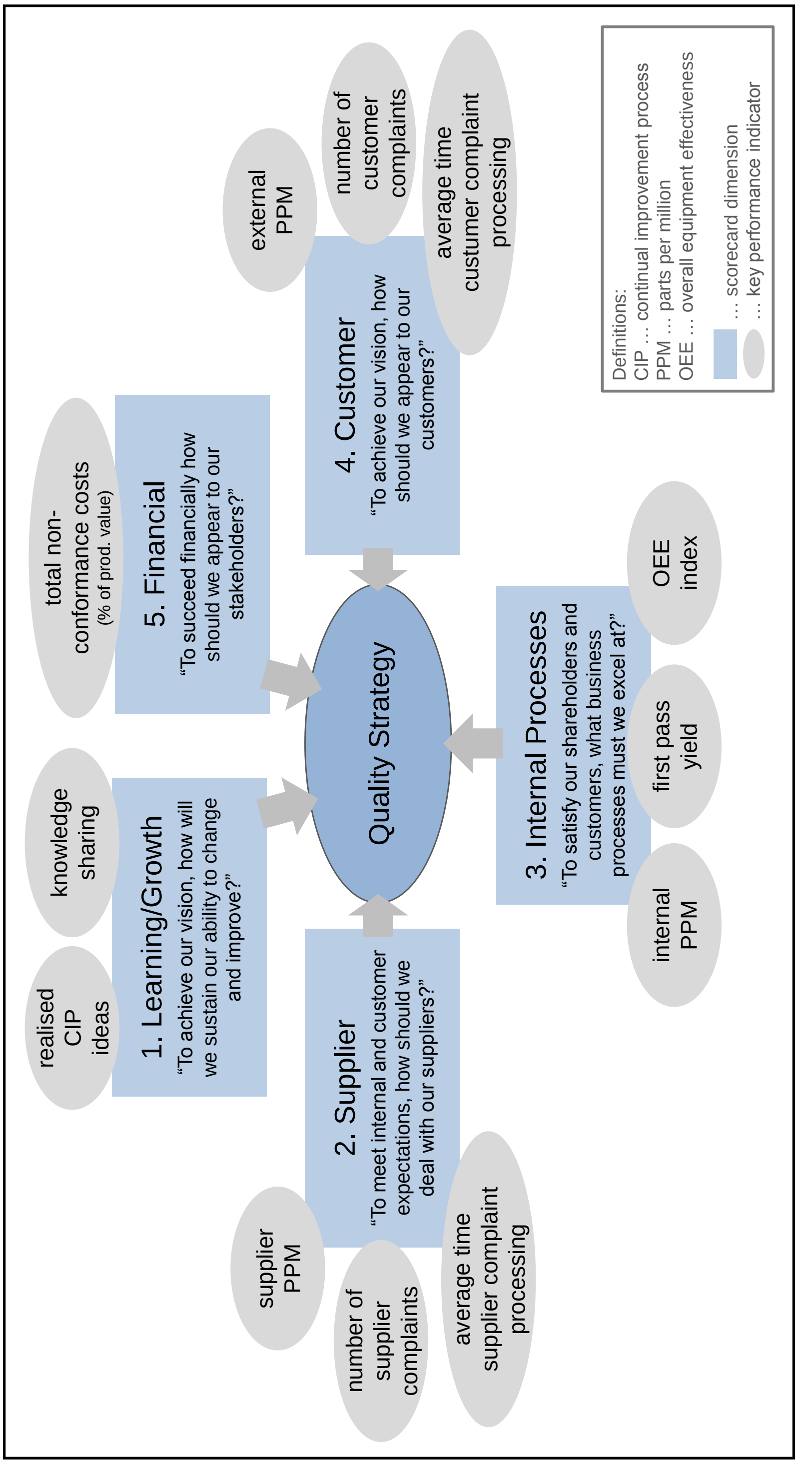

Figure 3.9.: Final quality performance scorecard. (Source: Author's illustration)

complete view of the three major parts of the supply chain, which was not given in the original balanced scorecard. Concerning the other dimensions, Learning/Growth can be seen as dimension that support the core operational functions, and Financial represents the result from the performance of the operations or supply chain functions.

Section 3.3.1 discusses the indicators within the five scorecard dimensions in detail.

Scorecard Validation

The validation of the scorecard and the KPIs was done in three steps:

The first validation step was a visual check after placing the KPIs on the scorecard, if all performance aspects and scorecard dimensions are sufficiently reflected by the chosen indicators. The purpose was to evaluate if the selection of indicators provides a balanced view, which – as a first approximation – is likely to be given when all scorecard dimensions are considered appropriately.

Second, the scorecard draft was discussed with executives, who gave remarks and raised suggestions for adaptation. Major outcome of the discussion was the introduction of the supplier dimension to the scorecard. Finally, it was found that, according to the impression of the executives, the real performance is represented well by the developed performance measurement model.

In the third step the quality performance scorecard, which was revised following the executive feedback, was compared against literature (Ahmad and Dhafr, 2002; Doolen *et al.*, 2006; Fernandes *et al.*, 2006; Bhasin, 2008; German Society for Quality, 2008) again. It was found that no conflicts were present and no important performance areas were missing within the scope of the PMS.

The development phase was concluded with the validated scorecard that represents the core element of the quality performance measurement concept. By applying the two-view methodology a comprehensive set of KPIs that build the scorecard could be found. The process ensured that the outcome is tailored to the needs and characteristics of Kendrion Passenger Car Systems

3.3. Implementation Phase: KPI Detailing

The following chapter provides a detailed definition of the chosen KPIs that was worked out in collaboration with the quality management, process engineering, operations support and accounting department and further discusses the IT implementation.

3.3.1. Key Performance Indicators Specification

The presented specification tables are based on internal specification forms at Kendrion as well as KPI specifications found in the ISO/DIS 22400-2 Draft (2011). They aim to answer the critical questions *"What is measured?"*, *"Why is it important?"*, *"When and where is it measured and reported?"* and *"How is the indicator calculated?"*.

In addition to the specification tables further investigation and definitions of the indicators are provided where necessary. The field named *Goal* was left blank on purpose, since it needs to be decided once the system is implemented and experience about the current performance is available. Table 3.5 gives an overview of the KPI definitions and the corresponding page number on which the specifications and explanations can be found.

Table 3.5.: Key performance indicators overview.

Dimension	KPI	Page
Learning/Growth	Realised CIP ideas	59
	Knowledge sharing	60
Supplier	Supplier PPM	62
	Number of supplier complaints	63
	Average time for supplier complaint processing	64
Internal processes	Internal PPM	66
	First pass yield	67
	Overall Equipment Effectiveness OEE	69
Customer	External PPM	72
	Number of customer complaints	73
	Average time for customer complaint processing	75
Financial	Total non-conformance costs (% of production value)	77

Realised continual improvement process ideas

Within the Learning/Growth dimension, the KPI for *Realised Continual Improvement Process (CIP) Ideas* (Table 3.6) plays a leading role. In the discussion it was often stated by several involved persons that the CIP success shall be captured by the quality performance measurement system. It is one of the initiatives the company takes to continuously optimise the operations within the whole organisation. While it is not directly a quality performance indicator, continual improvement at Kendrion Passenger Car Systems is closely linked with quality improvement in terms of product and especially process quality.

Table 3.6.: KPI: Realised Continual Improvement Process Ideas.

Realised CIP ideas	
Explanation – *What?*	Number of continual improvement process (CIP) ideas that are implemented.
Benefit/application – *Why?*	Measuring the number of realised ideas is a simple and reliable way of measuring CIP success.
Timing – *When?*	◯ real-time, ◯ per shift, ◯ daily, ◯ weekly, ◯ monthly, ⊗ yearly
Evaluation – *Where?*	◯ per line, ◯ per batch/order, ⊗ whole production
Formula – *How?*	Absolute number of CIP ideas that are implemented by CIP idea projects in the production.
Data source	CIP management documentation (manual data input)
Unit/dimension	#
Rating	Min: 0 Max: infinite Trend: the higher, the better
Goal	-

Different metrics for CIP success were investigated. The number of realised CIP ideas was considered as the most adequate one. On the one hand because of the simple calculation – basically only by evaluating the existing CIP documentation – and on the other hand because it is a both relevant and robust measure. It was favoured over *Number of submitted CIP ideas*, because experience with CIP programmes showed that the number of raw ideas can easily be increased by splitting ideas into smaller ones and by submitting ideas of questionable relevance. It was also favoured over *Savings from CIP implementations* because for making this metric comparable a significant effort for standardising the calculation is necessary. When evaluating the different options, the number of realised CIP ideas was seen as the best compromise between calculation effort and relevance.

Knowledge sharing

The second KPI in the Learning/Growth dimension, *Knowledge sharing* (Table 3.7), extends the learning initiative with a knowledge management component. There was a lack in information sharing between lines at one site, but also between company locations observed.

It was still under internal investigation how success in knowledge sharing shall be evaluated. Once the knowledge management system is in place, a performance indicator is included in the system.

Two ideas for setting up this indicator were found:

- First, a possible way to document knowledge sharing when closing complaints is by introducing a variable field "knowledge sharing" within the MES complaint module, which would allow automated KPI evaluation.

Table 3.7.: KPI: Knowledge sharing.

Knowledge sharing	
Explanation – *What?*	Success of knowledge sharing activities.
Benefit/application – *Why?*	The ongoing success of CIP implementations and successful complaint handling is also determined by sharing the generated knowledge within the company. Making it a KPI ensure that knowledge sharing is enforced within the complaint handling and CIP processes.
Timing – *When?*	○ real-time, ○ per shift, ○ daily, ○ weekly, ○ monthly, ⊗ yearly
Evaluation – *Where?*	○ per line, ○ per batch/order, ⊗ whole production
Formula – *How?*	*
Data source	*
Unit/dimension	#
Rating	Min: 0 Max: infinite Trend: the higher, the better
Goal	-

** Still internally investigated.*

- Second, when knowledge sharing is extended from complaint closing to CIP, more data is needed. Then a separate documentation system (for example an enriched CIP documentation) is required. Since the KPI *Realised CIP ideas* relies on the CIP documentation, this would be one promising way to generate the KPI *Knowledge sharing* as well.

