Reihe Informationsmanagement im Engineering Karlsruhe

Stefan Rafael Geis

Integrated Methodology for Production Related Risk Management of Vehicle Electronics (IMPROVE)

Band 2 – 2006

universitätsverlag karlsruhe

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Herausgeber
Universität Karlsruhe (TH)
Institut für Rechneranwendung in Planung und Konstruktion (RPK)
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Integrated Methodology for Production Related Risk Management of Vehicle Electronics (IMPROVE)

von
Stefan Rafael Geis

universitätsverlag karlsruhe

Dissertation, Universität Karlsruhe (TH), Fakultät für Maschinenbau, 2006

Impressum

Universitätsverlag Karlsruhe
c/o Universitätsbibliothek
Straße am Forum 2
D-76131 Karlsruhe
www.uvka.de

Universitätsverlag Karlsruhe 2006
Print on Demand

ISSN 1860-5990
ISBN 3-86644-011-1

Integrated Methodology for Production Related Risk Management of Vehicle Electronics (IMPROVE)

A Doctoral Thesis to Obtain the Degree of

Doktor der Ingenieurwissenschaften (Dr.-Ing.)

for Submission to the Faculty of Mechanical Engineering
of the University of Karlsruhe (TH)

DISSERTATION
by

Dipl.-Wi.-Ing. Stefan Rafael Geis

Day of vocal examination:	February 10th, 2006
First Doctoral Advisor:	o. Prof. Dr.-Ing. Dr. Jivka Ovtcharova
Second Doctoral Advisor:	Univ.-Prof. Dr.-Ing. Bernard Bäker

Preface of Publisher

One of the current challenges in the automotive industry is the individualization of products and customer wishes, which leads to an increasing number of product variants and vehicle functions. Due to the increasing innovation and competition pressure, product lifecycles are shrinking and therefore also the engineering times, which requires new innovative solution concepts.

In the future, 90% of all automotive innovations will be in the field of automotive electronics. This leads to an increasing number of automotive electronics in a vehicle and therefore increasing vehicle complexity. The consequence is a growing need for the integration of comprehensive intelligent systems, procedures, and processes in order to ensure the product quality and innovation maturity over the entire vehicle life cycle. Recently, some automotive business related legislations have changed and now require new concepts of technical risk management and documentation, expecially in the field of automotive electronics.

This scientific work is designated to provide an innovative and integrated conceptional approach to improve the assembly quality of automotive electronics. This is achieved by the reduction and elimination of production related risks of automotive electronics and the implementation of a sustainable solution process.

The focus is the development and implementation of an integrated technical risk management approach for automotive electronics throughout the vehicle life cycle and the vehicle production planning process. Design for Manufacturing solutions are integrated in this technical risk management, in order to influence the assembly process and the product for improvements in an early stage of the development process.

Also contained in this scientific work is the implementation of a Case Based Reasoning approach for the efficient and sustainable knowledge and case solution management of life cycles and company processes. The newly developed conceptional approach is integrated into existing business practices with a decision making process and related benefit calculations in order to master effectively future challenges.

Karlsruhe, March 2006 Jivka Ovtcharova

Acknowledgements

This dissertation results from my work as doctoral candidate at the DaimlerChrysler Corporation, Mercedes Car Group, Production Planning organization, in cooperation with the Institute for Applied Computer Science in Mechanical Engineering (RPK) at the University Fredericiana Karlsruhe (TH).

Special thanks to my first doctoral advisor, the institute leader Prof. Dr. Dr.-Ing. Jivka Ovtcharova for her excellent academic support, special encouragement and confidence, as well as the professional collaboration.

I would like to thank my second doctoral advisor Prof. Dr.-Ing. Bernard Bäker, institute leader of automotive technology professorship for vehicle mechatronics at the Technical University Dresden, for taking over the advisory opinion and for his excellent academic support, interest in my work, and professional collaboration. Prof. Dr.-Ing. habil. Georg Bretthauer I would like to thank for taking over the chair of examination and for his interest in my work.

For the industrial occupation at the DaimlerChrysler Corporation, I would like to thank Dipl.-Ing. Thomas Forchert, Dr.-Ing. Michael Stotz, and Dipl.-Ing. (BA) Wolfgang Greiner as well as the product and assembly planning team for the professional collaboration, project work, and support of my academic research. Thanks to Jodie Southgate for her language support.

Within scientific-industrial project collaborations, I would like to thank Dipl.-Ing. Konstantin Krahtov, Dipl.-Inform. Torsten Engel and all colleagues from the RPK Institute and the Research Center for Information Technologies (FZI) for the great collaboration and productive work.

Also, I am very thankful for the confidence and support of my parents, who enabled my path of life, and for the appreciation of my sisters and brother.

Special thanks to my girlfriend Karin, who supported me with exceptional understanding and encouragement, as well with great consideration for my dissertation work.

Karlsruhe, March 2006 Stefan Rafael Geis

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List of Abbreviations

ABS	Antilock Brake System
ACC	Adaptive Cruise Control
ADAC	German Automotive Association
AR	Augmented Reality
BCS	Brake Control System
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAN	Controller Area Networks
CBR	Case Based Reasoning
CMMI	Capability Maturity Model Integration
CRM	Customer Relationship Management
CRO	Chief Risk Officer
DFM	Design for Manufacturing
DFMA	Design for Manufacturing and Assembly
DIN	German Institute for Standards and Norms
DMU	Digital Mock-up
ECU	Electronic Control Unit
E/E/PE	Electrical/Electronic/Programmable
ERP	Enterprise Resource Planning
ESP	Electronic Stability Program
ETA	Event Tree Analysis
EUC	Equipment Under Control
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Modes, Effects and Criticality analysis
FTA	Fault Tree Analysis
FTC	First Time Capability
IMPROVE	Integrated Methodology for Production Related Risk Management of Vehicle Electronics
IQS	Initial Quality Study
IT	Information Technology
iViP	integrated Virtual Product creation
JiS	Just-in-Sequence
JiT	Just-in-Time
LiRiM	Lifecyle Risk Management

MOST	Media Oriented Systems Transport
NHTSA	National Highway Traffic Safety Administration
NUMMI	New United Motor Manufacturing Incorporation
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
QFD	Quality Function Deployment
OOBN	Object-Oriented Bayesian Networks
ORC	Operational Risk Counter
PDM	Product Data Management
PES	Programmable Electronic Systems
PLM	Product Lifecycle Management
POS	Point of Sale
ppm	parts-per-million
PPS	Production Planning System
PRA	Probabilistic Risk Analysis
RFID	Radio Frequency Identification
RPN	Risk Priority Number
SCM	Supply Chain Management
SOP	Start of Production
TPS	Toyota Production System
TQM	Total Quality Management
TREAD	Transportation Recall Enhancement, Accountability, and Documentation
US	United States
USB	Universal Serial Bus
VAR	Value-at-Risk
VDA	German Automotive Association
VDI	German Engineering Association
VE	Virtual Engineering
VOC	Voice of Customer
VR	Virtual Reality

Nomenclature

A_k	Assembly process analysis variable ($\forall\ k = 1, ..., K$)
α_κ	Specific case attribute ($\forall\ \kappa = 1, ..., MAX$)
C	Consequence of risk
C_{in}	Electronic component of category i and number n ($\forall\ n = 1, ..., N$)
D	Defect
D_m	Design analysis variable ($\forall\ m = 1, ..., M$)
$\delta(t)$	Failure rate over time t
δ_0	Failure threshold
E	Event
ϵ	Case attribute
Φ	Risk value threshold
f	Function
$F(t)$	Frequency of risk in Period t
η	Number of attributes in each case
I_{in}	Investment in component C_{in}
i	Component category
k	Number of assembly process analysis variables
L, L'	Solution
l, l'	Solution way
λ	Solution case
MAX	Maximal number of specific attributes α_κ
m	Number of product analysis variables
n	Number of components per category
P_{total}	Total saving potential
P_q	Saving Potential of category q ($\forall\ q = 1, ..., Q$)
P_1	Saving Potential of rework time reduction ($q = 1$)
P_2	Saving Potential of assembly time reduction ($q = 2$)
P_3	Saving Potential of warranty cost reduction ($q = 3$)
Pr	Probability
r	Risk type r ($\forall\ r = 1, ..., R$)
R	Risk

RC	Risk-Cause composite attribute
Re	Reliability
RV	Risk value
S	Situation
SO	Solution composite attribute
SY	Symptom composite attribute
σ	Similarity
t	Period
T	Target
Te_{in_t}	Assembly time of component C_{in} denoted in minutes (min) in period t
Tr_{in_t}	Rework time of component C_{in} denoted in minutes (min) in period t
τ	Similarity weighting factor
VDS_k^a	Value of Defect Susceptibility of assembly job a and variable k
VDS_m^d	Value of Defect Susceptibility of design d and variable m
w	Cost weighting factor
W_{in_t}	Warranty and goodwill cost of component C_{in} in period t
$x_{r_{in}}$	Technical risk value of risk type r ($\forall\ r = 1, ..., R$; $\forall\ i = 1, ..., 4$); $\forall\ n = 1, ..., N$)
Ω	Similarity value
Ψ	Similarity threshold

Chapter 1

Introduction

1.1 Motivation and Challenges

The automotive industry is facing currently a variety of challenges and changes in economical frame conditions. One challenge today is the **individualization of products** and customer wishes which leads to an increasing multitude of product variants, options, and an increasing number of niche models. Automotive manufacturers have to consider the high **demand for innovation**, especially in the fields of safety technology as well as information and communication technology integration in vehicles. In this context, about 90% of future automotive innovations are in the field of automotive electronics. This results in a **higher vehicle and related process complexity**. The permanent market changes and increasing customer wishes require permanent life cycle oriented customer loyalty and an integrated consideration of product and service. Recent studies have shown that a need for automotive companies exists, especially in the field of automotive electronics, to continuously improve the vehicle reliability and quality in order to ensure competitiveness in the global automotive market. **Product life cycles are shrinking** as competition of global players accelerates the race to get new products onto the new market. Thus, not only innovations are accelerated, but products need to be introduced to the market and ramped up to the volume much faster in order to gain premium pricing and profit. The "time-to-market" gets shorter and customers demands have to be integrated in the product creation process at an early stage. With automotive electronics in particular, the integration of system and sub-system as well as software and hardware poses a new challenge for automotive companies.

The current economy is affected by the **globalization** and merge of markets which leads to a closer collaboration of companies worldwide. Multi-cultural development and production collaboration gain in importance with worldwide networks and partnerships of suppliers and manufacturers. This closer enterprise collaboration increases the information sharing over common platforms and the demand for decision making over company and process comprehensive. The close network of suppliers and producers provides a better constellation of the **"Time-Cost-Quality"** optimization of product and processes. Companies are taking advantage of the outsourcing of labor, knowledge, and processes in order to increase specific expertise from other development partners and to access additional capacity for enhanced programs. These developments also increase the meaning of merger and acquisitions which has been practiced intensively in the automotive industry. While this provides increasing benefits for an automotive manufacturer, it also implicates additional effort when integrating processes and managing interfaces.

In the automotive manufacturing field the factor of **socialization** is increasing in terms of stricter guidelines regarding health, ergonomics, liability, and safety as well as environmental protection issues such as the reduction of CO_2 emissions. The usage of environmentally friendly materials and production technologies is gaining in importance especially in the manufacturing as well as in the recycling phase. Companies face the challenge of modernization with an intelligent requirement, change, and complexity management in order to achieve an enhancement in efficiency and performance. Companies must take advantage of creating dynamic and efficient organization and knowledge processes in order to be competitive. In addition, in the complex automotive business human factors as well as organizational and cultural influences have to be considered in the continuous improvement process and play an important role in influencing and defining the company's corporate culture. Increasing product and process complexity requires intelligent and effective business processes as well as integrated **technical risk management**.

1.2 Objectives and Benefit Potential

In this context, this dissertation is designated to perform a research approach to develop an **I**ntegrated **M**ethodology for **P**roduction related **R**isk Management **O**f **V**ehicle **E**lectronics (IMPROVE) to optimize the assembly quality of electronic components. The objects of investigation are automotive electronics, the related vehicle assembly process, and the process interface Design for Manufacturing between development, production planning, and production.

Objective 1.2.1 *Due to the increasing product and process complexity as well as changes of automotive related legislations, the main objective is to develop an integrated and continuous technical risk management for automotive electronics.*

Thus, this paper aims at analyzing all relevant data sources along the value creation chain in order to identify production related risks and the related scope for improvements with a technical risk management approach. The complexity and number of electronic components in a vehicle is increasing which results in an increasing complexity of assembling these components into the vehicle. Therefore, it can be ascertained that new design concepts are necessary in order to better support the assembly and connecting process on the assembly line.

Objective 1.2.2 *The objective is to provide a new approach for an efficient and sustainable Design for Manufacturing in order to influence the vehicle development at an early stage for an improvement in assembly quality.*

Further objective is to synchronize engineering, development, and production planning activities and to create a common cost understanding over the entire value creation chain. There exists also the challenge to intensify defect and failure analyses and to create an efficient quality management for automotive electronics. Thus, it is aimed to reduce defects and failure rates of automotive electronics and to integrate a defect-stoppage process efficiently and sustainably. In order to achieve this objective, the requirement to share the same information and knowledge to all involved participants along the entire value creation chain is to be fulfilled.

Objective 1.2.3 *Further objective is to integrate feedback information from the customer, after sales organization, and the assembly process and to provide a common knowledge and solution platform. For this objective the Case Based Reasoning (CBR) technology is used to provide an efficient knowledge management tool for the considered solution cases.*

Dependent on the company size, there is the challenge to integrate a new approach in existing business processes. Thus, the goal is to provide solutions in order to optimize the business processes and company structures. In this context it is aimed to provide solution ideas how to change the corporate culture by initiating a new quality and risk understanding in the automotive industry.

Statement 1.2.1 *The benefit potential in this scientific work can be categorized into product improvements, assembly process improvements, and process and interface improvements, as well as the car manufacturers' business improvements.*

Product improvements contain design changes in order to increase manufacturability on the assembly line. Assembly process improvements consider for example organizational changes of assembly steps, tools, and assembly technologies. Business process and interface improvements contain the collaboration and knowledge sharing between development and production planning for an efficient Design for Manufacturing and defect-stoppage process. The car manufacturers' business improvements contain the reduction of the share of rework time, assembly time, and warranty cost. This meets the challenge of taking over the leadership in low production cost and providing high quality and innovative products in the automotive industry.

1.3 Objects of Investigation

Automotive electronics

The first object of investigation is **automotive electronics** or vehicle electronics which is used in this dissertation as a common term for automotive electric and electronic components and is the main focus of this research work. Electric components are used for the energy supply. The on-board energy supply system consists of an energy store (battery), an energy converter (generator), and an energy consumer (electric and electronic units) [Baue-03]. On the other hand electronic covers the design and application of electric circuits in devices. Electronic also comprises the circuits components such as transistors or integrated circuits, for example the digital-analog converter or flip-flops. Additionally, electronic can be differentiated into analog electronic and digital electronic [Baue-03].

Automotive electronics are often categorized in electronic systems. An element of a system can be at the same time another system, named sub-system, which can be a control system and can contain hardware, software and human interferences [DIN-61508]. Automotive electronics are also described with their architecture. Architecture can be defined as a specific topology configuration of hardware and software elements in a system. Software is essentially a computer program and can have various functions such as controlling hardware, performing computations, communication with other software, human interaction, whereas firmware is software that is embedded in a hardware device [Baue-03].

Assembly process

The second object of investigation is the **vehicle assembly process of automotive electronics**. Current challenges are to optimize the assembly process by changing for example the assembly sequence, the assembly location of electronic components in the vehicle, or tools and fixing elements. The practice today is that car manufacturers need many stations on the assembly line to install the wiring harness into the vehicle. The increasing number of electronic components has led to an increase of wiring harness length and thereby a high complexity of installing automotive electronics. The installation and fixing of electronic components is a complex process as for example in some situations accessibility is not ensured.

Main objective in this context is to create a vehicle assembly process regarding automotive electronics which uses standards, color coded parts and connectors to reduce the probability of a defect on the assembly line. Challenges for planning and optimizing the assembly process are the reduction of the assembly and rework time, increasing the First Time Capability (FTC), elimination of waste, and reduction of damages and defects on the assembly line while having a high delivery quota. FTC is defined as the percentage of vehicles which run through the production process without being discharged out of the production line for additional reworks. The further objective therefore is to increase the FTC and to reduce the share of rework time in the assembly process.

Design for Manufacturing

The increasing number of electronic components and interfaces on the assembly line leads to high complexity in the vehicle assembly process. In order to master this complexity it is crucial to support the design process at an early stage, and to increase the manufacturability on the assembly line. Therefore **the third object of investigation** is the **Design for Manufacturing approach**. When designing automotive electronics it is important to test and to improve the installation process by changing for example the location in the vehicle or by improving connectors, clips, cables, or the component's material. It is therefore crucial to put emphasis on the interfaces between production, production planning, and the development process.

On the one side, development and part cost reductions are essential for the design process improvements. On the other side however, the manufacturability of electronic components and the increase of assembly reliability will be a decisive factor for car manufacturers. Investments in improving the manufacturability on the assembly line and reducing defects can be balanced with development and part cost. The objective is to create an integrated and comprehensive cost understanding between development and material cost, also considering downstream cost factors from production and after sales organizations.

1.4 Approach and Structure

The scientific approach of this dissertation is both to study theoretical concepts and to create a new research methodology and engineering solution to bridge theory and practice by analyzing related business environments in order to provide new solution concepts in the automotive industry. This is done by analyzing the current situation in the automotive industry in **Chapter 2**. Further on in this chapter, the benefit potential and improvement request for the automotive industry are described. In Figure 1.1 is shown the approach and structure of this research work.

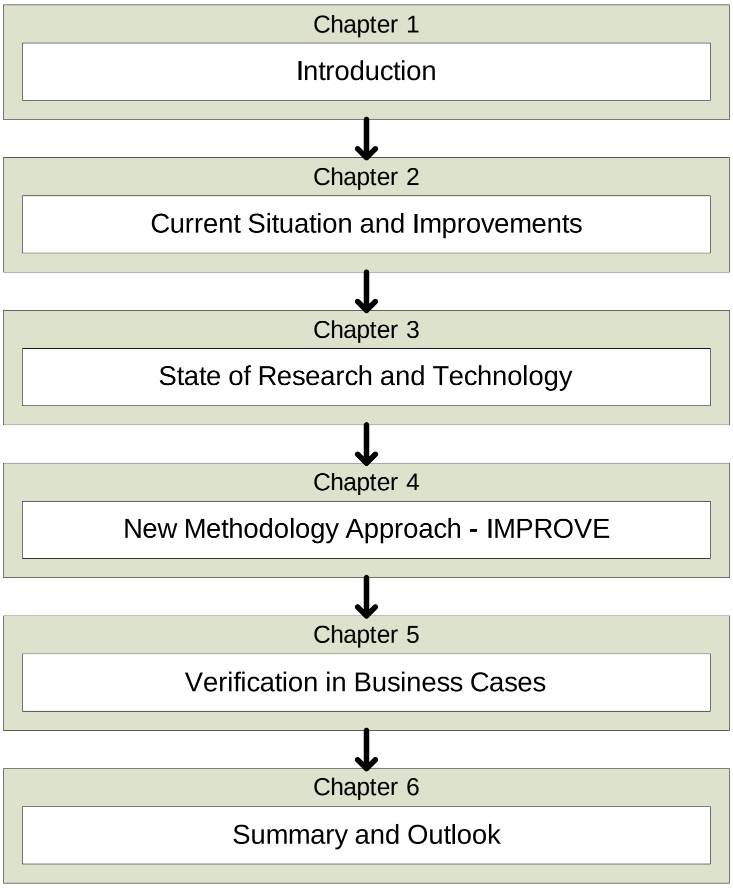


Figure 1.1: Approach and structure of work

In **Chapter 3** the state of research and technology is outlined. Each section is providing on the one side relevant theoretical methodologies, approaches and concepts as well as relevant patents and norms, and on the other side the industrial state of technology. The first section contains automotive electronics manufacturing methodologies, whereas the next section contains the state of production planning. After this the concepts of technical risk management as well as quality management methodologies are discussed. The following section provides introduction into the theoretical background of business strategy and process methodologies. The chapter ends with a summary and an evaluation of existing methodologies and approaches. This is performed by analyzing at first the applicability of existing methodologies, and secondly the extension of these methodologies to provide solutions for the described challenges.

Chapter 4 discusses first of all the detailed objectives and requirements for the new methodology approach IMPROVE, the scientific progress and industrial benefits. This new methodology contains a technical risk management approach in order to master the described challenges. The entire vehicle lifecycle is considered and important lifecycle steps are singeled out. The new methodology steps are described in detail and related definitions are provided. The next sections contain the implementation requirements in an industrial environment and related success criteria, followed by the chapter's summary.

After defining the new methodology approach, **Chapter 5** contains the verification in business cases in order to show the feasibility and usability in the industry. Therefore, the verification concept and the selection of appropriate application scenarios and business cases is described at first. The verification of the theoretical concept is performed in business case I with the example of the Brake Control System (BCS). In the second business case a software prototype is developed and programmed in order to verify the feasibility of the new methodology. This pilot is designated as a pre-version in order to integrate the new approach and methodology into companies' business processes.

Chapter 6 contains the summary of the essential results obtained in the dissertation. Further on, an outlook is provided on how the new methodology IMPROVE can be extended. Additionally, a perspective is provided for further changes of basic parameters in the automotive industry and for future trends of automotive electronics. Afterwards related product and assembly trends are outlined as well as future production planning challenges before the chapter and dissertation work ends with a conclusion.

Chapter 2

Current Situation and Improvement Request

Automotive manufacturers are facing throughout a vehicle's life cycle several important factors such as demand for innovation, product and process complexity, and several risk types. Additionally, quality requirements are increasing as well as the cost pressure in a highly competitive market, as denoted in Figure 2.1.

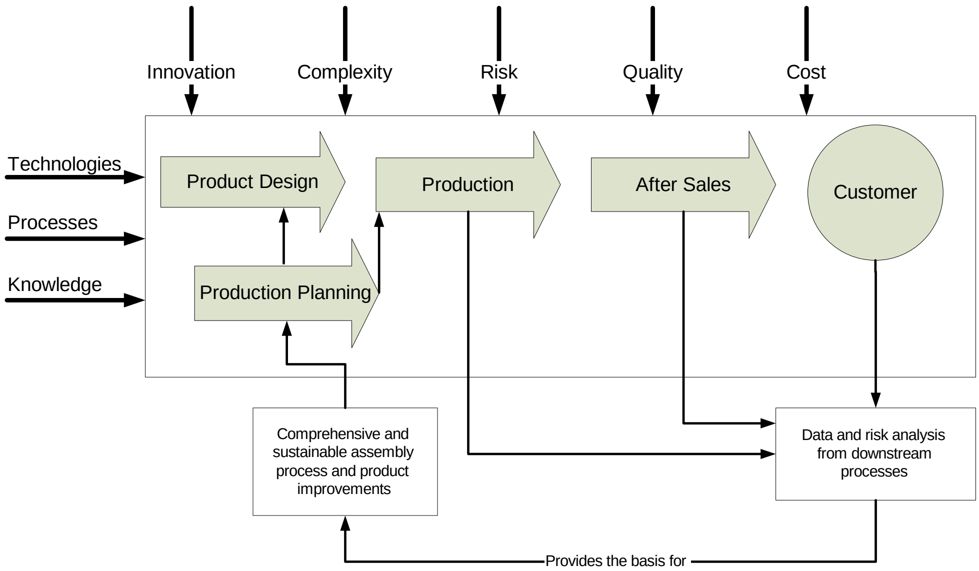


Figure 2.1: Requirements situation overview

With automotive electronic components in particular, car manufacturers find themselves in competition to provide the best quality to the customer and to ensure functionality of high complex electronic systems and components.

Statement 2.0.1 *For a successful quality management it is crucial that automotive companies put emphasis on an integrated, comprehensive, and detailed risk and data analysis from downstream processes such as production, after sales, and the customer feedback.*

This required data and risk analysis provides the basis for assembly process and product improvements. The production planning process plays a key role in this improvement process as it provides the interface between development and the production and assembly process, as shown in Figure 2.1.

The objective of this chapter is to describe the current situation and the related improvement request in the automotive industry for the described challenges in Section 1.1. In **Section 2.1** the current situation in the automotive industry is outlined considering in particular automotive electronics technology, industrial structure, and related production and quality management. Further on a quality data analysis throughout vehicle's life cycle is undertaken in order to identify the required data input for improvements. The next section contains the analysis and definition of technical risk management and illustrates its increasing importance for the automotive industry. In **Section 2.2** potentials of benefit and the concrete improvement request for the automotive industry are discussed, followed by the chapter's summary.

2.1 Situation in the Automotive Industry

During the last decades, vehicle technology has become highly intelligent and the vehicle's complexity has largely increased. Automotive manufacturers are facing the challenge to achieve the customer quality requirements of high complex products. On the other side, the number of Start of Productions (SOP) has doubled in the automotive industry during the last 20 years, having at the same time shorter product life cycles and reduced engineering time phases.

2.1.1 Automotive electronics technology

Currently in the automotive industry, the basic electronic architecture consists of a **voltage source**, **sensors**, **actuators**, and **Electronic Control Units (ECUs)** containing software and hardware, as demonstrated in Figure 2.2 [Baue-03]. The ECU plays an important role in the vehicle architecture and typically consists of a standard micro controller, specific signal processing, and a controller integrated circuit, as well as the necessary packaging, power supply, and power electronic components [BoHR-96]. Sensors and actuators build the interface between the vehicle with its complex brake, drive, and chassis functions

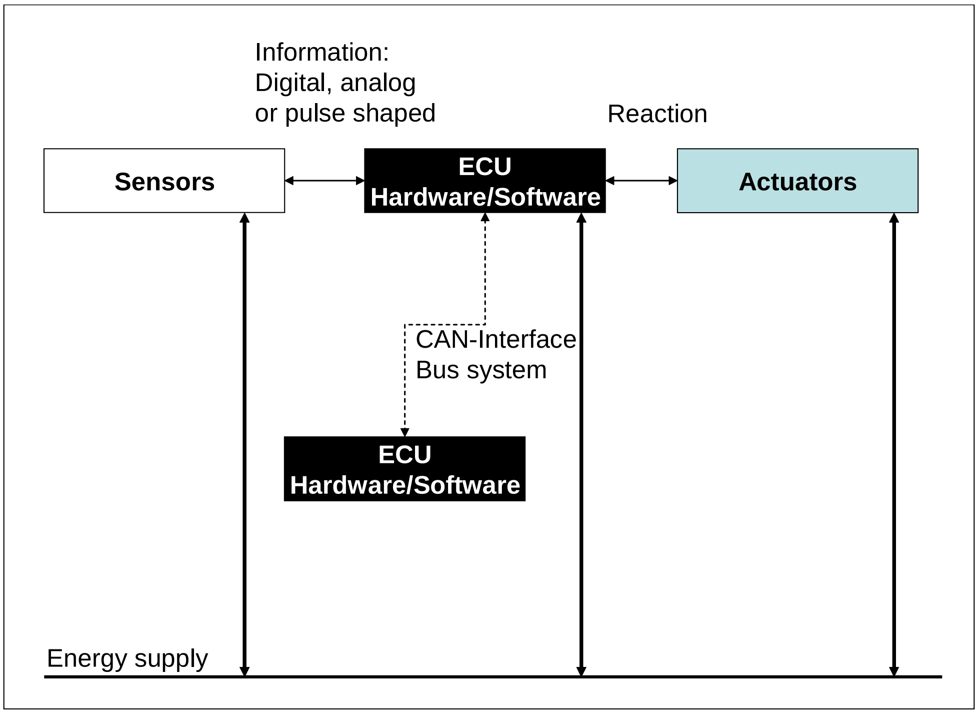


Figure 2.2: The basic automotive electronic system

and the mostly digital ECUs as processing units. Sensors transfer a physical or chemical value into an electrical value possibly over non electrical intermediate stages [Baue-03]. Sensors can be differentiated into three **reliability classes**:

1. Steering, braking, and passenger protection
2. Engine, power train, chassis, tires
3. Comfort, information/diagnosis, and anti-theft devices

As can be also seen in Figure 2.2 [Baue-03], actuators provide the interface between electronic signal processing (information processing) in an ECU and a related reaction. These signal converters combined with amplifier elements use the physical conversion principals between different energy forms which are electric, mechanical, fluid, and thermic [Baue-03]. Examples of actuators are the electro motor for seats, power windows, or an electronic supported servo steering. The requirements of the high number of sub-systems in a vehicle considering functionality, safety, and comfort can only be achieved by highly developed control systems [BrSe-03].

As is indicated in Figure 2.2, the different ECUs, sensors, and actuators are connected via bus communication interfaces, for example the **Controller Area Networks (CAN)**. The CAN technology has been established in the automotive industry and is a serial bus system which is characterized by the fact that the ECUs of different electronic systems are connected via a bus instead of a multiplicity of energy and communication cables [Baue-03]. The CAN works following the “multi-master” principle which enables the connection of several equitable control units. The advantages of this bus system are that it reduces wiring harness weight, increases harness reliability, enhances controlability, and allows increased options and enhancements with very low or no physical changes to the system. It provides centralized collection and processing of diagnostic information and is more economical [KhMc-94].

As demonstrated in Figure 2.3 [Baue-03], the basic CAN network architecture of a vehicle can be divided into Infotainment (multi-media) MOST CAN, the Chassis CAN, the Drive train CAN, and the Driving dynamics CAN which are connected via gateways.

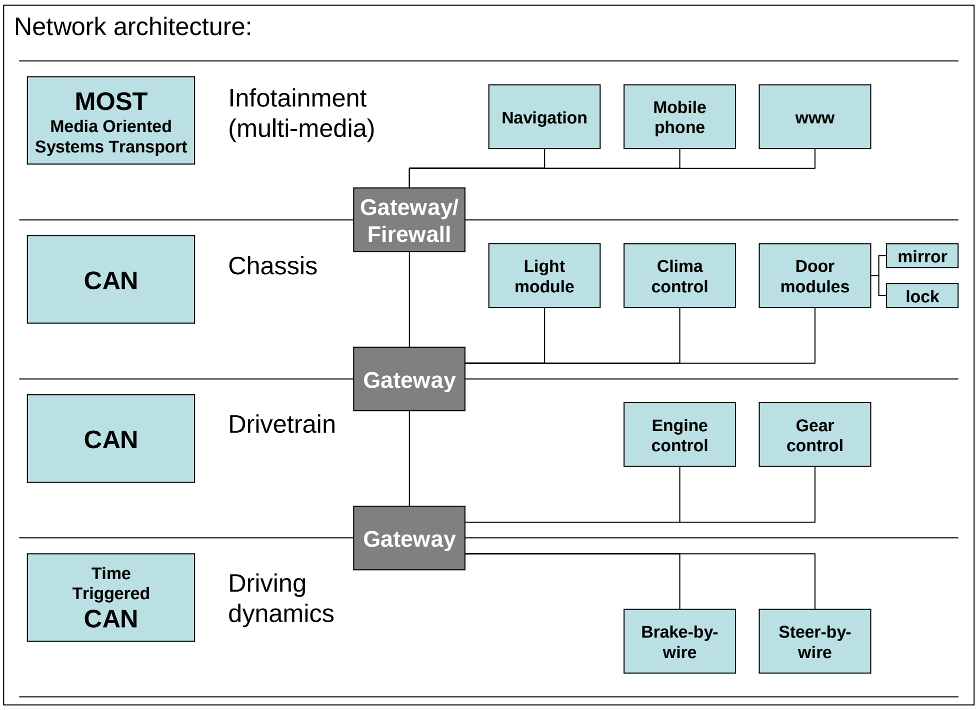


Figure 2.3: A sample of an automotive communication

Considering automotive electronics it is important to differentiate between a component and functional view. Components of an electronic system provide a function and result in possible consequences. In general, a function of technical systems is the transfer of input such as material, energy, and information with considerations of parameters into transformed output like material, energy, and information [Wiki].

As illustrated in Figure 2.4, the classical component view provides the basis for the functional structure.

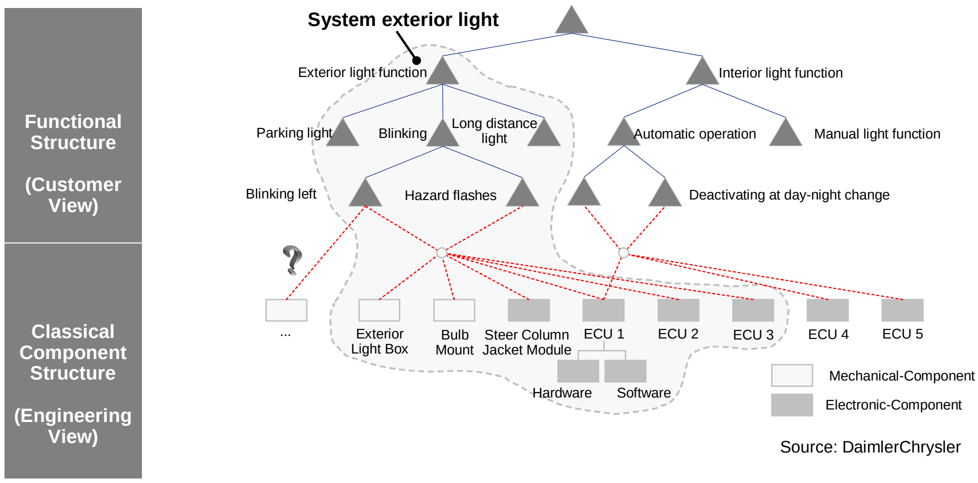


Figure 2.4: Dependency graph: Example of a functional structure hierarchy and corresponding component integration structure

One component can be involved in several functions. In a customer perspective the functional view is considered whereas for the assembly optimization in this work the component engineering view is more appropriate.

In recent years electrical and electronic system components, circuits, and accessories in automobiles have steadily increased, both in complexity and quantity. The need for innovations in comfort, convenience, entertainment, safety, security, communication, and environmental concerns requires improved electronic systems. The past four decades have witnessed an exponential increase in the number and sophistication of electronic systems in vehicles. In 1977, the value of electronics systems and silicon components such as transistors, microprocessors, and diodes in motor vehicles averaged $110 per vehicle, while in 2001 it had increased to $1,800 per vehicle [LeHe-02]. Today's top of the range vehicles may have more than 4 kilometers of wiring and more than 70 ECUs. Reducing this wiring mass through new network technologies in vehicles brings an explosion of new functionalities and necessary innovations. Vehicles become more like personal computers, creating the potential for a host of plug-and-play devices. Today, nearly 30% of the total vehicle cost is the automotive electronics share

On average, US commuters spend 9% of their day in an automobile. Thus, introducing multimedia and telematics to vehicles provide connectivity and entertainment for the customer and implies a huge market for automotive companies. The car is becoming an integral part of automotive and telecommunication services, which can give access to individual traffic and navigation information, breakdown assistance, and automatic emergency calls and traffic control. The car today contains sophisticated IT systems in order to enable multi-modality, and the ability to deal with electronic components in personal cars becomes more important in the future. The use of semiconductors and sensors grows dramatically. In the automotive industry, especially in the top end of the market, the following development can be observed.

Statement 2.1.1 *The functionality of electronic components becomes more and more complex at a very fast rate. About one third of development costs in the automotive industry is spent on electronics development nowadays, and this amount is still increasing [WeWe-02].*

This is the reason why the average number of ECUs of a high-end luxury car has increased in the last 20 years from 18 in 1995 to 72 in 2005 and will increase in the future, as shown in Figure 2.5.