As mentioned, the initiatives concerning knowledge sharing are still in the initiation phase. However, making it part of the scorecard was seen as important to ensure that the future-oriented Learning/Growth dimension has sufficient weight within the evaluation.

Supplier PPM

For supplier performance assessment the scorecard dimension Supplier was introduced. The KPI *Supplier PPM* (Table 3.8), the non-conforming pieces per 10^6 delivered pieces, is the one of the most common indicators, which was also suggested by Doolen *et al.* (2006) as part of supplier performance measurements. As described earlier, due to the elimination of incoming inspections Kendrion Passenger Car Systems needs to rely on conforming parts delivered by their supplier.

Table 3.8.: KPI: Supplier PPM (parts per million).

Supplier PPM	
Explanation – *What?*	Number of non-conforming pieces delivered by suppliers per 10^6 delivered pieces.
Benefit/application – *Why?*	Measuring supplier performance, long term goal to keep supplier PPM on low level. Supplier PPM is a strategic metric, important in the negotiations with the supplier.
Timing – *When?*	◯ real-time, ◯ per shift, ◯ daily, ◯ weekly, ⊗ monthly, ⊗ yearly
Evaluation – *Where?*	◯ per line, ◯ per batch/order, ⊗ whole production (breakdown to suppliers)
Formula – *How?*	$\frac{\textit{Rejected supplied pieces}}{\textit{Total pieces delivered}} \cdot 10^6$
Data source	Rejected supplied pieces: MES (accepted supplier complaints, complaint module) Total pieces delivered: ERP
Unit/dimension	PPM (parts per million)
Rating	Min: 0 Max: 10^6 Trend: the lower, the better
Goal	-

As all components are sourced externally and no inbound inspection is done, non-conforming supplied pieces are normally found during the assembly, when value (and in consequence cost) has already been added. Therefore, it is important that suppliers achieve lowest PPM levels in order to avoid those cases in which production has to be stopped and products need to be sorted out or scrapped. By monitoring PPM closely and communicating them to the suppliers, they are driven to achieve highest conformance levels.

Number of supplier complaints

In the past, a main supply chain performance indicator of supplier-customer relations in the automotive industry was the PPM rate. They are still important, but since the PPM rates improved over time it was realised that another significant measure for supplier-customer relations is the number of complaints, in this case the *Number of supplier complaints* (Table 3.9).

Every complaint case (accepted or refused) causes effort in the production, process engineering and/or quality management department. This causes additional costs for administration, testing, technical investigations; and whether the complaint is legitimate or not, an interruption of production or production setup can occur which can result in logistical problems and further costs for Kendrion.
However, only when the complaint is accepted, incurred costs including a standard rate can be charged to the supplier in order to cover the resulting costs.

Therefore monitoring and reducing the number of supplier complaints in order to take the next step towards optimisation of the supplier-customer relation is important.

Table 3.9.: KPI: Number of supplier complaints.

Number of supplier complaints	
Explanation – *What?*	Absolute number of complaint cases to supplier for non-conforming pieces. Differentiation between complaints accepted by supplier and refused by supplier.
Benefit/application – *Why?*	Measuring supplier performance. Not only the number of rejected pieces (supplier PPM) is relevant, also the absolute number of complaints since every case causes effort by quality/manufacturing staff.
Timing – *When?*	◯ real-time, ◯ per shift, ◯ daily, ◯ weekly, ⊗ monthly, ⊗ yearly
Evaluation – *Where?*	⊗ per line, ◯ per batch/order, ⊗ whole production (breakdown to suppliers)
Formula – *How?*	Absolute number of complaints to supplier per period (breakdown: accepted or refused)
Data source	MES (supplier complaints, complaint module)
Unit/dimension	#
Rating	Min: 0 Max: infinite Trend: the lower, the better
Goal	-

Average time for supplier complaint processing

The number of supplier complaints is certainly a main factor defining the effort required for complaint handling. Besides the pure number of complains, their duration is a driver for effort and costs as well. It is monitored in the KPI *Average time for supplier complaint processing* (Table 3.10).

Table 3.10.: KPI: Average time for supplier complaint processing.

Average time for supplier complaint processing	
Explanation – *What?*	Time needed from opening to closing a supplier complaint case. Possibly breakdown according to 8D report phases.
Benefit/application – *Why?*	Timely processing of complaint cases speeds up internal processes.
Timing – *When?*	◯ real-time, ◯ per shift, ◯ daily, ◯ weekly, ⊗ monthly, ⊗ yearly
Evaluation – *Where?*	◯ per line, ◯ per batch/order, ⊗ whole production (breakdown to suppliers)
Formula – *How?*	Average(date closed – date opened)
Data source	Rejected supplied pieces: MES (accepted supplier complaints, complaint module) Total pieces delivered: ERP
Unit/dimension	days
Rating	Min: 0 Max: infinite Trend: the lower, the better
Goal	-

In the automotive business complaints are commonly handled and documented according to the 8D ("Eight Disciplines Problem Solving") methodology, which is a structured way of managing complaints. The method relies on eight phases that are executed collaboratively by the supplier and the customer, therefore it results at least in administration effort on both sides. If this process can be accelerated, it means that Kendrion needs to deal less time with the supplier complaints, saving time and costs in the complaint management, which does not actually add value in the operations.

Another point to consider concerning complaint handling durations is the ISO/TS 16949 standard. It states requirements for response times to initial complaints that need to be met. Monitoring those and capturing the whole duration of complaint cases provides valuable information for improving the complaint management for both the supplier and the customer.

Internal PPM

In the scorecard dimension Internal Processes, the KPI *Internal PPM* (Table 3.11) is considered as the most important one, according to discussions with representatives of process engineering departments in the locations in Austria and Germany. Kendrion tends to accept higher internal PPM levels to ensure that ideally no non-conforming part leaves the factory, which could have severe financial and reputational consequences. Due to this policy the internal PPM is a main driver of quality costs that should be monitored.

The internal scrap rate is especially relevant for failure costs, since according to the applied manufacturing process rejects normally happen at the last manufacturing step when the product is already completely assembled. Therefore, the whole manufacturing costs needs to be charged as failure costs (see the failure cost progression according to the *"1-10-100 rule"*, Figure 2.3).

Scrapping one piece also means that per rejected piece a number of manufacturing cycles is lost. According to the manufacturing process normally one testing and one retesting cycle is performend before scrapping, therefore normally even two cycles are lost per rejected piece. Hence, a scrapped piece limits the capacity significantly. Consequently opportunity costs can be considered as well (for details see KPI *First pass yield*).

Table 3.11.: KPI: Internal PPM (parts per million).

Internal PPM	
Explanation – *What?*	Number of scrapped pieces per 10^6 pieces started.
Benefit/application – *Why?*	Measuring manufacturing performance, long term goal to keep internal PPM on low level.
Timing – *When?*	⊗ real-time, ⊗ per shift, ⊗ daily, ⊗ weekly, ⊗ monthly, ◯ yearly
Evaluation – *Where?*	⊗ per line, ⊗ per batch/order, ⊗ whole production
Formula – *How?*	$\frac{Scrapped\ pieces}{Total\ pieces} \cdot 10^6$
Data source	Scrapped pieces: MES (scrapped pieces, operating and machine data logging) Total pieces: MES (started pieces, operating and machine data logging)
Unit/dimension	PPM (parts per million)
Rating	Min: 0 Max: 10^6 Trend: the lower, the better
Goal	-

First pass yield

As described, the KPI *Internal PPM* is the major driver of failure costs. Kendrion was able to decrease internal PPM rates continuously by improving its processes. At low internal PPM rates the KPI *First pass yield*, the percentage of pieces that is produced without any rework or retesting, is of increasing interest (Table 3.12).

General aspiration is to manufacture items without any rework or retesting, since those unplanned process steps cause additional costs. First pass yield is therefore an important indicator for process quality.

Table 3.12.: KPI: First pass yield.

First pass yield	
Explanation – *What?*	Percentage of pieces that is produced without rework or retesting.
Benefit/application – *Why?*	Goal to manufacture products “first time right” to avoid unplanned steps that cause additional costs and limit capacity.
Timing – *When?*	⊗ real-time, ⊗ per shift, ⊗ daily, ◯ weekly, ◯ monthly, ◯ yearly
Evaluation – *Where?*	⊗ per line, ⊗ per batch/order, ⊗ whole production
Formula – *How?*	$\frac{Pieces\ manufactured\ without\ rework}{Total\ pieces}$ or $1 - \frac{Reworked\ pieces}{Total\ pieces}$
Data source	Reworked pieces: MES (reworked pieces, operating and machine data logging) Total pieces: MES (started pieces, operating and machine data logging)
Unit/dimension	%
Rating	Min: 0 Max: 100 Trend: the higher, the better
Goal	-

Besides time and costs for rework, the first pass yield has capacity implications as well. As mentioned for the internal PPM, on a balanced line every step should take the same time. If one product needs to be reworked, that means a process step has to be repeated, it causes a productivity loss of one piece. This may be without further capacity implication if spare (testing) capacity is available, which is the case at some of Kendrion's lines. In case the assembly line operates at a high utilisation and capacity is an issue, it may be feasible to consider opportunity costs for rework cycles with the following formula:

$$financial\ loss\ due\ to\ rework = reworked\ or\ retested\ pieces \cdot piece\ price \tag{3.1}$$

Source: Internal investigation

Certainly the consideration of opportunity costs following the *First pass yield* KPI pushes the optimisation of the manufacturing processes towards reduced rework and therefore increased capacity on existing equipment.