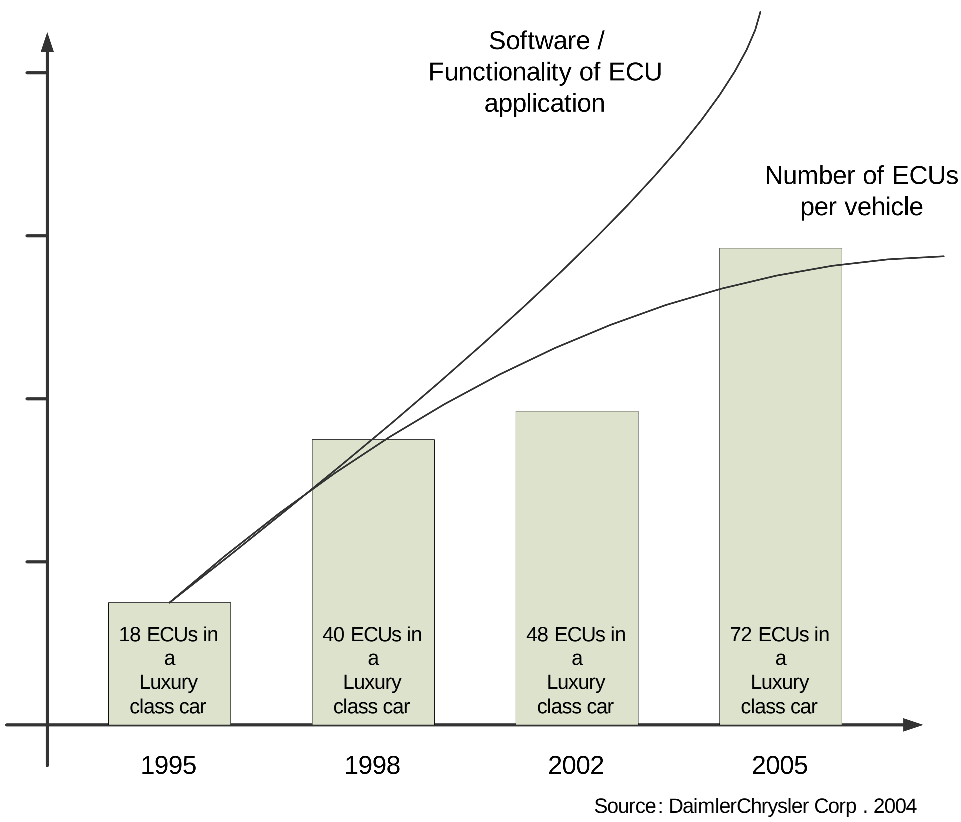


Figure 2.5: Increasing automotive electronic complexity

On the other hand, the functionality and software content per ECU will increase more in comparison to the number of ECUs. It is suggested that the number and the value of automotive electronics systems will grow at 10% per year [Broy-03].

Today, further challenges in the field of automotive electronics are the integration of mechanical and electronic components, the so called **mechatronics** which decreases the vehicle and component complexity. Another fact is that the common lifetime of a product in the consumer electronic industry is around 2 years and this is currently shrinking. Thereby, the challenge is to couple the world of electronics with the automotive electronics world, where the average product lifetime is about 10 years. A recent quote from the automotive industry shows that more than 90% of innovations in the automotive sector will be in electronic components which will be the battle field between consumer electronics, wireless communication, car electronics, and car manufacturing [Sang-00]. **Automotive electronics** are the greatest **innovation driver** in the worldwide automotive industry. The electronics value percentage of the entire vehicle amounted to approximately 25% in 2004 which should increase to 40% by 2010 [VDIr-04].

Automotive safety systems are also gaining in importance and are an innovation field which promise success. After installing the Electronic Stability Program (ESP) in vehicles in series, accidents were reduced by 42% in 2002/2003. Since the ESP system has been in series the number of road accidents with highest injury severity has decreased from 15% to 5%. If all vehicles would have ESP in series today, it would be possible to prevent 20,000 road accidents and 27,000 road casualties per year [Daim-04] which is a reason for increasing safety technology innovations in the automotive industry. On the other hand, safety systems such as the Adaptive Cruise Control (ACC) imply a high risk for car manufacturers as malfunctions of these systems result in legal and liability consequences [WeWe-02].

2.1.2 Automotive industry structure

The automotive industry is currently facing a dramatic change in its added value structure. Following the Mercer FAST study [Merc-04], it is expected that the total added value in the automotive industry will increase from 2002 until 2015 by approximately 250 billion euros. The added value of Original Equipment Manufacturers (OEMs) however will decrease from 35% to 23%, whereas for suppliers the added value will increase from 65% in 2002 to 77% in 2015. At all added value steps the OEMs are reducing their internal activities especially in module production, series development, and module assembly.

This added value development is demonstrated in Figure 2.6 [Merc-04].

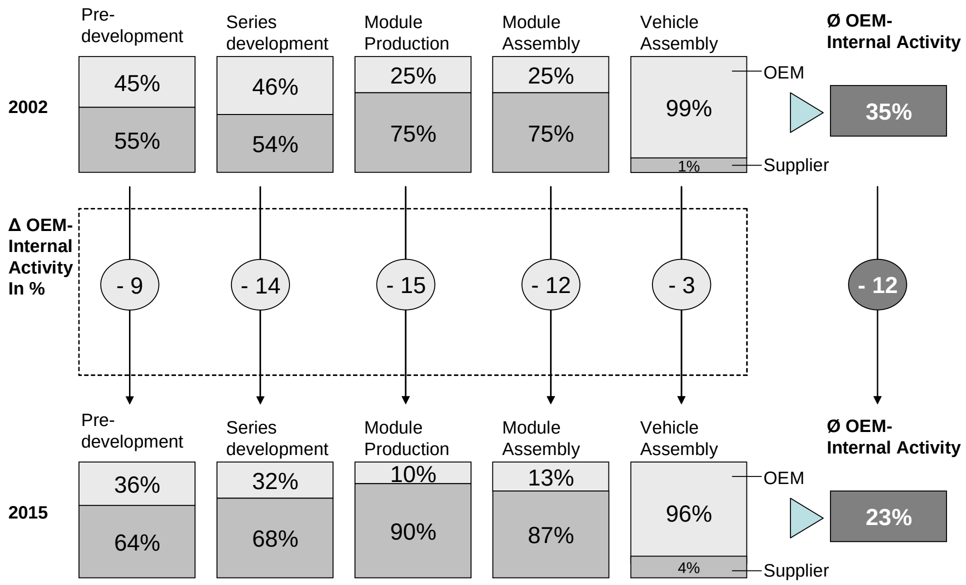


Figure 2.6: Added value development between OEM and supplier

From this follows that a better system integration competence is needed on the OEM side. Considering again the period from 2002 until 2015, a significant cost reduction is required in almost all main modules such as engine and transmission. A significant added value will be reached only in automotive electronics.

Statement 2.1.2 *Considering the ration of added value between OEM and supplier, in all main modules except electronics an added value movement will occur from OEMs to suppliers.*

This structural change leads to a continuing consolidation process along with the expectation of a bisection of the amount of suppliers. The **consequences for the OEMs** are an **outsourcing process** with or without resource transfer and a rededication of resources such as human resource capacities corresponding to core competencies for example. Additional consequences are the outsourcing of divisions and the build up of confirmed and permanent cooperation partnerships to ensure competencies and capacities access.

Extensive consequences of the changes in the added value systems for the suppliers are competency transfer and build-up on the suppliers side, as well as the build-up of product and service offerings being consistent between suppliers and OEMs (**"Synchronization"**). Other consequences are the massive investment demand of suppliers and the requirement of having a close relationship with chosen key customers (**"Networking"**). These changes require new forming of cooperations and innovative business models with a new quality of relationship. Innovative business models are related to vehicles, modules, added value steps, and regions whereas the new quality of relationships is related to strategy, structure and competency, and management and steering, as well as processes, systems, laws, and capital. This new quality of relationship becomes apparent in a high degree of networking of all involved partners, and win-win strategies with key suppliers of defined positioning technologies. The current **six steps for success** of cooperations and relationships in the automotive industry as follows, in accordance with [LiCh-05]:

1. Understanding the suppliers' methods of operation.
2. Seeing supplier rivalry as a chance.
3. Monitoring the suppliers.
4. Enhancing suppliers' abilities.
5. Changing information intensively but selectively.
6. Performing improvements together with suppliers.

The supplier management receives additionally increasing importance in terms of negotiating supplier contracts, defining interfaces, and monitoring action control limits.

2.1.3 Production management

The **increasing complexity** of electronics in vehicles and the new automotive industry structure also affect the production and **vehicle assembly process** of electronic components. The installation process of electronics on the assembly line requires new concepts and solutions to improve the product and the process, in order to have highest reliability of fixing and connecting electronic components. The car manufacturers are facing new challenges when developing and assembling electronic components such as the fact that the ratio of software will increase in the next years from 20% to 38%, whereas the hardware share will decrease from 80% to 62% [WeWa-03].

Another complexity enhancement is for example the **increasing variants** to be assembled on the assembly line due to different language and foreign legislations. This will increase developing complexity as well as software setup and testing complexity in the assembly process. Another challenge is that the standards for system integration of electronic components do not exist as required in the automotive industry and that the simultaneous development of hardware and software is problematic, as there is still no general quality standard for software systems in car manufacturing. There is a trend towards integrating electronic components directly into plastic parts of the car such as instrument panels. This may save manufacturing steps, however it needs new rework and repair concepts for the OEMs. The increasing functionality and number of electronic components in a vehicle increase the wiring harness length as well as the number of electronic interfaces on the assembly line which require new innovative assembly concepts.

Vehicles can be mostly configurated according to individual customer wishes. This leads to the fact that almost every car in the production process is different from the others and this variety of variants makes the production process very complex. In general, the entire production process and production networks in the automotive industry have become more complex in the past years. The supply chains of electronic components, from manufacturing small micro controllers to installing an electronic component into a vehicle on the assembly line, have become sophisticated production and supply networks. In order to be competitive in the future, OEMs can meet the **challenges of manufacturing** and assembling electronics taking into consideration the following issues [Hall-04]:

- Efficient and sustainable Design for Manufacturing.
- Optimization of the assembly processes through standardization.
- Elimination of waste.
- Change of the production framework such as flexibility of working times and capacities

In fact, in order to ensure the highest reliability of the assembly process, the Design for Manufacturing approach has become more important for car manufacturers as tremendous savings of the total vehicle cost can be realized when applying this approach [Dvor-94]. Japanese automotive companies in particular have demonstrated that this is a successful way to carefully analyze the manufacturing process and to completely develop the vehicle from an assembly view.

Statement 2.1.3 *Successful Design for Manufacturing is achieved by formalized and standardized processes, sustainable lessons learned between life cycles, minimal invisible product changes, as well as high product and assembly maturity at an early development stage.*

2.1.4 Quality management

Quality management aims to maintain and improve all aspects of the quality of the products and services supplied by an organization, and the processes within that organization. This activity may be divided into **quality assurance** and **quality control** [DIN-9000]. Quality assurance concentrates on the manufacturing process and attempts to ensure that the work is performed correctly. Quality control aims to test that the product is free of defects [DIN-9126]. A **quality system** is the organizational structure, responsibilities, procedures, processes and resources for implementing a quality management [DIN-9000].

In the past few years the automotive industry has been in the spotlight due to new future innovations in electronics, but also sometimes due to not achieved quality objectives as following examples show:

> *"Toyota will recall 880,000 vehicles which is the biggest recall in the company's history." 05/20/05 [VDI-2005]*

> *"General Motors Corp. said on Monday that it was recalling more than 2 million vehicles to fix a variety of potential safety defects, most of them on cars and trucks sold in the United States." 04/25/05 [Detr]*

> *"DaimlerChrysler recalls worldwide 1,300,000 vehicles of Mercedes-Benz to the service stations. Diesel pump defects from Robert Bosch company shut down the production of DaimlerChrysler and BMW for several days." 03/31/05 [Fazn]*

Following the German Federal Office for Motor Transportation, the number of official recalls in Germany over the time period 1992 - 2001 increased from 62 in 1992 to 113 in 2001 [LeFH-03]. The **cost of quality problems** are increasing dramatically in the automotive industry. In Figure 2.7 the loss of profit margin based on the example of an upper mid-range passenger car are shown. The increasing complexity of the interaction of electronics, mechanics, and software in the vehicle requires new concepts and solutions in quality management. The fact that the worldwide market volume of automotive hardware and software will grow from 110 billion Euros in 2000 to 270 billion Euros in 2010 will increase the complexity of quality management in the automotive industry [LeFH-03]. Other challenges for effective quality management are the continuous vehicle software changes and the fact that sometimes failures firstly occur when interacting with other components. The reason is, that today it is not possible for OEMs to test all possible combinations and variants in advance as it would require per vehicle several days of testing time. The failure and defect localization becomes more complicated as mostly different suppliers and sub-suppliers are involved in the process.

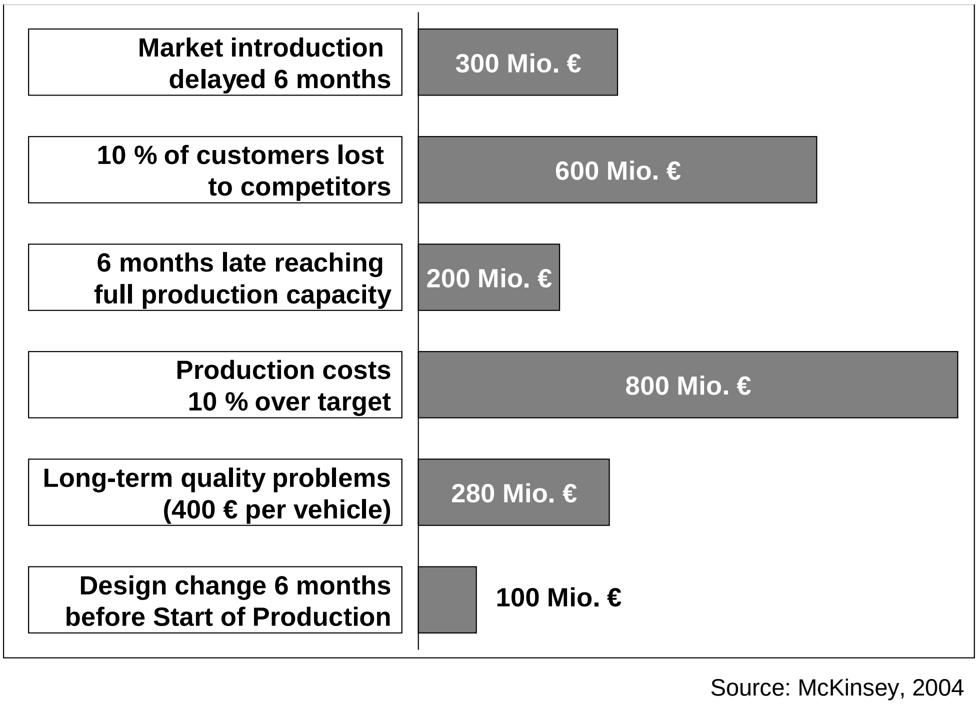


Figure 2.7: Cost of quality problems

Statement 2.1.4 *Automotive manufacturers will have to meet the challenge of increasing complexity and quality requirements by new concepts of quality and risk management throughout the entire vehicle life cycle.*

Quality data analysis

In order to perform this quality and risk analysis and to create transparency over the value creation chain it is decisive to analyze in detail the quality data of electronic components along a vehicle's life cycle. The objective is to identify defects and failures as well as related causes and consequences [Biro-04].

Definition 2.1.1 *A failure is the termination of the ability of a functional unit to perform a required function [DIN-61508]. A failure is also defined as missing the mark or falling short of achieving goals, meeting standards, satisfying specifications, fulfilling expectations, and hitting the target [With-94].*

A defect can cause the failure of a function. A fault however is an abnormal condition, which can cause the reduction or lost of the ability of a functional unit to perform a required function [DIN-61508]. A fault is hence a state resulting from a failure [BlMu-00]. An error is a discrepancy between a computed, observed, or measured value or condition and the true, specified or theoretically correct value of information [IEC-50].

A failure mode is the description of a fault [IEC-50]. Failure modes can be identified by studying the function of the item. As a first approach **different failure modes** can be described as follows [BlSh-94]:

1. Intermittent failures are failures that last only for a short time
2. Extended failures continue until corrective action rectifies the failure. Extended failure can be divided into two categories:
    - Complete failures which result in the total loss of a function (Catastrophic or gradual
    - Partial failures which result in the partial loss of a function (Sudden or degraded)

A failure cause is the circumstance during design, manufacturing, or use which has led to a failure [IEC-50]. The **failure cause** is a useful information for the prevention of failures or their reoccurrence and is classified in relation to the vehicle life cycle as can be seen in the following Figure 2.8 [IEC-50]. **Firstly**, **design failures causes** which occur due

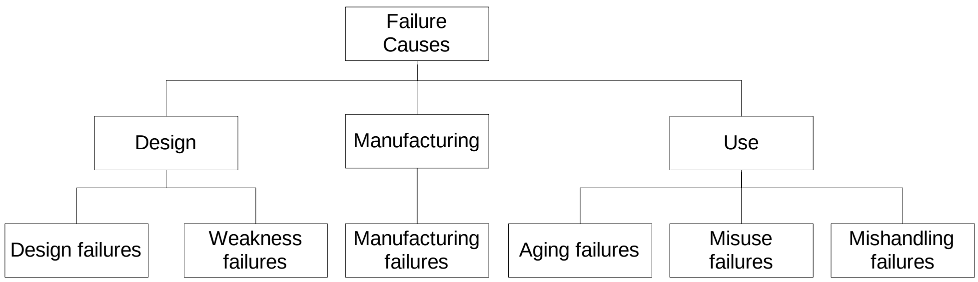


Figure 2.8: Failure cause classification

to inadequate design, and **secondly weakness failures** due to an inherent or induced weakness in the system meaning that the system cannot stand the stress it encounters in its normal environment. **Thirdly, manufacturing failures** can be mentioned which occur due to nonconformity during manufacturing. In the **use phase** aging failures can occur due to effects of age and/or usage, misuse failures due to misuse of the system for example when operating in environments for which it was not designed, and mishandling failures due to incorrect handling and/or lack of care or maintenance.

The **failure rate** is a measure for knowing the **reliability of an item depending on time**. Reliability is a collective term used to describe availability performance and its influencing factors such as reliability performance, maintainability performance, and maintainability support performance [DIN-9000].

The typical shape of the failure rate $\delta(t)$ over time of a large population of statistically identical and independent items is shown in Figure 2.9 [Biro-97], often representing the form of a bathtub curve.

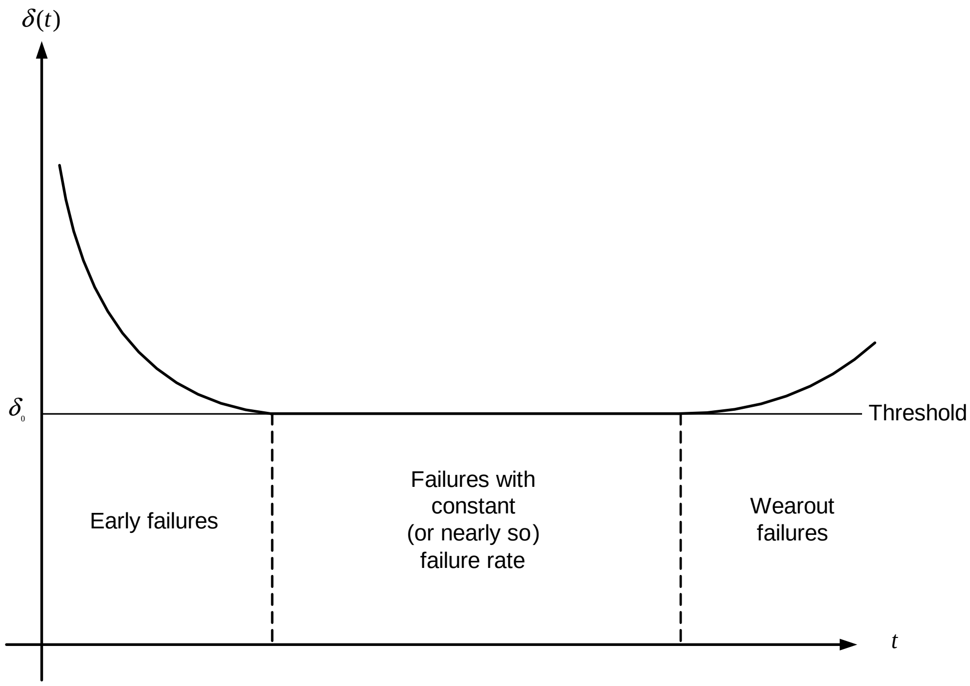


Figure 2.9: Typical shape of a failure rate

Three different **types of failures** occur:

1. The early failures, where $\delta(t)$ decreases rapidly with time,
2. failures with constant or nearly constant failure rate where $\delta(t)$ is approximately constant and equal to the threshold δ_0, and
3. wear out failures where $\delta(t)$ increases with time.

The probability of failure depends on the sum of the failure rate over time t, which is mathematically demonstrated in Appendix A.

The objective is to gather and analyse defects and failures throughout the entire value creation chain. Suppliers are challenged by rising requirements at lower cost to simultaneously improve overall quality, reduce lead-times, supply customers just-in-time on a global basis, take increasing responsibility for managing the entire value chain below the tier-one level, and cut costs at the same time [Schm-01]. The interesting figure for car manufacturers is the **parts-per-million (ppm) defect rate** at the state of delivery on the assembly line. The ppm defect rate is defined as the number of rejected units related to a statistical sufficient total number which are selected with defined criteria. The 0 km-breakdown is defined as the detection of a defective component in assembly until the transfer to after sales organization at the Point of Sale (POS). The 0km ppm defect rate is defined as the number of defective components which are detected on the assembly line. The OEMs are today not prepared to test all supplied parts. Therefore there is a risk that a defect part may be assembled on the vehicle. However, for each supplied part a view control is performed before installation.

The optimal condition would be to test all parts supplied to the assembly line and to check all functions of a vehicle at the end of the assembly line. This however is not possible as it is too time intensive and costly. The OEMs would need more than 2 days for a mid-size vehicle to check all functions. However, in the automotive industry tests are operated and quality data gathered during manufacturing which is discussed in Section 3.1 in detail. **Quality data from after sales organization** can be categorized into **internal data** and **external data**. Internal data provides information received from service stations and after sales organization about defects and failures which occur after the POS. External information can be gathered from public associates such as J.D. Power or automotive clubs. There are several other external data sources such as the National Highway Traffic Safety Administration (NHTSA) [Nhts] in the United States of America or associations such as the German Automotive Association (ADAC) providing quality rankings. However, in most cases the data granularity is not sufficient for performing a detailed analysis. Quality data analyses are often critical as the result is only as good as the information available, which can lead to incompleteness of information. An additional challenge is the inaccuracy of the data due to wrong or missing information and the multiplicity of unknown influences. Quality data analyses are therefore often operated using probabilities, instead of calculating with exact data.

2.1.5 Technical risk management

In the literature several different risk definitions can be found such as:

Definition 2.1.2 *Risk is a combination of the probability of harm and the extent of a harm [DIN-61508]. Alternatively, risk is defined as the combination of the probability of an event and its consequences [ISO-73], or risk is the possibility of loss, damage, or any other undesiderable event [Deci].*

Technical risk management aims at identifying technical risks of products and processes for the entire product life cycle. Technical risk is defined as the possibility of an economical benefit or loss as a consequence of developing, implementing, and managing a certain technology from which advantages or disadvantages can occur [Rine]. A hazard is a situation in which there is actual or potential danger to people or the environment [Stor-96].

When analyzing risk **two dimensions** have to be considered:

1. Where and which risks exist?
2. How significant is the risk?

Modern approaches contain an integrative risk management which means that risks to a company have to be considered entirely as well as the dependencies between the different risks. The **operational risk management process** as can be seen in Figure 2.10 [Kend-98], starts with a risk analysis, which is risk identification and evaluation .

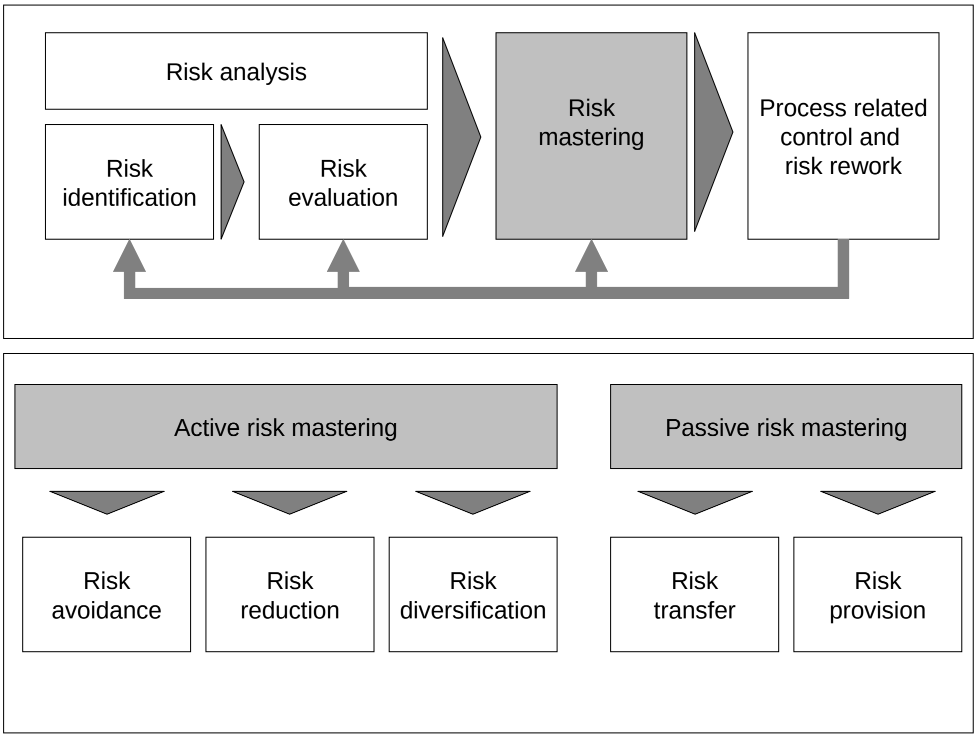


Figure 2.10: Operational risk management process

In this risk analysis the dimensions of the company's risk have to be determined. After evaluating the risk, the second phase follows where the risk mastering takes place. Risk mastering can be classified into active and passive as can be seen in the lower box of Figure 2.10. Active risk mastering is risk avoidance, risk reduction, and risk diversification. On the other side, passive risk mastering is defined as risk transfer and risk provision. The last box contains the process related control and risk rework where it has to be checked if all arisen risks have been identified, if the risks have arisen with the probability and dimension in which they were forecasted, and if the risk mastering measures taken brought the effects desired.

Risk is often only seen as the deviation from an expected value which is related to a disadvantage or loss, the one-side risk definition. However, risk can be defined with a two-sides risk definition with the positive or negative deviation of a value from its expected value.

Statement 2.1.5 *The two-sided risk definition places emphasis on the fact that risk is also related to chances and opportunities. The takeover of risks can provide the chance to gain additional benefits.*

Therefore, a company which understands their risk types, risk factors and interdependencies better than its competitors improves its business [MeSF-04].

In the focus of this work are production related risks which can be defined as the sum of influences and consequences when manufacturing products. **Three types of production** risk can be differentiated.

1. Input risks which are related to the production factors.

2. Process related risks during time of production.

3. Output risks.

Output risks are related to products which are for example not produced or damaged products, or those which cannot be used anymore [Rogl-02].

There are several developments which have increased external risks to companies which are result of markets and stock exchanges, natural catastrophes and terrorism, the globalization, product piracy and political decisions, as well as internal risks such as financial, liability, and production risks. The increasing risk led to the introduction of new legal regulations. This is at first the **"Corporate Sector Supervision and Transparency Act" (KonTraG**) which require incorporated companies to install a risk management system with early risk detection. This is concretized for example in the **German Commercial Code in §289** that companies have to address risk development in the their economical reports [Meie-05].

Malfunctions of vehicle electronic systems due to design or assembly defects are very critical to car manufacturers and imply liability and legal consequences along with high cost [VeMT-03]. Product liability is the responsibility of a manufacturer to compensate for losses due to injury to persons, material damage, or other unacceptable consequences caused by a product [Biro-04]. Responsible in a product liability claim are all those responsible managers involved in the design, production, and sale of the product, including suppliers [Lind-04]. Strict liability is essentially applied and the manufacturer has to demonstrate that the product was free from defects [Biro-04]. For the study of recent and former liability cases is referred to the summary of [HaRi-05]. In a case of non-legal consequences the car manufacturer can be hit by other consequences such as sales reduction, loss of reputation, and brand and image damage.

There has been a rapid increase in product liability claims, alone in the USA from 50,000 in 1970 to over one million in 1990 [Biro-04]. One important example demonstrating the requirement for integrated risk management is the Firestone tire recall in 2000, when Firestone recalled 17 million tires at a cost of 7.1 billion US dollars. Perhaps the most deadly auto safety crisis in American history, the tire recall of 2000 is associated with approximately 270 deaths and over 800 catastrophic injuries [DeMM-04]. The tire defect of 2000 was caused by a fabrication error whereas deficiencies were identified in the quality control process. As a result of the tire recall, hundreds of lawsuits were filed against Bridgestone/Firestone Incorporation [Riw2].

The Ford/Firestone example triggered the enactment of the **"Transportation Recall Enhancement, Accountability, and Documentation" Act (TREAD Act)** in the United States in November 2000. This act enhances the penalties that could be imposed on automotive manufacturers that fail to report defects [VeMT-03], [Rine]. European companies which are involved in the US market assure 136 % more liability issues in comparison to companies focusing on the European market. The number of product liability claims has increased dramatically in the last 10 years [VDI-1805].

The legislation and product liability laws are different from country to country. In Europe, directives for product safety contain important new provisions and amendments regarding the recalling of defective products. These are the development of technical standards, effective monitoring of the market, and obligations to inform the public authorities in case of hazardous products. For automotive manufacturers and suppliers the **German Product Liability Law (ProdHaftG)** says in §1 [PrHG-05]:

§1 Liability (1) : *If somebody is killed , injured, or a thing is damaged due to the failure of a product, the manufacturer of the product is in debt to the damaged person to pay for the arisen damage.*

On the 6th of January 2004 the new Devices- and Product Safety law (Geräte- und Produktsicherheitsgesetz (BGB I 2004, 2)) was passed in Germany, and is valid for marketing and exhibition of products, as far as this is done autonomous in the context of a company.

Therefore, for electronic components in particular a great importance of technical risk management exist throughout the entire vehicle life cycle. This has to contain the entire supply and production network from the vehicle concept phase until the customer contact.

2.2 Improvement Request for the Automotive Industry

"The concentration on mature products, robust processes, and a holistic product consideration over the entire process chain and all interfaces are success promising for automotive manufacturers." [VDI-2005].

Taking this into consideration, in this section the improvement request for the automotive industry will be introduced based on the problem description and current situation outlined in Section 2.1. The objective is to realize product, assembly process, and business improvements for automotive manufacturers in order to increase significantly the assembly quality of automotive electronics. The following sections contain propositions and solution approaches for potential improvements in the automotive industry. The solution approaches are general improvements which have to be considered with respect to economic efficiency and are different from case to case. The detailed usage of these improvements and the related implementation is described later on in this work. This improvement request is based on an industrial analysis project.

2.2.1 Product

The focus of the potential product improvements does not lie on the entire vehicle, but addresses the improvement of the product in terms of better manufacturability on the assembly line with main stress on automotive electronics. The number of electronic components in a vehicle has increased in the last decades which has led to marginal space for electronics and thereby fewer assembly locations for electronic components in the vehicle. Considering product improvements of automotive electronics the next sections put special focus onto connectors, hardware, and wiring harness improvements.

Connectors

In order to improve the connecting process on the assembly line, **connectors and couplings** could be **geometrically coded and color-coordinated** in order to prevent the mixing up of connectors when plugging several of them into an ECU. This would improve the process safety of the connecting process. Another improvement would be that **plug connections provide audible and visible feedback** when they are properly connected. As assembly locations in the vehicle are mostly dark and other components black, the base coding of connectors could be white for a better contrast. When more than one connector has to be connected to a component, further color differentiation could be applied. These connector related requirements help to improve the process safety of plug connections. Additional improvements could be achieved by avoiding sharp edges on connectors, because of the risks of injury to the worker and damages to the wiring harness. The structural design of connector casings and plug connections could be optimized so that the pins cannot be broken off, squashed, or bent during connection, even when the plug is connected askew. The costs of rework would thereby be reduced.

There is also a high saving potential when **connectors and couplings would be further standardized**. The objective thereby is to reduce the quantity and variety of different connectors and to use standardized connectors. The focus here should be on the plug connections, the geometry of casings and the pins. When interlock concepts are also standardized another potential could be realized. The **reproducibility of plug connections** should be ensured, to the extent that the connection and disconnection characteristics of a plug should not have changed or deteriorated after some time. This results in a reduction in the time required for rework. Despite this, the goal during assembly is that only one plugging process is required. If the plug needs a locking mechanism, it should be sufficiently robust so that the necessity for rework can be reduced. The potential **improvement request considering connectors** can be summarized as follows:

- Increasing process safety of the connecting process.
- Reduction of risks of injury to the worker and damages to the wiring harness.
- Reduction of defects, assembly and rework time.

Hardware

Due to the increasing complexity of the assembly process and the number of hardware components to be installed on the assembly line, the objective and one possible improvement is a **reduction of ECUs, by integration and clustering concepts**. In order to improve the vision in dark assembly spaces, an improvement would be to make the casings of electronic parts which are not visible to the customer in white color.

In order to increase process safety when picking up the right parts, the **font size on ECU labels** should be the appropriate size for **better legibility**. Labels are best positioned so that they can be read even once the control unit has been installed. Additionally, **different versions of each ECU** could be made **more distinguishable** by using symbols or colors on their labels. This reduces the risk of mix-ups and highlights important information. If a batch is installed incorrectly, it can be quickly established which vehicles have to have their ECU changed. This requirement should be viewed with consideration for the size and design requirements for ECUs.

Another improvement could be that the **mounting position for an ECU** is **clearly identifiable** right up until installation. By eliminating unnecessary experimentation for finding the exact assembly position, this reduces assembly time. If the configuration of connectors on electronic components is always identical in number and positioning so that the worker should always carry out the **same plugging-in process on an ECU**, the assembly processes can thereby be standardized and the sources of errors minimized. Another improvement would be that **plug panels are systematized**. The plug panel on any ECU with more than two connections could be divided up into a structured sequence by for example the indication of different wiring harnesses with colors. The results of this **improvements request** can be outlined as follows:

- Standardization reduces assembly and rework time.
- Clear classification simplifies the assembly process for the worker, and reduces costs, and the share of rework.

Wiring harness

The wiring harness is a complex product and needs several assembly steps until it is outlaid in a vehicle. Wiring should be easily mountable, with the use of locators, on pre-defined points on the vehicle body. The locators would be pre-attached to the wiring loom and delivered as such to reduce assembly times. **Wiring length tolerances** should be designed so that excessive play in cables cannot cause them to be left lying loose. If, because of overlap, the same line lengths are used on different vehicles, excess length should be taken up along **defined wiring channels** Process safety is thereby increased and trapped cables and un-connected socket connections are avoided.

From an assembly point of view another improvement would be that **earth wires should**

be routed together to a cable shoe in order to reduce the number of earth points, so that only one connection per earth point is necessary. When choosing locations for earth points, it should ensured that easy access with a screwdriver is possible. Moreover, all **earth points** should be better designed to accept the **same bolts and the same amount of torque** which reduces the assembly time significantly.

In order to avoid noise and to **protect wiring from scrubbing**, an alternative solution to the use of felts could be applied to secure wiring looms with for example moldings, specific wiring channels, or locators. The use of felts is associated with long assembly times, and cannot be consistently installed, which results in increased material costs. Another improvement could be that the clip that is to be mounted first at a line intersection is color-coded, in order to inform the worker where to start with the connections at the intersection. This reduces assembly times and improves process safety. Additional improvement potential could be to **reduce the number of plug connections**, for example through the integration of plug connectors into control units. Small plug connectors should be integrated with larger plug connectors into a single part which reduces assembly times. The various configurations for special equipment should be allowed for by corresponding configurations of plug pins. As a result of this using fewer large plug connections instead of more small ones requires more assembly space and agreements between packaging and development departments at an earlier stage. It would however significantly reduce the probability of defects on the assembly line and also downstream after POS. In the following, the potential **improvement request** for the **wiring harness** is summarized:

- Defined wiring channels increase the process safety
- Using the same bolts and torque for earth points reduces the assembly time significantly
- Applied alternative wiring protect solutions reduces material cost
- Reduction of plug connections reduce the probability of defects

2.2.2 Assembly process

The increasing numbers of electronic components which have to be installed into a vehicle increase the complexity on the assembly line and logistics, testing, and handling processes, which requires new assembly methodologies to increase the process safety. One improvement could be for example ,that the mounting concept for a module is consistently designed with **standardized screws and tools**, and with **fixing elements integrated into the component**. This allows to screw in with both hands, which reduces assembly times and possible damages. The installation position for an electronic part should be easily visible and ergonomically accessible to the worker. Another improvement would be to **position as many components as possible near the edge of the body** so that the need for the worker to climb into the vehicle can be avoided. This reduces assembly times and avoids damage to any connectors or other electronic parts lying loose inside the vehicle.

Another improvement would be if **threading points** along the wiring harness, especially at the rear of the vehicle, **are avoided**. Threading points lead to increased quality risks during assembly as plugs and wires can be damaged during threading, and as a result, threading is associated with longer assembly times. In locations where threading points cannot be avoided, the assembly process should be assisted by threading bags, delivered with the wiring harness. Unavoidable threading points should be sufficiently large in diameter, and positioned in ergonomically accessible locations. Considering the **assembly process**, the **improvement request** can be abstracted to the following:

- Standardized screws and tools increase the process safety and reduces assembly and rework time
- Reduction of damages to the cable loom by avoiding threading points

Ergonomics

Ergonomics is the study of designing objects to be better adapted to the shape of the human body and/or to correct the posture [Wiki]. Ergonomics is an important topic for car manufacturers and the evaluation and research on ergonomics can be done in the following five stages: Workability and danger, fatigue and tolerability, productivity and quality, regulation of work, health and safety, and contentedness.

Current statistics show that 30% of all assembly worker illness and injuries can be put down to overstressing and that back injuries account for 22% of all damages. As an example, German companies lose in average a total of 22 billion Euros added-value potential per year through absence from work which can be traced back to work related illness [Land-03]. The necessity of ergonomical labor organization for the majority of single work places and assembly line design can be verified micro- and macro economical. Micro economical for workers' health protection and companys' cost-benefit calculations, and macro economical for employers' health insurance associations and other insurance institutions.

Statement 2.2.1 *The objective is to establish a more ergonomic assembly process in order to improve the posture of the worker during installation.*

Another objective could be to reduce the use of tools and the swapping of tools during the installation of electronic components. Early agreements with the packaging and development departments are required for an ergonomy improvement with respect to the overall benefit and efficiency calculation. In this context the human being motivation aspects and incentives for better work performance should be taken into consideration.

Assembly organization

Assembly organization improvements are mainly related to the standard assembly concepts which are re-used in the automotive industry by some manufacturers. The **standardization** can be described so that only one worker does **one assembly step** within a **defined station on the assembly line**. The concept also contains that tools are only used in this station and that material is provided only in this station. With this concept processes can be optimized, clearly defined, and the process synchronized as jumping between stations is not possible. Job rotation can be used in order to enable changing tasks. The assembly organization should take into consideration the influence on the supply and logistic concept. Additional improvements could be made by changing the **logistic concept of supplying material in different boxes or racks** to the assembly line in order to ease the pick-up of material. Thereby, labeling concepts should be used to reduce the danger of confusion of different variants by providing additional information to the assembly worker.

2.2.3 Automotive manufacturers' business

One of the top business objectives of automotive manufacturers' when considering electronic components is to deliver vehicles at the highest quality and functionality at adequate cost, in order to fullfil the customer requirements. The management of an automotive company has to balance a **variety of decision alternatives and trade-offs** such as:

- High delivery quote **versus** a maturity and quality grade.
- Postulated variant demand from after sales organizations and the market **versus** a technical feasibility in development and production.
- Considering the Design for Manufacturing interface a better manufacturability **versus** material and development cost.
- Fast production ramp up to satisfy the customers with a point of delivery in time **versus** taking time to increase the product and manufacturability maturity grade.
- Fulfilling innovation requirements **versus** technical feasibility, increasing vehicle complexity, and integration possibilities into the electronic architecture.

In this decision context, automotive manufacturers have the business objective to **reduce assembly and testing time** and thereby assembly cost for automotive electronics. Assembly time can be divided into the primary and secondary time. The primary time is defined as the added value operation and the secondary time as the non-added value operation such as transportation or preparation of parts [VDI-2234]. The primary time can be influenced by improving manufacturability. The secondary time can be reduced by changing for example the supply concept to the assembly line and thereby to reduce ways [LaLu-01]. **Reduction of the secondary time implies a high saving potential**. Additionally, by improving assembly concepts, defects and failures are reduced. This reduces the share of rework time and related rework cost.

Statement 2.2.2 *If defects are reduced, the rework cost such as additional assembly space, human resources capacities, material cost, and thereby the related bound capital can be decreased.*

Another improvement would be to eliminate waste when using new assembly materials. While increasing the product quality until POS, a warranty cost reduction and increasing customer satisfaction can be achieved. The defined improvements can only be successful with respect to the cost effectiveness of the solutions. These objectives can be achieved by identifying production risks of electronic components, creating solutions in order to reduce defects and risks, and implementing solutions which improve the quality of vehicles.

2.3 Chapter Summary

In Section 2.1.1 the analysis of the situation in the automotive industry is performed, obtaining the following results:

- The automotive industry faces an increasing complexity of automotive electronics and a change of the automotive industry structure.
- A clear and sustainable quality data analysis has to be operated by automotive manufacturers in order to improve the decision basis for improvements and to integrate a sustainable defect-stoppage process.
- Technical risk analysis is identified to provide transparency across the entire process and supports the identification of the request for change.
- Technical risk management receives an increasing importance in the automotive industry due to the increasing complexity of automotive components and changes in legal regulations.

Further on in **Section 2.2**, the **improvement request for the automotive industry** is analyzed and described which can be classified into product, assembly process,and business improvements. The focus thereby is laid based on an analysis of the automotive industry which can be applied differently dependent on the context. Initial ideas for the improvement request are discussed. However, a multiplicity of additional improvements also exist which have to be considered in the related context and application. This section contains the most relevant improvements with respect to the focus of this dissertation work. Based on the overview of the current situation and improvement request, the next chapter discusses the scientific methodologies, approaches and concepts as well as the industrial state of technology.

Chapter 3

State of Research and Technology

This chapter discusses the state of research and technology, **describing and analyzing existing methodologies and approaches** in the field of production planning, technical risk management approaches, and product quality improvement methodologies. This is performed by focusing on scientific approaches which correspond to the challenges outlined in Chapter 2. The analysis in this chapter contains in addition the study on standard specifications, norms, and patents. It is also aimed at describing and analyzing the **state of technology in the automotive industry** in order to understand the current usage and application of existing approaches and to derive industrial needs and requirements. The objective is to analyse appropriate methodologies for the application or extension, or to identify the necessity for new developments.

Each section of this chapter focuses on both the state of scientific research and the industrial state of technology.

- **Section 3.1** discusses the automotive electronics manufacturing methodologies, with main stress on the assembly process, its supply process, and the lean manufacturing concepts.
- **Section 3.2** outlines the current production planning practice, the Design for Manufacturing (DFM) approach as well as the digital planning of automotive electronics.
- **Section 3.3** illustrates technical risk management analyzing risk analysis according to DIN 61508, the Failure Mode and Effects Analysis (FMEA), the operational risk assessment, as well as Probabilistic Risk Analysis (PRA).
- **Section 3.4** discusses the practice of quality methodologies for automotive electronics starting with general approaches and continuing with quality data methodologies.

- **Section 3.5** outlines business strategy and process methodologies such as Strategy Maps in order to implement and integrate new approaches in the automotive industry. For organizing the related knowledge efficiently appropriate methodologies are analyzed,such as the concept of Product Lifecycle Management (PLM).
- **Section 3.6** summarizes the chapter with a discussion and evaluation of the described and analyzed methodologies.

3.1 Automotive Electronics Production Methodologies

3.1.1 Requirements and impacts

Production is defined as the transformation of raw materials into finished goods for sale, or intermediate processes involving the production or finishing of semi-manufactures. Some industries, such as semiconductor and steel manufacturers, use the term fabrication [Pela-97]. In accordance with Fraunhofer IAO [Bull-03], the automotive industry is facing new requirements and impacts on its production process as demonstrated in Figure 3.1.

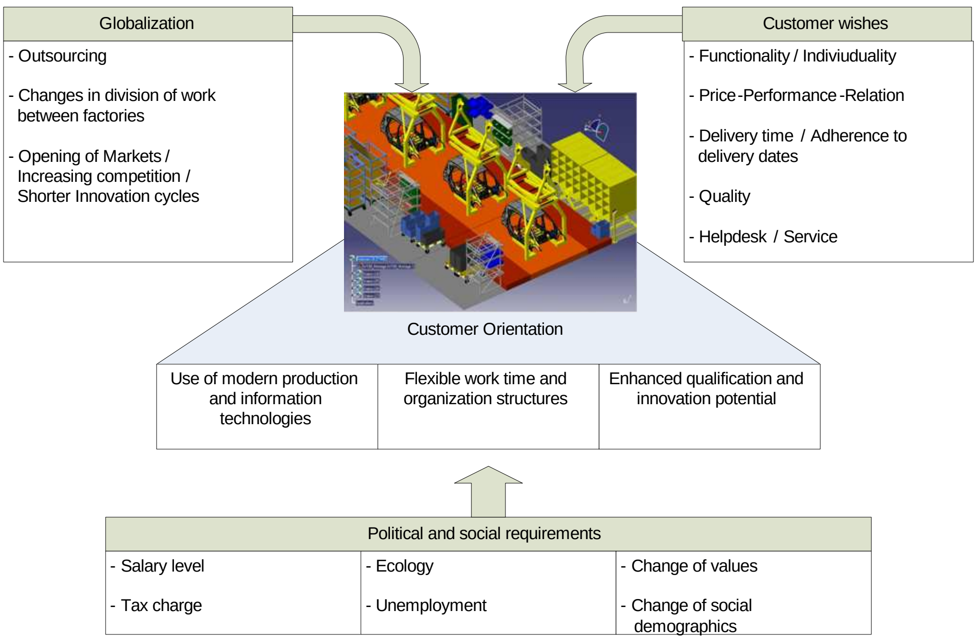


Figure 3.1: Requirements and impacts on production processes

A main influence is the **globalization**, which has changed production strategies in the automotive industry significantly. Furthermore, as the customer can usually configure the new vehicle individually, **customer wishes** also have a large influence on production and increase the process complexity. Another influence which has gained in importance is the change of political and social requirements as illustrated in Figure 3.1.

In order to respond to new market trends and demands, car manufacturers are pursuing a set of **production and assembly strategies** that are common among major companies, outlined in the following [Velo-00]:

1. The adoption of a global perspective in their operations.
2. The reorganization of the vehicle portfolio around product platforms and car modules and systems.
3. Capturing more of the section of the value chain that links them to the final customer, including dealerships and services. This is a result of the increasing importance of design, brand management, and customer relationship management.

OEMs are becoming less involved in producing and assembling, as the responsibility of developing, production, and assembling important sections of the car are passed onto their suppliers, which is discussed in the next section.

3.1.2 Supply chain

Automotive **1st tier suppliers gain in importance and responsibility** through innovative assembly approaches, for example suppliers assemble a number of modules in the final assembly plant and attach them directly to the vehicle themselves. Most of the supply companies are **component specialists**, working at a **2nd or 3rd tier level**. Component specialists can be further divided into component manufacturers and subassembly manufacturers [Velo-00]. A component manufacturer is a process specialist who has the responsibility for the design and testing of the components it manufactures, but not the design of the entire subassembly. Their direct customers are subassembly manufacturers who are process specialists with additional assembly, integration, and design capabilities.

As demonstrated in Figure 3.2 [Velo-00], recent developments show that suppliers evolve from component, through subassembly to module systems suppliers. The growth can mainly be seen in the added value which requires capabilities in several manufacturing processes needed to produce the component, abilities to manage its own supply chain, and to have improved presence in regions where automakers are assembling the vehicle.

The development of **product platforms** is a dominant strategy implemented by automotive manufacturers in order to improve their efficiency. A product platform is defined

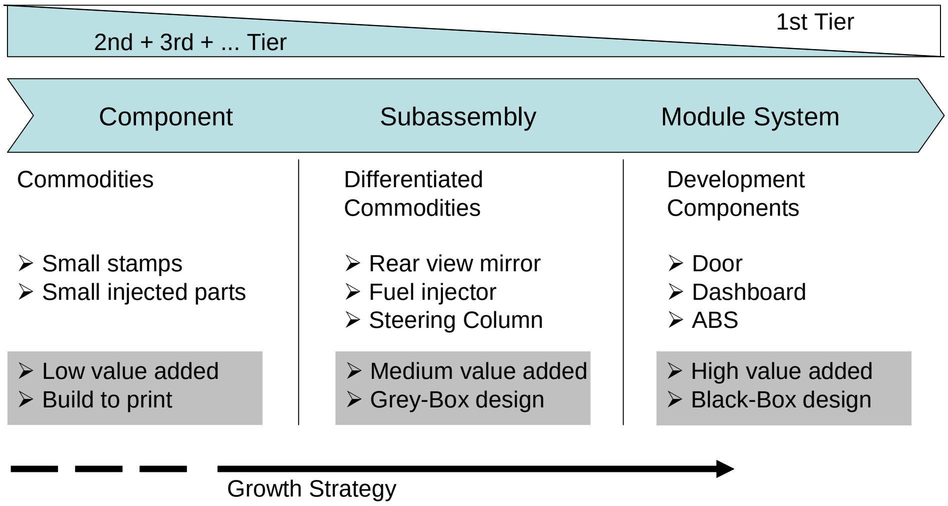


Figure 3.2: Company positioning in the supply chain

as a relatively large set of product components that are physically connected as a stable sub-assembly and are common to different final models. The goal of developing product platforms is to reduce the number of components while allowing models to be clearly differentiated. Product platforms can have a significant impact at the production strategy since models can be assembled using the same production processes.

3.1.3 Production and assembly

In today's mass production, a huge number of units of the same product are produced. This is only possible with a high degree of division of labor. Since Adam Smith (1776) it has been known that division of labor will train the required skills of the workers and will increase productivity to a maximum. The maximum degree of division of labor is obtained by organizing the production as an assembly line system [Amen-01]. The main problem in assembly line systems is how to divide the total work to be done by the total system among the single stations of the line, the so called **"Assembly Line Balancing"**. The work load of each station is restricted by the cycle time, which depends on the fixed speed of the conveyor and the length of the stations. The cycle time is defined as the time between the entering of two consecutive product units in a station [Amen-01].

Another assembly method is the application of **modules** which are preassembled systems of several components and can be assembled more easily. Modules can be tested before fitting them to the vehicle, which improves the possibilities for quality assurance. Another advantage of modules is the better control of the variant management. Considering the mounting location in the vehicle in current or future car concepts, electronic components are mounted in almost any location in the car. The environmental requirements for each specific application greatly depend on its mounting location [ISO-16750]. There exists a variety of handling and assembly techniques described in [VDI-2860] and workplace measurements discussed in [DIN-33406] and [Wald-93] for automotive electronics.

The assembly process of automotive electronics can be categorized into **manual and automatic assembly**. In manual assembly, parts are transferred to the assembly line where workers manually assemble the product or components of a product [Pela-97]. Hand tools are generally used to aid the workers. Fixed or hard automation is characterized by customized machines that assemble one specific product and requires a large capital investment.

When production volume increases, the share of the capital investment compared to the total manufacturing cost decreases. Indexing tables, parts feeders, and automatic controls typify this inherently rigid assembly method which is also called “Detroit-type” assembly. Soft automation or robotic assembly incorporates the use of robotic assembly systems. This can take the form of a single robot, or a multi-station robotic assembly cell with all activities simultaneously controlled. Although this type of assembly method can also have large capital costs, its flexibility often helps offset the expense across many different products [DIN-8593].

In this paragraph are listed some **patents** which provide an insight into different methodologies of assembling automotive electronics. The patent “Approach for electric contacting of at least flat conducting components at motor vehicle assembly” describes the connection process of connectors with electronic components [BaGG-04]. In the Unites States patent “Electrical Connector System” an electrical connector assembly is disclosed, particularly adapted for connecting an electronic control system to an adjustable automotive suspension component [PaPP-93]. The patent “Approach and structure of an automated assembly of a wiring harness to a motor vehicle” contains to flange an ECU box integrated in a wiring harness [DiHF-00]. The patent “Electronic architecture for a vehicle” contains an electronic architecture concept for networking and assembling ECUs [Dome-04]. In these patents are described the theoretical concepts of assembling automotive electronics, the actual practice however is described in the industrial state of technology.

3.1.4 Lean manufacturing approach

"It is important to have all the elements together to a system. It must be practiced every day in a very consistent manner - not in spurts - in a concrete way on the shop floor." — Fujio Cho, President, Toyota Motor Corporation [Like-04]

The automotive industry is currently faced with the rebirth and global ascendancy of lean and flexible manufacturing, realized for example with the Toyota Production System (TPS). The goal is to eliminate waste that raises costs but does not add value to the product [Abre-98]. A concept of TPS is **Just-in-Time (JiT)** which contains a synchronization of the production process and the supplier without having any time buffer between delivery and the point in time when the product is used on the assembly line [Geis-04]. A further development is **Just-in-Sequence (JiS)** which means that the production speed and sequence is dynamically accommodated to changes in demand [JaGi-97]. Lean manufacturing can be defined as an integrated, single piece production flow, in small batches having low inventory by using JiT [Spat-03]. It is characterized by a flexible, team based work organization with a multi-skilled workforce including an active involvement in root cause problem solving in order to maximize the added value [Heid-94]. Other **TPS principles** are outlined in the following [Ohno-93]:

- Management decisions are based on a long-term philosophy, even at the expense of short-term financial goals.
- A continuous process flow is created to bring problems to the surface and to build a culture of stopping to fix problems, to get quality right the first time.
- Standardized tasks are the foundation for continuous improvement and employee empowerment.
- The pull system is used to avoid overproduction.

The TPS philosophy is characterized by making decisions slowly by consensus, thoroughly considering all options, and rapid implementation. The partners and suppliers of the extended network are integrated and the OEM helps to improve their processes. The automotive company becomes a learning organization through **relentless reflection** (Japanese: Hansei) and **continuous improvement** (Japanese: Kaizen) [Like-04].

3.1.5 Industrial state of technology

Automotive electronics assembly

As described in Section 2.1.1, car manufacturers are facing increasing complexity when it comes to installing electronic components in a vehicle. In automotive assembly plants the wiring harness is installed to the vehicle and after this all ECUs are mounted and connected. Over many years, **automotive connector technology** has advanced but is still regarded as the weak link in the vehicle's electrical reliability chain [Swin-00]. Contact failure mechanisms can be divided into three groups: Chemical, mechanical, physical, and the synergistic effects caused by combining mechanisms. Electrical contacts depend on the use of materials with high electrical and thermal conductivity, such as coper, gold, and silver [McBr-93].

Very commonly used in the automotive industry is **mixed-model production** which is the manufacturing of similar products on a single assembly line which increases additionally the process complexity. The great benefit is to efficiently use production facilities adjusted to customer demand [ChIs-04].

In order to increase process safety and reliability of the assembly process, the automotive electronics assembly is sometimes organized with the **standard assembly method using the one-cycle process**. A station contains a complete working content which is performed by one worker in one specific step. All steps have the same cycle time and the assembly worker moves in the shape of an assembly triangle which is the basic model for the working procedure in one assembly station. It is ensured that in the standard procedure, the worker's walking ways are generally similar and determined. Each step is created to fulfill one working content. The assembly is in best case operated without tools and frequent tool changes. The assembly procedures are designed simply and the parts for the assembly process are labeled clearly.

The benefits of this approach is the elimination of waste and non added value work. Material which is assembled in a particular station is only supplied in this station and tools are also station related. The steps are planned so that workers do not interfere one another and having more than two workers per station should be prevented.

Due to the increased complexity of automotive electronics it can be observed that the vehicle assembly process of automotive electronics components has changed back to **standardization**, which seems to be a successful way.

The following study of the Massachusetts Institute of Technology shows the interesting differences of the Japanese assembly approach in comparison to the American and European, which is shown in Table 3.1 [WoJR-91].

	Japanese plants in Japan	American plants in North America	All European plants
Team work in Assembly (%)	69,3	17,3	0,6
Quality assurance in production	Integrated	Specialized	Specialized
Problem solution in production	Integrated	Specialized	Specialized
Training effort for new workers in production (h)	380	46	173
Job rotation (0 seldom, 4= frequent)	3,0	0,9	1,9
Number of suggestions of improvements per worker	61,0	0,4	0,4
Absence (%)	5,0	11,7	12,1

Table 3.1: Key differences of assembly structure

The integrated quality assurance and problem solving in production particularly leads to a higher number of suggestions of improvements per worker. The team work and job rotation decreases the percentage of absence. Although Japanese culture has different roots and history [Toyo], however the culture of avoiding failures and continuous improvements leading to a high worker motivation gains in importance in other countries. Therefore one example is the “New United Motor Manufacturing Incorporation (NUMMI)” which is a pioneering joint venture of General Motors Corporation and Toyota Motor Corporation. This has changed the automobile industry in the United States by introducing the TPS and a teamwork-based working environment [Numm]. The success of Japanese automotive manufacturers is characterized by robust and stable processes which are strictly operated and in general maintained permanently [DyNo-00]. The ability to effectively create and manage network-level knowledge-sharing processes explains the productivity advantages [Park-00], [Gann-96]. These knowledge sharing processes include continuous improvement processes and an integrated suggestions and change management.

Automotive electronics test steps

In an automotive manufacturing process the vehicle is assembled and tested in several different steps, as demonstrated in Figure 3.3 [GeMO-05]. On the **trim line** the interior assembly of the wiring harness and related ECUs is completed where the vehicle’s plug connections are freely accessible. At the end of this line an initial test is performed on the wiring and related ECUs. However, as the sensors and actuators are usually not all cabled at this point, only an incomplete test is possible. On the **final line** the exterior assembly is completed and the chassis is joint to the drive train, which is called in the automotive industry “marriage”. On the **tester line** the correctness of the part number, and the electrical connection is tested, compare with the new testing concept by [FoBa-05]. On

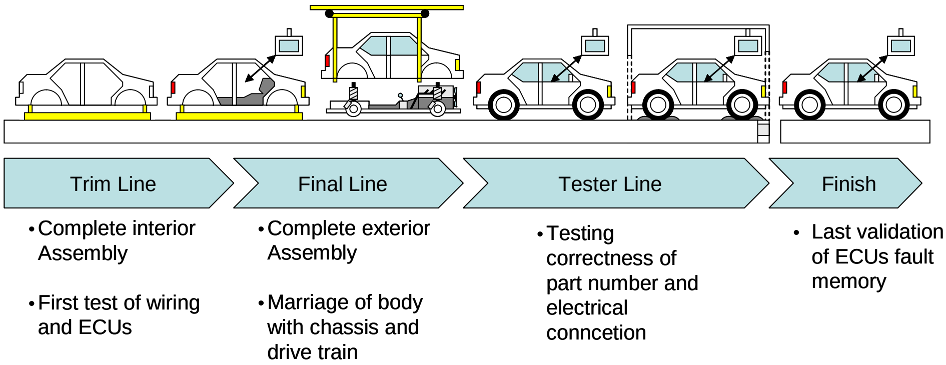


Figure 3.3: Testing process steps

the roller test stand all tests which are related to the driving of the vehicle are performed (dynamic testing). The correct justification of the engine settings is the purpose of the engine check. In the **finish** step the last validation of the ECUs' fault memory is conducted. Necessary rework is done on the assembly line, or relevant vehicles are discharged out of the production chain.

Test devices are used on the assembly line to test the added value and functionality. The complete added value is achieved when components are installed properly and cabling between components is correct. It also has to be tested if the right ECU is installed by evaluating the part number. The last task of this test is the adaptation of the ECU to the individual vehicle by inserting the code data. In order to perform a test, the test device communicates via a standard diagnostic interface with the ECUs for example by using the diagnostic CAN. The test hardware is a standard computer which is connected to the diagnostic box with the corresponding communication hardware.

3.2 Production Planning Methodologies

The production planning process is conditioned by high cost and time pressure as vehicle life cycles are shrinking and therefore the production process has to be ramped up much faster. Extensive and intensive physical assembly and disassembly tests are more time critical which is also a reason for the fast growth of digital tools [KiSt-01]. In a long term perspective, the corporate planning provides the task and limits for the product planning. The product planning includes the systematical research and selection of semi product ideas and the further pursuance based on the company's objectives and goals [VDI-2220]. The product planning is a preliminary stage of development and design and influences also the production planning process. Innovative production planning for an intelligent production is performed by developing new advanced production facilities and processes which focus on the customer and life cycle cost [Bull-04].

Definition 3.2.1 *Production planning is defined to be the important interface between development and manufacturing, to plan capacities such as machines, operating facilities, human resources, as well as the assembly order and organization [Geis-03].*

Production planning comprises all planning activities in order to ensure a process secure production [Pfei-01]. Due to the described challenges automotive manufacturers are facing, the responsibilities of production planning has gained in importance.

Statement 3.2.1 *As vehicle and process complexity of automotive electronics is increasing, production planning departments are the crucial interface between the production process and development to improve the manufacturability.*

Therefore, the Design for Manufacturing approach gains in importance which is discussed in the next section.

3.2.1 Design for Manufacturing (DFM)

The current key topics of product design and development are the interaction between development and manufacturing, digital engineering, and collaborative engineering [AlAF-04]. Development departments in automotive companies face the challenges of a total life cycle cost minimization, safety enhancement and accident risk reduction while reducing at the same time weight and fuel consumption and increasing the comfort for passengers [Axel-01]. Innovations demanded by the market and customer increase the vehicle complexity of automotive electronics which also increases the assembly complexity.

Therefore, DFM is used to design parts in order to improve the assembly process, to prevent defects, and to enhance thereby ergonomics [LoSc-94]. DFM supports the planning of efficient assembly processes and reduces assembly times according to given quality standards. The greatest success with DFM can be reached by operating it at an early stage of the product development. The term **"Design for Manufacturing (DFM)"** dates back to the late 1970s when Boothroyd and Dewurst developed a methodology for evaluating the assembly of mechanical structures [Tryb-95]. In this approach is verified that the decision of a part or component in development has a large influence on the cost and quality of the assembly process, the assembly efficiency, and the environment of the assembly system [PaBe-97].

Statement 3.2.2 *Approximately 80% of manufacturing decisions are the direct result of product design decisions. Cost and quality of a product are already determined in the concept phase of a product [VlLK-99]. Once the design goes into production, the possibilities for effective cost reductions are therefore limited [AnKL-85].*

DFM according to Boothroyd and Dewurst

The necessity to consider manufacturability at an early development stage led to the development and application of **Design for Manufacturing and Assembly (DFMA)**[1]. The origin of this approach goes back to a set of construction guidelines by Geoffrey Boothroyd in 1981 [Dfma]. Boothroyd and Dewurst are one of the major researchers of DFMA, publishing several books such as [BoDe-83], [BoAl-92], and [BoDK-01]. Quality starts with the product design and the procedure how it is integrated into the manufacturing process. The idea behind DFMA techniques is that an apparently trivial detail in the design phase might have huge manufacturing cost consequences later on. Benefits of the DFMA approach are the reduction of assembly time, improvement in quality, standardization of parts, and the fulfillment of ecological requirements [Schm-00]. The DFMA methodology is basically differentiated into the following approaches [Schm-00]:

1. **Design for Assembly** is an approach for the preventive reduction of product cost and quality improvement with robust and defect resistant construction as well as optimized producibility.

2. **Design for Manufacturing** approach is used for the identification of manufacturing cost, finding the most profitable processes, and the early reduction of part cost.

3. **Design for Service** is an approach for the determination and optimization of future service tasks, increasing customer satisfaction, and reduction of life cycle cost.

4. **Design for Environment** approach points out the ecological and economical consequences at the life cycle end. DFE supports the reduction of environmental pollution, increases reusability, and reduces thereby the recycling cost.

The global objective of these approaches is to move from a cost reduction to a cost prevention.

[1]DFMA is a trademark of Boothroyd Dewurst Incorporation.

PROKON

PROKON[2] stands for "Production Based Construction" and covers all integrative measures in order to improve the production process. The objective of this method is the realization and **evaluation of weak points** in the design process which lead to difficulties in the assembly process. PROKON has to be part of the product creation process, the department's development, production planning, manufacturing, quality and sales in order to use potentials efficiently. In the method assembly difficulties are defined, evaluated, and set at a value. The sum of single values of all difficulties of the assembly of an entire product provides a statement about the quality of the construction with respect to assembly efficiency [Sanz-03]. PROKON has been successfully applied for example at AUDI corporation achieving an average assembly time reduction of 10 % in the considered areas.

Other approaches and methodologies

The **Assemblybility Evaluation Method (AEM)** is another approach to analyze the motions and operations which are necessary in order to assemble each component of a product [MiOh-86]. Penalty points are awarded for every motion or operation that is different, or in addition to, the simplest motion. The procedure begins by entering the motions and operations necessary for assembly in an AEM form. The form is used to compare the assembly processes with the target, and gives them a penalty from the synthetic assembly data [SuOA-03]. A further approach is the Design for Assembly Cost Effectiveness [Yama-88], which takes additional cost into consideration. **Assembly Oriented Design** is another approach for assembly design which uses a number of design and analysis tools to help the designer plan out and analyze assembly schemes prior to having detailed knowledge of the geometry of the parts [SuSm-03]. This ability is important for a product design group in order to improve quality while shortening the product development time [ZhDQ-01]. All these techniques are evaluative methodologies that analyze the cost at an early stage in the design process, and use their own data to provide guidelines and metrics to improve the design in its ability to be assembled [UlEp-95].

Statement 3.2.3 *In spite of its success, these methodologies do not provide an integrated procedure to consider the overall cost of design and manufacturing, and have not been applied for automotive electronics.*

[2] PROKON was published in the MTM Report 2003 (MTM = Methods-Time Measurement membership corporation). URL http://www.dmtm.com/index/index.php

3.2.2 Digital production planning

Digital planning is based on the concept of **Virtual Engineering (VE)**. Virtual Engineering covers the early, continuous, networked and integrated process support concerning the voting, evaluation, and concretion of the development results of all used systems with the help of virtual prototypes [Ovtc-05]. Early means that the basis for an evaluation or voting is generated back in the concept phase of the product development. Continuous means that results can be verified not only once but at any time. Networking and the consolidation of single processes means that these can be seen as one single virtual process [ScMG-98].

VE reduces the time for tool design and the planning and simulation of production and assembly processes. These tasks can be relocated to an earlier phase which reduces the development time, as can be seen in Figure 3.4 [Schu-03].

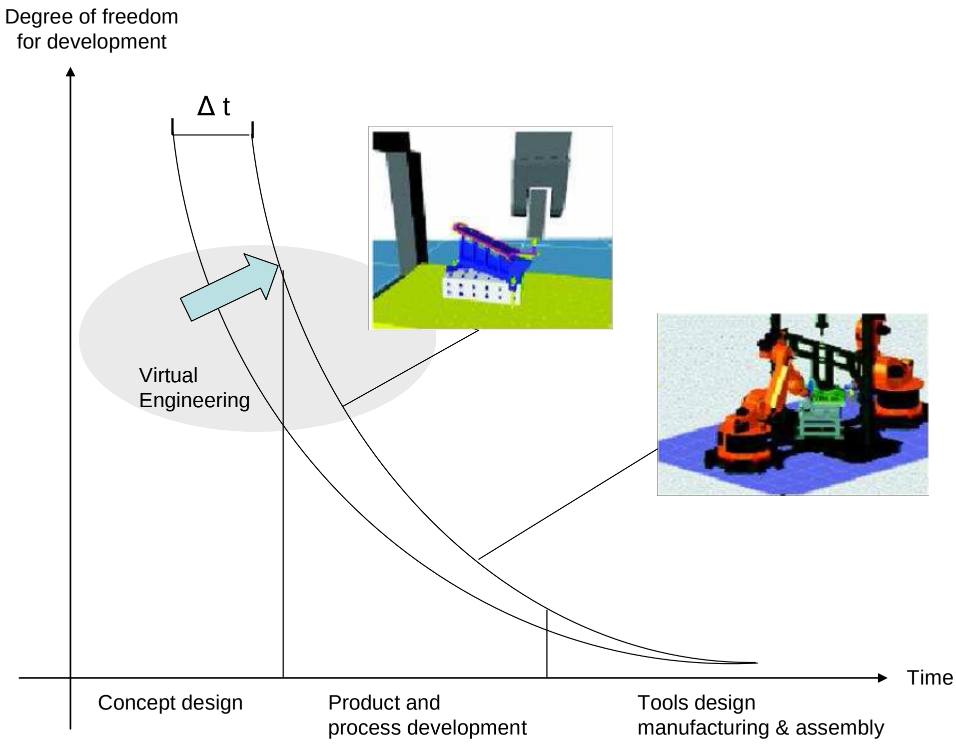


Figure 3.4: Benefits of Virtual Engineering

Another benefit of digital planning is the increasing planning flexibility which is reached by fast access to existing resources, abilities and information of other partners or companies within the cooperation network.

A **Digital Mock-up (DMU)** is a virtual build product which can be used for simulation and digital research [EiSt-01]. DMUs can be applied for the testing of collisions of parts in the ready product, measurements of critical distances between parts as well as access- and availability research for each part and part groups. In production and assembly planning in particular a fitting, tolerance, ergonomics, factory layout, and workflow simulation can be performed with DMUs [Pfei-01]. In the integrated Virtual Product creation (iViP) project for example innovative technologies such as DMUs, Virtual Reality (VR), and multi media tools for the early product creation phases, as well es future oriented organization, communication, and information systems are integrated with one uniform interface [Ivip].

Digital production planning brings the benefit that the product development and production planning departments can improve the manufacturability simultaneously at an early stage. Using digital planning tools is expected to save up to 30% of planning time and up to 15% of cost in the production planning process [Baum-03]. Additional advantages are higher planning efficiency, planning rates, and planning quality as well as better agreements between development and production planning [Hall-04]. Simulating before producing helps to optimize production capacity and detects weak points which are very costly later on [VDI-3505].

3.2.3 Industrial state of technology

Due to increasing competition in the global automotive market, automotive companies aim at reducing assembly times and cost, as well as defects on the assembly line. Therefore the DFM approach has gained in importance as high savings can be achieved. Many DFM projects and process changes have been initiated and some of them have been successful implemented. This contains the requirement to prevent covered and blind assembly, to consolidate single components to complete and testable modules, to prevent justification work on the assembly line, and to provide functional integration for part reduction. Some standardized fixing elements are used and parts are made which hold the fixing location until the worker completes the fixing process. However, it can be ascertained that a comprehensive and integrated DFM approach for automotive electronics integrated in existing processes has not been implemented to a necessary extent and is still a challenge for automotive manufacturers.

The automotive industry has already started to use and implement digital tools. Digital production planning of automotive electronics is performed with consistent data. Assembly planning and ergonomy analysis can also be operated. In order to use digital planning for automotive electronics it would be essential to display "folding flabby elements" such as cables, spouts, or rubber plugs.

Statement 3.2.4 *In current practice however, DMUs are generated with only static consideration in the installation position. The deformability of parts themselves and during assembly is very difficult to present digitally.*

The display of "folding flabby parts" in digital system is currently a research topic and at an early stage in planning departments. A practical data model for analyzing and illustrating the characteristics of all automotive electronic components is currently not yet available. The objective would be to simulate the installation process of an ECU together with the movement of cables and the related connecting process in order to perform an efficient Design for Manufacturing of automotive electronics.

The state of technology is the **digital display of cables between fixed points**. The cables can be moved freely between these fixed points. Also possible is the movement between clip points with a minimal remaining movement. For cylindrical parts such as cables a functional prototype exists, this is however not practicably applied. In order to receive usable results the parameters like such as flexural rigidity or the radius have to be inserted. The vision of digital planning requires that no production plant or process will be planned, built, and used without being tested beforehand with digital planning tools. If the mentioned shortcomings for moving cables together with components are eliminated there exists a huge potential for implementing and using digital tools for the production planning of automotive electronics. Recapitulating the **advantages**, digital tools provide

- pre-simulation possibilities,
- a transparent system engineering and assembly planning, and
- a fast feedback loop approach back to development.

As product lifecycles are shrinking and thereby also engineering times, digital tools will gain in importance in the future.