Overall Equipment Effectiveness OEE

The KPI *Overall Equipment Effectiveness (OEE)* (Table 3.13) is a condensed metric indicating how effectively production facilities are utilised.

Overall Equipment Effectiveness is a combined measure of product, process and planning quality as well as utilisation, that can be used in operational manufacturing management as well as for comparison between lines or companies. For the latter purpose extensive literature and experience reports on typical *Overall Equipment Effectiveness* values for specific industry segments are available. While manufacturing coordination normally looks primarily at the performance of machines that are in actual operations, the *Overall Equipment Effectiveness* measure extends the view to planning aspects as well.

As found by Dal *et al.* (2010) an important prerequisite for an effective and sensible use of the *Overall Equipment Effectiveness* indicator are accurate sets of machine and production control data. This is achieved at Kendrion

Table 3.13.: KPI: Overall Equipment Effectiveness OEE.

Overall Equipment Effectiveness OEE	
Explanation – *What?*	Metric how effectively a manufacturing facility is utilised considering availability, cycle time performance and quality rate.
Benefit/application – *Why?*	Overall equipment effectiveness is a characteristic number in operations that needs to be maximised on order to improve manufacturing performance.
Timing – *When?*	⊗ real-time, ⊗ per shift, ⊗ daily, ◯ weekly, ◯ monthly, ◯ yearly
Evaluation – *Where?*	⊗ per line, ◯ per batch/order, ⊗ whole production
Formula – *How?*	OEE = Availability x Performance x Quality
Data source	Reworked pieces: MES (reworked pieces, operating and machine data logging) Total pieces: MES (started pieces, operating and machine data logging)
Unit/dimension	%
Rating	Min: 0 Max: 100 Trend: the higher, the better
Goal	-

Passenger Car Systems by using the capabilities of the MES system, which captures all of the required factors for the evaluation. The calculation of the OEE KPI is already pre-implemented in the upcoming MES system, making the setup easy and cost effective. Having the data available in real-time, enables timely assessment of the manufacturing performance.

OEE consists of the three factors Ⓐ *Availability*, Ⓟ *Performance* and Ⓠ *Quality*; their relationship is visualised in Figure 3.10.

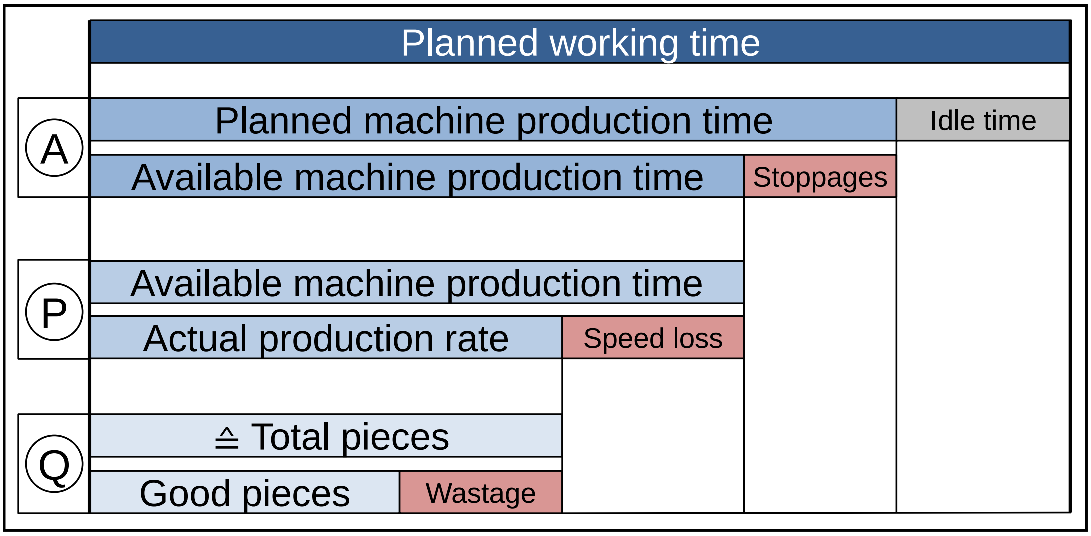

Figure 3.10.: Overall Equipment Effectiveness (OEE) illustrated. (Source: Author's illustration adapted from OEE Impact, 2012)

The formulae for Ⓐ *Availability* and Ⓟ *Performance* are given in the Equations 3.2 respectively 3.3.

$$\text{Ⓐ } Availability = \frac{Available\ machine\ production\ time}{Planned\ machine\ production\ time} \tag{3.2}$$

Source: Wudhikarn (2012)

$$\text{Ⓟ } Performance = \frac{(Pieces\ produced) \cdot (ideal\ cycle\ time)}{Available\ machine\ production\ time} \tag{3.3}$$

Source: Wudhikarn (2012)

For the calculation of Ⓠ *Quality* different definitions exist. Dependent on the source either the total quality rate (using the number of good pieces including reworked pieces, Equation 3.4) or the first pass yield (good pieces excluding reworked pieces, Equation 3.5) is considered.

$$\text{Ⓠ}\ Quality\ (1) = \frac{Good\ pieces}{Total\ pieces} \tag{3.4}$$

Source: Dal *et al.* (2000)

$$\text{Ⓠ}\ Quality\ (2) = \frac{Pieces\ manufactured\ without\ rework}{Total\ pieces} \tag{3.5}$$

Source: Wudhikarn (2012)

The decision whether Equation 3.4 or 3.5 shall be used needs to be made by the production managers. Both definitions are used in academia and in industry by various companies. It is important to use a common specification for the calculation of the indicator at all company locations; also for benchmarking careful consideration of the used definition is suggested.

External PPM

The Customer dimension of the quality performance scorecard is the counterpart to the Supplier dimension, containing similar KPIs. The KPI *External PPM* (Table 3.14) – as equivalent to the *Supplier PPM* – is one of the most important metrics in automotive supply chains. Companies tend to accept higher internal PPM rates in order to avoid any non-conforming part going to the customer. Monitoring the PPM is therefore a basic requirement of the quality scorecard.

Table 3.14.: KPI: External PPM (parts per million).

External PPM	
Explanation – *What?*	Number of non-conforming pieces rejected by customer per 10^6 delivered pieces (accepted complaints).
Benefit/application – *Why?*	External PPM is critical in automotive business, long term aspiration to achieve external PPM of approx. zero. It is also one of the KPIs that are part of the corporate-level PMS.
Timing – *When?*	◯ real-time, ◯ per shift, ◯ daily, ◯ weekly, ⊗ monthly, ⊗ yearly
Evaluation – *Where?*	⊗ per line, ⊗ per batch/order, ⊗ whole production (breakdown to customers)
Formula – *How?*	$\frac{\textit{Rejected delivered pieces (accepted complaints)}}{\textit{Total pieces delivered}} \cdot 10^6$
Data source	Rejected delivered pieces: MES (accepted customer complaints, complaint module) Total pieces delivered: ERP
Unit/dimension	PPM (parts per million)
Rating	Min: 0 Max: 10^6 Trend: the lower, the better
Goal	-

Number of customer complaints

For the KPI *Number of customer complaints* (Table 3.15) the same principles as for the *Number of supplier complaints* apply. The effort of handling the complaint by analysis, sorting or testing creates costs that are mostly independent from the actual failure rate. Therefore, there is a general interest on keeping the number of complaint cases down.

Table 3.15.: KPI: Number of customer complaints.

Number of customer complaints	
Explanation – *What?*	Absolute number of complaint cases from customer for non-conforming pieces. Differentiation between complaints accepted and refused by Kendrion.
Benefit/application – *Why?*	Measuring own performance towards customer. Not only the number of rejected pieces (external PPM) is relevant, also the absolute number of complaints since every case causes effort by quality/manufacturing staff and may be recognised by the customer as non-conformance, potentially harming the company's image.
Timing – *When?*	◯ real-time, ◯ per shift, ◯ daily, ◯ weekly, ⊗ monthly, ⊗ yearly
Evaluation – *Where?*	⊗ per line, ◯ per batch/order, ⊗ whole production (breakdown to suppliers)
Formula – *How?*	Absolute number of complaints from customer per period (breakdown: accepted or refused)
Data source	MES (supplier complaints, complaint module)
Unit/dimension	#
Rating	Min: 0 Max: infinite Trend: the lower, the better
Goal	-

A special additional cost driver for the supplier (in this case Kendrion Passenger Car Systems) is the fact, that a customer typically sends back a whole palette or delivery once a non-conforming part was found. Normally, according to PPM levels in the single digit range, only a few parts per million are actually defective. Therefore sorting of the returned parts is normally done at the supplier to be able to reuse the conforming parts of the batch. This is a time consuming activity which is either done by internal staff or externally by other companies. In both cases significant costs arise.

From a technical point of view the evaluation of this KPI is very easy, only the number of complaint cases within a given period needs to be calculated. Given the functionality of the MES, a differentiation between accepted and refused complaints can be done, which can give further insight into the customer-supplier relationship.

Average time for customer complaint processing

Same as a decrease of the *Average time for supplier complaint processing*, speeding up the *Average time for customer complaint processing* (Table 3.16) can cause less effort and therefore reduces costs in administration. Additionally, professional and fast complaint processing is an important factor for perceived supplier performance and therefore builds a good image for Kendrion as a supplier.

Furthermore, there is an important implication for timeliness of total quality costs evaluations. Typically the complaint case closure, and as a result the reporting of complaint costs, are delayed some weeks to a few months from the occurrence date of the failure, which may distort the quality cost measurement. When achieving shorter complaint processing times, the allocation of complaint costs to the correct quality cost monitoring period becomes easier.

By using the integrated complaint management functionality of the upcoming MES/CAQ system, documenting the complaint cases is much easier

Table 3.16.: KPI: Average time for customer complaint processing.

Average time for customer complaint processing	
Explanation – *What?*	Time needed from opening to closing a customer complaint case. Possibly breakdown according to 8D report phases.
Benefit/application – *Why?*	Timely processing of complaint cases speeds up internal processes and is an important factor for creating a good company image.
Timing – *When?*	◯ real-time, ◯ per shift, ◯ daily, ◯ weekly, ⊗ monthly, ⊗ yearly
Evaluation – *Where?*	◯ per line, ◯ per batch/order, ⊗ whole production (breakdown to customers)
Formula – *How?*	Average(date closed – date opened)
Data source	MES (customer complaints, complaint module)
Unit/dimension	days
Rating	Min: 0 Max: infinite Trend: the lower, the better
Goal	-

and more traceable than previously, when spreadsheet-based documentation was used. The solution allows to link certain complaint cases to batches/orders, which themselves are consistently documented concerning production equipment, quality records or staff. In total, the system provides most of the necessary information that facilitates an effective management of complaints and helps solving and reporting the problems in a timely manner.

Total non-conformance costs

The KPI *Total non-conformance costs (% of production value)* (Table 3.17) finally brings together the different costs arising from non-conformance.

Table 3.17.: KPI: Total non-conformance costs.

Total non-conformance costs (% of production value)	
Explanation – *What?*	Sum of all (selected) non-conformance cost in a period, compared to production output (value) of the period.
Benefit/application – *Why?*	The main financial target metric that needs to be optimised in quality management. It is also one of the KPIs that are part of the corporate-level PMS.
Timing – *When?*	◯ real-time, ◯ per shift, ◯ daily, ⊗ weekly, ⊗ monthly, ⊗ yearly
Evaluation – *Where?*	◯ per line, ◯ per batch/order, ⊗ whole production
Formula – *How?*	$\frac{Sum\ of\ captured\ non-conformance\ costs\ [1]}{production\ value\ [2]}$ Ad [1]: see Figure 3.11 below Ad [2]: Production value (PV) $\neq$ turnover. PV considers and harmonises: turnover, changes in inventory, other operating income (e.g. revenue from fixed assets sales)
Data source	Production failure costs; complaint costs (internal, to supplier, from customer, extra position: additional transport): MES Production value: ERP
Unit/dimension	days
Rating	Min: ~ 0 Max: infinite Trend: the lower, the better
Goal	-

The KPI is a highly condensed metric that summarises the most important quality cost elements for Kendrion Passenger Car Systems to provide one top-level indicator for quality performance. For reporting purposes it is important to have those condensed numbers; however, they may hide relevant information. To be able to draw sensible conclusions despite the issues of limited transparency, the KPI construction, given in Figure 3.11 needs be common across company locations as well as the reporting implementation needs to be identical to ensure that all company locations follow the same calculation methods. Only by achieving this common calculation a meaningful comparison between the locations is possible.

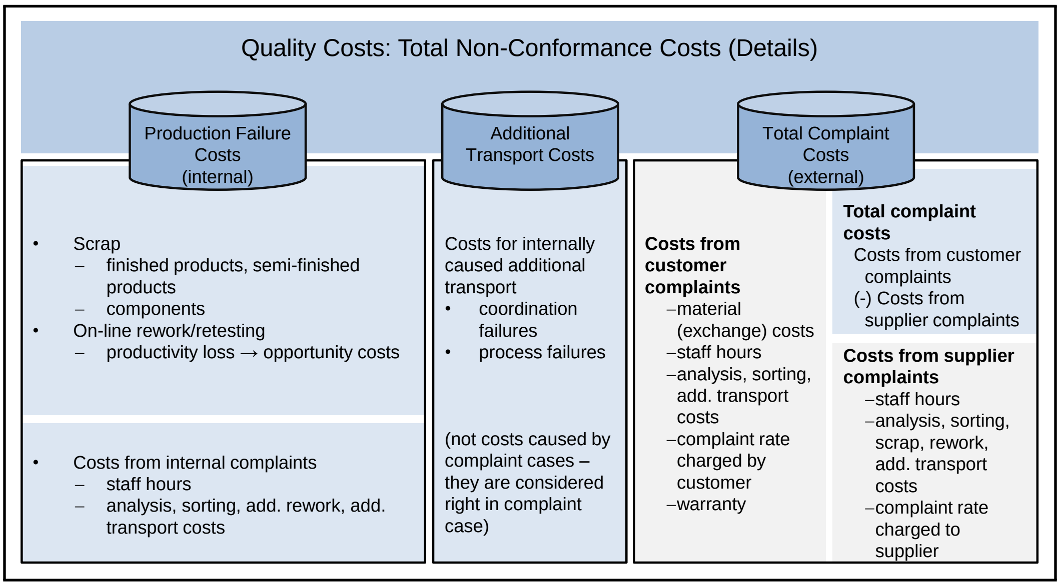

Figure 3.11.: Calculation scheme of the total non-conformance costs. (Source: Author's illustration)

The KPI is based on recommendations by Yang (2008) and is specifically adjusted for Kendrion. It takes into account both internal and external non-conformance costs. The internal costs include the costs for scrap of finished products, semi-finished products and components and rework of flawed products. The calculation of rework costs is based on the described fact (see *First pass yield*), that in a balanced assembly line in every cycle one piece is produced. If an additional rework cycle needs to be performed, one cycle or the equivalent of one piece of output is lost. In case the assembly line runs at high utilisation and does not have spare rework capacity, for every rework cycle the opportunity cost of one product can be charged. Assigning a cost to rework is in line with the attempt to drive capacity optimisation. The second part of internal failure costs are the costs from internal complaints. Previously those costs for investigation of internal problems, such as sorting activities or special analyses were not covered at all in the quality cost calculation. Since the new MES/CAQ system provides the possibility to capture those cases as internal complaints, it is practical to evaluate their costs as well. This creates more transparency for costs, which were only booked as overhead costs before.

For the external costs the complaint management provides the relevant data. They include costs from material exchange, staff hours for investigating and reworking, additionaly analysis, sorting or handling and a standard complaint rate that is charged by the customer for work associated with the complaint case. In case of customer complaints also the special costs for warranty have to be considered. The total complaint costs consist of cost from complaints from the customer and complaints to the supplier. Significant for the total external complaint cost is the originator of the problem associated with a complaint case. In case the customer rejects defective parts and the source of the problem is within Kendrions responsibility, the resulting costs are added to the total external failure costs. In contrast, if Kendrion rejects parts delivered by a supplier, which are flawed because of non-conformance within the supplier's responsibility, the resulting costs are subtracted from the total external failure costs. Only costs that are caused by Kendrion's internal failures shall be reflected as failure costs within the KPI. As a result of this method the calculation can also account for cases where the root cause of a customer complaint lies in the area of responsibility of the supplier. Costs are effectively passed through the calculation of external failure costs.

The third section of non-conformance costs are additional transport costs, for example for express air freight due to delayed completion of parts. For those costs contradicting suggestions were found in literature. While Yang (2008) sees quality costs in a wider scope in terms of overall product and process quality and therefore includes any occuring transport costs resulting from non-conformance to the quality costs, the German Society for Quality (DGQ) suggests to strictly separate quality from logistics costs. Since both approaches are sensible, a decision for either including additional transport costs or excluding them has to be made. This may also have internal political implications between departments about who takes responsibility for those deficiencies in the operations.

3.3.2. Implementation within the MES

As discussed previously, the MES is the most suitable system for the reporting, since the available data meets the bidirectional system's needs. Moreover, MES normally has strong reporting functionality pre-implemented which makes setting up the reporting simpler and more cost effective. Figure 3.12 shows the new reporting concept in which the process data streams (a) process data, such as records from automated testing, and (b) process control data, such as inspection chart data and scrap booking, are automated and happen in near real-time. MES, consisting of operating and machine data logging and CAQ modules, is able to exchange data with the ERP. By combination of the relevant data the reporting can be executed effectively within the MES.

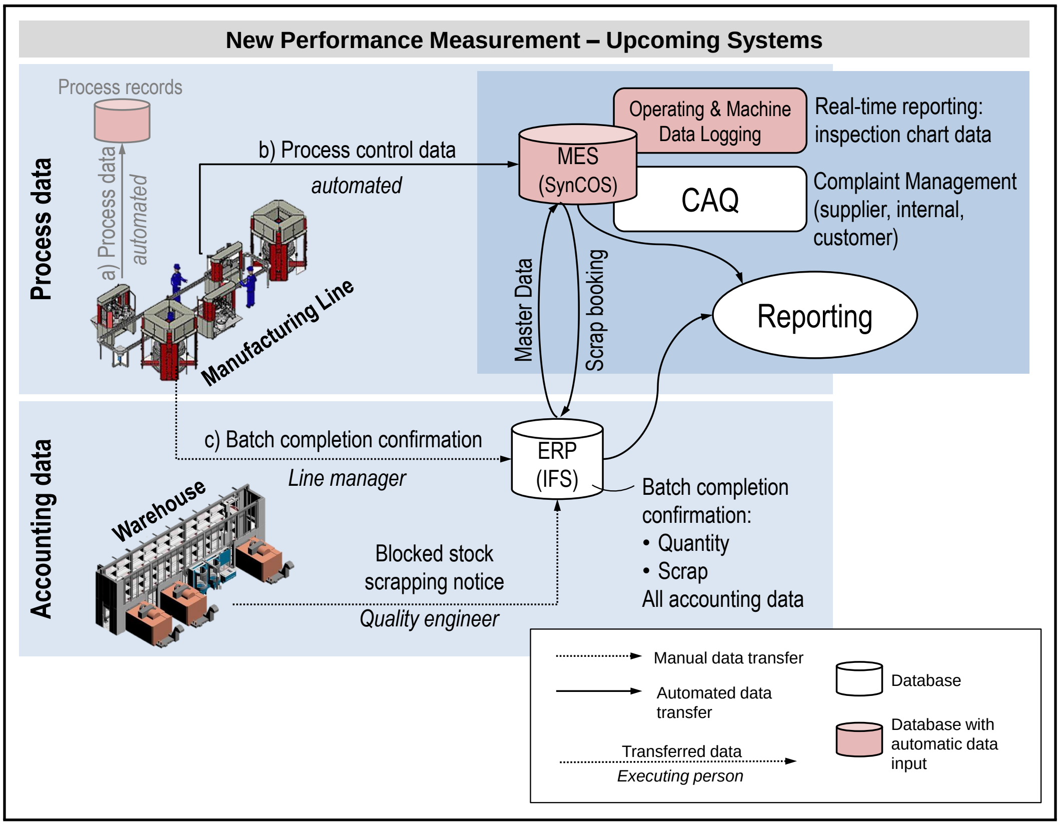

Figure 3.12.: New performance measurement process using the upcoming IT systems. (Source: Author's illustration)

The KPI specifications provide a solid foundation for the implementation by defining the calculation formulae, the general data source, the calculation frequency and the evaluation area. Due to postponed roll-out of the ERP and MES, a more detailed implementation preparation could not be done within the project's time frame. The delay caused a lack of the software-specific information that would have been needed for further detailing activities.