3.3 Technical Risk Management Methodologies

For a successful and efficient technical risk management the objective for technology companies is to create transparency over the entire value creation chain like a kind of "vitreous company". Risks have to be made transparent by detecting all qualitative and quantitative coherences.

Definition 3.3.1 *Technical risk management for automotive electronics is defined as a process to create transparency across the entire process chain in order to identify and quantify different risk values, types, and influences [Meie-05]*

Therefore, it is very important to create a common risk understanding within a company. As defined and analyzed in Section 2.1.5, risk has always both the dimension: where and which risk exist, and how significant the risk is. Risk is a function f dependent on the parameters frequency of risk and consequence of risk which can be formulated as follows:

$$Risk = f(Frequency, Consequence) \tag{3.1}$$

Risk management has three elements: the risk, the extent, and the probability of occurrence of damage which is illustrated in Figure 3.5 [DIN-1050].

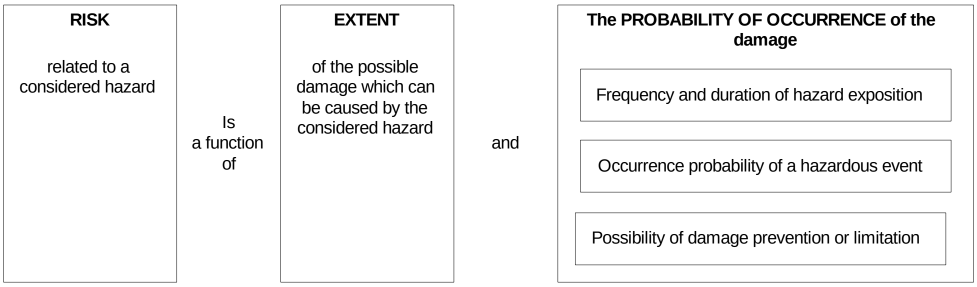


Figure 3.5: Risk management elements

Risk management contains coordinated activities to direct and control an organization with regard to risk. In the context of [DIN-62198], risk management is defined as the systematic application of management principles, procedures, and practices for context determination, identification, analysis, evaluation, steering, monitoring, and communication of risks so that organizations can increase chances and reduce losses. A **risk analysis** is the systematic use of information to identify sources of risk and to estimate risk consequences. A risk evaluation is the process of comparing the estimated risk against given risk criteria to determine the significance of the risk. Risk assessment is the overall process of risk analysis and risk evaluation [ISO-73].

Companies are facing a variety of risk areas such as market, financial, and sales risk. Other risk areas are supply, production, and technology risk, as well as IT security and product piracy risks. Companies also face legal, liability, and political risks as well as risks derived from natural catastrophes. All these risk areas depend on each other in a complex network of reciprocal influences.

According to [MeSF-04], three general steps exist which are appropriate for a successful risk management. **Step 1** contains the identification, measurement and documentation of risks. In order to measure risks it first has to differentiate between measurable risks whereby models and data exist in order to measure these risks, and non-measurable risk whereby a data history and related models do not exist. A risk map provides an overview to identify risks of an industrial company and to document them as is shown in an example in Figure 3.6 [MeSF-04].

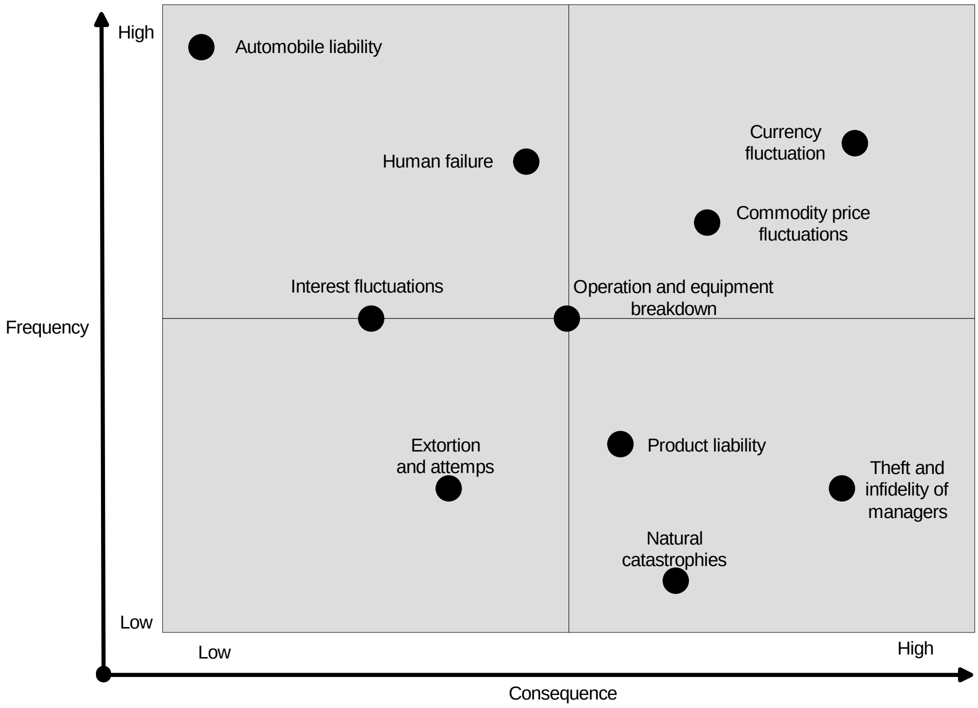


Figure 3.6: Risk map of an industrial company

It is useful to analysis the consequences (x-axis) and the frequency (y-axis) and place them in a coordinate system. This helps analysis in a first step critical risks of a company.
Step 2 contains four possible risk strategies:

1. To reject the business and thereby the risk,
2. To take risks consciously,
3. To take risks but to minimize them,
4. To assign risks to a third party.

Most of the companies decide between risk avoidance, which can lead to bring the business offside, or to commit risks blindly which can be very dangerous. Apart from this the solution scope can be extended by implementing and applying a professional risk management whereby **Step 3** contains the organizational integration of risk management. In this context a differentiated, but clear allocation of the multifarious risk management tasks is advisable. Further important handbooks in the field of risk analysis are [VeGo-81], [KuHe-96], as well as the internet sites [Esra], [Ieee], and [Riw1].

3.3.1 Failure Mode and Effects Analysis (FMEA)

The FMEA emerged in the 1960s as a formal methodology in the aerospace and defense industries. Since then, it has been adopted and standardized by many industries worldwide. FMEA is a method of identifying and prioritizing potential failures of a product or process. The FMEA requires information on system specifications, functional description, functional block diagrams, and description of use conditions.

Definition 3.3.2 *FMEA considers the failure of any component within a system and tracks the effects of this failure to determine its ultimate consequences [DIN-25448].*

The process makes assumptions about the failure modes of the components and then determines their effects on the complete system [Stor-96]. A failure mode is the manner in which a component, subsystem or system could potentially fail [KmFI-99]. The **procedure of the FMEA** is as follows:

1. Identify the process and the product.
2. List possible problems.
3. Tabulate the problem regarding the probability of occurrence (Occ), the consequences (Severity (Sev)) and the probability of detecting a failure (Det).
4. Calculate the Risk Priority Number (RPN).
5. Reduce the risk by developing actions.

The Risk Priority Number (RPN) is the product of the three mentioned elements [RhIs-02]:

$$RPN = Occ \cdot Sev \cdot Det \tag{3.2}$$

FMEA involves much detailed and demanding work and is therefore expensive to apply to large complex systems in their entirety [Stor-96]. Increasing complexity of technical products often leads to problems and a high time effort when creating a FMEA [MuBe-02]. Another disadvantage of the FMEA is the static approach a reason that it becomes less important for complex products.

The **Failure Modes, Effects and Criticality Analysis (FMECA)** is an extension of FMEA that takes into account the importance of each component failure and identifies those sections of the system where failures are most important [Stor-96]. Another further development of the FMEA is the Bayes probabilistic network FMEA which provides a language for design teams to articulate physical system failure cause-effect relationships, and the uncertainty about their impact on customers with greater precision and consistency [Lee-01]. A **Product FMEA** analyses the design of a product by examining the way that item's failure modes affect the operation of the product [PeAt-02]. The Process FMEA analyses the processes involved in design, building, using, and maintaining a product by examining the way that failures in the manufacturing or service processes affect the operation of the product [IEC-60812].

The **System FMEA** is a method for failure prevention and is applied during an early phase of the product creation process. It is a further development of the FMEA in order to consider additionally the functional coherences of all components systematically, the possible failures in single process steps, and the systematic analysis of the entire manufacturing process [VDA-4].

3.3.2 Risk analysis according to DIN 61508

What is more safety critical, an airbag which is initiated without an accident or an airbag which is not initiated in an accident? The statistical population for the initiated airbag without accident is much higher than the population of accidents. According to [DIN-61508], the initiated airbag without accident is therefore more safety critical. The International Standard [IEC-61508] and the German version of the standard [DIN-61508] contain the functional safety of electrical/electronic/programmable (E/E/PE) safety-related systems, which is described in detail in Appendix B.

Definition 3.3.3 *Functional safety is defined as a part of the entire safety, which depends on the correct function of the E/E/PE safety related systems, safety related systems other technologies, and external equipment for risk reduction, related to Equipment Under Control (EUC) [DIN-61508].*

EUC is defined as equipment, machines, or devices used for manufacturing, substance conversion, transportation, medical and other operations [DIN-61508](Part 4). The **first objective** of the standard's hazard and risk analysis is to determine all hazards and hazardous incidents of the EUC and the EUC control and steering system in all operation modes for all reasonably predictable circumstances, including defect conditions and misuse. The **second objective** is to determine the procedure of events which leads to certain hazardous incidents, and thirdly to determine the EUC risk related to the determined hazardous incidents. The essential risk reduction has to reach the tolerable risk for a certain situation which is indicated as qualitative or quantitative. The purpose of determining the tolerable risk for a certain hazardous incident is to demonstrate the frequency or probability of the hazardous incident and its consequences and severity [DIN-61508].

3.3.3 Operational risk assessment

Value-at-Risk (VAR) concept

The VAR is defined as the maximum deviation expressed in monetary units of the actual value of a position from its expected value within a defined space of time and within a defined safety or confidence interval [MeSF-04]. The risk value is calculated using a risk position, a risk factor, a weighting function, a probability distribution, and the volatility. It is an established risk method which is especially applied in the financial sector. The challenge when using this approach is that not everything can be quantified clearly and the risk quantification has to be extended with a stress-test or worst case scenarios.

- In **Step 1** of this concept is the trend of the considered data.
- The percentage change of rates are determined in **Step 2** for the defined space of time.
- In **Step 3** the probability distribution for the daily or monthly growth characterized with the Expected Value and the standard deviation is determined.

After defining the aimed security level, the Value-at-Risk (VAR) can be read out of defined statistic tables [HeHa-02].

Event Tree Analysis (ETA)

The Event Tree Analysis (ETA) takes as its starting point the events that can affect the system and tracks them forward to determine their possible consequences. These events include both those associated with the expected operation of the system and fault conditions, such as the failure of a component [Stor-96]. The **ETA is an inductive analysis** starting from an initial event such as a component failure, and acquires the following events until possible final conditions of the considered unit are reached. The initial event induces an effect on the considered unit, displayed with a line. The first required function is asked if the function is fulfilled or not. An arborization is reached with several possible following events for which exact graphic symbols are defined in the standard [DIN-25419].

Fault Tree Analysis (FTA)

The purpose of the Fault Tree Analysis (FTA) is the **systematic identification** of all **possible failure combinations** which lead to undesired events and to acquire reliability numbers such as the probability of occurrence of a failure combination. The fault tree consists of graphic symbols for inputs and connections which are defined in the standards [DIN-25424] and [IEC-1025]. Connections are logical coherences of a boolean type within the fault tree.

The FTA differs from the use of the ETA in that it tackles the problem in the reverse direction. Event trees start with all possible events and work forwards to determine their outcomes [Stor-96]. The analysis of the FTA is generally undertaken in two stages, the qualitative and quantitative analysis. The qualitative analysis involves obtaining the various combinations of events which cause system failures and then in the quantification is calculated the probability of frequency that system failure will occur.

Further approaches

Another operational risk approach is the **Cause and Effect Analysis** which combines several approaches. A critical event is chosen, and both the causes and the possible consequences are researched. In this analysis the breakdown of each component of a system is considered in a defect model and in a bottom-up search the impact on the entire system [Mont-05]. Another useful approach is the comprehensive hazard analysis technique for safety-critical automotive systems which contains the Preliminary Hazard Analysis, Reliability Block Diagrams, FTA, FMEA, FMECA, and the Common Cause Analysis [AmCD-01]. This is however very extensive and time consuming [Dunn-03]. Another simple approach for the early recognition of operational risks is the **Operational Risk Counter (ORC)** which starts with the identification of individual risks $1, ..., n$. The value of the sum of all individual risks provides the basis for determining the severity of risk. A stoplight principle is used to categorize the severity with colors [Rome-04].

3.3.4 Probabilistic Risk Analysis (PRA)

Probabilistic Risk Analysis (PRA) is currently being widely applied in some industry sectors such as transportation, construction, energy, aerospace, and sometimes to project planning and financial management. PRA answers the questions of what can happen, how likely is it to happen, and given that it occurs, what are the consequences. The big milestones in the development of PRA have been from Neumann in 1947 [NeMo-47], Raiffa in 1968 [Raif-68] to Savage in 1972 [Sava-72]. PRA has been evolved to model the response of a complex engineered system to disturbances during operations, and to identify the types and levels of damage that could result from different system responses. PRA provides not only qualitative but also quantitative measures of risk and includes a quantitative assessment of the uncertainty in the results [Bier-97]. It is an approach to provide not only an assessment of the current level of risk, but also information on risk contributors and potential risk management actions [ShKO-05]. In the context of this research the Bayesian approach and the Lifecyle Risk Management (LiRiM) framework are introduced as follows.

Bayesian probability and networks

A Bayesian probability is defined as the degree of belief of a decision maker, based not only on statistical data but also on all relevant information such as test data, field data, surrogate data, engineering models, or expert opinion. Coupled with system analysis, Bayesian methodologies can be used to compute the probability of different possible problem scenarios when observations of imperfect signals are given [PaHa-04]. Assuming that the considered system has a defect D and events E, $Pr(D)$ is then defined as the probability of defect D which is the prior probability. The probability of event E under probability of D is then denoted as $Pr(E|D)$ (Likelihood). The pre-posterior probability $Pr(E)$ is the probability of event E. The posterior probability is then $Pr(D|E)$ which is the probability of defect D under the condition of event E. With this information the **Theorem of Bayes** can be formulated as follows:

$$Pr(D|E) = \frac{Pr(D) \cdot Pr(E|D)}{Pr(E)} \tag{3.3}$$

PRA has also been applied in the automotive industry and is in fact a powerful methodology to quantify risk. One example is the risk analysis for monitoring and diagnosis of problems in the automotive industry [PaHa-04]. Designed in this approach is a warning system using an influence diagram, which is separated into an utility function for the driver and for the car manufacturer with the related interactions. The key issue is that not all signals have the same value of information nor the potential to permit a correct and timely diagnosis that may alert a serious problem [PaHa-04].

Bayesian networks are directed acyclic graphs, also called causal-nets, in which nodes represent uncertain variables which can adopt different values. The edges between the nodes represent probabilistic interactions between the corresponding variables [Beng-99]. One example of a Bayesian network is described in the patent "Bayesian net based expert system for diagnostics, risk analysis, and function recovery, particularly with motor vehicles" which contains a transformation of each technically component of a technical complete system through at least three variables which are behavior, mode, and steering. With this expert system different functions can be realized by multi propagating of the determined condition variables [BaRR-05].

Bayesian networks have established themselves as an effective and principle framework for knowledge representation and reasoning under uncertainty. Despite this success, Bayesian networks are inadequate as a general knowledge representation language for large and complex domains. In a traditional Bayesian network, each node corresponds to some basic attribute of the domain. The set of nodes and the network structure are fixed in advance, so that the network can only be used in the specific domain for which it was created. **Object-Oriented Bayesian Networks (OOBN)** are a powerful and general framework for large-scale knowledge representation using Bayesian networks [KoMP-97]. The basic element of an OOBN is an object, and the most basic object is a random variable. OOBNs allow generalization over multiple objects and can be defined formally as classes of objects, all of which are described using the same probabilistic model [KoPf-97].

Lifecycle Risk Management (LiRiM)

Lifecycle Risk Management (LiRiM) is a framework for analyzing the technical risks in complex, engineered systems and the economic risks to the firm stemming from product defects, as illustrated in Figure 3.7 [HaGe-05].

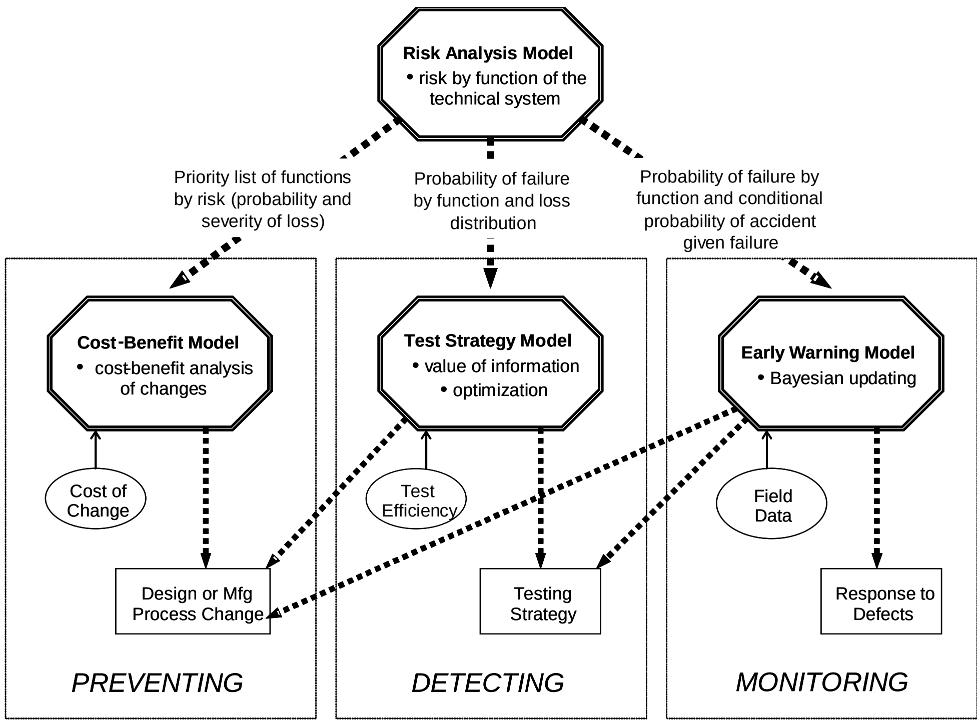


Figure 3.7: Lifecycle Risk Management (LiRiM)

The models in LiRiM help to assess the dependencies across key decisions and uncertainties throughout a product's life cycle in order to enable the most informed decision-making possible at each life cycle stage [HaGe-05]. The framework contains the superordinated

Risk Analysis model, the Cost-Benefit model for preventing defects, the Test-Strategy Model for detecting defects, and the Early-Warning Model for monitoring defects. Better informed decisions, especially during early stages such as development, may lower the probability of defects, and thus avert preventable financial losses from warranty expenses, product liability law suits, reduced future revenues, and a damaged reputation.

3.3.5 Industrial state of technology

Technical risk management in the automotive industry is often performed with the FMEA in particular with the System FMEA and Process FMEA. In the development and engineering stage the FMEA is used for system risk analysis which is often performed in collaboration with the suppliers. The FMEA is extensive and time consuming and a static consideration. With increasing number of functions and components this approach comes to a limit.

The requirements derived from the DIN 61508 have been identified in the automotive industry and the related documentation duties are currently implemented. Due to the described changes in legal liability regulations, the DIN 61508 will also be a key topic in the future. The PRA, the Bayesian, and LiRiM approach have been used in some cases in the automotive industry are however difficult to implement due to the large amount of used statistical data and assumptions.

Statement 3.3.1 *For the comprehensive and integrated technical risk management along the vehicle life cycle cannot be found usable approaches to identify risk and possible defects for automotive electronics.*

3.4 Quality Management Methodologies

The major requirement for an efficient technical risk management is a substantial data basis. The objective is to create transparency over the entire value creation process for automotive electronics in order to identify actual strength and shortcomings. At first general approaches are described in this section, followed by specific quality data methodologies.

3.4.1 General approaches

Quality management consists of three core fields which are customer orientation, process control, and continuous improvement [BoRo-00]. This section discusses quality methodologies for automotive electronics in these core fields. In the following the three methodologies

- for customer orientation Quality Function Deployment (QFD),
- for process control the Six Sigma approach, and
- for continuous improvement Total Quality Management (TQM) and Poka-Yoke

are briefly discussed.

Quality Function Deployment (QFD)

QFD is a management tool that provides a visual connective process to help development teams to focus on the needs of the customers throughout the total development cycle of a product or process. It provides the means for translating customer needs into appropriate technical requirements for each stage of product and process development and supports to develop customer-oriented products. The starting point of any QFD project is to gather **customer requirements**, often referred to as non-measurable characteristics such as how it looks and how it feels. These requirements are then **converted into technical specifications** which is referred to as the engineering characteristics or measurables. The QFD process involves four phases: the product planning with the “house of quality”, the product design with parts deployment, the process planning, and the process control using quality control charts. A chart or matrix represents each phase of the QFD process. The complete QFD process requires at least four houses to be built that are extended throughout the entire system’s development life cycle, with each house representing one QFD phase [BoRo-00].

Six Sigma

Created by Motorola in 1987, the basic idea of Six Sigma is that quality comes not from inspection but rather from changes to the way processes are performed to prevent defects [Snee-04]. A decisive requirement is that Six Sigma is integrated comprehensive in all company processes and positioned in the corporate culture [Schu-03]. Six Sigma is a structured approach that combines understanding of customer needs, disciplined use of statistical methodologies of data collection and analysis, and careful attention to process management in order to improve business performance [Jogl-03]. The goal of Six Sigma is to increase profits by **eliminating variability, defects and waste** which undermine customer loyalty [PaNC-01].

This is achieved through the application of the two sub-methodologies **“Define Measure Analyze Improve Control” (DMAIC**) and **“Define Measure Analyze Design Verify” (DMADV)**. The Six Sigma DMAIC is an improvement system for existing processes which fall below specification and to look for incremental improvement. The Six Sigma DMADV process is an improvement system used to develop new processes or products at the Six Sigma quality levels. The tools used are mainly based on the statistical size the deviation *Sigma*. Assuming a Gaussian distribution the objective is to reduce the deviation by six times denoted in "6 *Sigma*" where the methodology's name comes from [PaNC-01]. If the specification limits for that characteristic are at least *Sigma* above and below the process mean, defects will be under 3.4 parts per million [HaSc-00]. Companies that have applied Six Sigma realized that about 80% of the problems they fix and the money they save are determined by design [Smit-98]. Therefore, new approaches such as Design for Six Sigma are used to prevent problems by building quality control measures into the design process [Smit-01].

Total Quality Management (TQM)

Total Quality Management (TQM) is a form of quality management that emphasizes continuous quality improvement of processes [DIN-9000]. TQM refers to a management process and set of disciplines that the organization consistently meets and exceeds customer requirements [Jord-02]. The **TQM principles** are **customer and process orientation**, as well as **continuous improvement** [VDI-5500]. What distinguishes TQM from other organizational quality standards such as Business Process Reengineering is that it is not a radical management tool that can completely "pull apart" an organization [DIN-8402]. Instead, TQM seeks to permeate an organization through steady quality improvement throughout all of its current processes, rather than creating new ones [Gucan-03]. Additional TQM approaches are the European Foundation for Quality Management (EFQM) and the Business Excellence Program.

Poka-Yoke

Introduced in the 1960s, Poka Yoke is a Japanese quality control management tools and essentially means **"mistake proofing"** (Japanese: "poh-kah yoh kay"). It is a set of rules and techniques designed to mistake-proof a process or a product, and to eradicate flaws [Robi-97]. This mistake-proof objective is accomplished by the following two principles: firstly, that a product or process is designed and carefully planned in such a way that an error cannot possibly be made (defect prevention) [Spat-03]. Secondly, the product design is so well planned, that any possible defect becomes obvious to the user and is immediately corrected (defect detection) [Jord-02].

3.4.2 Quality data approaches

In the literature there is no specific methodology for gathering supplier data mentioned. In order to build up a successful supplier integration and a common data basis it is crucial to set up tight networks which are called in the Japanese industry “Keiretsu” [LiCh-05]. The characteristics of these networks are continuous learning, improvements, and enhancements together between OEMs and suppliers based on the quality management approach [AcMi-04].

In automotive manufacturing plants there is a variety of quality control methodologies for the inspection of products. The identification of quality problems is usually performed statistically, and solutions are frequently derived based on experience. One possible methodology is the **defect-focused Quality Control** in a manufacturing process which is realized in a hierarchy logic, as shown in Figure 3.8 [LoHu-03].

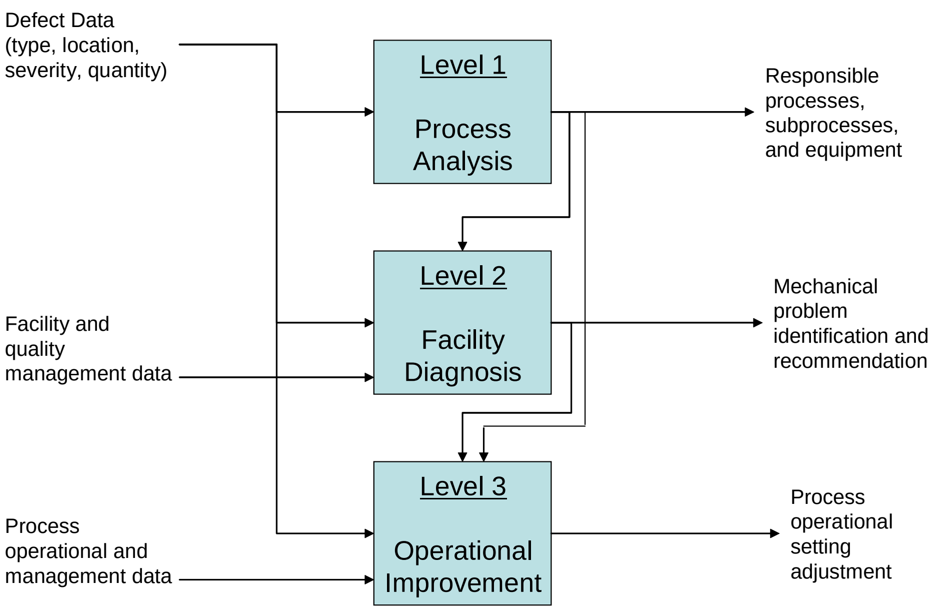


Figure 3.8: General decision hierarchy for proactive Quality Control

In most manufacturing operations, once a quality problem is detected, the responsible processes are detected next. The information for decision making is required at different levels of the hierarchy. For **level 1** (Process Analysis) the least information is required, while for the last level (Operational Improvement) the most information is required [LoHu-03]. After the facility diagnosis on **level 2**, the required operational improvements are undertaken on **level 3**. In addition to this approach there exists the patent “Approach for quality management of a manufacturing process” which is a statistical method recommended for this quality management of a manufacturing process [RaRe-95].

Field and customer data can be differentiated into company's **internal and external data**. Internal field data is gathered from internal system and processes whereas external data is gathered from associations such as J.D. Power, institutes, and other organizations. The approach of [RaSi-05], shown in Figure 3.9, contains control and noise factors on a clear field data analysis and warranty cost calculation.

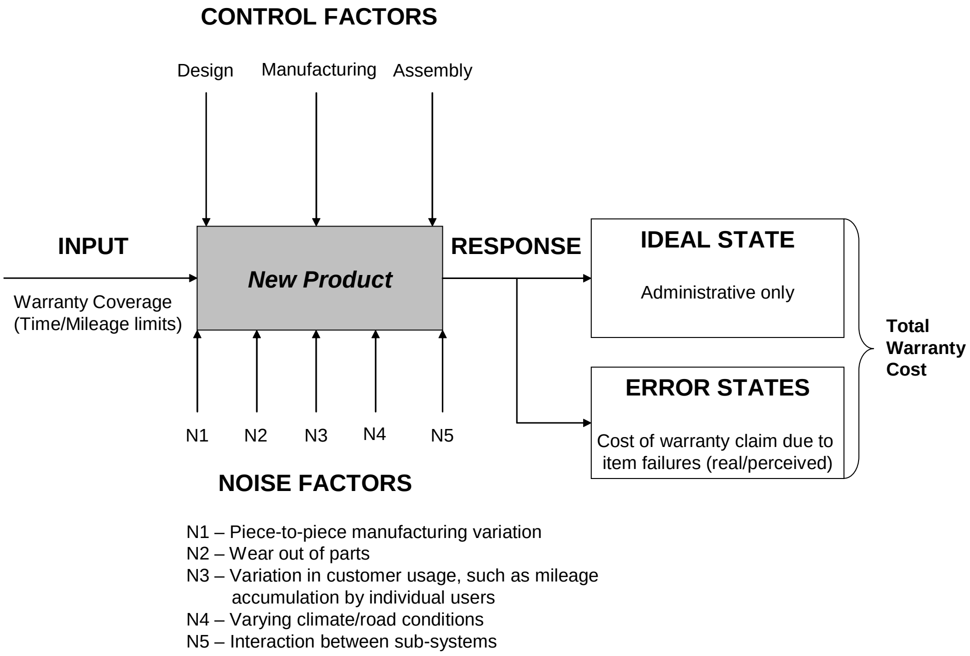


Figure 3.9: Factors influencing warranty cost

Statement 3.4.1 *Due to the described external influences and the variety of data sources, a clear procedure and approach for quality data management for automotive electronics cannot be found [Galb-98].*

3.4.3 Industrial state of technology

Six Sigma was first used by General Electric and in the automotive industry by Ford. Six Sigma is in fact a useful approach in the industry for focusing on the customer, data and facts driven management, and pro-active and collaborative management. TQM as well as Poka Yoke has been used already and is widely spread in the automotive industry.

Considering the quality data approaches in the automotive industry there is a variety and multitude of systems and activities. **Manufacturing quality data** from the assembly line contain defects which are often pointed out without detailed cause. The challenge is to filter out electronic system defects which are not caused by production and assembly process defects. The added value test in the automotive industry, in which the test devices communicate with the ECUs of the vehicle in order to check their functionality, is one objective data source. The failure messages are such as for example *"failure during communication with the ECU"* or *"test run stopped by assembly worker"*. For this messages a detailed cause analysis is required which is sometimes difficult to perform on the assembly line directly due to the time pressure. Car manufacturers use different reporting systems for the collection of defects, damages and problems on the assembly line. It can be ascertained in the automotive industry, that no general methodology for collecting defects, analyzing causes and risks, and creating solutions based on this has been established.

Internal quality data from after sales organization is useful information for the automotive manufacturer. The major task is to gain information about the quality of the vehicle in the usage phase of the life cycle and service reports. This information can be failures noticed by the customer, or from test and inspection in the service station. Similar to the case above there is no general methodology for data integration from after sales organizations as the procedures are mostly company specific. External quality data from the market can be received for example from J.D. Power in the Initial Quality Study (IQS). From this data source, the information for example *"the Antilock Brake System (ABS) light indicated a problem"* can be gathered. For a detailed failure, defect and risk analysis this information is not deep enough to analyze the real cause of failure for a specific component and related assembly step. Another disadvantage is that the analysis of the data is very time intensive and costly. However, the J.D. Power reports are taken very seriously by the management of a car manufacturer and the objective in the automotive industry is to reach a high ranking in the IQS.

The following example shows the **importance and complexity of quality data** approaches for automotive electronics. A mid-sized vehicle contains today approximately 50 ECUs, each ECU containing about 300 devices. Assuming a failure rate of 1 ppm per device could lead to 15,000 ppm which is 15,000 failures out of 1 million produced vehicles. This is a defect probability of 1.5% [Geye-04]. In order to reach an average failure rate of 500 ppm, the system suppliers of ECUs require a defect probability of less than 10 ppm. This requires that each of the 300 devices in an ECU has to show a failure rate less than 1 ppm which means it must lie in the 0 ppm or in the parts per billion range [Geye-04].

Statement 3.4.2 *Considering quality data in the automotive industry it can be generally observed that there is a variety of data sources whose granularity and accuracy is often not appropriate for a detailed cause and risk analysis for automotive electronics [HaMi02].*

3.5 Business Strategy and Process Methodologies

Based on the objective of this research and the situation in the automotive industry, this section discusses business strategy and process methodologies for an efficient implementation in an organization.

In the past, traditional product development and production processes were functional and serial whereby each function performed their roles and passed it on to the next one in the chain, as is shown in Figure 3.10 [Davi-04].

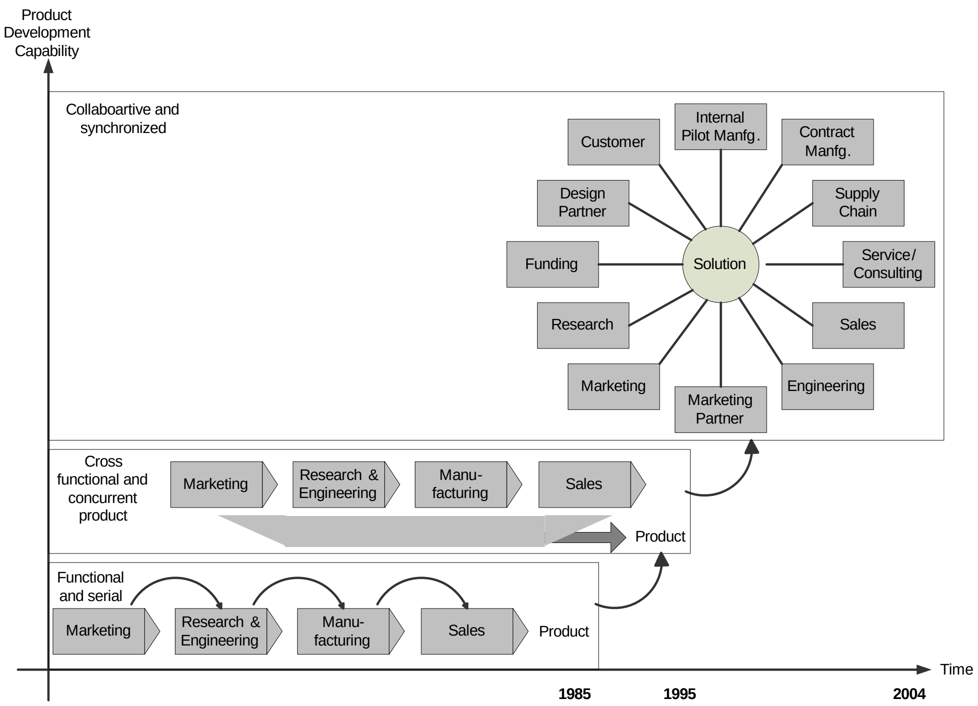


Figure 3.10: Product development capability over time

These functional walls were later broken down by cross-functional product teams which led a product through a concurrent development process. Today, organizations develop a “plug and play” world of synchronized collaboration of functions and partners. Four challenging areas of **collaborative and synchronized product development** exist:

1. The development process with the imperative to optimize, communicate, and accelerate development projects.

2. The design and engineering with the imperative to simplify and reuse design data in order to cut development time and cost.

3. Supplier operations, with the objective to flawlessly manage increasingly complex supplier operations.

4. Customer integration with the duty to integrate customer input early and consistently in the process.

3.5.1 Strategy Maps

A successful strategy transformation or change in order to be successful requires both describing the strategy and managing the strategy. Adapted to the specific strategy of an organization, a Strategy Map describes how immaterial assets act as drivers to increase output for internal processes which have a maximized effect on added value for customers, shareholders, and society [KaNS-04]. Strategy Maps contain a **financial perspective** on the treatment of shareholders for financial success, a **customer perspective** on the treatment of the customer, and an **internal perspective** for business processes improvement as well as the training and development perspective, as shown in Figure 3.11.