However, the important aspects ranging from conceptualisation to fundamental specifications as defined in the aims and objectives were carried out. The actual reporting of the scorecard KPIs needs to be realised when the enabling IT systems are in place.

In extension to the scorecard, investigation of further possible steps has been conducted. As an example, a suggested Quality Performance Dashboard is presented as mock-up in Figure 3.13. This kind of information system, targeted at the production managers, has already shown potential for facilitating the improvement of manufacturing operations performance (Greeff, 2011; Unver, 2012).

This MES-based dashboard provides a real-time representation of the operational performance by visualising elements of the scorecard, which are relevant for production control. It allows the production manager to get a fast and practical overview of the critical performance indicators and helps to control the production accordingly. It uses the strengths of the MES in terms of timeliness of the data and the granularity that allows very detailed traceable evaluation. Purpose of the presented mock-up is to show the principle of a Quality Performance Dashboard; the selection and representation of the relevant KPIs need further investigation.

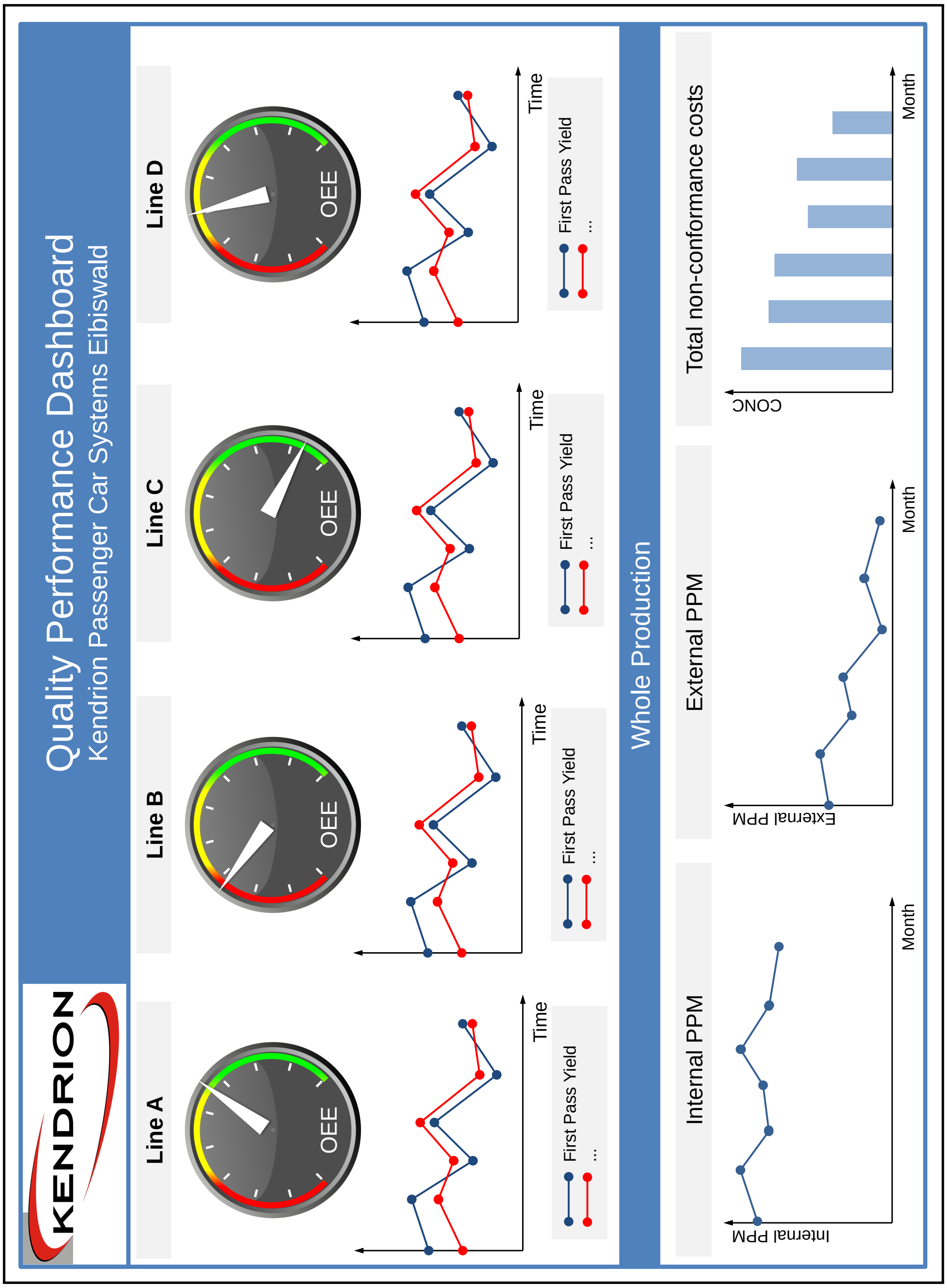

Figure 3.13.: Mock-up of a MES-based Quality Performance Dashboard. (Source: Author's illustration)

3.4. Discussion

The study presents a scorecard based quality performance measurement system for Kendrion Passenger Car Systems. It follows a tailored methodology for achieving a both strategy and data-oriented solution, and provides a detailed definition of the performance indicators that build the scorecard.

By constructing the scorecard with financial and non-financial KPIs a more comprehensive picture of the quality performance can be captured by the PMS. Instead of purely transforming all failures to costs, what causes a loss of information and transparency, certain process indicators for performance are taken straight into the evaluation without monetary assessment. Besides an unaltered view on the process performance, the non-financial indicators allow to cover a wider evaluation scope since they are able to capture performance that can hardly be charged as cost. Although authors tried to quantify complex quality costs areas, for example costs resulting from lost sales due to lost customer goodwill (Jaju, 2009), those calculations can be vague. Furthermore it is difficult to put harder tangible facts such as scrap costs into comparison with those less defined, softer numbers. It was found that in this case measuring influencing factors, such as customer complaint issues, is a more feasible and more practical approach than trying to quantify them monetarily.
However, as complement to non-financial indicators, robust financial indicators are essential to serve reporting purposes and to fulfill legal and industry standard obligations. In addition, the fact that financial figures in the form of highly condensed KPIs are easily understandable, also for

persons with less quality management background, makes them a useful communication tool that helps to express quality in the language of management (Dale and Plunkett, 1991). Therefore, a combination of both types was found to be the best way.

Related with the decision for additionally capturing non-financial indicators is the general policy for indicator accuracy. It was found that absolute accuracy often can only be achieved with very high effort in data collection and processing. However, in many cases the absolute number is less important than the identification of trends and tendencies. Therefore the most important criterion for the selection was to find indicators that facilitate the spotting of trends and not ones that represent the considered costs with highest precision (which is in line with findings by Dale and Plunkett, 1991). For comparison between locations the important aspects are the common KPI definition, data source and calculation. If those prerequisites are given, the comparison of the indicators is sensible.

A general issue of KPI based performance measurement systems is selective optimisation. As every model, it can only partially describe the real system. In the case of a quality PMS, the set of KPIs can only provide a selective representation of the real quality performance. Since the goal is to optimise the given performance indicators, there exists an inherent risk that those indicators are optimised at the expense of other areas, which are not captured by the indicators. The developed PMS addresses this issue by (a) a widespread KPI selection which is tyed to the strategic direction of the company, (b) a selection process that involves a number of representatives to gather a broad view on the operations and finally (c) a larger number of indicators that form the scorecard. While the number may seem high, it was chosen on purpose in order to overcome the discussed issues. Since a high level of automation in the reporting can be achieved, a larger number of indicators does not necessarily cause a higher processing workload.

3.4.1. Benefits of the New System

Compared to the previously used quality cost reporting system at Kendrion Passenger Car Systems five major benefits can be gained from the new quality performance measurement system.

- The system is bidirectional, compared to the previous unidirectional quality reporting approach. It provides traceability from reports back to the origin of quality performance problems, which is a key purpose of quality costing but a common deficiency of existing systems.
- Following the recommendations found in literature, a high priority goal was to provide a broad view on the operations. It is achieved by using a multidimensional scorecard approach that drives holistic thinking and by involving people from different departments that bring in various views on the quality performance.
- Additionally, the scorecard is not limited to financial measures, but also captures more difficult to quantify factors, which are represented by non-financial indicators.
- By utilising modern IT systems for automated processing, a reduction of calculation effort is achieved.
- The system is built with suitability for different company locations in mind. On the one hand it tries to take a significant development step forward in the provision of quality performance information, but on the other hand it is designed in a way that it is practically implementable and compatible with the given data. It acts as a concept for harmonising the quality cost figures across the company group and puts comparison onto a common basis.