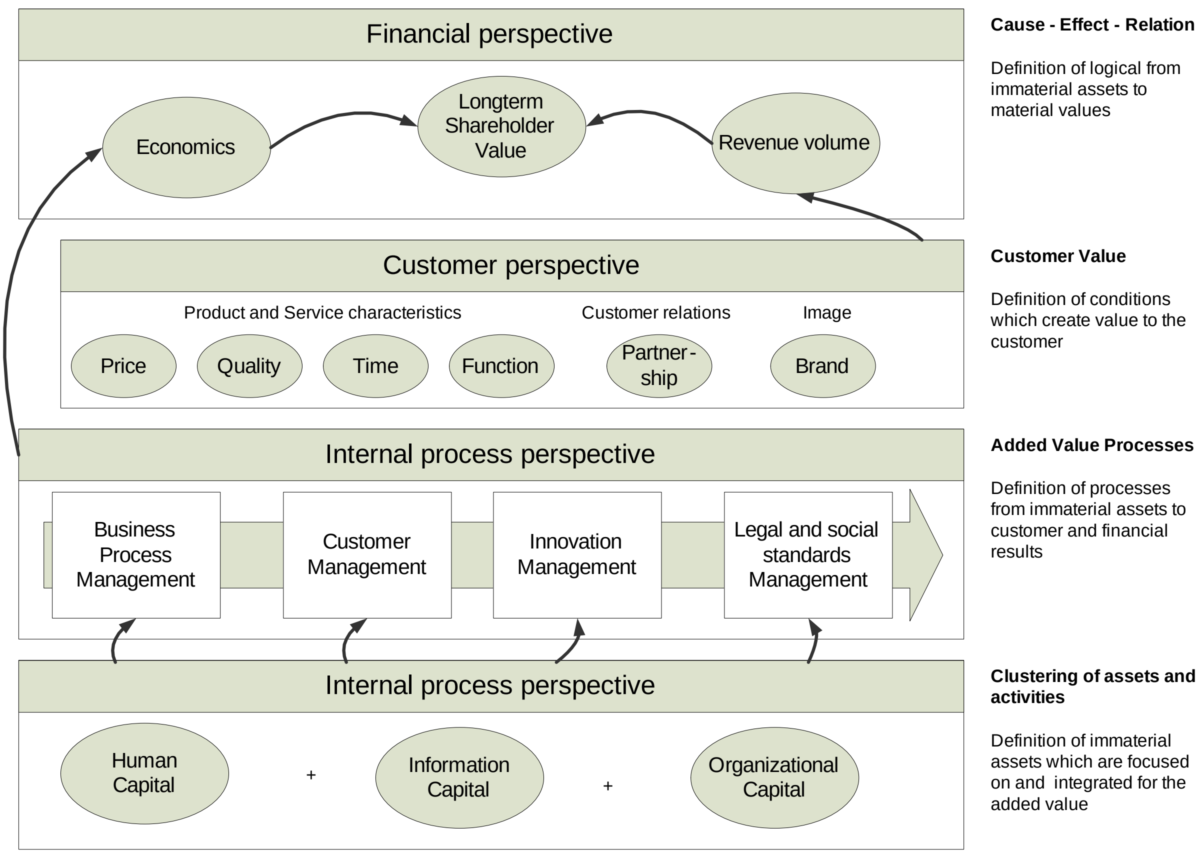


Figure 3.11: The structure of a Strategy Map

The cause-and-effect architecture for connecting the four perspectives is the structure for developing a Strategy Map. The internal process perspective contains the clustering of assets and activities with the definition of immaterial assets, which are focused on and integrated for the added value. In this added value process, the definition of processes from immaterial assets to customer and financial results occurs. This leads to the customer perspective in which conditions are defined which create value for the customer. In the cause-effect relation a logic is defined which comes from immaterial assets to material values. In most cases (approximately 70%), the real challenge for companies is not the development of the strategy but its implementation [KaNS-04].

3.5.2 Business process

Business architecture design

The idealized business architecture design following the **"system thinking" approach** by [Ghar-99], is subject to three constraints: the technological feasibility, the operational viability, and learning and adaptation. This approach contains an iterative process and each iteration addresses the system as an integrated whole, as demonstrated in Figure 3.12 [Ghar-99].

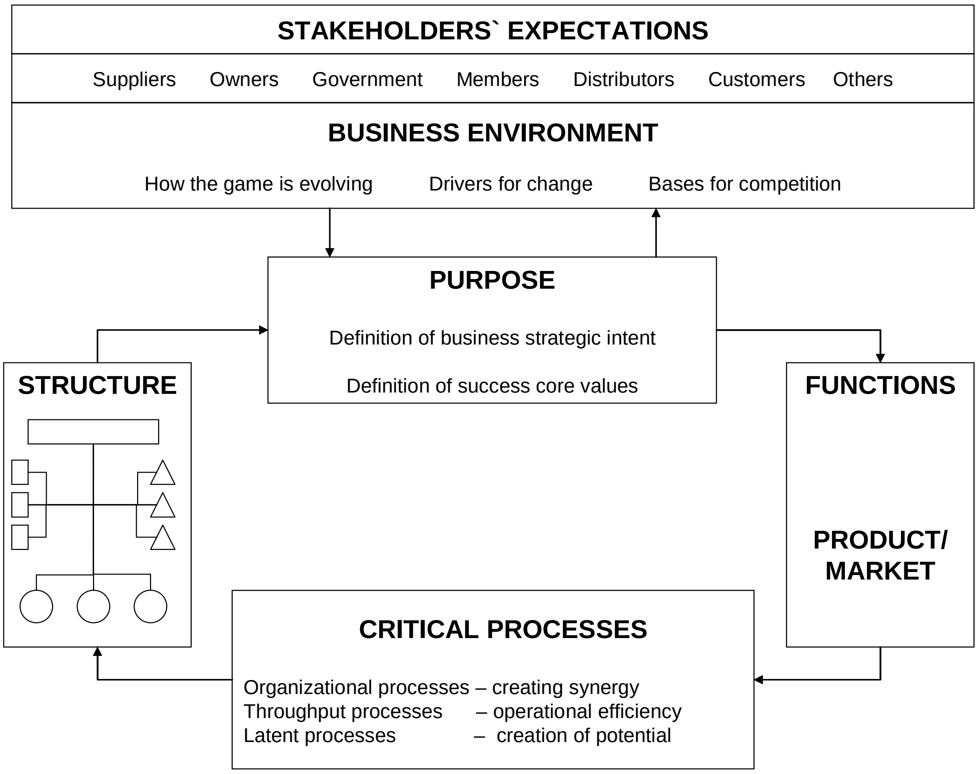


Figure 3.12: Designing a business architecture

In order to design a business architecture, the first step is to understand the behavior of the stakeholders. The best way to frame the business environment is to understand what the bases for competition are, how the "game" is evolving, and what the drivers for change are. For example, the bases for competition is to change from dispensable cheap labor as a variable cost, to the knowledge worker as a fixed asset and a sustainable competitive advantage.

Statement 3.5.1 *The crucial step is to define the purpose of the business by defining the strategic intent, the measure of success, and the core values.*

The next step is to define the functions and products for the market. In oder to produce the structure that fits the purpose the relationships among all peer units must be explicitly known and understood. The final element in developing the business architecture is the design of throughput processes and organizational processes [Ghar-99].

Capability Maturity Model Integration (CMMI)

CMMI is a process improvement approach that provides organizations with the essential elements of building effective processes. It can be used to guide process improvement across a project, a division, or an entire organization [ChKS-03]. CMMI helps to integrate traditionally separated organizational functions, to set process improvement goals and priorities, to provide guidance for quality processes, and provide a point of reference for appraising current processes [CMMI]. CMMI is a **process model** for the evaluation and improvement of an organization's product **development process quality**. CMMI consists of best practices that address the development and maintenance of products and services covering the product life cycle from conception through to delivery and maintenance. Currently, four bodies of knowledge are available when planning process improvement using CMMI: Systems engineering, software engineering, integrated product and process development, and supplier sourcing. CMMI allows users to select the model representation that best suits their business objectives [AhCT-01].

3.5.3 Knowledge management

"The successful engineering enterprise of this century will be characterized by an organization that supports process thinking and manages experiences and intelligence based on information." [Ivip].

Information management plays a key role in defining processes. The management level provides the strategy containing market trends and business objectives, as it is demonstrated in Figure 3.13 [OvWS-05].

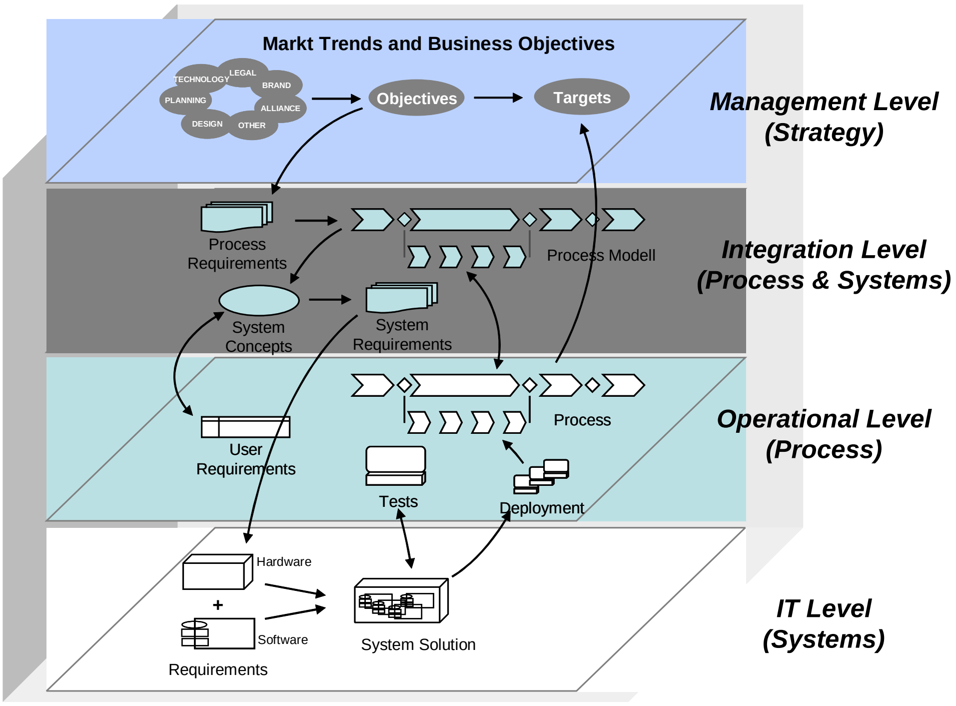


Figure 3.13: Levels of process and system integration

The IT level is the lowest where systems are provided and above the operational level where processes and user requirements are defined. Crucial is the integration level between management level and operational level containing the process model which is adjusted to the management strategy on this level.

Case Based Reasoning (CBR)

One possible knowledge management methodology is CBR, which is a discipline of Artificial Intelligence and is a methodology to model human reasoning, for building intelligent application systems, and for storing, sharing, and using individual experiences. The objective is to **solve new problems by selecting previous cases of similar problems** and adapting them to current problems. Cases can obtain text, numbers, or symbols [Aifb].

A solution can be found for the current problem situation T (Target) for an unknown solution L' without knowing the solution way l', as demonstrated in Figure 3.14 [Luek-03].

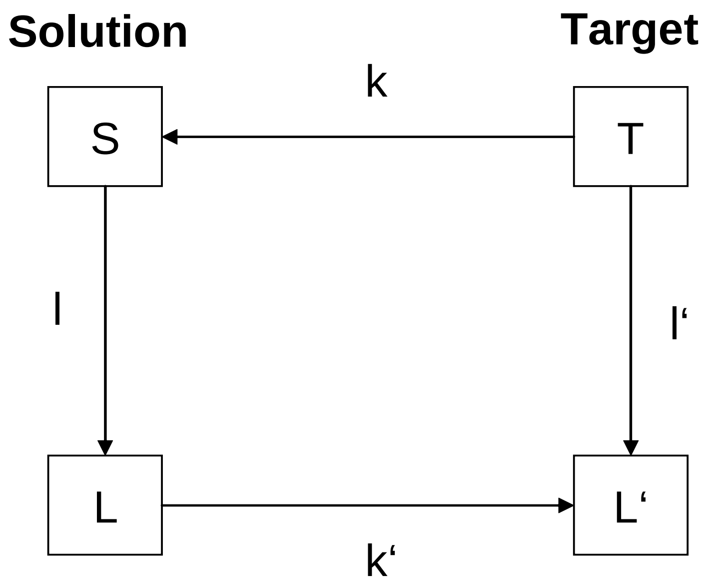


Figure 3.14: Case-Based Reasoning (CBR)

On the left side is illustrated a situation S, the related solution L, and the solution way l which leads to solution L. Using similarities of S, l, and L, it is attempted to find a new solution L' to the problem situation T and the related solution way l' [PfRi-93]. **Similarity is the most important concept in CBR** with the basic assumption that similar problems have similar solutions. The objective of similarity modeling or computation is to provide a good approximation.

The most widely used technology in CBR is the **nearest neighbor approach** which is provided by the majority of CBR tools. This algorithm starts in step 1 with the similarity σ of the problem T case to a source case S in the case library by the similarity function f for each case attribute ϵ. This similarity measure may then be multiplied by a weighting factor τ. After this the sum of the similarity of all attributes is calculated, to provide a measure of the similarity of that case in the library to the target case. The variable η is defined as the number of attributes in each case [Kolo-92]. These facts can be represented by the equation [PuGP-97]:

$$\sigma(T, S) = \frac{\sum_{\epsilon=1}^{\eta} f(T_\epsilon, S_\epsilon) \times w_\epsilon}{\sum_{\epsilon=1}^{\eta} w_\epsilon} \tag{3.4}$$

CBR has grown from a rather specific and isolated research area to a field of widespread interest. The CBR methodology is based on the existence of a case base containing experiences in solved problems and the reuse of cases. Four basic tasks are defined in a **CBR 4R-cycle** in order to perform this activity, which is illustrated in Figure 3.15 [AaPl-94].

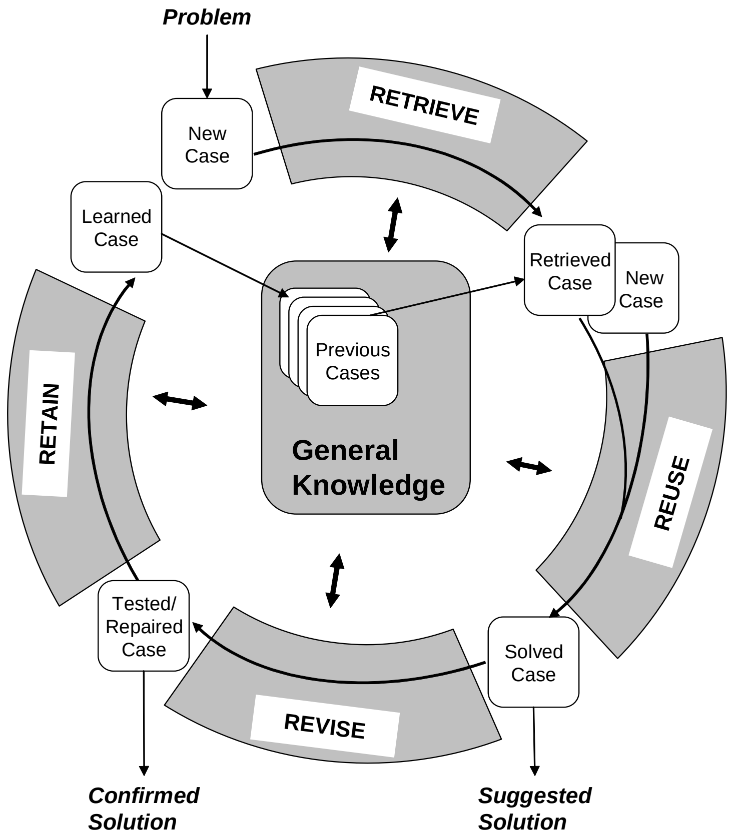


Figure 3.15: The CBR 4R-cycle

A new problem is solved by retrieving one or more previously experienced cases, reusing the case, revising the solution based on reusing a previous case, and retaining the new experience by incorporating it into the existing case base [AaPl-94]. CBR is an approach to incremental and sustainable learning, since a new experience is retained each time a problem has been solved, making it immediately available for future problems [Kolo-92]. Further background information can be found in the research centers [Wats-05], [BeAl-05], and [Aha-05].

3.5.4 Product Lifecycle Management (PLM)

A product life cycle is defined as the entire process chain of a product, starting with a product idea and product planning up until product recycling. PLM is an integrated concept for the **IT based organization** of all product creation steps over the **entire life cycle** with the objective that the necessary information is available at all relevant steps [ArDE-05]. The core function of PLM is to close the product cycle between the end customer and the development of a new product generation and acts as the integrational function for all involved partners. PLM is a conceptional solution which provides the advantage to be the holistic integration platform of various IT systems [Ovtc-04].

Statement 3.5.2 *The crucial benefit of PLM is to have a central administration system for all project, product and process relevant information in the total product life cycle [Ovtc-05].*

PLM systems provide the opportunity to integrate existing systems such as Product Data Management (PDM), Enterprise Resource Planning (ERP), Supply Chain Management (SCM), or Customer Relationship Management (CRM) over one interface [SuXR-04], as it is demonstrated in Figure 3.16

Figure 3.16: PLM integration function

PDM plays a key role in PLM systems and is the integrated center of data management and data transfer from generation systems such as CAD or CAE to a destination system such as Production Planning System (PPS) or SCM [EiSt-01]. The PDM system is the core element for internal and external communications in the engineering process [Edle-01].

3.5.5 Industrial state of technology

Strategy Maps have been used already in the automotive industry for example by Tata Auto Plastic Systems [KaNS-04]. The application and implementation of the **Strategy Map** was very successful as the energy and material consumption has been significantly decreased. Other benefits were the better IT management and the creation of a cost consciousness on all company levels.

Designing business architecture following the **“systems thinking” approach** was applied by Commonwealth Energy Systems for example. The shareholders’ expectations have changed as changes in the business environment operations are no longer seen to provide a significant growth opportunity and imply an investment risk. Therefore, a business architecture redesign is operated following Figure 3.12 in Section 3.5.2 with the three activities of regulated business, customer oriented business, and technology oriented business which can be mentioned as an successful example [Ghar-99]. CMMI is also widely applied in the industry, especially in the space industry. A case study from the United Space Alliance shows an efficient way to improve the process of maintaining space systems after they have been put into use [ChKS-03].

A variety of industrial **CBR software solutions** exist that enable firms to effectively use the experience and know-how within an organization. An example from the automotive industry for using the CBR technology is the Chrysler’s Service Technical Assistance Resource Center. Technicians input the vehicle problem in natural language to start a troubleshooting session, which narrows down the problem with follow-up questions. More difficult problems are handled by call center agents who use the same application.

The results of using this solution is that **dealerships’ service technicians** perform a faster vehicle service by streamlining the process of providing information on how to address a particular vehicle problem, as well as providing consistent, timely information to all dealerships to better serve customers, including smaller dealers with fewer qualified technicians. Another benefit is to keep vehicle recalls to a minimum and lowering vehicle warranty costs by automating and centralizing the capture of product related quality issues, and communicating quality issues with internal business units and suppliers to provide an effective solution to a particular problem [Kaid-05].

The increasing product, process, and service complexity of automotive electronics and the reduction of the product life cycle are reasons for increasing importance of PLM solutions. **A continuous growth of the worldwide PLM market** from 13 billion US $ today to 20 billion US $ in 2008 is estimated by market researchers [VDI-1205]. A current survey of the PLM software company UGS shows an increasing importance of PLM, as 27% of 382 manufacturing companies attribute a very high importance, 34% a high importance, but only 11% of the respondents have a pure PLM manager [VDI-3905]. In 41% of the respondents the PLM responsibility cannot be assesed clearly, in 14% the product managers are responsible for PLM. The results show that PLM is not considered to an appropriate extent in order to master the future challenges of complex product structures, global supply and production networks.

Statement 3.5.3 *A drastical reduction of development cost of 10% in 2 years and 20% in 5 years as well as a development time reduction of 20% in 2 years and 34% in 5 years is estimated using PLM [VDI-3905].*

Without a clear integration in the business process and organization chart, and an explicit responsibility assessement the benefits and the potentials of PLM cannot be efficiently used in the future. In the industry PLM systems are used to provide several product model views and accompany the product during the entire life cycle. In particular, for the assembly of automotive electronics the visualization of the vehicle in the Virtual Reality/ Augmented Reality (VR/AR) environment supports to identify and analyze weak points and collision possibilities. All modifications are documented in the PLM system, the execution of important modifications occurs, the product structure is newly configured and is continuously updated. The continuous synchronization of the product structure provides the advantage of using always up to date information, the so called "living data" [Ovtc-05].

3.6 Chapter Summary - Evaluation of Methodologies

In this section the existing methodologies are recapitulated, and potentials and shortcomings towards the objectives of this research are identified and evaluated using the following classification:

- In **Section 3.6.1** the methodologies are analyzed and evaluated for **applicability** to solve the described objectives and to master the challenges of improving the assembly quality of automotive electronics.
- In **Section 3.6.2** the methodologies are discussed and evaluated towards the capability for **extension** in a possible new methodology to provide solutions for the challenges in the automotive industry.

The **criteria of this analysis** are the methodology's feasibility

1. to master the automotive electronics complexity,
2. to handle automotive electronics data structure and granularity,
3. to integrate product and assembly process improvements,
4. to integrate the entire value creation chain,
5. to realize an integrative cost approach, and
6. to be integrated in existing business processes in the automotive industry.

3.6.1 Applicability of methodologies

Automotive electronics manufacturing methodologies are described in Section 3.1 whereby it is realized that there is no integrated approach with the focus only on assembling automotive electronics. The discussed supply and assembly methodologies are partly feasible to master the complexity of automotive electronics. The evaluation results towards the applicability of the discussed methodologies are summarized in Table 3.2

++ Feature completely accomplished + Feature partly accomplished ° Feature basically accomplished -- Feature not accomplished | not relevant		**Applicability towards the problem description**					
		Feasibility to master automotive electronics complexity	Feasibility to handle automotive electronics data structure and granularity	Feasibility to integrate product and assembly process improvements	Feasibility to integrate entire value creation chain	Feasibility to realize integrative cost approach	Feasibility for the integration in business processes in the automotive industry
Section 3.1 Automotive Electronics Production Methodologies	Supply Methodologies [Velo-00]	+	|	+	|	|	+
	Assembly Methodologies	--	|	+	|	|	++
	Lean manufacturing [Like-04]	+	|	++	|	|	++
Section 3.2 Production Planning	Design for Manufacturing	o	--	++	+	--	++
	Digital Production Planning	o	o	+	++	++	++
Section 3.3 Technical Risk Management	FMEA	--	o	--	o	o	+
	Value-at-Risk, ETA, FTA	--	+	o	--	o	--
	Probabilistic Risk Analysis (PRA)	o	+	+	o	+	o
Section 3.4 Automotive Electronics Quality Methodologies	QFD	o	--	+	--	o	+
	Six Sigma	+	o	o	+	+	o
	TQM	+	+	+	+	+	o
	Poka Yoke	++	++	++	|	|	+
	Quality Control [LoHu-03]	o	o	o	o	o	o
Section 3.5 Business Strategy and Process Methodologies	Strategy Maps [KaNo-04]	++	|	+	++	++	++
	System Thinking [Ghar-99]	o	|	o	o	o	o
	CMMI [ChKS-03]	o	o	o	+	+	o
	CBR [AaPl-94], [Luek-03]	++	++	++	++	++	++
	PLM	++	++	++	++	++	+

Table 3.2: Evaluation results towards applicability

The assembly methodologies are appropriate to integrate product and assembly improvements and to be integrated into business processes in the automotive industry. It can be ascertained that there is no production methodology which improves the automotive electronics assembly process based on direct **feedback data** along the value creation chain.

Considering production planning concepts, the **DFM approach** is in fact beneficial as products are easier to assemble and to disassemble, and thereby the handling in service stations is improved. The DFM approach is however also in some cases controversial, as product life cycles are shrinking and the DFM approach is time intensive [Nahm-01]. With existing DFM methodologies it is difficult to realize potentials by balancing additional investment cost with reduced assembly defects. DFM methodologies can be however integrated efficiently in existing business processes [Dvor-94]. The production planning departments of automotive manufacturers are taking advantage of using digital tools in the planning process. These tools provide support to reduce planning time and cost as well as to identify and prevent assembly difficulties and defects in advance using simulation tools. Considering automotive electronics it is showed in this chapter that the movement of “folding flabby” elements such as cables and is currently not possible to realize in digital tools. In fact, digital tools are feasible to be integrated in existing business processes over the entire value creation chain, supporting an integrative cost approach.

The **technical risk management approaches** FMEA, Value-at-Risk (VAR), Event Tree Analysis (ETA), and Fault Tree Analysis (FTA) are static approaches and requiring a high effort and capacities. Additionally, these concepts are not feasible to master the complexity of automotive electronics. Probabilistic Risk Analysis (PRA) is a powerful approach to quantify risks and to use this as an input for decision analysis. Part of PRA is the Bayesian approach which has already been implemented in some industrial applications as it is demonstrated in this chapter. For the described problem field however and the object of integrating this new approach in an industrial environment it has the shortcoming of making many assumptions when calculating the Bayesian probabilities. Due to the complexity of automotive electronics and the data granularity of related feedback data an application and **implementation** is therefore difficult.

Considering the analyzed quality methodologies for automotive electronics, Quality Function Deployment is focused on integrating the customer into the engineering process which can be therefore efficiently used. For complex products such as automotive electronics, the approach is however very complex and time consuming and cannot be used as an integrative approach. The Six Sigma approach is used already in the automotive industry successfully. Six Sigma however is not appropriate for managing the data input for a product and assembly process improvement. TQM is a general quality approach whose principles have been integrated and used already in the automotive industry. Poka-Yoke is appropriate and essential for product and assembly process improvements and for mastering the complexity. It can be ascertained that no **quality method** for automotive electronics exists which considers the direct feedback information and provides decision support for assembly process and product improvements. The described quality data methodologies and sources are a first step to integrate feedback information in a production planning process which however do not go far enough.

In terms of business strategy and process methodologies a **Strategy Map** is a very useful method to identify the important scope for changes and necessary requirements for changes. Designing business architecture using the “systems thinking” approach is useful for identifying critical processes. It is however a theoretical concept which is still difficult to transfer in an industrial environment and is complicated to use as an effective approach. The CMMI approach puts emphasis on specific processes and thereby important integration requirements are missed out. Other critical issues are the inadequate integration and inconsistent representation of generic goals and practices. In order to steer and efficiently manage new and existing knowledge, the **CBR approach** is a very efficient and intelligent tool for knowledge storing and reusing. The similarity concept helps to prevent redundancy work and to reuse necessary information along the product life cycle. The decision threshold value for a certain similarity consideration can possibly underlie some inaccuracy. The determination of similarity thresholds depends on the related business model and application cases. **PLM and PDM concepts** are methodologies which provide advantages in the planning process, having also integrated digital tools and an efficient data management. Due to shorter product life cycles and the increasing complexity these methodologies gain in importance. PLM is rather a concept than an integrated concluded solution. The implementation and integration of PLM systems in existing business processes are a great challenge for automotive companies due to their dimension and complexity, but absolutely success promising.

3.6.2 Extension of methodologies

In fact, the discussed production methodologies are feasible to be extended in a new methodology approach and can be efficiently integrated, which are shown in Table 3.3.

<table>
<tr><td colspan="2" rowspan="2">++ Feature completely accomplished
+ Feature partly accomplished
° Feature basically accomplished
-- Feature not accomplished
| not relevant</td><td colspan="6">Extension in new methodology</td></tr>
<tr><td>Feasibility to master automotive electronics complexity</td><td>Feasibility to handle automotive electronics data structure and granularity</td><td>Feasibility to integrate product and assembly process improvements</td><td>Feasibility to integrate entire value creation chain</td><td>Feasibility to realize integrative cost approach</td><td>Feasibility for the integration in business processes in the automotive industry</td></tr>
<tr><td rowspan="3">Section 3.1
Automotive Electronics Production Methodologies</td><td>Supply Methodologies [Velo-00]</td><td>++</td><td>|</td><td>+</td><td>|</td><td>|</td><td>+</td></tr>
<tr><td>Assembly Methodologies</td><td>--</td><td>|</td><td>+</td><td>|</td><td>|</td><td>++</td></tr>
<tr><td>Lean manufacturing [Like-04]</td><td>++</td><td>|</td><td>++</td><td>|</td><td>|</td><td>++</td></tr>
<tr><td rowspan="2">Section 3.2
Production Planning</td><td>Design for Manufacturing</td><td>++</td><td>++</td><td>++</td><td>++</td><td>++</td><td>++</td></tr>
<tr><td>Digital Production Planning</td><td>+</td><td>+</td><td>++</td><td>++</td><td>++</td><td>++</td></tr>
<tr><td rowspan="3">Section 3.3
Technical Risk Management</td><td>FMEA</td><td>--</td><td>--</td><td>--</td><td>--</td><td>o</td><td>o</td></tr>
<tr><td>Value-at-Risk, ETA, FTA</td><td>--</td><td>--</td><td>--</td><td>--</td><td>o</td><td>--</td></tr>
<tr><td>Probabilistic Risk Analysis (PRA)</td><td>o</td><td>--</td><td>--</td><td>+</td><td>o</td><td>o</td></tr>
<tr><td rowspan="5">Section 3.4
Automotive Electronics Quality Methodologies</td><td>QFD</td><td>--</td><td>--</td><td>+</td><td>--</td><td>+</td><td>--</td></tr>
<tr><td>Six Sigma</td><td>o</td><td>o</td><td>o</td><td>o</td><td>o</td><td>o</td></tr>
<tr><td>TQM</td><td>++</td><td>+</td><td>+</td><td>+</td><td>+</td><td>o</td></tr>
<tr><td>Poka Yoke</td><td>++</td><td>++</td><td>++</td><td>+</td><td>|</td><td>++</td></tr>
<tr><td>Quality Control [LoHu-03]</td><td>+</td><td>--</td><td>+</td><td>+</td><td>o</td><td>o</td></tr>
<tr><td rowspan="5">Section 3.5
Business Strategy and Process Methodologies</td><td>Strategy Maps [KaNo-04]</td><td>++</td><td>|</td><td>++</td><td>++</td><td>++</td><td>++</td></tr>
<tr><td>System Thinking [Ghar-99]</td><td>o</td><td>|</td><td>o</td><td>o</td><td>o</td><td>o</td></tr>
<tr><td>CMMI [ChKS-03]</td><td>o</td><td>o</td><td>o</td><td>-</td><td>o</td><td>o</td></tr>
<tr><td>CBR [AaPl-94], [Luek-03]</td><td>++</td><td>++</td><td>++</td><td>++</td><td>++</td><td>++</td></tr>
<tr><td>PLM</td><td>++</td><td>++</td><td>++</td><td>++</td><td>++</td><td>+</td></tr>
</table>

Table 3.3: Evaluation results towards extension

As the automotive industry faces increasing complexity in electronic components and processes, a new approach however is required which integrates **lean assembly** and new assembly concepts for automotive electronics.

The **DFM methodologies** can be extended and integrated in a new approach and there is a high potential to realize assembly quality improvements for automotive electronics. As soon as there is made process in the research field of digital tools for automotive electronics in particular for "folding flabby" parts, it has to be considered in new methodologies.

The discussed technical risk management methodologies can be extended by using only the idea of creating transparency in order to identify risks for automotive electronics. Due to new **liability and legal regulations**, technical risk management is gaining in importance both in science and in industry and is therefore a high important topic to deal with. In order to meet the challenges a concept is required adjusted to the structure of automotive electronics including a continuous and dynamic data and **technical risk management**.

The existing data methodologies for automotive electronics can be extended and should be considered for creating new production planning concepts. The **Poka-Yoke approach** should be integrated in any assembly planning process for automotive electronics combined with an effective Design for Manufacturing. The major objective however is to consider the **life cycle data** chain by collecting failure symptoms from the assembly and after sales processes, analyzing risks and causes, and to create beneficial solutions based on the analyses to prevent defects in the future.

The concept of **Strategy Maps** is very useful to be applied and extended in order to implement a new production planning methodology in an existing business process. The "system thinking" and CMMI approach for business process design is due to the described shortcomings not appropriate to be extended for the described objectives. **CBR** is useful to be applied and to be further developed in a new methodology approach. This can be done by creating a new domain model and similarity functions adjusted to the specific application. Other advantages of CBR are to make predictions of the probable success of a proffered solution, learning over time, and reasoning in a domain with a small body of knowledge. Benefits are also to avoid repeating all steps that need to be taken to achieve a solution, providing a means of explanations, and extending to many different purposes [PaSh-04]. In fact the implementation and integration of PLM systems along the entire product life cycle will gain in importance and will support managing and optimizing business processes using digital tools. Considering automotive companies particularly in this sector, it is important to use feedback information from downstream processes for the development of the next car generation [GeMO-05]. Therefore PLM will play a key role in the future for data and process organization and to control the process complexity [SaIm-04]. In order to provide solutions and new concepts for the automotive industry it is very useful to follow the **PLM approach** and to consider its principles and characteristics.

Statement 3.6.1 *The evaluation of the feasibility to apply existing approaches and to provide innovative solutions shows that there exists a gap and the need to create a new methodology approach to meet the future challenges of automotive electronics.*

Derived from this evaluation, the advantages and shortcomings are taken into consideration when developing an innovative solution. The objectives, advantages, and requirements of the new methodology approach as well as the detailed methodology steps are introduced and described in the next chapter.

Chapter 4

The New Methodology - IMPROVE

After studying the state of research and technology as well as evaluating related methodologies and approaches, this chapter contains as core of this research the new developed **I**ntegrated **M**ethodology for **P**roduction related **R**isk Management **O**f **V**ehicle **E**lectronics (IMPROVE). This chapter discusses

- in **Section 4.1** the objectives of IMPROVE,
- in **Section 4.2** the methodological approach,
- in **Section 4.3** the introduction of the detailed methodology steps,
- in **Section 4.4** the implementation requirements,
- in **Section 4.5** the results of IMPROVE, and
- in **Section 4.6** the chapter summary.

4.1 Objectives

The methodology IMPROVE is designated to provide an innovative and integrated conceptional approach with the following objectives:

Objective 4.1.1 *Improve the* **assembly quality** *of automotive electronics by the reduction and elimination of production related risks of automotive electronics and the implementation of a sustainable solution process*

The first objective of the methodology IMPROVE is to increase the **assembly quality** of automotive electronics by the identification of production related risk and the reduction and elimination of these risks. Therefore, all relevant data of production related risks of automotive electronic components from suppliers, the assembly process, after sales organization, and the end customer are analyzed and summarized. This data analysis creates transparency over the entire vehicle lifecycle and is input for an integrated and sustainable technical risk management for automotive electronics.

Objective 4.1.2 *Development and implementation of an integrated* ***technical risk management*** *approach for automotive electronics throughout the vehicle life cycle and the vehicle production planning process*

In the future 90% of all automotive innovations will be in the field of automotive electronics. This leads to an increasing number of automotive electronics in a vehicle and a related increasing complexity. The consequence is a growing need for the integration of comprehensive intelligent systems, procedures, and processes in order to ensure the product quality and the innovation maturity over the entire vehicle life cycle. This requires an efficient and sustainable **technical risk management** for automotive electronics. The basis for this is to identify all operating figures of the entire process and to analyze all relevant data. The benefit of this analysis is the creation of process transparency in order to identify possible potential for improvements.

Another reason for a technical risk management is the **change of legislation** and legal frame conditions. Due to some severe casualties the enactment of the "Transportation Recall Enhancement, Accountability, and Documentation" Act (TREAD Act) was introduced in the United States in November 2000. This act enhances the penalties that could be imposed on automotive manufacturers that fail to report defects [VeMT-03]. In Germany on the 6th of January 2004 the new Devices- and Product Safety law was passed and is valid for marketing and exhibition of products, as far as this is done autonomous in the context of a company. This law says, if somebody is killed, injured, or a thing is damaged due to the failure of a product, the manufacturer of the product is in debt to the damaged person to pay for the arisen damage, which can be compared with Section 2.1.5.

Another reason for the necessity to implement a technical risk management for automotive electronics is the introduction of the international standard [IEC-61508] and the German version [DIN-61508] which are illustrated in detail in Appendix B. This standard defines the functional safety which depends on the correct function of E/E/PE safety related systems, safety related systems other technologies, and external equipment for risk reduction related to EUC. As a consequence of this, the automotive industry is facing new documentation duties for vehicles in order to ensure the functional safety of a vehicle at any step of the product life cycle.

The new methodology IMPROVE is therefore designated as an approach which enables automotive companies to implement and integrate a technical risk analysis for automotive electronics in their planning process. It is aimed at identifying possible risks and implementing concrete solutions in order to improve the vehicle assembly quality. The goal is to come from a negative to a positive risk understanding. This comprehends to see identified and quantified risks as a chance to gain additional benefits.

Objective 4.1.3 *Integration of* ***Design for Manufacturing*** *solutions in this technical risk management in order to influence the assembly process and the product for improvements in an early state of the development process.*

Further objective is to integrate a defect stoppage process and symptom-cause-solution process in the car manufacturer's product life cycle management, from after sales and production back to development and production planning processes. The focus thereby is to improve the **Design for Manufacturing** interface in order to increase the manufacturability on the assembly line and to reduce defects and damages. This could be for example improvements of connector coding, improving ergonomics, or the standardization of parts and processes. Furthermore, additional assembly process and product improvements are already described in Section 2.2. The objective related is to integrate the Design for Manufacturing process in existing product development and production planning processes.

This DFM approach creates the benefit to increase the First Time Capability and to reduce assembly and rework times in the assembly process. These savings imply a high cost reduction for the automotive manufacturer which influence also the a warranty and goodwill cost reduction. The objective is to create a new cost understanding with the methodology by a comprehensive cost approach.

Objective 4.1.4 *Implementation of a* ***Case Based Reasoning*** *approach for the efficient and sustainable knowledge and case solution management over life cycles and company processes*

The new methodology IMPROVE aims at influencing vehicle design and development at an early stage of a new type series and for a model upgrading. The objective is to create an efficient and sustainable learning process between type series for assembly improvements. This is realized with the **CBR technology** which supports the knowledge management of Design for Manufacturing solution cases and improves the communication and coordination process. The CBR approach is used as it is an efficient approach to reuse existing knowledge of former cases, and to provide this knowledge for future cases. The similarity concepts provides the possibility to reuse the most similar case for the the problem and narrows down the solution space, which can be seen in detail in Chapter 3. The usage of

CBR reduces the planning redundancies between type series and vehicle generations and provides an increased process transparency. It is aimed at creating a common problem solving understanding with an effective case solution management along the entire added value chain.

Objective 4.1.5 *Integration of IMPROVE in existing* ***business processes*** *with a decision making process and a benefit calculation*

Another objective is the integration of IMPROVE in existing **business processes**. It is aimed at using Strategy Maps in order to identify and illustrate the necessary process steps for a beneficial technical risk management. The goal thereby is to integrate a decision making process and a related benefit calculation in order to realize the identified saving potentials.

4.2 Methodological approach

The methodology is determined by a general structure as illustrated in Figure 4.1, in order to implement an effective solution process.

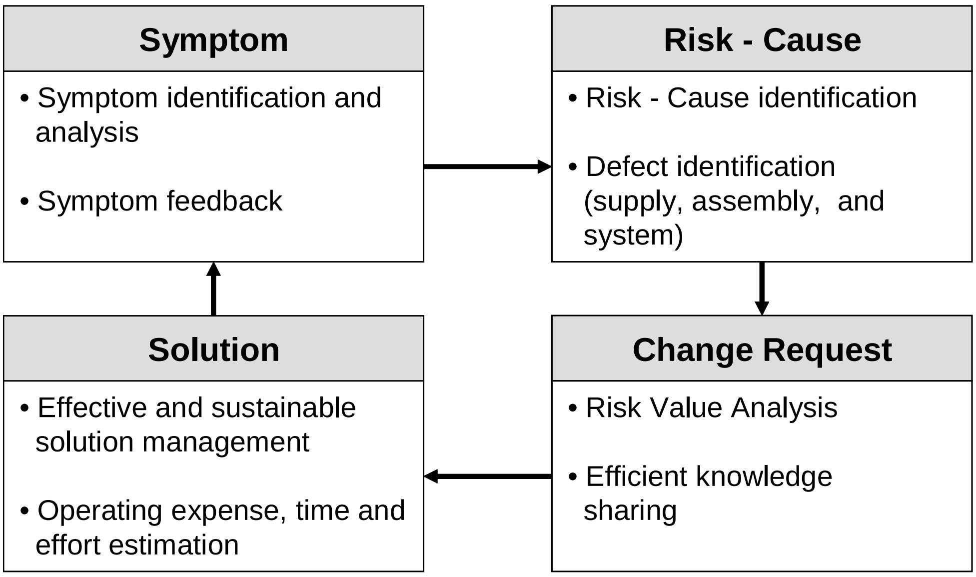


Figure 4.1: The general structure of IMPROVE

It starts by identifying symptoms of vehicles and gathers a detailed feedback of symptoms. A symptom is defined here as failures which are experienced by the customer due to defects of the vehicle. This is the input for the symptom analysis and comprehension in order to identify the risk-cause of a defect. The cause identification can show the result of a supply or part defect, an assembly or production defect, or a system failure. This risk-cause analysis then provides input change request phase where the risk values are analyzed and a knowledge process takes places. This is input to the solution phase in order to create repair and stoppage measures. The requirement for continuous learning is an efficient and sustainable solution management. The creation of solutions occurs with an operating expense, time, and effort estimation. This has to be integrated and implemented in the business process as a continuous closed loop system, which is indicated in Figure 4.1 with the arrows.

The new methodology IMPROVE contains five steps, as demonstrated in Figure 4.2.

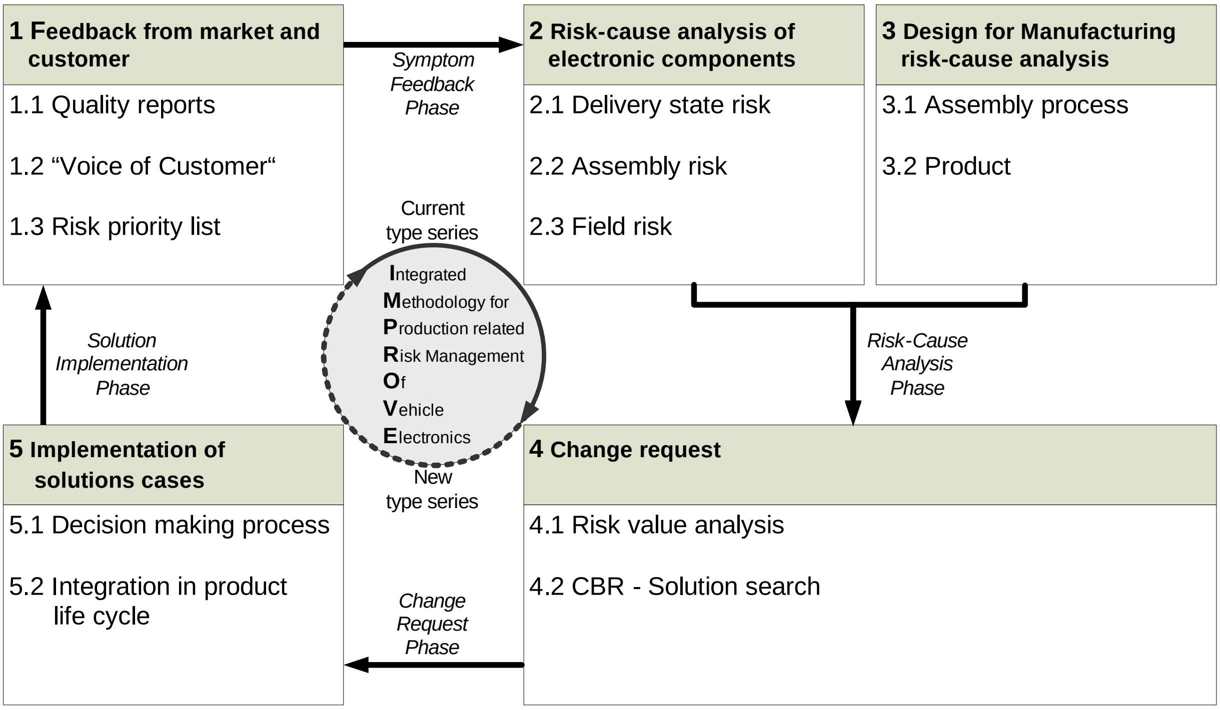


Figure 4.2: The new methodology IMPROVE

- **Step 1** is defined as symptom feedback from market and customer. This step aimes at analyzing quality reports such as for example J.D. Power, and to gather the direct “Voice of Customer (VOC)”. The result of this *symptom feedback phase* is a risk priority list of automotive electronic systems and related components. One electronic system and related components is determined, which is subject to necessary improvements and changes in the following steps of IMPROVE.
- After identifying the symptoms, the **Step 2** is the analysis of possible causes and defects, which build the content of the *risk-cause analysis phase*. This phase is

splitted into a risk-cause analysis of electronic components, analyzing the delivery state risk, the assembly risk, and the field risk.

- In **Step 3** of the methodology a risk-cause analysis of the assembly process and the product focusing on Design for Manufacturing is performed.
- After this the *change request phase* in **Step 4** contains the analysis risk values and the search for related solution cases using the CBR-cycle.
- **Step 5** contains the implementation phase in which the decision making process about implementing solution cases takes place and how to integrate them into the vehicle life cycle of the considered type series. At this point the *solution implementation phase* ends and the closed loop starts again, analyzing symptoms for the next iteration.

The required solution case management is realized in the new methodology with the CBR approach for an efficient and sustainable knowledge management process. The methodology steps are described in detail in the next Section 4.3.

4.3 Methodology Steps

This section contains the detailed description of the methodology IMPROVE, structured in different steps as already shown in Figure 4.2.

4.3.1 Feedback from market and customer

The objective of this **Step 1**, as demonstrated in Figure 4.3, is to gain feedback from after sales organizations and the market considering symptoms of the entire vehicle (vehicle view). This is performed by analyzing quality reports and to receive the direct "Voice of Customer". The generated risk priority list provides the decision basis to focus on one electronic system and related components in the next step of the methodology (system view).

Quality reports

In order to gather symptoms of possible failures and defects of automotive electronics quality reports from automotive associations or organizations can be used. In this approach, as an example the IQS from J.D. Power is used, which is described in detail in Section 3.4.2. The IQS gains in importance and priority in the automotive industry. The IQS

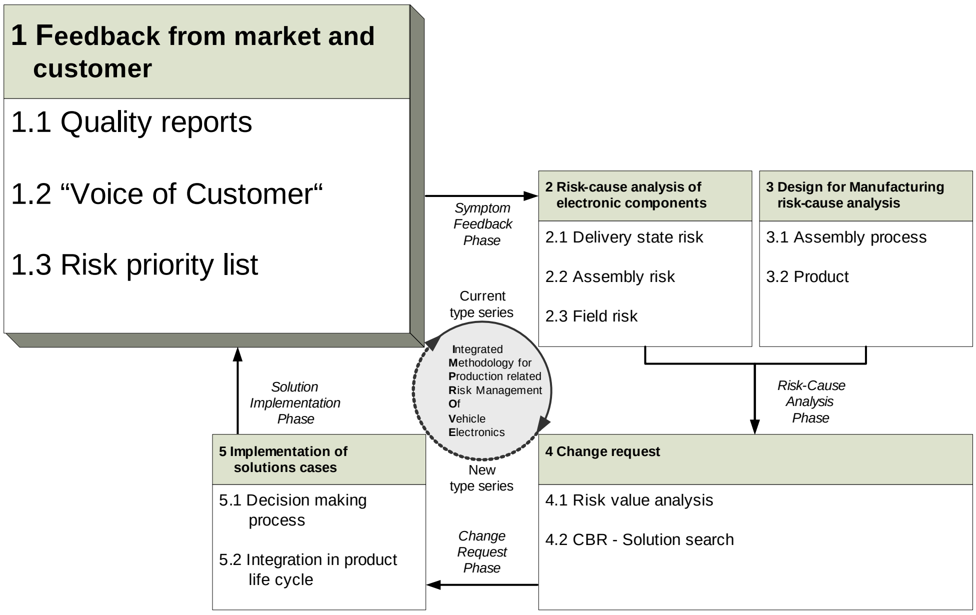


Figure 4.3: Step 1 of IMPROVE

is a list containing a ranking of car manufacturers “problems per 100 vehicles” divided into 9 categories each with several sub-categories. The entire list of IQS categories and sub-categories can be seen in Appendix C.

Possible described IQS symptoms are for example: “ABS light indicated a problem” with a problem rate per 100 vehicles of 2.4, or “Traction Control System Problem” with a problem rate of 1.2 problems per 100 vehicles. However, as analyzed in Section 3.4.2, the value of information for a detailed cause analysis is not high enough. Despite this, the study can be used to identify the areas where improvements are necessary, with the objective of reaching a better IQS ranking in the follow-up study and to increase customer satisfaction.

“Voice of Customer (VOC)”

The second feedback is an company internal process to gather the direct VOC, and to analyze symptoms which are realized and experienced by the customer. One important input source is the customer contact in a service station where through a so called **“dialog reception”** a problem description by the customer is received. Another input source is the dashboard signal which the customer recognizes and could provide as a symptom feedback information. Other sources are the company’s internal customer surveys and feedback information received by call centers when talking to customers.

Risk priority list

The described symptom feedback sources from the market and the customer are used now to create a risk priority list, in order to decide which electronic systems require detail cause and defect analyses. The described data sources can be used in order to find out the vehicle's state of quality during usage. In fact, the value of information has to be considered with caution as there are a variety of influences and interdependencies which are difficult to analyze. The feedback however can be used to focus on customer experiences and to start a detailed cause analysis dependent on customer needs.

The **risk priority list** can be created by comparing the rankings of the IQS list and the VOC list and summarizing the different attributes in one list. Other procedures can be used for the creation of this ranking with the result of a priorization of electronic systems. It is important to have an integrated view on the electronic systems and to consider all dependencies and interrelations between systems and components. The car manufacturer has the possibility to adjust its situation by creating the risk priority list differently in case of having different or more specific information. However, the result and input for the next step of IMPROVE, the *risk-cause analysis phase*, must be a sensible configuration of electronic components and electronic system choice in terms of dependencies, connections, and system integration.

4.3.2 Risk-cause analysis of electronic components

The objective of **Step 2** is a detailed risk-cause analysis for the considered electronic system, as demonstrated in Figure 4.4. Therefore, first of all the difference and logical coherence between damage, hazard, and risk is discussed. One characteristic is the difference between real and imaginary consideration. A damage is something concrete and real whereas a hazard is something imaginary or abstract. The cause of risk is a hazard, and the effect of risk is the damage. Risk combines cause and effect and is the causality between hazard and damage. Therefore, risk is something complex and contains a real and an imaginary part.

Technical risk was defined in Section 2.1.5 which is now specified for IMPROVE.

Definition 4.3.1 *A technical risk value x_r is defined as the defect of an electronic component of an electronic vehicle system with the risk types r ($\forall\ r = 1, ..., R$) such as delivery risk, assembly risk, or field risk. This technical risk can cause a hazard to any driver with the potential to cause damage.*

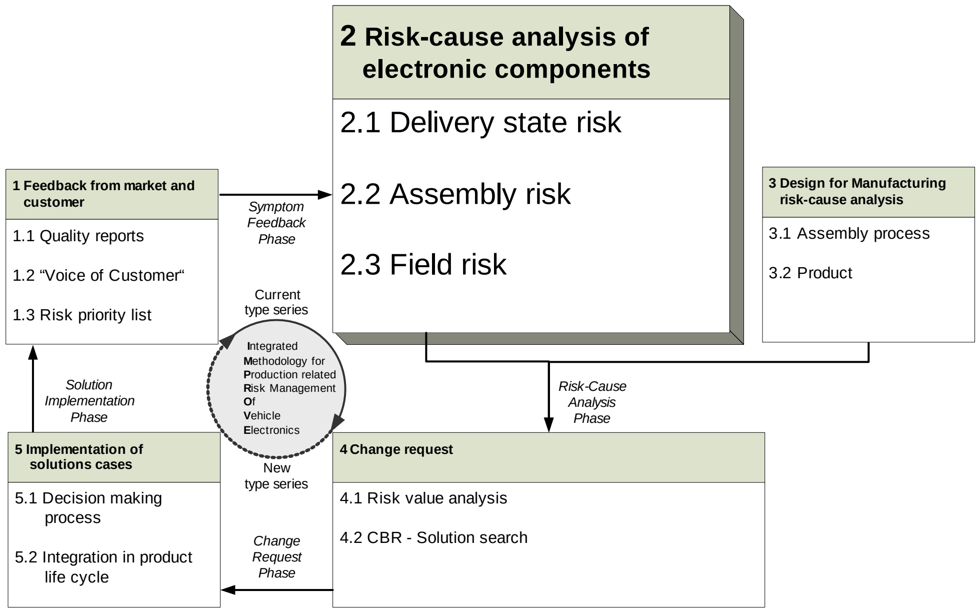


Figure 4.4: Step 2 of IMPROVE

According to this definition, the aim is to identify the supply risk at state of delivery, denoted in the ppm rate, the assembly risks on the assembly line, and the field risk after POS of electronic system's related components. In order to begin this analysis, all relevant components of the considered electronic system have to be identified and listed. The **components** are differentiated into the **main categories** ECU ($i = 1$), sensors ($i = 2$), actuators ($i = 3$), and other parts ($i = 4$) and listed together with the related CAN class. For each category i all relevant components C_{in} ($\forall\ n = 1, ..., N$) are listed before the detailed analysis starts. The variable n is the number of components per category and can be different from case to case. Additionally, the assembly step is listed when the component is assembled to the vehicle. This can be for example the interior assembly step, the exterior assembly step, or the marriage assembly step. The different steps are described in detail in Section 3.1.5.

Due to a variety of data sources and formats and the different value of information, there norm format is created in IMPROVE in order to compare the different risk types. The following **risk analysis contains**:

1. Listing the defect description or component, and

2. the related defect frequency denoted in %.

This defect percent value is defined as the **technical risk value** x_r of risk type r.

Delivery state risk

This sub-step contains the defect rate at delivery state and is defined as “0km ppm” defect rate. This is the rate of defective supplied components which are detected on the assembly line. This includes defects which are caused from the point of delivery up until the part is installed to the vehicle, which follows the ppm definition in Section 2.1.4. The parts delivered from suppliers to the OEM are mostly calculated in defect ppm. Due to the large number of electronic components supplied to the assembly line, the OEMs mostly do not have the time or capacities to test all incoming parts. The first component test is the test on the assembly line which is described in the next section. In this approach the ppm rate is analyzed for all components C_{in} ($\forall\ i = 1, ..., 4;\ \forall\ n = 1, ..., N$) which is the **technical risk value** $x_{1_{in}}$ of the risk type **delivery state risk** ($r = 1$).

Assembly risk

The next risk data source is the added-value test on the assembly line, carried out with test devices, as it is described in Section 3.1.5. Usable data for this risk analysis is the information about defects and damages on the assembly line. The objective is to test the added value, the correct connecting, and the functionality of the electronic components on the assembly line by using specialized test devices such as the IS-Tester described in Section 3.1.5. The variable $x_{2_{in}}$ is defined as the **technical risk value of an added-value test** ($r = 2$) for all electronic components C_{in} ($\forall\ i = 1, ..., 4;\forall\ n = 1, ..., N$). Possible defect messages are for example: “ECU is not completely tested” or “test stopped by worker”, “interface defect with CAN”, or “defect with sensor or actuator”. However, this risk-cause analysis for this technical risk value is often very difficult due to the vehicle complexity .

Car manufacturers are using different data systems on the assembly line to enter defects and damages directly. The objective of this analysis is to gather data and information about defects and damages directly from the assembly process. This data source depends on the accuracy and quality of entering the information into the system. For IMPROVE the optimal situation would be car manufacturers having experts on the assembly line to enter problems and defects directly into the related system. The variable $x_{3_{in}}$ is defined as the **technical risk value assembly feedback** ($r = 3$) for all electronic components C_{in} ($\forall\ i = 1, ..., 4;\ \forall\ n = 1, ..., N$). Possible feedback messages are for example: “connector not connected” or “cable damaged”.

Part of this assembly risk analysis is the **quantification of assembly and rework times** in order to measure the success and potential of a solution later on. In this step the objective is to quantify the variables “assembly time” of related electronic component C_{in}

denoted in Te_{in} in minutes (min), and the "rework time" of related electronic component C_{in} denoted in Tr_{in} in minutes (min), which are defined as follows:

Definition 4.3.2 *The assembly time Te_{in} is defined as the time for the entire assembly step to install the related electronic component C_{in} in the vehicle. The rework time Tr_{in} is defined as the time it takes to repair and to eliminate identified defects on the assembly line of component C_{in}. This can be done if time allows during the running line in the related assembly step, or the vehicle is discharged out of the assembly order.*

The quantification of the variables Te_{in} and Tr_{in} is used as a metric to measure the improvements and benefits in a later process step. In order to calculate the benefits and savings the identified times are transferred into a cost metric using the **transformation**

$$Te_{in} = 1\ min \cong 1\ Euro/vehicle \tag{4.1}$$

$$Tr_{in} = 1\ min \cong 1\ Euro/vehicle \tag{4.2}$$

which is an assumption derived from analysis experiences.

Field risk

The feedback from after sales organization is internal information from the car manufacturer's existing data sources. This quality data source should contain defects related to components and warranty and goodwill cost. Goodwill costs are costs which the customer does not have to pay, even though the warranty period is over. The data input **field feedback** ($r = 4$) is a manufacturer's internal information from after sales organization and service institutions which vary between OEMs. The data input should provide a defect description with the defect percentage which is the **technical risk value** $x_{4_{in}}$ for all components C_{in} ($\forall\ i = 1, ..., 4;\ \forall\ n = 1, ..., N$). One example is a changed component in a service station due to a failure with a related amount of warranty cost.

4.3.3 Design for Manufacturing risk-cause analysis

The objective of **Step 3** is to **quantify the assembly process** directly on the assembly line and the real product, as it is demonstrated in Figure 4.5

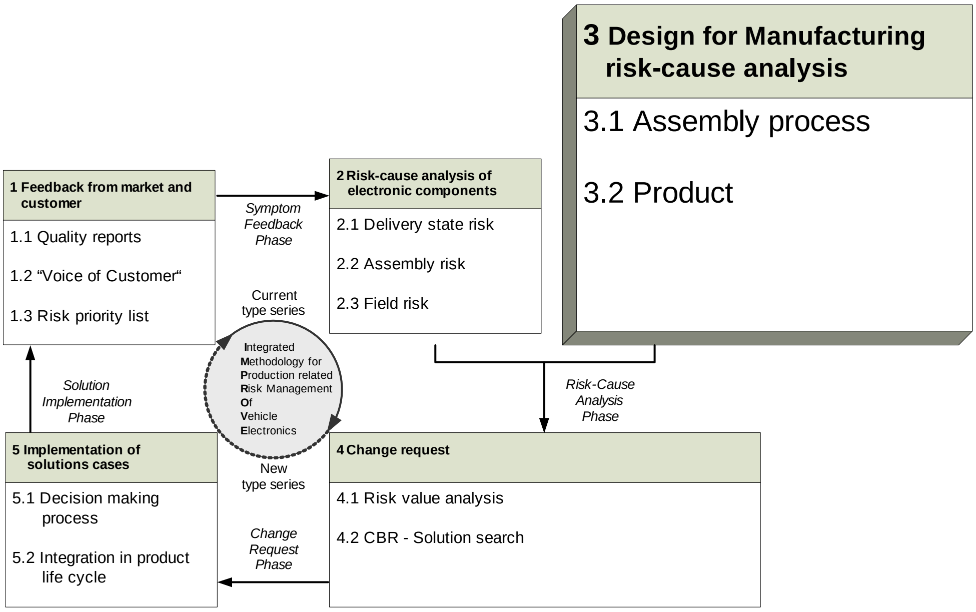


Figure 4.5: Step 3 of IMPROVE

Assembly process analysis

For this assembly process quantification, the related variables are defined as follows:

Definition 4.3.3 *The variables* A_k $(\forall\ k = 1, ..., K)$ *are defined as analysis variables of the assembly process in order to quantify the manufacturability of automotive electronic components. The number* K *of variables can vary and can be adjusted to the specific industrial application case.*

Based on an analysis in the automotive industry, the most relevant **assembly process variables** A_k $(\forall\ k = 1, ..., 8)$ are listed in Table 4.1.

After identifying the appropriate variables, each variable A_k is assigned with a **Value of Defect Susceptibility (VDS)** of the assembly job which is defined as follows:

Definition 4.3.4 *The Value of Defect Susceptibility* VDS_k^a *of an assembly job a is defined as the ability and severity of operating the assembly job a and the impairment of the assembly worker's concentration, fatigue, health, and energy expenditure. Each variable* A_k *can be assigned with a* VDS_k^a *with the value range* $VDS_k^a = [0, 1, ..., 10]$. *The values are*

Variable A_k	Definition
A_1 Posture	A human posture refers to a position of a human body. While not moving, a human can be in one of the following main positions. "Standing" which requires sufficient headroom, "sitting" which requires a more or less horizontal structure, "lying" which requires sufficient space in one direction as well as "kneeling" [HeWo-93].
A_2 Light condition	The level of illumination, the brightness allocation, the limitation of glare, and the shadiness.
A_3 Accessibility	The ability for the worker to access the part which has to be assembled and where interferences occur.
A_4 Connecting process	The required connecting power and space for the connecting process.
A_5 Cable length and space	Sufficient length of cables for the connecting process and for the store space for cables in the vehicle.
A_6 Tool choice	The appropriate tool for the assembly step such as power screwdrivers.
A_7 Assembly sequence	The assembly order and sequence if defects can be prevented by changing the sequence.
A_8 Part supply	The appropriate supply process of the electronic components if the right boxes, racks, or supply principles such as single/multi principles are used.

Table 4.1: Assembly Process Variables A_k

categorized from 0 *no impairment of the job, to* 5*, middle impairment of job and workers concentration and health, up to* 10 *having a large energy expenditure and impairment of an assembly job.*

This assembly process analysis is done for all of the systems' electronic components C_{in} (main categories $i = 1, .., 4$; number of components per category $n = 1, ..., N$). After assigning each variable A_k with a VDS^a_k, its sum over all A_k can be calculated as follows:

$$VDS^a = \sum_{k=1}^{8} VDS^a_k \tag{4.3}$$

This value can be transformed in a percentage value dependent on the possible total sum of all VDS^a_k. Considering A_k ($\forall\ k = 1, ..., 8$) the total sum is 80 and a VDS^a for component C_{in} of 8 for example would be equal to 10%.

The structure of the analysis is comprised in Table 4.2.

	Components C_{in}			
Variables A_k	C_{11}	$\rightarrow$	C_{in}	$\sum$
A_1	$VDSa_1$	$\rightarrow$		
$\downarrow$	$\downarrow$	$\searrow$		
A_k			$VDSa_k$	
$\sum_{k=1}^{8} VDS_k^8$				
$VDS^a = x_{5_{in}}$ in %				

Table 4.2: Assembly process variables

The VDS^a for component C_{in} in percent is the result of this analysis, which is seen in the bottom line. The result of this **assembly process analysis** ($r = 5$) is the **technical risk value** $x_{5_{in}}$ for component C_{in} ($\forall\ i = 1, ..., 4$; $\forall\ n = 1, ..., N$).

Product analysis

In order to quantify the condition of the product **Design for Manufacturing** of the vehicle, the related variables are defined as follows:

Definition 4.3.5 *The variables* D_m ($\forall\ m = 1, ..., M$) *are defined as product Design for Manufacturing analysis variables, in order to quantify the manufacturability of a vehicle's automotive electronic components for initiating product changes or improvements.*

Based again on an analysis in the automotive industry, the most relevant Design for Manufacturing variables D_m ($\forall\ m = 1, ..., 8$) of automotive electronics are listed in Table 4.3. Depending on the specific case and application, more variables may be considered. After identifying the Design for Manufacturing variables, each variable D_m is assigned with a **Value of Defect Susceptibility (VDS)** related to the product design which is defined as follows:

Definition 4.3.6 *The Value of Defect Susceptibility* VDS_m^d *of the design* d *of the electronic component* C_{in} *is defined as the Design for Manufacturing quality of electronic components. Each variable* D_m *is assigned with a* VDS_m^d *with the value range* $VDS_m^d = [0, .., 10]$*. If the Design for Manufacturing corresponds to a defect-free installation,* VDS_m^d *is equal to* 0*, if interferences occur values up to* 5 *are assigned, and if a defect-free installation becomes impossible values up to* 10.

Variable D_m	Definition
D_1 Assembly location	The assembly location or installation location in the vehicle. Product changes in order to improve D_1 are mostly related to conceptional and electronic architecture changes with high time and cost effort.
D_2 Color	The color contrast of connectors and parts to check the reliability of the connecting process.
D_3 Coding	The polarization of connector and related socket to supports the Poka Yoke process.
D_4 Rough edges	The design of electronic components concerning rough edges to reduce injuries and damages to the wiring harness.
D_5 Joining process	The joining process of connectors and other electronic components.
D_6 Material choice	The material choice of connectors and components, also defined as fail safe.
D_7 Labeling	The legibility of labels to allocate the right parts to the right vehicle and assembly step.
D_8 Fixing process	The fixing process of screwing, plugging, using felts or other materials.

Table 4.3: DFM analysis variables D_m

This product analysis is performed for all of the system's electronic components C_{in} (Main categories $i = 1, 2, 3, 4$; Number of components per category $n = 1, ..., N$). After assigning each variable D_m to a VDS_m^d its sum over all D_m can be calculated.

$$VDS^d = \sum_{m=1}^{8} VDS_m^d \tag{4.4}$$

The result of this **product analysis** ($r = 6$) is the **technical risk value** $x_{6_{in}}$ for component C_{in} ($\forall\ i = 1, ..., 4;\ \forall\ n = 1, ..., N$). This value can be transformed into a percentage value dependent on the possible total sum of all VDS_m^d, similar to the assembly process variables which can be seen in Table 4.2.

4.3.4 Change request

The objective of **Step 4** is to identify the **request for changes**, as demonstrated in Figure 4.6

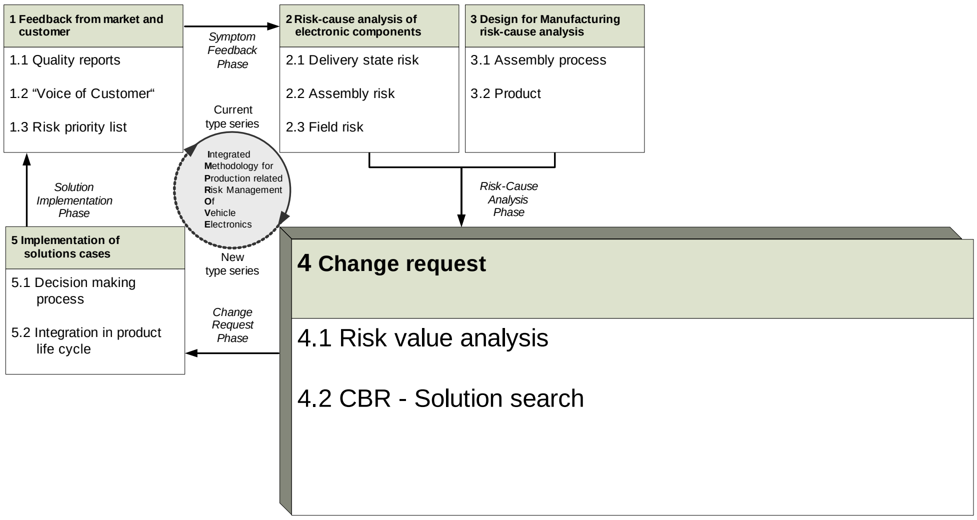


Figure 4.6: Step 4 of IMPROVE

Risk value analysis

In order to identify the change of request, the aim is to create transparency throughout the entire process according to the risk definition in Section 3.3. The technical risk is calculated with the **technical risk values** x_r of all risk types r ($\forall\ r = 1, ..., R$) as a result of the risk analysis and is denoted in the analysis risk value RV, which is defined as follows:

Definition 4.3.7 *An analysis risk value RV is defined as the sum of all risk types r ($\forall$ $r = 1, ..., R$) which is both the result of the risk-cause analysis of electronic components (Step 2) and the analysis of the assembly process and product (Step 3) for each component C_{in} (Main categories $i = 1, 2, 3, 4$; Number of components per category $n = 1, ..., N$).*

This can be expressed in the mathematical equation:

$$RV = \sum_{r=1}^{R} x_{r_{in}} \tag{4.5}$$

The structure of the considered **risk types in IMPROVE** ($\forall\ r = 1, ..., 6$) can be seen in Table 4.4. The risk value RV is the sum of all technical risk values x_r without an unity. The analysis risk value RV can have the lowest value 0 and no risk exists related to this

		Components C_{in}				
Step	Risk category	C_{11}	...	$\rightarrow$	...	C_{in}
2	Delivery State Risk	$x_{1_{11}}$	...	$\rightarrow$	...	$x_{1_{in}}$
2	Added-Value Test	...	$\searrow$			
2	Assembly System	$\downarrow$				
2	Field Risk					
3	Assembly Process Analysis					
3	Product Analysis	$x_{6_{11}}$				$x_{6_{in}}$
	$RV = \sum_{r=1}^{6} x_{r_{in}}$					
	Priority					

Table 4.4: Analysis summary of Risk Values (RV)

component. The maximal value of RV could be the sum of all x_r maximal values which is theoretical possible, however not practical.

In Table 4.4, the **final results of the risk analysis** are shown. In the bottom line the analysis risk values of the electronic system's components can be used to create a component priority list across all C_{in} in order to start creating solution cases, at first for the most critical components.

In the general context of risk management the best case is a single risk which is isolated from all others. However, the reality is more complex as a risk tends to be actively linked to one or more risks.

Statement 4.3.1 *A risk also has the tendency to passively follow one risk or several other risks [Meie-05].*

The **coherences of the two different risk tendencies** are illustrated in the coordinate system in Figure 4.7.

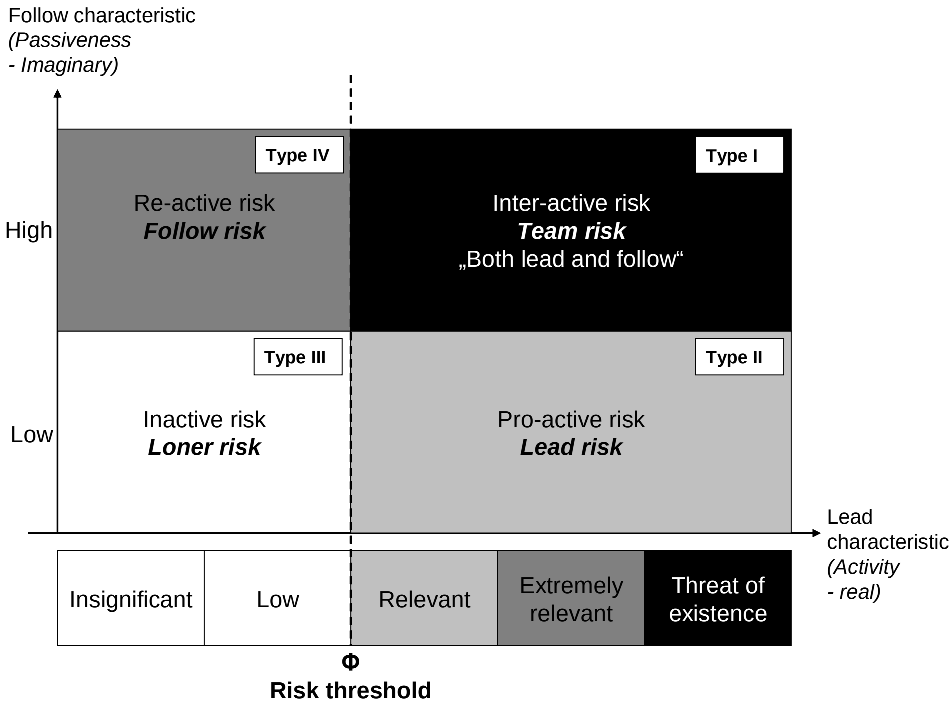


Figure 4.7: Lead and follow risk categorization

The x coordinate axis shows the lead characteristic of a risk with a real activity. The technical risk values x_r are defined in this methodology as the lead risk. Therefore the x axis contains the risk values RV. The **analysis risk values** RV **have the lead characteristic**, as they can be identified as real risks. The **y coordinate axis** is denoted with the **follow risk**. The follow risk has a passive and imaginary character as the consequences cannot be identified and determined clearly. Even though a technical risk exists it is not ensured that a follow risk occurs. Dependent on the technical lead risk RV of automotive electronics, the follow risks can be for example financial risks, brand risks, image risks, or liability risks.