Technical aspects of the new monitoring system

From a technical point of view, the distinctive advantages in terms of system architecture of the new quality performance measurement over the old quality cost reporting are revealed in a direct comparison (Figure 3.14 on the following page). An obvious change is the use of process data for the quality performance reporting, while in the old system only accounting data was used for calculating the costs. Furthermore, the use of the new MES and ERP systems makes spreadsheet-based evaluation obsolete and improves data accessibility. As a result of the integration of the IT systems, more automated data exchange is possible and the data collection and data transfer is simplified. The actual quality performance processing can now be operated at a much higher degree of automation. Finally, a major implication for the employees as the end users of the system is that all major functionality is provided in two main systems, eliminating the need for various manual data input into separated systems and spreadsheets. This may also improve the data quality, since mistakes by employees at the manual data entry can be avoided.

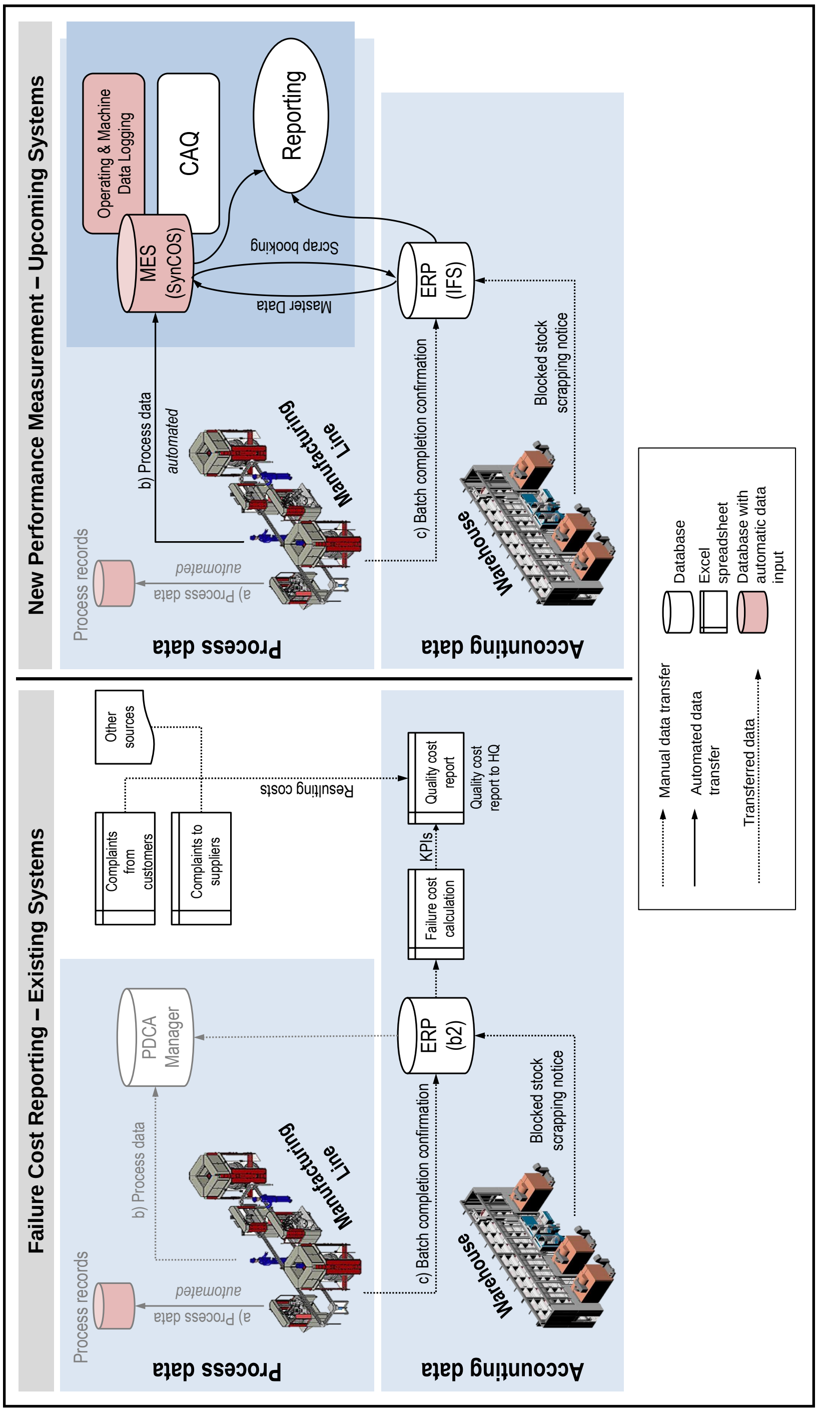

Figure 3.14.: Comparison of the old quality cost reporting (left) and the new quality performance measurement (right). (Source: Author's illustration)

3.4.2. Comparison Against Initial Aims

In comparison against the very first goal definition – a revised quality cost calculation – the result represents a significantly more comprehensive solution. It effectively extends the quality costing to a much broader quality performance measurement. The very first aim, to develop a revised quality cost reporting, is represented by the KPI *Total non-conformance costs (% of production value)* within the quality PMS.

The required continuity of the monitoring system could be realised by using the MES as leading system. In comparison to an ERP-based solution, which was in the past coupled with an Excel-based calculation, the MES can provide evaluation in a more timely manner, since its data is continuously and automatically fed into the system and available for processing. The extended use of process data allowed to meet the second major objective. Improved transparency is given due to (a) the use of actual process data that realises an extended traceability and (b) the use of non-financial indicators. Non-financial metrics do not cause information loss due to transformation to costs, which is normally necessary when calculating financial indicators. The developed scorecard provides a comprehensive and holistic view on the operations and therefore facilitates a more transparent performance assessment.

A consolidated view shows that the initial aims and objectives could be met. The use of state-of-the art literature led to an extension of the aspirations to a more comprehensive system, that makes best use of the existing processes, data and the upcoming systems. It allows Kendrion Passenger Car Systems to monitor the quality performance in a timely, more holistic way.

3.4.3. Limitations of the Study

The suggested quality performance measurement concept was able to meet the objectives set by Kendrion Passenger Cars Systems. However, as in every concept chosen premises and assumptions resulted in limitations.

From a conceptual point of view the study was based on the analysis of existing systems and processes for quality cost evaluation. In the next step the changes due to the planned IT systems were identified to form the foundation of the new PMS. Compared to a development methodology that puts ultimate focus on the aspirational state without rooting in the current state, the result is certainly influenced by the current situation which may limit novel approaches up to a certain degree. In the presented study, the evolutionary approach of basing the system on existing data and information and evolving it by using the new systems as enabler was considered as the most practical and sensible way for Kendrion Passenger Car Systems.

In terms of evaluation scope, the developed system considers only a part of the total quality costs. Following the rationale in section 3.1.1, the study was limited to non-conformance costs and excluded the conformance costs. However, with the methodology in place, the company is able to repeat the development for conformance costs as well.

4. Conclusion and Outlook

The study has suggested a revised quality performance measurement system for Kendrion Passenger Car Systems, which represents an extension of the existing pure quality cost reporting. It has presented a structured development methodology, that fills the research gap found in the area of IT-enabled quality performance monitoring, and suggested a five dimensional scorecard. Starting from those findings, Kendrion Passenger Car Systems is able to implement the performance measurement system within their upcoming IT systems.

4.1. Value for Kendrion Passenger Car Systems

For Kendrion Passenger Car Systems the study created value mainly in three major aspects:

- First, the developed performance measurement system provides managers with a comprehensive view on the company's operations in terms of product and manufacturing process quality. Having timely information allows more effective control of the operations and therefore facilitates better decisions. Compared to the existing system at Kendrion significantly higher transparency of quality performance is achieved.

- Second, due to the bidirectional setup it is possible to trace failure back to their origin. This helps to identify areas that need general improvement but additionally assists in identification of the causes of already occured defects.
- Third, because of the implementation within the MES and its automated evaluation functionality, the more detailed quality performance does not require more manual work than the previous system or even reduces manual work.

Intermediate outcomes such as the process and IT systems map have been valuable results for Kendrion as well, since detailed documentation was not available before. Discussion with employees have demonstrated increased awareness that there are areas that can be improved. Furthermore, the project has entailed a best-practise transfer between the sites in Villingen-Schwenningen and Eibiswald and facilitated a knowledge exchange within the group.

In conclusion the developed concept helps Kendrion to keep up with the demanding automotive market that requires highest quality and strict cost management and has shown considerable volatility in the recent years. By applying a continuous and timely quality performance measurement system, Kendrion has a tool to stay well-informed about current performance and to take better decisions based on actual facts.

4.2. Academic Value

The presented study has a strong foundation in existing literature on cost of quality and performance measurement. Compared to existing publications there are valuable new findings made in this study. The methodological approach takes elements from existing performance measurement and scorecard implementation concepts and combines them to a new process, which is tailored for a medium sized company such as the Kendrion Passenger Car System sites. By following the process, the executing person or team implicitly applies the recommended strategy orientation. The strong foundation in existing infrastructure and data makes it easily applicable and therefore practical for medium-sized enterprises. Furthermore, the developed scorecard can act as a model for similar implementations. While the indicators will look differently for every company since the available data and the strategy differ, the presented result can act as a reference for feasibility and validity checks.

4.3. Further Work

The scope of the study ranged from analysis of the existing situation at Kendrion Passenger Car Systems, to PMS conceptualisation and implementation preparation. Further steps for Kendrion include the actual implementation that can rely on the prepared specifications. Once the system is in place, a review of the experiences with the systems should be done, since there will be a need for revisions and adaptations. After the system is tested at the Eibiswald site, the roll-out to other sites can be planned. Additional ideas for extending the system were found, which can be further investigated in order to optimise the impact of the presented concept.

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List of Abbreviations

CAQ	Computer-aided quality assurance
CIP	Continual improvement process
COC	Cost of conformance
CONC	Cost of non-conformance
DIS	Draft International Standard
EOL	End-of-line (inspection)
ERP	Enterprise resource planning
FPY	First Pass Yield
ISO	International Organization for Standardization
KPI	Key performance indicator
MES	Manufacturing execution system
OEM	Original equipment manufacturer
P–A–F	Prevention, appraisal, and failure (costs)
PCS	(Kendrion) Passenger Car Systems
PDCA	Plan–do–check–act
PPM	Parts per million
PV	Production value
SPC	Statistical process control
TQM	Total quality management
5S	Sorting, straightening, systematic cleaning, standardising and sustaining
8D	Eight Disciplines Problem Solving

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Appendix

Appendix A.