The **lead risk** RV can be categorized into **5 different levels** starting with an insignificant risk and low risk. After this two categories, a risk value threshold Φ is defined. This threshold has to be determined dependent on the economic condition and risk situation in the company and is updated after a fixed period. All RV over this threshold Φ $(RV \geq \Phi)$ indicate that the company has to invest and create solutions in any case to reduce or eliminate the risks, as these RV can have follow risks of risk type I. Risk type I shown in the upper right square in Figure 4.7 is defined as the *team risk* as it is inter-active having a high activity and passiveness. The related risks affect and are affected, and influence and are influenced. The risk type III *loner risk* is an isolated risk with the attribute inactive as it neither affects nor is affected.

Type I and III are opposites towards a high and low networkability. Type II is a linked risk with the attribute pro-active with a high lead tendency and a low follow tendency. It is a *lead risk* which draws other risks. The last risk type IV *follow risk* has the attribute re-active having low lead and high follow risks. Risks of type I and II have the highest priority and strategic importance in risk management. Risks of type III and IV are often difficult to handle as the follow risk is difficult to calculate and to determine, a reason to give type I and II highest priority.

CBR-Solution search

After identifying and determining the analysis risk values RV, the next important step is to reduce risks by searching and creating solutions. The **basic information of a solution case** λ is the Case ID λ_{new1}, the type series X_{000}, the component C_{in}, and all related analysis risk values $RV = (x_1; x_2; x_3; x_4; x_5; x_6)$. Additional information is a solution description including whether it is related to an assembly process change (A) or product change (P) as well as possible investments $I_{in_{t+1}}$ in the next period $t + 1$. One possible solution case template can be seen in Figure 4.8.

Due to cost pressure in the automotive industry, it is crucial to integrate a **cost-benefit calculation** in the IMPROVE approach in order to verify possible changes. Automotive manufacturers have to put emphasis on an integrated cost approach over the entire value creation chain for new type series and model upgrading decisions. Therefore the first assumption is that with the new solution case the Values of Defect Susceptibility VDS^a and VDS^d can be reduced. The reduction of VDS^a or VDS^d in the assembly process reduce the rework time $Tr_{in_{t+1}}$ of component C_{in} by the same amount after implementing the solution in period $t + 1$. The cost factor w_1 for 1 minute saved rework time is w_{11} $Euro/min$ and additionally saved indirect cost such as assembly line space, rework space, and management cost which are denoted in w_{12} $Euro/min$. The **first savings potential** P_1 ($\cong$ Saved rework time) per vehicle is then calculated as follows:

$$P_1 = (Tr_{in_{t+1}} - Tr_{in_t}) \cdot min \cdot (w_{11} + w_{12}) \cdot Euro/min \tag{4.6}$$

The second assumption is that investments in innovative assembly concepts and simplified installation processes reduce the assembly time Te_{in} and influence a reduction of the VDS^a and VDS^d. This results in an assembly time $Te_{in_{t+1}}$ of component C_{in} in period $t + 1$ after implementing the solution case. This potential can also be transfered into monetary

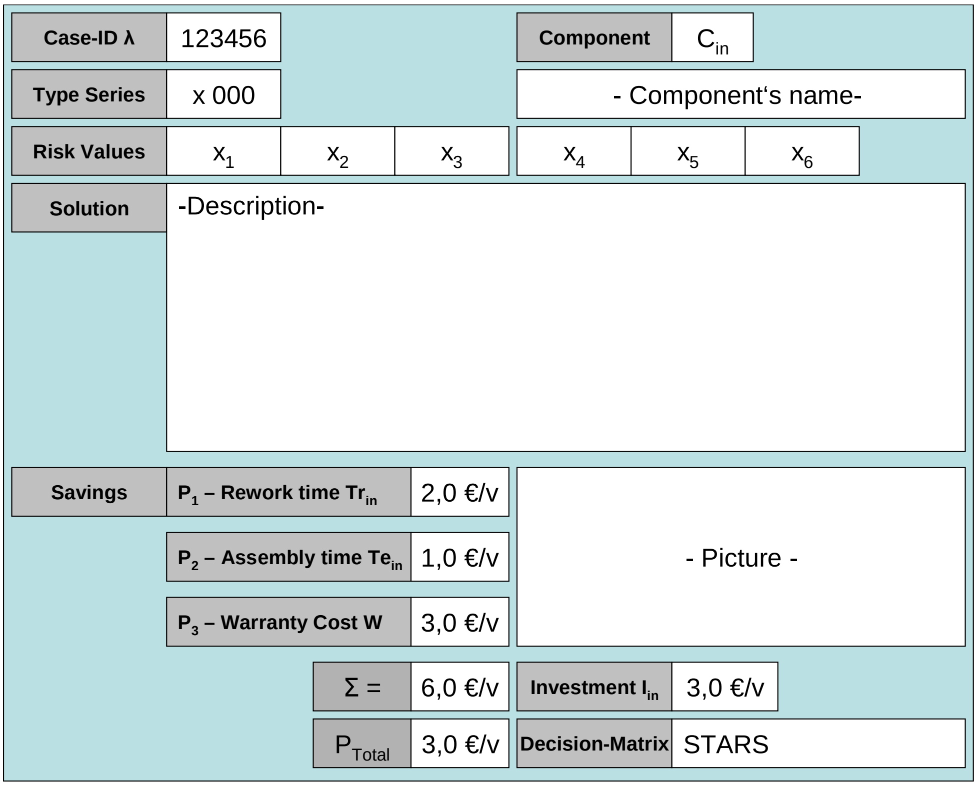


Figure 4.8: Solution case template

units with w_2 $Euro/min$. This assembly time **savings potential** P_2 per vehicle can be calculated as follows:

$$P_2 = (Te_{in_{t+1}} - Te_{in_t}) \cdot min \cdot w_2 \cdot Euro/min \tag{4.7}$$

The assumption for calculating the **savings potential** P_3 is that a reduction of the VDS^a and VDS^d can reduce the warranty and goodwill cost W_{in_t} of component C_{in} with solution case in period $t+1$. The potential P_3 are the saved warranty and recall costs between time periods, which is calculated as follows:

$$P_3 = (W_{in_{t+1}} - W_{in_t}) \cdot Euro \tag{4.8}$$

The **entire benefit potential** P_{total} is then calculated by the sum of all saving potentials P_q ($\forall\ q = 1, ..., Q$) reduced by the investment I_{in_t} per component C_{in} as follows:

$$P_{total} = \left(\sum_{q=1}^{Q} P_q \right) - I_{in_t} \tag{4.9}$$

Poor vehicle quality can lead to a follow risk such as the loss of customers or reduced sales combined with a financial follow risk. In that case it also can happen that the car manufacturer's image is influenced which can result in a brand obsolescence and can be quantified with a capital market reaction. The enhancement or reduction of the shareholder value is one possible signal to gather the follow risk of related lead risks. The quantification of follow risks is very difficult to operate and is only possible using a probability approach as well as many assumptions, wherefore it is not considered in the basic information of a solution case.

After providing the basic information of a solution case, the decisive issue is the efficient reuse of existing knowledge as well as the related revise and retain management of solution cases. Therefore the **CBR-cycle** is integrated in IMPROVE in order to gather similar cases which can be used and have been successfully implemented before, as described in Section 3.5.3. There are many advantages for the use of this approach for storing, sharing, and using individual experiences. Discussing some arguments, CBR supports the process of using knowledge of former cases efficiently and therefore saves the need to find new solutions again. The similarity concept of CBR efficiently supports the knowledge sharing process, prevents redundancies, and is appropriate to build intelligent application systems.

The CBR approach contains the retrieve, reuse, revise, and retain phases, as described in Section 3.5.3 and as shown in Figure 3.15. In order to apply the CBR technology, all basic information of a solution case have to be defined in a domain model with attributes $\alpha_1, \alpha_2, ..., \alpha_\kappa$. For each attribute a similarity measure has to be defined in order to compare a new case with an existing case. Existing cases are stored in a database which is called here the **"General knowledge" database**. The objective is to search in this database for similar previous cases *(RETRIEVE Phase)*. The crucial part of CBR is a **similarity calculation** between new cases and previous cases. Therefore a variety of similarity functions exist, which defines the procedure for searching a similar case in a query.

One example for a similarity function is discussed as follows. A similarity value of a solution case λ to another solution case λ' can be calculated by subtracting the values of all related single attributes $\alpha_1, \alpha_2, ..., \alpha_\kappa$ of λ and λ'. A solution case λ has the greatest similarity σ to another solution case λ' if the sum of all subtractions' absolute values multiplied with a similarity weighting factor τ_κ is minimal. The similarity σ between λ and λ' can thus be expressed in the following mathematical equation:

$$\sigma(\lambda, \lambda') = \frac{\sum_{\kappa=1}^{MAX} \tau_\kappa |\alpha_\kappa - \alpha'_\kappa|}{\sum_{\kappa=1}^{K} \tau_\kappa} \tag{4.10}$$

The greatest similarity Ω between λ and λ' is reached if σ is the minimum of all similarities:

$$\Omega = MIN(\sigma_1, \sigma_2, ...) \tag{4.11}$$

Afterwards, a **similarity threshold** Ψ has to be defined in order to decide whether to use an existing case out of the "General knowledge" database or a new solution case *(REUSE* *phase)*. The similarity threshold Ψ can be derived from experiences after operating several queries, and is updated in a fixed period dependent on the results. All existing cases with a **similarity value** $\sigma \leq \Psi$ are considered and the case with the greatest similarity is used if the threshold condition is restrained. With cases under the similarity threshold, a detailed discussion of existing alternatives takes place. After this a new suggested solution is provided which is a solved case. In the next step the proposed solution is revised. The solution is evaluated for the new problem with the result of a confirmed solution which is a tested or repaired case *(REVISE phase)*. In the last step the acquired experience is stored in the "General knowledge" database in order to use this experience for future problem solving *(RETAIN phase)*.

4.3.5 Implementation of solution cases

Step 5 contains the implementation of solution cases, which is illustrated in Figure 4.9

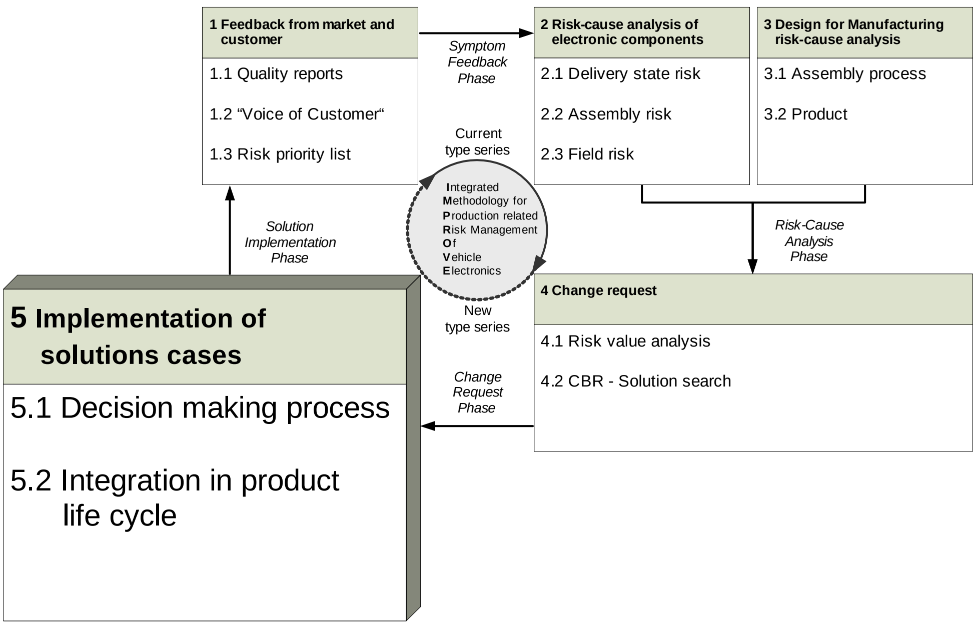


Figure 4.9: Step 5 of IMPROVE

After this is researched on integrating the solution cases into the development and production planning process.

Decision making process

Decisions about implementing a solution case are made both on account of risk and economic efficiency. The **economic efficiency calculation** is performed by calculating the benefit potential P_{total} of all saving potentials P_q ($\forall\ q = 1, ..., Q$) and investments I_{int_t}, described in Section 4.3.4. In order to make an implementation decision, the beneficial solution cases can be gathered from a portfolio analysis [Woeh-00], which is shown in Figure 4.10. The **x-axis** of the portfolio decision matrix is denoted with the **investment** I_{in_t} per

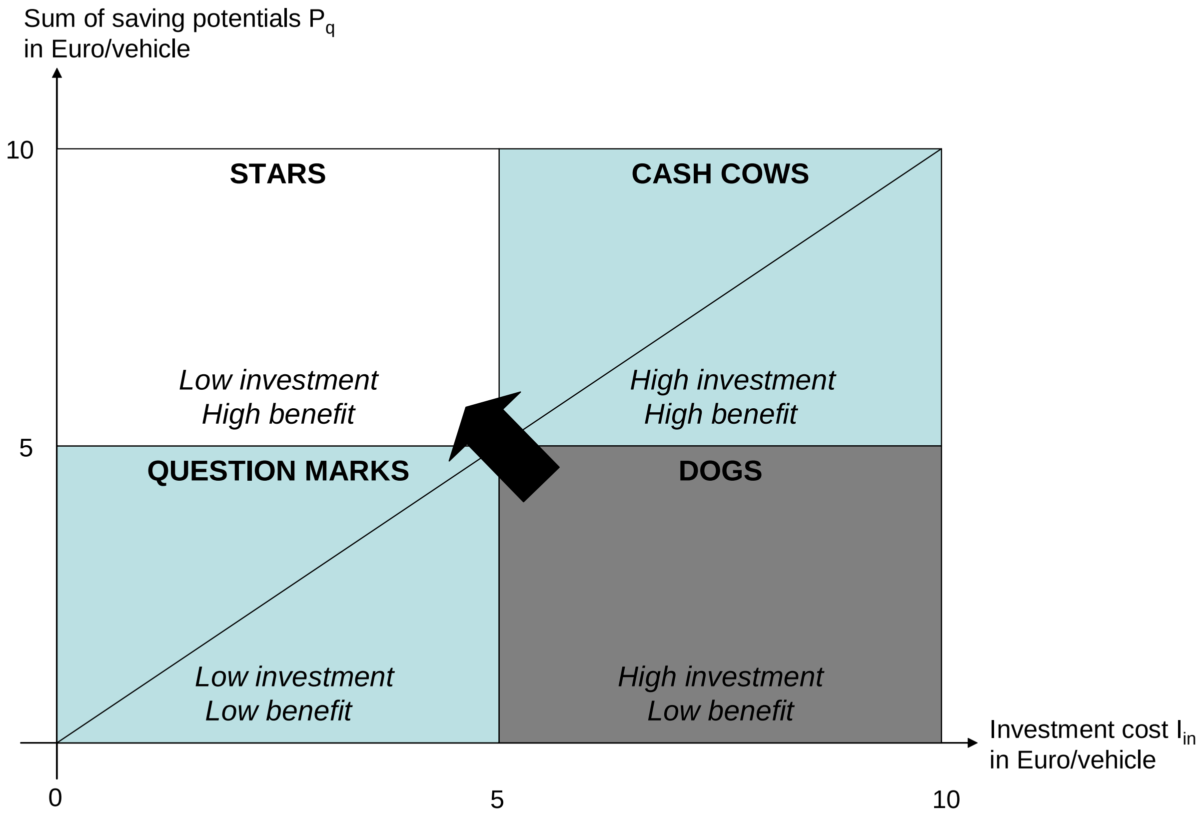


Figure 4.10: The solution case decision matrix

component C_{in} and the **y-axis** with the sum of all **saving potentials** P_q ($\forall\ q = 1, ..., Q$). The upper left square of the decision matrix can be denoted as *Stars*, as the solutions cases in this square have low investment cost and high potential savings. Solution cases in the upper right square are defined as *Cash Cows*, as the high savings can be only realized with high investment cost. Solutions cases above the diagonal are beneficial to the company, however each solution case has to be considered separately. *Question Marks* are located in the lower left square which have low investment cost but also low savings. The solution cases in the lower right square are not beneficial for the company having high investment cost and low benefits. They are problematical for implementation and therefore denoted as *Dogs*. The ideal solution cases are Stars and the direction is marked in Figure 4.10.

The risk value (RV) analysis, as described in Section 4.3.4, provides the basis for the **decision making process** for implementing solution cases, as demonstrated in Figure 4.11.

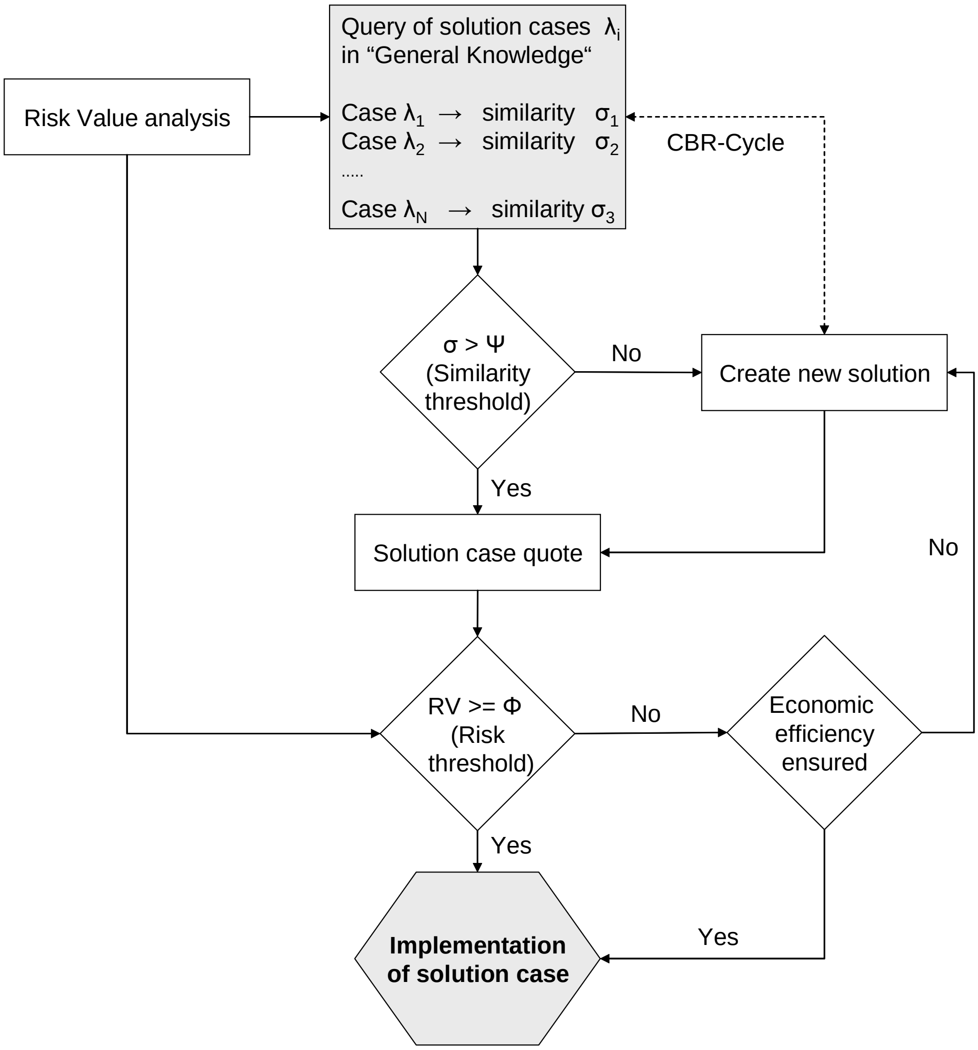


Figure 4.11: The decision making process

The results of the risk-cause analysis are used to make a query in the "General knowledge" database. Solution cases having a similarity value $\sigma \geq \Psi$ are designated for the solution case quote or else a new solution has to be created. If the risk value is greater than the threshold $RV \geq \Phi$, the company has to implement the solution case in anyway in order to reduce or eliminate the risk, and to prevent follow risks. In this case, additional benefits can be gained from taking into consideration beneficial solutions. If the risk value is less than the threshold $RV < \Phi$, the solution case has to be checked for economic efficiency. If the solution case is beneficial, as described above in this paragraph, the solution is implemented, or else a new solution case has to be created.

Integration in product life cycle

The methodology IMPROVE can be adapted to the **development and production planning process**, as can be seen in Figure 4.12.

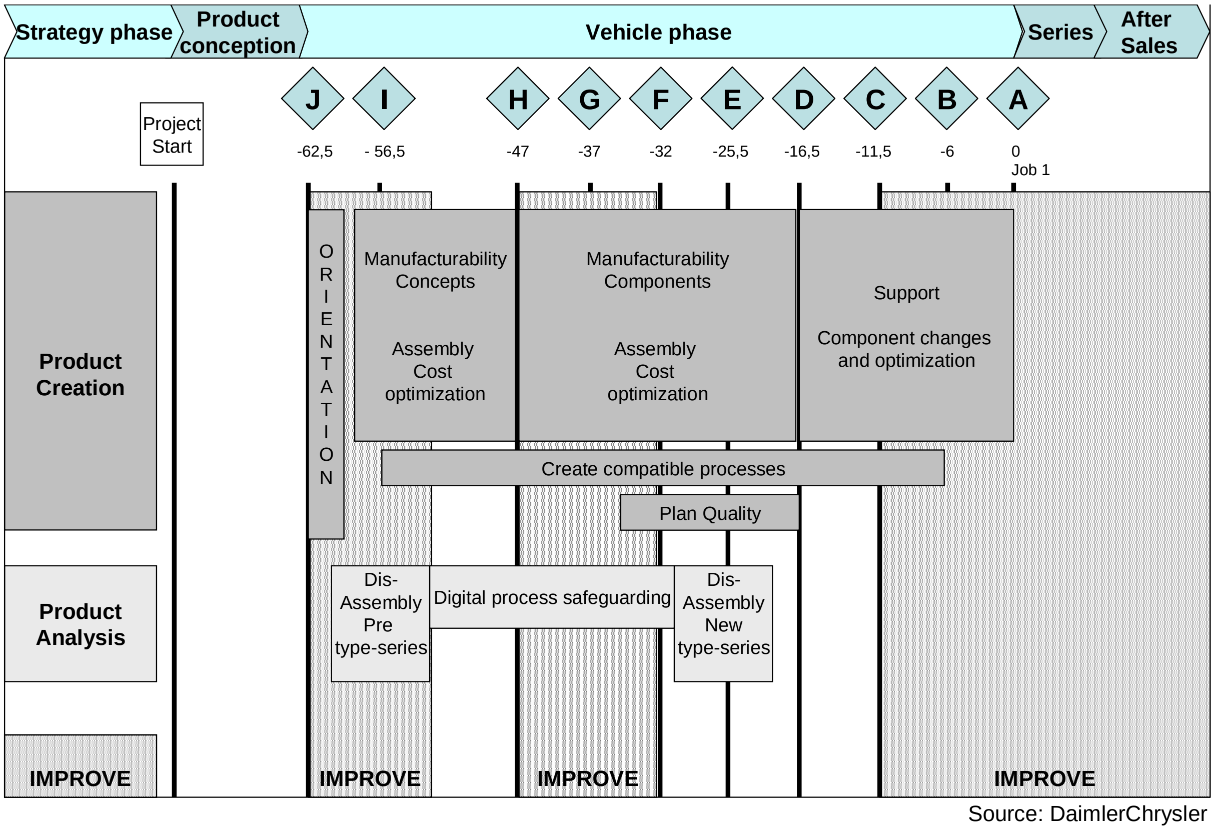


Figure 4.12: Integration of IMPROVE into the development process

In the automotive industry the so called **quality gates (J-A)** are clearly defined, at which certain development and planning activities are completed. The figures below the quality gate indicate the remaining time in month until job # 1. The job # 1 is defined in the automotive industry as the first regular produced and assembled vehicle in the production process. The Design for Manufacturing process of a automotive manufacturer can be subdivided into the product creation phase and the product analysis phase.

In the product creation phase, manufacturability concepts between quality gate I and H are performed as well as the manufacturability test of components between quality gate H and D determined by an assembly cost optimization. Between D and A component changes and related optimizations are supported. Simultaneously to this, compatible processes are created and the quality is planned. In the product analysis phase around quality gate I the dis-assembly of the pre-type series is performed and the digital process safeguarding follows. Around quality gate E the new model is dis-assembled for a vehicle analysis.

The biggest success when **applying IMPROVE** can be reached by active participation at the **quality gates J and I**, as demonstrated in Figure 4.12. Quality gate J is usually approximately 62 months ahead job # 1 and contains the concept sheet phase in which the identified improvements are integrated in the process. This first phase continues until quality gate I, which is approximately 56 months ahead job # 1. The next active period of IMPROVE is between quality gate H and F. Quality gate H is usually 47 months and quality gate F 32 months before job # 1. At quality gate G the series capability of the entire vehicle is ensured. IMPROVE is active until quality gate F where the design freeze and the fixing of specification sheets is completed. After **quality gate C**, IMPROVE is active for identifying the next **change request**. In general, it can be determined that the earlier risks are realized, changes are initiated, and product or processes are influenced, the better it is for the successful implementation of technical solutions.

4.4 Implementation Requirements

The objective of this section is to discuss the requirements for the implementation of the methodology IMPROVE in existing company business process. This is done firstly by describing the integration in the business strategy using a Strategy Map. Secondly, success criteria and possible initiatives for a successful implementation are discussed.

4.4.1 Integration in business strategy

A variety of methodologies and approaches for the definition and illustration of business strategies exist, some of them are described and evaluated in Chapter 3. The most appropriate methodology to show the integration of IMPROVE in a business process is a Strategy Map [KaNS-04], which is introduced and described in Section 3.5.1. Reasons for using Strategy Maps are the cause-effect relation from immaterial assets to material assets, and the feasibility to combine and integrate different contents. A current development in the automotive industry is the customer orientation and individualization of products. This is considered in Strategy Maps with the integration of the customer perspective, which is in fact an important issue in the new methodology IMPROVE.

In order to integrate IMPROVE in a company's business strategy, the **learning and development perspective** in the Strategy Map contains firstly the creation of a technical risk management understanding **(L1)**, as can be seen in Figure 4.13. Part of this perspective is the build up of competencies in DFM and in the CBR technology **(L2)**. Another requirement is the integration of a IMPROVE software pilot in the company specific IT

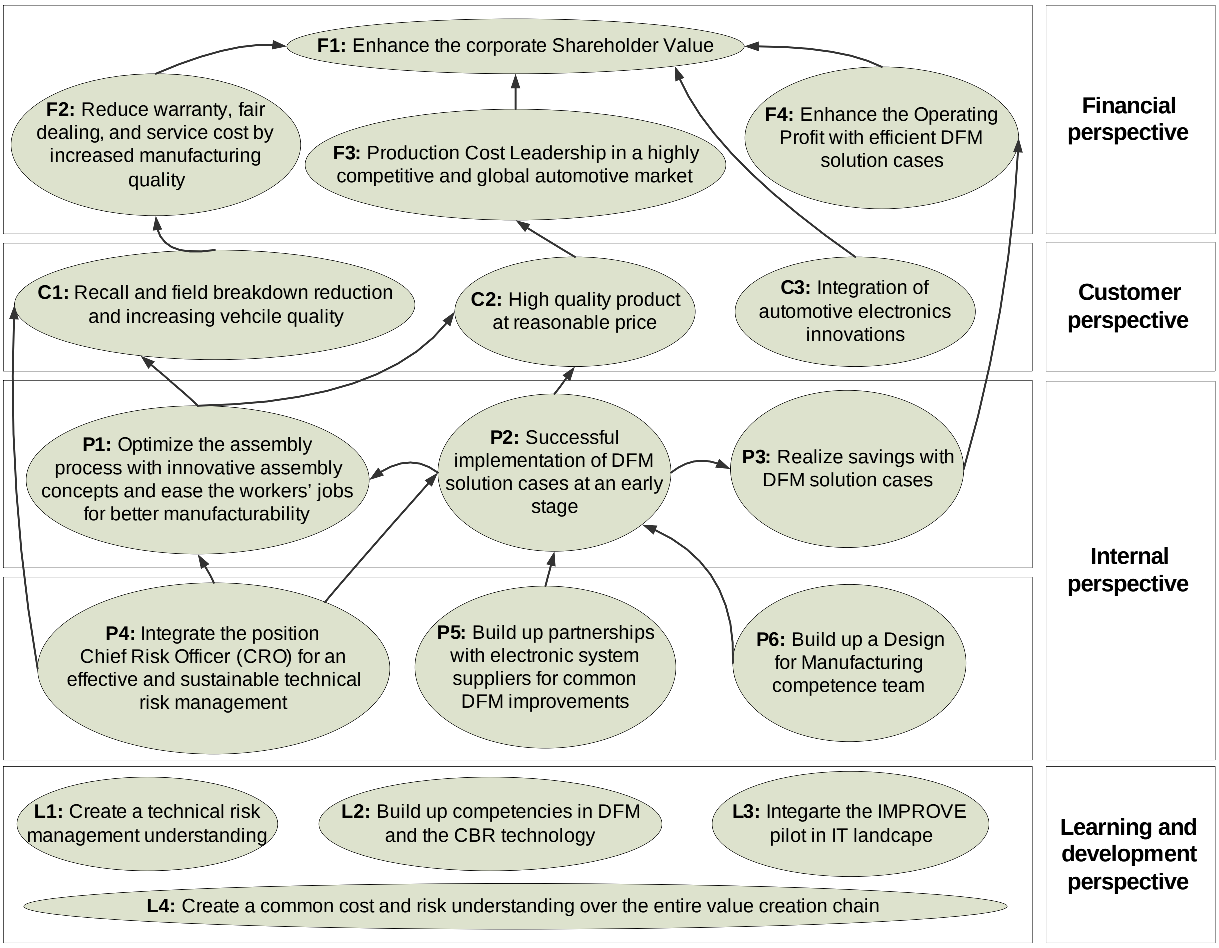


Figure 4.13: The Strategy Map of IMPROVE

landscape **(L3)**. However the most important learning and development issue is the creation of a common cost and risk understanding over the entire value creation chain **(L4)**.

The **internal perspective** contains the optimization of the assembly process with innovative assembly concepts for automotive electronics and to ease the workers' jobs for better manufacturability **(P1)**. The key issue however is the successful implementation of DFM solution cases at an early stage **(P2)** and the realization of savings with the implemented solution cases **(P3)**. A requirement for this is firstly the integration of a newly created position, called the Chief Risk Officer (CRO) for effective and sustainable technical risk management **(P4)**. Secondly, it is helpful to build up partnerships with electronic system suppliers for working on common DFM improvements **(P5)**, as well as the build up of a DFM competence team **(P6)**.

The **customer perspective** is determined by the objective of a recall and field breakdown reduction and increasing vehicle quality **(C1)**. The automotive company becomes successful by providing high quality products at reasonable prices **(C2)** and by integrating automotive electronic innovations to meet customer demands **(C3)**.

The **financial perspective** is defined as the top-level goal to enhance the corporate shareholder value **(F1)**. This can be reached by a reduction of warranty, fair dealing, and service cost resulting from increased manufacturing quality **(F2)**. Another objective in the financial perspective is to reach the production cost leadership in a highly competitive and global automotive market **(F3)**. In order to increase the shareholder value, the operating profit has to be enhanced with efficient DFM solution cases **(F4)**. The interdependencies and interfaces are shown in Figure 4.13 in detail.

4.4.2 Success criteria

"It is not the strongest species nor the most intelligent that will survive, but the one that is most adaptable to change." — Charles Robert Darwin.

The integration of the new methodology IMPROVE into the business strategy and process is a challenge for companies as it goes along with the change of a mindset and attitude. For successful implementation, a first criteria is the change of the **corporate culture** by a new risk and quality understanding. This understanding is determined by using downstream defect and failure feedback for assembly process and product design decisions.

Statement 4.4.1 *A success criteria is to implement technical risk management not as an isolated solution but rather as an integrated approach over the entire value creation chain. In order to reach the greatest success the position of a Chief Risk Officer (CRO) is proposed, in order to exactly determine the related responsibilities.*

Further criteria is the **synchronization** of the development and production planning process along the related development system. Solution cases can be successfully implemented at an early stage if a direct collaboration and integration between development and production planning exists. The new methodology approach will work successfully only with a close collaboration between development, production planning, and the production plants with efficient communication channels such as a CBR tool. This can be also reached by integrating DFM quality gates in the development process with an approval and confirmation process. Another important success criteria with the new approach is to integrate more the **assembly worker** on the assembly line in the feedback and change process. On the assembly line the added value is created, wherefore the objective can be derived to integrate a direct feedback from both the assembly line and from after sales organizations. The integration can take place using professional change management concepts [KrBF-04].

If the success criteria are taken into consideration, there is in fact a great chance for a successful implementation.

4.5 Results of IMPROVE

4.5.1 Scientific added value

The results of IMPROVE contain the following scientific added value:

- The creation of a new approach for the efficient and sustainable Design for Manufacturing of automotive electronics based on a thorough data and defect analysis. This sustainably improves the assembly process and product for defect reductions.
- An efficient vehicle life cycle management in order to learn from pre-type series and prevent defects in advance for the next vehicle generation and model upgrading.
- A new scientific technical risk management approach for analyzing defects and failures of automotive electronics and to create related solutions.
- An innovative way to manage the knowledge and experience transfer between vehicle life cycles to improve the vehicle assembly steps and thereby the quality of automotive electronics. It combines the CBR approach with the DFM approach to plan and optimize the assembly process and vehicle using existing knowledge and experience.
- Considering the cost and benefit calculation, IMPROVE proposes a new cost understanding of quantifying and balancing rework and assembly cost directly with Design for Manufacturing investments, aiming to find the overall optimum.
- It is a new approach for integrating and implementing the symptom-cause-solution relation for an effective defect stoppage process, which can be compared with [GeMO-05].

Statement 4.5.1 *The new methodology leads to a new scientific solution which integrates the research fields of technical risk management, Design for Manufacturing, and the CBR approach.*

4.5.2 Industrial benefits

The IMPROVE methodology is designated for automotive manufacturers and creates benefits of enhancing the quality of automotive electronics as follows:

- Benefits are realized by assembling a vehicle "right the first time" with product and assembly process changes which reduces assembly time and the share of rework time. The Design for Manufacturing approach generates the reduction of defects and interferences on the assembly line as well as related breakdowns in the usage phase to achieve reduced warranty cost.
- Defect and interference reduction on the assembly line to increase the First-Time-Capability (FTC) and saves high investments in rework facilities, human resources and rework time which decreases the fixed bound capital.
- A crucial benefit for automotive manufacturers is the integration of a sustainable and comprehensive technical risk management in their business processes throughout the entire value creation chain. As a variety of risk definitions and different perspectives exist, a common risk understanding is created within a company together with an efficient coordination of risk reduction solutions.
- Great potentials are realized by implementing a failure and defect stoppage process from downstream processes to upstream processes to prevent defects and failures as early as possible in the vehicle development and assembly planning process.
- Identified and analyzed risks of automotive electronics are seen as a chance to prevent these risks in the future. In fact, automotive manufacturers gain from the transfer from a negative to a positive risk understanding to see determined risk as a chance to reduce and eliminate risks.

The IMPROVE methodology creates benefits for business process and interface improvements between development, production planning, and the production process as follows:

- Creating a common understanding and knowledge basis of Design for Manufacturing over and between vehicle generations as well as for model upgrading.
- This is efficiently operated by creating defined cases in order to learn from former and existing challenges and to provide the same knowledge base for all involved departments.
- The usage of the CBR technology to manage the cases enables the efficient sharing and providing of data feedback, knowledge, and technical solutions to all involved participants, which significantly prevents the redundancies in the informational business process.
- The corporate culture and management philosophy is changed by creating a common quality and risk management understanding. With this new understanding human and organization influences can thereby be reduced.