KPI Mind Map and Description

Figure A.1 shows the resulting KPI mind map. For readability reasons a reduced view is provided. The following pages cover the found KPIs.

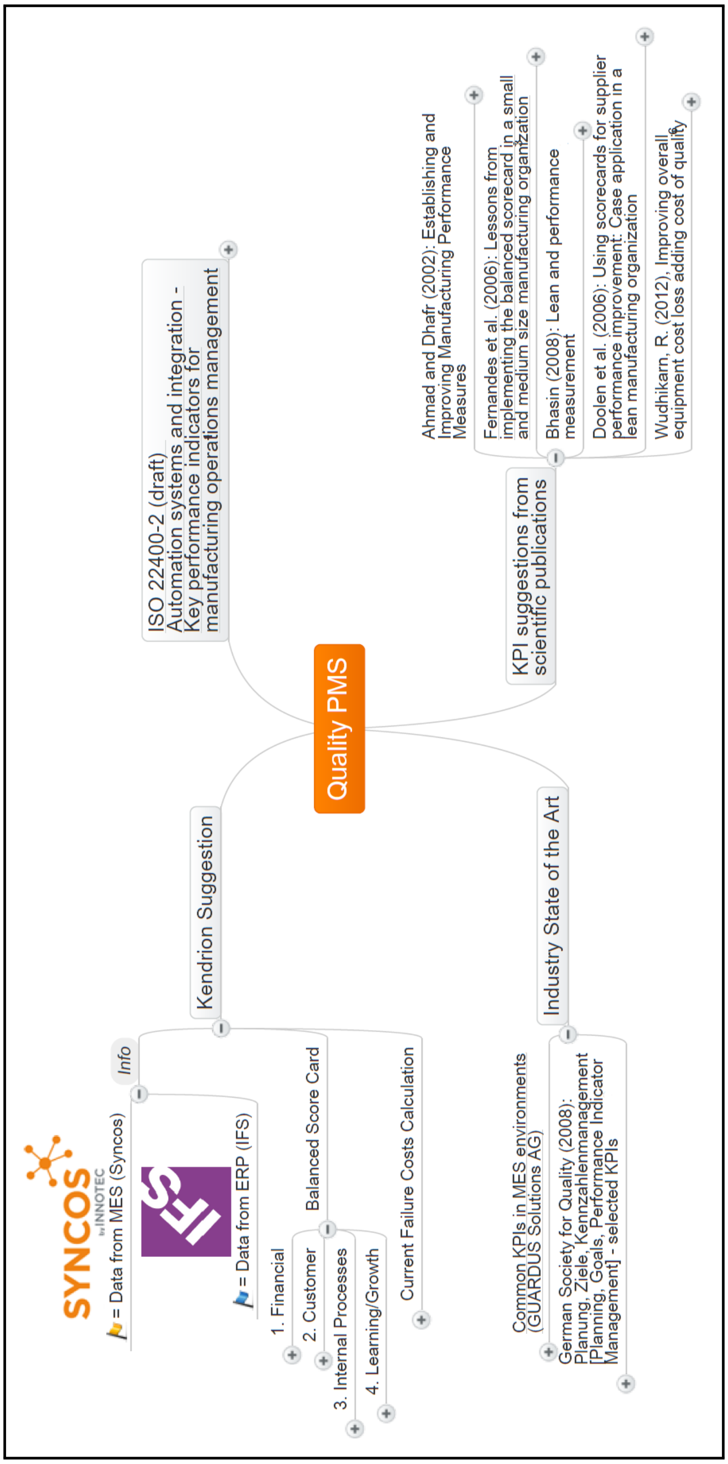

Figure A.1.: KPI Mind Map (reduced view). (Source: Author's illustration)

A.1. KPI Collection

A.1.1. ISO/DIS Standard

ISO/DIS 22400-2 Draft (2011)

Source: ISO/DIS 22400-2 Draft (2011), "Automation systems and integration - Key performance indicators for manufacturing operations management - Part 2: Definitions and descriptions", version 13 October 2011.

- Worker efficiency
- Allocation ratio
- Throughput rate
- Allocation efficiency
- Utilization efficiency
- Overall Equipment Effectiveness (OEE) Index
- Net Equipment Effectiveness (NEE) Index
- Availability
- Effectiveness
- Quality Ratio
- Setup Rate
- Technical Efficiency
- Production Process Ratio
- Actual to planned scrap ratio
- First Pass Yield (FPY)
- Scrap Ratio
- Reworking Ratio
- Falloff Ratio
- Machine Capability Index (C_m)
- Critical Machine Capability Index (C_{mk})
- Process Capability Index (C_p)
- Critical Process Capability Index (C_{pk})
- Comprehensive Energy Consumption
- Inventory turns
- KPIs for input-output (quality of manufacturing process)

  - Finished Goods Ratio
  - Integrated Goods Ratio
  - Production Lost Ratio
  - Storage and Transportation Lost Ratio
  - Other Loss Ratio
- Equipment Load Rate
- Mean Operating Time Between Failures (MTBF)
- Mean Time To Failure (MTTF)
- Mean Time To Restoration (MTTR)
- Corrective Maintenance Ratio
- From older draft version: Environmental compatibility KPIs
  - Emission ratio
  - Energy ratio
  - Ratio of used material
  - Harmful substances
  - Hazardous waste

A.1.2. KPI Suggestions From Scientific Publications

Ahmad and Dhafr (2002)

Source: Ahmad, M. and Dhafr, D. (2002), "Establishing and Improving Manufacturing Performance Measures", Journal of Robotics and Computer Integrated Manufacturing, Vol. 18, Iss. 3, pp. 171-176(6).

- Output
- Uptime
- Product delivery performance (OTIF)
- Adherence to production plan
- Customer complaints
- Product rate
- Quality rate
- Availability
- OEE
- Absenteeism

- Average training days/employee

Fernandes et al. (2006)

Source: Fernandes, K. J., Rajab, V. and Whalley, A. (2006), "Lessons from implementing the balanced scorecard in a small and medium size manufacturing organization", Technovation 26, p.623-634.

- Finance
  - Revenue growth
  - Return on equity
  - Unit cost
  - Economic value addition
  - EBIT
- Customer
  - % of sales from new products
  - On-time delivery
  - Share of key accounts
  - No. of cooperative efforts (customer partnership)
- Internal processes
  - Cycle time
  - Efficiency
  - Actual launch vs delay
  - Reduction in W/F (employee turnover)
- Learning and Growth
  - Time to new process maturity
  - % of product representing 80% sales
  - Time to market

Bhasin (2008)

Source: Bhasin, S. (2008), "Lean and performance measurement", Journal of Manufacturing Technology Management, Vol. 19, Iss. 5, p. 670 –

684.

- Finance
  - Earnings per share
  - Rate of return on capital employed
  - Current ratio
  - Profit after interest and tax
- Customer/market measures
  - Market share by product group
  - Customer satisfaction index
  - Customer retention rate
  - Service quality
  - Responsiveness (customer defined)
  - On-time delivery (customer defined)
- Process
  - NPD lead time
  - Cycle time
  - Time to market for new products
  - Quality of new product development and project management processes
  - Quality costs
  - Quality ratings
  - Defects of critical products/components
  - Material costs
  - Manufacturing costs
  - Labour productivity
  - Space productivity
  - Capital efficiency
  - Raw material inventory
  - WIP inventory
  - Finished goods inventory
  - Stock turnover
- People
  - Employee perception surveys
  - Health and safety per employee

  - Accidents
  - Absenteeism
  - Labour turnover
  - Retention of top employees
  - Quality of professional/technical development
  - Quality of leadership development
- Future
  - Depth and quality of strategic planning
  - Anticipating future changes
  - New market development
  - New technology development
  - Percentage sales from new products

Doolen et al. (2006)

Source: Bhasin, S. (2008), "Lean and performance measurement", Journal of Manufacturing Technology Management, Vol. 19, Iss. 5, p. 670 – 684.

- Cost
  - Cost reductions (%)
  - Cost reduction proposals
  - Cost reduction implementations
- Quality
  - PPM
  - Factory disruptions
  - Fault analysis
- Delivery
  - On-time delivery (%)
  - Lead-time (%)
  - Lead-time reduction (%)
  - Flexibility (%)
- Customer support

    - request for quotes response time
    - purchase order confirmation time

Wudhikarn, R. (2012)

Source: Wudhikarn, R. (2012), "Improving overall equipment cost loss adding cost of quality", International Journal of Production Research, Vol. 50, Iss. 12, pp. 3434-3449.

- Overall equipment effectiveness (OEE)
- Overall equipment cost loss
- Cost of quality
    - prevention
    - appraisal
    - internal failure and external failure costs

A.1.3. Industry State of the Art

Common KPIs in MES environments (GUARDUS Solutions AG, 2012)

Source: Gardus Solutions (2012), "KPI Production Cockpit", available at `http://www.guardus-solutions.de/en/solutions/process-management/31-kpi-cockpit.html`, (accessed 25th August 2012)

- Staff efficiency
- Occupancy rate
- Flow rate
- Effective occupancy rate
- Utilisation rate
- OEE index (Overall Equipment Efficiency)
- NEE index (Net Equipment Efficiency)
- Availability
- Effectiveness
- Quality rate
- Setup rate

- Technical efficiency
- Production process rate
- Scrap degree
- First pass yield
- Scrap rate
- Rework rate
- Fall off rate
- Machine capability index
- Critical machine capability index
- Process capability index
- Critical process capability index
- Breakdown rate
- Reject costs
- Corrective action index

German Society for Quality (2008)

Source: German Society for Quality (2008), „Planung, Ziele, Kennzahlen-management [Planning, Goals, Performance Indicator Management]", available at `http://www.dgq.de/regional/dateien/RK_OS_Kennzahlen_20081113.pdf`, (accessed 25th August 2012)

- Customer satisfaction
- Supplier ppm
- Supplier delivery
- Rework
- Scrap
- Cycle time
- Downtime
- Utilisation
- OTIF delivery
- Number of complaints
- Warranty costs
- Absenteeism
- Employee satisfaction
- Employee training

A.1.4. Kendrion Suggestion

The following KPI suggestions are the result of internal investigations at Kendrion Passenger Car Systems which took place during the analysis and development phase of the study.

- Financial
  - productivity loss due to rework
  - total quality costs
- Customer
  - external complaint rate (external ppm)
  - number of rejected parts
  - (accepted) complaint costs
    * total per period
    * per part
    * per shipped order
  - number of complaints
    * total per period
    * per shipped order
  - time for processing
    * average (complete processing)
    * average (to first reply)
  - Logistics
    * additional transport costs
    * OTIF delivery
  - Internal Processes
    * OEE
    * internal scrap rate (internal ppm)
    * internal rework rate
    * first pass yield (FPY)
    * failure rate
  - Learning/Growth
    * realised CIP ideas

Appendix B.

Considered Quality Cost Categories at Kendrion Passenger Car Systems

The table below compares the quality cost categories reported by Yang (2008) with the cost types considered in Kendrion's quality cost calculation.

After Yang, C.C. (2008), "Improving the definition and quantification of quality costs". Total Quality Management & Business Excellence, Vol. 19, No. 3, pp.175-191

Area	Category	Cost Elements according to Yang	Currently Considered For Quality Cost Reporting
Manufacturing (Assembling) and Process Quality Control	Prevention Costs	Operations process validation	no
		Operations quality planning	no
		Design and development of quality measurement and control equipment	no
		Operations support quality planning	no
		Operator quality education and training	no
		Operator SPC/process control	no
		Salaries of quality administrators	no
		Administrative expenses for quality planning and control	no
		Quality program planning	no
		Quality performance reporting and analysis	no
		Quality education	no
		Quality improvement	no
		Quality system audits	no
		Investment in tools and equipments of quality control	no
	Appraisal Costs	Planned operations inspections, tests and audits	no
		Salaries of checking labors	no
		Miscellaneous quality evaluations	no
		Inspection and test materials	no
		Set-up inspections and tests	no
		Process control measurements	no
		Laboratory support	no
		Investments and maintenance expenses of measurement (inspection and test) equipments	no
		Salaries of maintenance and calibration labors	no
		External appraisal costs	no
		Field performance evaluation	no
		Review of test and inspection data	no

Appendix B. Considered Quality Cost Categories at Kendrion Passenger Car Systems

Area	Category	Cost Elements according to Yang	Currently Considered For Quality Cost Reporting
[Manufacturing (Assembling) and Process Quality Control]	Internal Failure Costs	Material review and corrective action costs	no
		Disposition costs for defects in the process	no
		Troubleshooting or failure analysis costs (operations)	no
		Costs of operations corrective actions	no
		Operations rework costs	no
		Operations repair costs	no
		Investigation support costs	no
		Re-inspection/retest costs	no
		Costs in labor hours associated with scraps in process	yes
		Costs in materials associated with scraps in process	yes
	External Failure Costs	Costs of complaint handling	no
		Costs of handling and repair of returned goods	no
		Costs of scraps of returned goods	no
		Warranty claims	yes
		Liability costs	yes
		Salaries of repair labors	no
	Other costs*	Waste of labor hours and scrap of other parts destroyed, which were caused by failure operations in the process	yes
		The increase costs of downtime, additional inventory due to the poor quality in process	no
		The resultant costs of the defect bypass the quality control system	no
		Freight and insurance premium costs	yes
		The resultant costs by inadequate quality, delivery and reliability	no
		The increase costs caused by the delayed order delivery	yes
		Penalties of customer damage caused by defective goods	yes
		The lost sales owing to poor quality in the past	no
		Loss-of-reputation costs	no
		The opportunity cost of lost customer loyalty	no
		The delay launch of new product due to the poor quality in process	no
		Brand image damage	no

Area	Category	Cost Elements according to Yang	Currently Considered For Quality Cost Reporting
Finished goods inspection and quality assurance	Prevention Costs	Product quality planning	no
		Quality system audits	no
		Design and development of quality measurement and control equipment for final inspection	no
		Quality educatior	no
	Appraisal Costs	Product or service quality audits	no
		Outside endorsements and certifications	no
		Special product evaluations	no
		Investments and maintenance expenses of final inspection and function tests equipment	no
		Salaries of final inspection labors	no
		Salaries of maintenance and calibration labors	no
		Investments and maintenance expenses of 'burn-in' test or reliability test equipments	no
		Costs of product used as the test samples	yes
	Internal Failure Costs	Disposition costs for defects in the final inspection and test	no
		Troubleshooting or failure analysis costs (finished product)	no
		Downgraded end-product	no
		Rework and repair costs of finished goods	no
		Re-inspection/Retests costs	no
		Costs in labor hours associated with scraps of finished product	yes
		Costs in materials associated with scraps of finished product	yes
	External Failure Costs	Costs of handling and repair of return goods due to the failure on inspection of the finished goods	no
		Cost of scraps of returned goods due to the fail inspection of the finished goods	no
	Other costs*	The increase costs caused by the delayed delivery due to the poor performance of final	no
		The extra costs due to the failure of final inspections and tests	no
		The external failure costs caused by the defective finished goods bypass the final inspections	no
		Customer dissatisfaction costs	no
		Decrease the customer/user goodwill	no
		Loss-of-reputation costs	no
		Brand image damage	no

Appendix C.

Interview List

(Table see next page)

Note:
EBW = Eibiswald/Austria, VS = Villingen-Schwenningen/Germany
Regular discussions with colleagues at the quality management department: A. Schulter, E. Lambauer, A. Pust, B. Heiserer, M. Hainzl, W. Garber

Interview list.

Nr.	Date	Time	Person	Site	Department	Note
1	2012-05-24	09:00	A. Schulter	EBW	Quality Manager	Basic quality reporting & KPIs, Kendrion products
2	2012-05-24	15:00	S. Wolf	EBW	Controlling / Finance	showed contribution margin accounting, offered more detailed explanations
3	2012-05-25	09:00	A. Pust	EBW	Quality Management	Suppliercomplaint management
4	2012-05-29	10:00	E. Presnitz	EBW	Assistance Managing Director	intoduction accounting, supplier complaint management
5	2012-05-29	14:30	M. Haindl	EBW	Quality Management	following 8D, only directly charged costs considered
6	2012-05-30	08:40	A. Haindl	EBW	Quality Laboratory	works for QM, PE and Engineering (1/3 of time each)
7	2012-05-30	09:00	R. Reisser	EBW	Process	only reporting scrap, no times. ERP and PDCA (individual reporting)
8	2012-05-31	10:00	A. Schulter	EBW	Quality Manager	discussing first findings & next steps
9	2012-05-31	14:00	C. Hofstätter	EBW	Process Engineering	databases and on-line quality checks
10	2012-06-05	09:45	C. Hofstätter	EBW	Process Engineering	demonstration assembly line

Continued on next page

Table C.1 – *Continued from previous page*

Nr.	Date	Time	Person	Site	Department	Note
11	2012-06-05	11:30	J. Waltl	EBW	H&S and Environmental Management	scrapping and environmental costs
12	2012-06-05	13:00	G. Theissl	EBW	Process Engineering	special rework situation at AL, mismatch PDCA ¡-¿ b 2
13	2012-06-06	08:30	M. Resch	EBW	Process Engineering	demonstration winding machines
14	2012-06-11	09:15	M. Kollmann	EBW	Managing Director	Administrative discussion, suggests working with Köster and Brödel
15	2012-06-12	14:00	M. Resch	EBW	Process Engineering	Future of PDCA Manager unclear (dep. on Villingen)
16	2012-06-12	15:00	M. Resch	EBW	Process Engineering	System architecture captured correctly
17	2012-06-13	10:00	A. Schulter	EBW	Quality Manager	Preparation visit to HQ Villingen-Schwenningen
18	2012-06-21	08:30	R. Wieland	VS	Operations and Quality Manager	Project Sponsor, discussion on aims etc.
19	2012-06-21	10:00	H. Wanzeck	VS	Quality Management	Demonstration of weekly/monthly quality reporting and IFS
20	2012-06-21	13:00	A. Merz	VS	Operations Support	Introduction to MES, demonstration

Continued on next page

Table C.1 – *Continued from previous page*

Nr.	Date	Time	Person	Site	Department	Note
21	2012-06-21	16:00	S. Steimle	VS	Quality Manager	Plans on MES, time reporting
22	2012-06-22	10:15	H. Wanzeck	VS	Quality Management	Procedures for inspection and complaint cost reporting
23	2012-06-22	10:30	A. Merz	VS	Operations Support	Plans on MES, time reporting
24	2012-06-22	11:00	M. Kreutter	VS	Project Management	Introduction to PLANTA project management software (focus time reporting)
25	2012-06-25	08:00	A. Schulter	EBW	Quality Manager	Recap visit VS
26	2012-07-10	13:30	A. Merz	VS	Operations Support	Validation and MES functionality
27	2012-07-16	09:30	S. Wolf	EBW	Controlling/Finance	Turnover vs. Production Value
28	2012-07-16	13:00	G. Theissl	EBW	Process Engineering	Machine databases, rework opportunity costs
29	2012-07-17	15:00	A. Schulter	EBW	Quality Manager	Checkpoint prior to selection and validation step
30	2012-07-24	10:00	M. Kollmann	EBW	Managing Director	Discussion on KPI selection and validation
31	2012-08-08	13:00	R. Wieland	VS	Head of Operations	Validation