- Automotive manufacturers create benefits with a cost potential calculation by considering arising cost holistic from the downstream processes of service and assembly to upstream processes towards design and development. This advantage of finding the overall cost optimum is an argument for investments in Design for Manufacturing solution cases to decrease defects and the share of rework time.

These benefits meet the challenges in the automotive industry which are described in Section 1.1 and generate sustainable success for an automotive business.

4.6 Chapter Summary

This chapter introduced the new methodology IMPROVE, beginning with a description of the objectives, performed on the basis of the evaluation of the state of research and technology. Further on, the methodology steps are described in detail including a decision making process and the integration into the product life cycle.

Afterwards the implementation requirements are discussed in order to apply and integrate the new methodology in an industrial environment and existing business processes. This is performed by developing a Strategy Map which contains the financial, customer, and internal as well as the learning and development perspective. Further on, the success criteria for implementation are discussed. Additionally, both the scientific and industrial benefits are illustrated in order to point out the importance and the usability of the methodology.

Chapter 5

Verification in Business Cases

5.1 Introduction

5.1.1 Objective

After describing the new methodology approach in Chapter 4, the verification, feasibility test, as well as the practicability is topic for discussion in this chapter. The objective is to demonstrate the practicability in an industrial environment in the automotive industry and to prove the feasibility and usability in existing business processes and environments with a software prototype.

5.1.2 Verification concept

In order to achieve this objective, the verification is divided into two business cases. **Business case I** aims at verifying the theoretical concept of IMPROVE by operating one iteration of the new methodology. This is done with the example of the **Brake Control System (BCS)** as the complexity and possible improvements can be perfectly demonstrated.

In **business case II a pilot software prototype** is developed and implemented in order to verify the practicability in a specific industrial environment. With this software prototype the feasibility with integrating input sources and end-users in an industrial environment is proved. Also shown is how to extend the company's IT landscape with the integrative approach of IMPROVE.

5.1.3 Definition of application scenario

The verification of IMPROVE is performed within the operative environment of **automotive manufacturer** SPEED[1], a company operating in the automotive industry. The automotive manufacturer SPEED provides several type series and has production plants worldwide. Part of its product range is the model "Flash-1" which is accepted by the market and promises high sales rates. Additionally, SPEED provides the vehicle types "Flash-2", "Flash-3", and "Sunshine". The automotive manufacturer SPEED operates in a global and highly competitive automotive market and has currently started to develop the new generation of Flash-1. The sales and marketing department of SPEED recently analyzed in their customer survey that more customers would buy the new generation of Flash-1 if it provides more electronic functions and innovations. In a competitor analysis, the production planning department determined that the production time and cost of Flash-1 are too high. Recently, some quality problems occurred in the assembly process and in the usage of Flash-1.

Therefore the model program manager initiated a **new project in order to reduce assembly and rework times and in consequence assembly and lifecycle cost**. The objective is to improve the quality of the next model generation and model upgrades significantly. This is performed by identifying current symptoms of Flash-1 experienced by the customer and provided by the after sales organization. After this the aim is to analyze production related risks and the scope of changes based on a detailed data and product analysis. The focus is to improve the manufacturability by an early influence on the product development. The management of SPEED identified the requirement to integrate this project in the business process and strategy in order to be successful.

The automotive manufacturer SPEED owns an **existing network of service stations**. One is chosen for the concept verification which is an authorized dealership of SPEED. The service station is subordinated to the central after sales organization of SPEED. The service station has no direct communication or contact to development, production planning, or the production plants. This is the reason why the feedback process back to engineering is very time intensive and intransparent. A delta between the technical knowledge in service station and the development and production planning departments occurs. The service station has to get authorization from the central after sales organization for each part over a certain cost level, which has to be changed in the warranty period. The warranty period of SPEED is 2 years allowing some exceptions for goodwill. During this warranty period the service station has a low decision competency.

[1]SPEED is a ficticious company - Similarities or common grounds to official trademarks and brands are excluded.

The **service station has an existing call center system** where customer calls are received, which is the first possibility for direct customer contact. The service station operates a "dialog reception" together between the customer and the team foreman and if necessary, a test drive. The service station identified the necessity of integrating the "Voice of Customer" in the after sales organization process better, and of making it structured available to the whole company. Additionally, it is an requirement to implement a fast information process between service station and the development and production planning departments of SPEED. This should enable a close collaboration and experience exchange for the start-up phase of new vehicle generations.

The improvements, changes, and decisions are coordinated and initiated in the **production planning department**. The production planning department of SPEED has the tasks and objectives as defined and described in Section 3.2. In the context of IMPROVE, the department is responsible for the Design for Manufacturing of automotive electronics based on a detailed feedback analysis from the assembly process and after sales organizations. The related development and engineering departments are involved and integrated according to the development and planning system illustrated in Figure 4.12. The automotive manufacturer SPEED has the objective of reaching significant improvements in the assembly process with related assembly process and product changes, and of putting emphasis on customer orientation by integrating customer feedback in the improve process.

5.2 Business Case I: Brake Control System

The objective of business case I is to verify the theoretical concept of IMPROVE with the electronic system **Brake Control System (BCS)**. The business case steps correspond to the IMPROVE methodology steps defined and described in Section 4.3. The business environment of SPEED is used with focus on the type series Flash-1 and the next Flash-1 generation. The metric used in the example is cost denoted in Euros. The data is fictious and not real, and no similarities to any customer or manufacturer is intended.

5.2.1 Feedback from market and customer

The automotive manufacturer SPEED firstly performs a **data analysis** from its internal after sales organization in order to get a quality feedback of the electronic systems. The result of this data analysis is a list of all ECUs of Flash-1 with related warranty cost over a time period of one year. The list contains firstly the Hydraulic Unit with 1, 267, 000 Euros warranty cost, the ECU Brake Control System (BCS) with 655, 464 Euros, the ECU battery with 643, 706 Euros, the CD Navigation with 640, 786 Euros, the Navigation ECU with 595, 546 Euros, and the ECU Audiogateway 570, 023 Euros. The other ECUs showed minor warranty cost values and are therefore not considered here.

The feedback from the market is gained from the J.D. Power IQS and comprises of a list of problems per 100 vehicles. The results show the criteria *Vehicle pulls* with the rate of 4.5 problems per 100 vehicles; *Antilock Brake System (ABS) light indicated a problem* (1.4), *Traction Control System Problem* (1.2), *Shifts roughly* (0.8), and *CD changer does not work properly* (0.4). The other criteria showed the value 0 and can therefore be disregarded. The entire list of possible IQS criteria is shown in Appendix C.

After analyzing these two quality sensors, a **risk priority list** is generated by comparing the rankings of both lists. In places 1 and 2 from after sales organizations and in places 2 and 3 from the IQS are electronic components which belong to the BCS. Therefore the decision is made to begin the *Risk-Cause Analysis Phase* for the BCS. The other systems are considered in separate projects. After this *Symptom Feedback Phase* it can be determined that this is only initial feedback without a detailed data and technology analysis.

5.2.2 Risk-Cause analysis of BCS components

This part starts with a short introduction of the BCS, an active safety system for the improvement of vehicle stability in all driving conditions. It works by individual brake interference on one or more wheels on the front or rear axle. The BCS stabilizes the vehicle when driving around curves, when braking or when rolling without drive and keeps it safe in the trace. The BCS is a control system in the brake system and in the power transmission which also prevents sideways break-out. It supports the driver also in cross-dynamic critical situations and provides extended driving stability [BrBP-04]. BCS is a mechatronic system and supplements the well-known functions of the antilock brake system (ABS), the drive slip regulation, and the engine dragging moment regulation. The stability regulation is superordinated with its function in comparison to the monitoring systems ABS and drive slip regulation. Apart from the active brake interference of BCS, an engine transmission management influence also occurs [LiMS-04]. A detailed description of the BCS functionality can be found in Appendix D.

As described in Section 4.3.2, firstly the relevant components of the focused electronic system have to be identified and listed. If the electronic components are not part of a CAN, the components are conventionally cabled components and subsystems. The type series Flash-1 has an Brake Control System (BCS) which components are listed in Table 5.1. In this table the category of the component and the CAN affiliation is listed as well

Category	i	C_{in}	CAN	Description	Assembly Step
ECU	i=1	C_{11}	C	Brake Control System	Interior
ECU	i=1	C_{12}	C	Transmission	Marriage
ECU	i=1	C_{13}	C	Engine Electronics	Marriage
ECU	i=1	C_{14}	B+C	Electronic ignition lock	Interior
ECU	i=1	C_{15}	C	Steering Column Jacket Module	Interior
ECU	i=1	C_{16}	B	Control rear	Interior
ECU	i=1	C_{17}	B	Upper Control Panel	Interior
Sensor	i=2	C_{21}		Rotational-speed sensor (rear/front each left/right)	Marriage
Sensor	i=2	C_{22}		Micromechanical torsion rate sensor	Interior
Sensor	i=2	C_{23}		Steering angle sensor	Interior
Sensor	i=2	C_{24}		Brake Booster	Marriage
Actuator	i=3	C_{31}		Hydraulic Unit	Interior
Other parts	i=4	C_{41}	B+C	Instrument Cluster	Interior
Other parts	i=4	C_{42}		Switch BCS OFF	Interior

Table 5.1: Automotive BCS components

the related assembly step. The different assembly steps are explained in Section 3.1.5. The **BCS system is shown in the block diagram** in Figure 5.1 [Baue-03], containing all BCS relevant components as well as the interface to CAN B and CAN C.

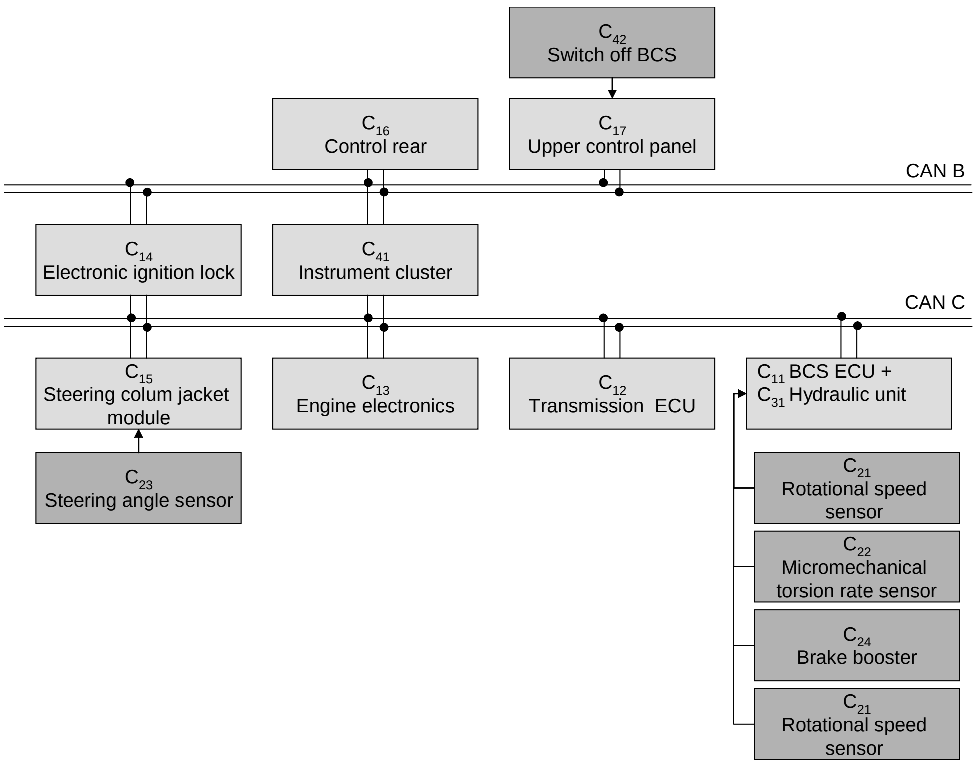


Figure 5.1: The automotive BCS system

After knowing the components and the structure of the BCS system, the next step is to analyze the different risk sensors.

The **delivery state risk** is denoted in the ppm rate and was defined as component's 0 km defect rate. The car manufacturer analyzed a ppm rate of the BCS related components as shown in Table 5.2 which is a sample of existing feedback.

C_{in}	**Description**	ppm rate	in %
C_{11}	Brake Control System	306	17.9
C_{12}	Transmission	138	8.0
C_{13}	Engine Electronics	227	13.3
C_{14}	Electronic ignition lock	138	8.0
C_{15}	Steering Column Jacket Module	183	10.7
C_{16}	Control rear	227	13.3
C_{17}	Upper Control Panel	49	2.9
C_{22}	Micromechanical torsion rate sensor	20	1.2
C_{23}	Steering angle sensor	10	0.6
C_{31}	Hydraulic Unit	200	11.7
C_{41}	Instrument Cluster	12	0.7
C_{42}	Switch BCS OFF	200	11.7

Table 5.2: PPM rate of BCS components

In the right column the ppm rate percentage of the component C_{in} related to all ppm values of the BCS is denoted, which is the risk value $x1_{in}$, compare with Section 4.3.

The first step of the **assembly risk analysis** contains the data feedback from the added value test. The first risk is the feedback message *ECU is not completely tested* or *test is stopped by the worker* which is in the example 67% of all defect test messages of the component C_{11}. Other messages are *interface defect with CAN*, *defect with sensor/actuator*, and *other defects*.

The second input of the assembly risk analysis is the **production feedback system** of SPEED in which the data is entered directly on the assembly line by the assembly workers. The data format is the percentage related to all BCS components in this input step. It is analyzed that in 56.7% of all defects the cause of defect is unknown as on the assembly line the time and knowledge for a detailed analysis is not given. In 3.46% of all defects the ECU BCS was wrong or not connected, or a pin of the connector was damaged. One major result is therefore that a not connected connector or a damaged connector or pin was the most frequent cause of defect. The micromechanical torsion rate sensor has a defect rate of 2.29%, the rotational speed sensor rear right and left 2.3%, the rotational speed sensor front right and left 0.43%, the Control rear 4.2%, and the hydraulic unit 2.1%. Other defects amount to 28.52% of the considered component.

This shows that for the BCS system the major cause of defect on the assembly line is related to the connecting process. Due to this fact, the SPEED management is discussing the alternative to install quality or risk officers directly on the assembly line for inserting and analyzing the defects directly which would improve the technical descriptions and may provide first solutions for defect prevention. Additionally in this analysis step, the **assembly time** Te_{in} and the **rework time** Tr_{in} of all considered BCS components is gathered from the assembly planning system.

In the next step a **field analysis** of model Flash-1 is performed in order to identify the risks which occur in usage and in service stations. In this input from after sales organizations the defects in percentage of all BCS components are gathered in order to identify the risks in the field. The after sales organization analyzed in 27.9% of BCS components a defect with the steering angle sensor, in 21.5% with the BCS ECU, in 21.2% brake light switch, and in 7.4% a defect with the brake booster. Additionally, the defect rate of the micromechanical torsion rate sensor is 6.5%, of the hydraulic unit 6.4%, of the rotational speed sensor 2.7%, and other defects amount to 6.4%. After this analysis the first part of the *Risk-Cause Analysis Phase* is completed and the second part follows with a detailed Design for Manufacturing risk-cause analysis of the assembly process and product.

5.2.3 Design for Manufacturing risk-cause analysis

As a next step, the production planning department of SPEED uses the new methodology IMPROVE to analyze the **assembly process** and the vehicle Flash-1. As described in Section 4.3.3, the objective is to analyze risks and potentials for improvements both directly on the assembly line and related to the product. It is decided to analyze firstly all electronic components C_{in}, which are assembled on the trim line where the interior assembly is completed. Assembled components on the trim line are mostly free and accessible which makes the detailed analysis easier. The under-carriage assembly is a different process line and is separately analyzed. Considering the BCS for the interior assembly the components C_{11}, C_{14}, C_{15}, C_{16}, C_{17}, C_{22}, C_{23}, C_{31}, C_{41}, and C_{42} are installed on the trim line and are therefore relevant for the next steps. The objective is now to assign each variable A_k with a Value of Defect Susceptibility VDS_k^a ($\forall\ k = 1, ..., K$) for all relevant components in order to quantify risks on the assembly line.

The **results of this analysis** can be seen in Table 5.3. After accumulating all variables A_k ($\forall\ k = 1, .., 8$), it can be seen that the Control rear C_{16}, the BCS ECU C_{11}, and the micro mechanical torsion rate sensor C_{22} are the most critical components in the assembly process. Considering the variables A_k it can be seen that the variable A_4 *Connecting process* and A_5 *Cable length and space* are the most critical assembly process variables.

According to the methodology steps of IMPROVE described in Section 4.3.3, the following

A_k	Variable	C_{11}	C_{14}	C_{15}	C_{16}	C_{17}	C_{22}	C_{23}	C_{31}	C_{41}	C_{42}	Σ
A_1	Posture	2	3	1	3	2	6	2	2	3	2	26
A_2	Light condition	3	2	2	7	1	5	1	1	2	2	26
A_3	Accessibility	6	1	1	5	1	4	3	2	1	1	25
A_4	Connecting Process	6	3	3	3	4	8	4	5	4	4	44
A_5	Cable length and space	8	4	2	6	2	5	6	1	3	2	39
A_6	Tool choice	2	3	1	6	6	2	3	2	2	6	33
A_7	Assembly sequence	4	2	0	2	0	2	1	3	1	0	15
A_8	Part supply	3	1	3	4	4	1	2	1	4	4	27
Σ		34	19	13	36	20	33	22	17	20	21	235
D_m	Variable	C_{11}	C_{14}	C_{15}	C_{16}	C_{17}	C_{22}	C_{23}	C_{31}	C_{41}	C_{42}	Σ
D_1	Location in vehicle	3	1	1	3	3	3	4	2	1	2	23
D_2	Color	1	4	4	6	2	2	3	3	3	1	29
D_3	Coding	4	3	3	8	4	4	2	2	3	2	35
D_4	Rough edges	7	1	3	3	1	3	5	4	4	2	33
D_5	Joining process	8	2	1	5	3	2	4	1	3	3	32
D_6	Material choice	2	4	2	2	2	4	3	3	2	2	26
D_7	Labeling	0	2	4	3	4	2	2	2	5	1	25
D_8	Fixing process	4	1	2	5	3	4	4	3	3	4	33
Σ		29	18	20	35	22	24	27	20	24	17	236

Table 5.3: Value of Defect Susceptibility of A_k and D_m

step is to quantify the VDS_m^d of the product Flash-1 which can be also seen in Table 5.3. The result is that the components C_{16} and C_{11} are again the most critical ones. The most critical product Design for Manufacturing variables are D_3 *Coding*, D_4 *Rough edges*, and D_8 *Fixing process*. At that point of IMPROVE it is already obvious that the connecting and fixing process of the components C_{16} and C_{11} imply high potential for improvement.

5.2.4 Change request

After the *Risk-Cause-Analysis Phase* the objective of the following *Change Request Phase* is to **summarize the analysis risk values**, **identify the scope for improvements**, and **search for solutions cases** with the CBR-cycle in order to reduce the technical risks of the automotive manufacturer.

Therefore, the analysis risk values are summarized in Table 5.4. For each component the sum of all technical risk types x_r is generated which results in the analysis risk value $RV = \sum_{r=1}^{6} x_r$. After this the categorization of the identified lead technical risks is done in accordance with Figure 4.7. The risk threshold Φ in order to implement and invest in a solution is assumed to be $\Phi = 100$, derived from previous iterations. In Table 5.5 are shown the allocation of components to the defined risk interval. High risk values are related to this choosen example. For all components with a RV over $\Phi = 100$, even though solution cases are not beneficial, the company has to invest in assembly process

Step	Risk category	C_{11}	C_{14}	C_{15}	C_{16}	C_{17}	C_{22}	C_{23}	C_{31}	C_{41}	C_{42}
2	Delivery State Risk	17.9	8.0	10.7	13.3	2.9	1.2	0.6	11.7	0.7	11.7
2	Added-Value Test	67	43	33	63	53	3	24	3	0	0
2	Production Feedback System	3.46	0	0	4.2	0	2.29	0	2.1	0	0
2	Field Risk	21.5	0	0	0	0	6.5	27.9	6.4	0	0
3	Assembly Process Analysis	34	19	13	36	20	33	22	17	20	21
3	Product Analysis	29	18	20	35	22	24	27	20	24	17
	Risk Value Σ xr_{in}	173	88	77	152	98	70	102	60	45	50
	Priority List	1	5	6	2	4	7	3	8	10	9

Table 5.4: Analysis results of Risk Values (RV)

Insiginifcant Risk [0,...,50]	Low Risk [50,...,100]	Risk Treshold Φ 100	Revelant [100,...,150]	Extremely Relevant [150,...,200]	Thread of existence [200,...,250]
C_{41}	C_{42}		C_{23}	C_{16}	-
	C_{31}			C_{11}	
	C_{22}				
	C_{15}				
	C_{14}				
	C_{17}				

Table 5.5: Allocation of components to risk interval

and product improvements. The company has not identified yet any follow risks such as liability or image risks, which could be derived from the technical lead risks.

The next step of IMPROVE is the **CBR-solution search**, in order to use existing knowledge for the potential improvements. The production planning department performs a search for components C_{11} BCS ECU and C_{16} Control ECU rear which have an extremely relevant technical risk.

The BCS ECU case

In order to provide a solution for the component C_{11} **BCS ECU**, which has an extremely high risk, the basic information of the new case λ_{new1} is summarized first of all. The component is C_{11} BCS ECU, the type series is Flash-1, and the analysis risk values are $RV = (17.9; 67.0; 3.46; 21.5; 34.0; 29.0)$. The values of the variables A_4 *Connecting process*, A_5 *Cable length and space*, D_4 *Rough edges* and D_5 *Joining process* are the highest. Therefore, a first solution idea is to change the connector of the ECU BCS to improve the connecting process and to reduce the Value of Defect Susceptibility $VDSd$. The **saving potentials** of component C_{11} amount to

- saved rework time $Tr_{11} = 2.0$ min

- saved assembly time $Te_{11} = 1.0$ min
- saved warranty and goodwill cost to $W_{11_t} = 2.0$ Euros.

After transformation and summarizing, this results in a savings potential of 5.0 Euro per vehicle.

The automotive manufacturer SPEED has a knowledge database the so called **"General knowledge"**, filled with solution cases. In this database it is possible to search for similar cases using the CBR technology in order to provide new solutions *(RETRIEVE Phase)*. In this application, a similarity value of the new case λ_{new1} to another solution case λ' in the database can be calculated by subtracting the values of all related single attributes $\alpha_1, \alpha_2, ..., \alpha_\kappa$ of λ_{new} and λ'. The single attributes α_κ correspond in this case to the analysis risk values RV. The weighting factors are set to $(\tau_1; ....; \tau_6) = (0.3; 0.6; 0.2; 0.8; 0.5; 0.5)$. The case λ_{new1} has the greatest similarity σ to another solution case λ' if the sum of all subtractions' absolute values multiplied with a weighting factor τ_κ is minimal. The similarity σ between λ and λ' can be expressed in the following mathematical equation:

$$\sigma(\lambda_{new1}, \lambda') = \frac{\sum_{\kappa=1}^{6} \tau_\kappa |\alpha_1 - \alpha'_\kappa|}{\sum_{\kappa=1}^{6} \tau_\kappa} \tag{5.1}$$

The greatest similarity Ω between λ_{new1} and λ' is reached if σ_n is minimal, which is mathematically expressed as follows:

$$\Omega = MIN(\sigma_1, \sigma_2, ...) \tag{5.2}$$

The first query in the database shows a list of existing solution cases λ' categorized into component C_{in}, λ Case ID, the similarity σ, type series, and the decision matrix position, as shown in Table 5.6.

C_{in}	λ Case ID	Similarity σ	Type Series	Decision Matrix
C_{11}	λ_{101042}	$\sigma_1 = 7.6$	SUNSHINE	STARS
C_{11}	λ_{102033}	$\sigma_2 = 17.4$	FLASH-1	CASH COWS
C_{11}	λ_{100234}	$\sigma_3 = 18.3$	SUNSHINE	CASH COWS
C_{11}	λ_{101045}	$\sigma_4 = 20.4$	FLASH-1	QUESTION MARKS
C_{11}	λ_{111036}	$\sigma_5 = 24.5$	SUNSHINE	DOGS
C_{11}	λ_{121347}	$\sigma_6 = 30.6$	FLASH-1	DOGS
C_{11}	λ_{101044}	$\sigma_7 = 35.7$	SUNSHINE	STARS
C_{11}	λ_{103542}	$\sigma_8 = 40.5$	FLASH-1	CASH COWS

Table 5.6: Results of BCS query in case database

The decision maker in the production planning department has to decide if the retrieved case is used or a new case has to be created. Therefore, a similarity threshold $\Psi = 10$

is defined based on experiences from previous iterations. Considering the results of the query, case λ_{101042} has a similarity value $\sigma_1 = 7.6$ and is beneficial due to the STARS position in the decision matrix. The **provided solution** can be seen in Figure 5.2.

Case-ID λ	101042			**Component**	C_{11}	
Type Series	Sunshine			Brake Control System		
Risk Values	13.3	63.0	4.2	20.0	30.0	28.0
Solution	The connector of the BCS ECU is changed to a form-looking connector which prevents the damaging of PINs and which can be easier assembled and disassembled. Additionally, the connector has no rough edges in order to reduce damages.					
Savings	**P_1 – Rework time Tr_{in}**		2.0 €/v			
	P_2 – Assembly time Te_{in}		1.0 €/v			
	P_3 – Warranty Cost W		3.0 €/v			
		Σ =	6.0 €/v	**Investment I_{in}**	3.0 €/v	
		P_{Total}	3.0 €/v	**Decision-Matrix**	STARS	

Figure 5.2: Solution case λ_{101042}

As the similarity σ_1 is less then the similarity threshold Ψ ($7.6 < 10$), the solution case λ_{101042} is set in the solution case quote, compare with Figure 4.11. As the risk value ($RV = 173$) is greater then the risk threshold $\Phi = 100$, the company has to invest in any case in order to prevent or reduce follow risks. The follow risks could be very critical in this case, as the BCS is a safety-critical system. The company gains additional benefits as solution case λ_{101042} has the *Stars* position in the decision matrix. It is decided to reuse this solution and to integrate it in the development and planning process of the new generation of type series Flash-1.

The Control ECU rear case

Another extremely relevant risk is identified for component C_{16} **Control ECU rear**, as can be seen in the priority list of Table 5.4. At first, the basic information for the new case λ_{new2} is gathered. The component is C_{16} Control ECU rear, the type series is Flash-1, and the Risk Values are $RV = (13.3; 63.0; 4.2; 0.0; 36.0; 35.0)$. As the variables A_2 *Light* *condition*, A_5 *Cable length and space*, D_2 *Color*, and D_3 *Coding* have the highest values it is analyzed that the coding of connectors for the Control ECU rear is a possible solution to reduce the Value of Defect Susceptibility $VDSd$. The query for this problem leads to the following results in Table 5.7. The solution case λ_{134042} has the best similarity value

C_{in}	λ Case ID	Similarity σ	Type Series	Decision Matrix
C_{11}	λ_{134042}	$\sigma_1 = 20.6$	FLASH-1	DOGS
C_{11}	λ_{142033}	$\sigma_2 = 30.4$	FLASH-1	CASH COWS
C_{11}	λ_{156234}	$\sigma_3 = 31.3$	SUNSHINE	CASH COWS
C_{11}	λ_{145045}	$\sigma_4 = 32.4$	SUNSHINE	QUESTION MARKS
C_{11}	λ_{157036}	$\sigma_5 = 36.5$	SUNSHINE	DOGS
C_{11}	λ_{134347}	$\sigma_6 = 40.6$	FLASH-1	DOGS
C_{11}	λ_{101564}	$\sigma_7 = 41.7$	FLASH-1	DOGS
C_{11}	λ_{143542}	$\sigma_8 = 50.5$	FLASH-1	CASH COWS

Table 5.7: Results of Control ECU rear query in case database

$\sigma_1 = 20.6$, which is however greater than the similarity threshold Ψ ($\sigma_1 = 20.6 > 10$). This means there is no appropriate solution for the new problem λ_{new2} in the *RETRIEVE Phase* out of the database. As the risk value $RV = 152$ is greater than the threshold $\Phi = 100$ the company has to invest in a new solution in any case in order to prevent or reduce follow risks. From that it follows that a new solution case has to be created, shown in Figure 5.3, which solves the case λ_{new2} complemented with a benefit estimation. The solution is tested in the *REVISE phase* by updating the entire case information, and is saved in the database in the *RETAIN Phase*.

5.2.5 Implementation of solution cases

The **first decision making process is completed** and the cases λ_{101042} and λ_{134043} are then implemented with the new generation of Flash-1. The solution cases are implemented between quality gate J and I for the next type series generation or the model upgrading. This is performed by integrating the solutions in the related development and production planning groups. After this components with relevant, low, and insignificant risks are considered. The case information, in particular the analysis risk values as well as savings and investments, is evaluated and updated in this next iteration.

Case-ID λ	101043			**Component**	C_{16}	
Type Series	FLASH-1			Control ECU rear		
Risk Values	-	-	-	-	-	-
Solution	The connectors to the Control ECU rear have to be color coded and in best case consolidated to less connectors. The cable ways and cable length to the Control ECU rear should be exactly defined and marked at the wiring harness and the chassis.					
Savings	**P_1 – Rework time Tr_{in}**	1.5 €/v				
	P_2 – Assembly time Te_{in}	1.0 €/v				
	P_3 – Warranty Cost W	3.0 €/v				
	Σ =	5.5 €/v		**Investment I_{in}**	2.5 €/v	
	P_{Total}	3.0 €/v		**Decision-Matrix**	STARS	

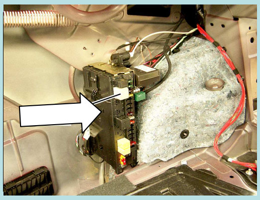


Figure 5.3: Solution case λ_{134043}

5.3 Business Case II: Software Prototype

5.3.1 Introduction

Situation and challenges

The automotive manufacturer SPEED identified the **necessity to implement an integrated feedback mechanism** and defect-stoppage process for its vehicle types. The integration of a direct customer feedback is a shortcoming of business case I. Therefore, business case II is extended now by integrating the "Voice of Customer" directly in the feedback process and by handling the entire data, information, and knowledge in one software system. Currently no effective data and risk-cause analysis exists in order to create appropriate solutions to realize improvements across departments.

Therefore, this business case aims to bridge between symptoms, causes, and related solutions. This information should be provided and made available to all participants. The company faces the challenge of integrating an effective and sustainable life cycle management in order to learn in between vehicle generations and type series and to integrate the feedback information efficiently in existing business processes. It is aimed at preventing redundancies by inventing an intelligent knowledge management system in order to handle the amount of data. These challenges are met by developing and programming the software prototype in this business case.

Objective and approach

The objective of this business case is to **develop a software prototype** for verifying and realizing the theoretical concept of IMPROVE in a specific business environment. The aim is to demonstrate the efficient usage and integration of feedback data both from after sales organizations and the assembly line, and to generate appropriate solutions. As a variety of data sources, systems, and information already exists, the prototype uses the CBR technology to meet the challenges and to provide knowledge to involved departments.

Following the new methodology concept, the **first step in the prototype** is to gather symptoms from the customer. This occurs with the dialog reception which is operated in service stations of the automotive manufacturer SPEED. In the dialog reception the vehicle is analyzed together with the customer for symptoms noticed by the customer. If necessary, the customer and the service staff therefore use test drives or lifting platforms together. The resulting information is inserted as **Input 1** into the software system, which is shown in Figure 5.4. The service station staff inserts in **Input 2** the field risk which is for example the defect rate, changed components, and diagnosis failures. Additionally, the service station staff can enter possible causes, related components, and detailed problem description into the system. **Input 3** comes directly from the assembly line and contains the defect rate, possible causes, and problem descriptions. The entire information is entered into one system and each new problem is entered as a different case.

All cases are stored in the case database "Central knowledge". This is an essential benefit for the automotive manufacturer SPEED as knowledge and information is collected and provided to all users in real-time. The sequence and logic of how to insert data and to make queries is determined by the domain model, is discussed in the next section. The responsible production planning department identifies then the **change of request** using the CBR technology and performs the implementation, following the theoretical concept of IMPROVE. For the benefit calculation the cost metric denoted in Euros is used.

5.3.2 Domain-model structure and technology

At the beginning, the domain model structure is defined and the CBR technology adjusted to this business case is described, which was introduced in Section 3.5.3. CBR is a methodology which has its origin in analogical reasoning. The main intention is to reuse

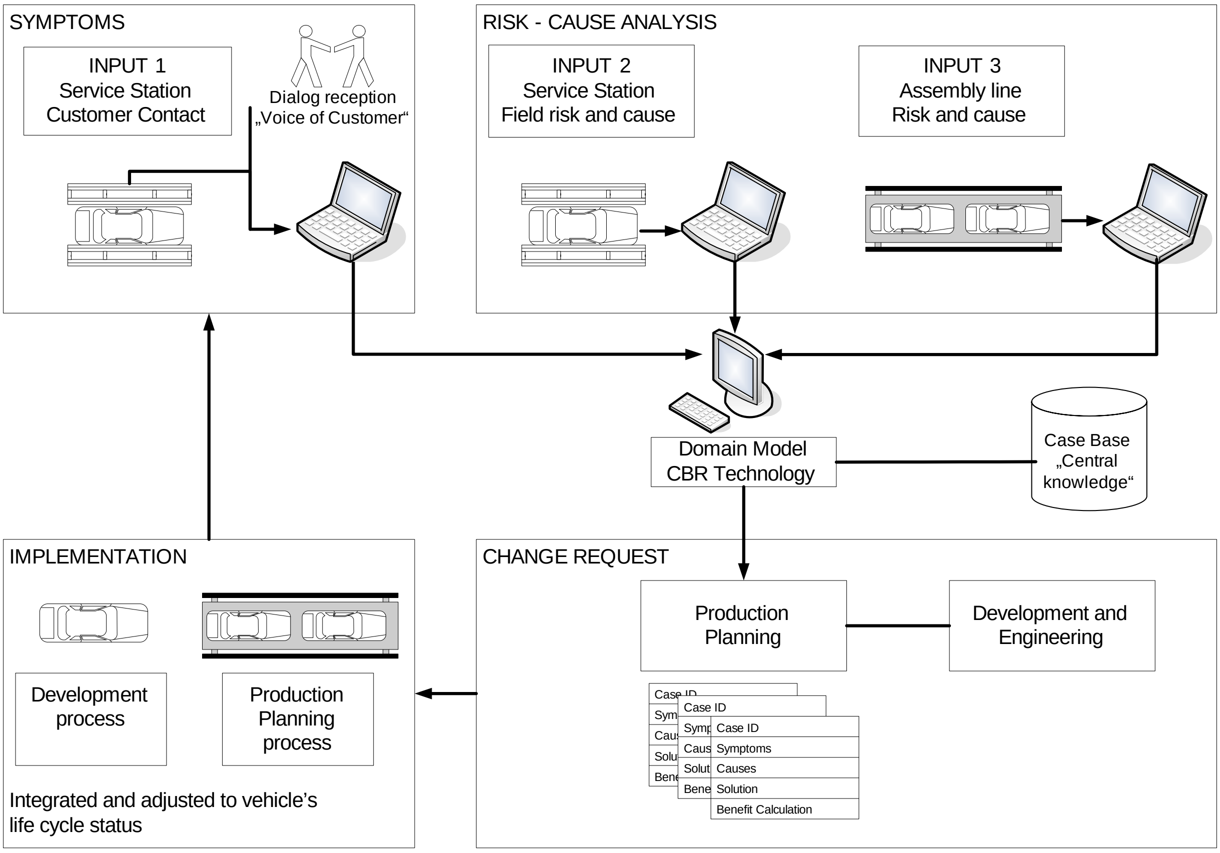


Figure 5.4: Overview of application scenario

previous experiences for current problems. The difficulty arises when the current situation is not identical to a previous one. Therefore, the CBR technology allows exact or approximate reasoning in a controlled manner. Cases are described by a set of attributes. The attribute-based domain model defines a common vocabulary that is used to describe the cases. The cases are entered using standardized forms and can be imported from existing databases. In this business case, the case database "General knowledge" is characterized by both the domain model and the input of cases.

Definition 5.3.1 *An attribute is a particular feature described by a name, the cardinality Min or Max, and the reference to a type.*

A type defines the values that an attribute may have which can be a symbolic type which is a list of values, a taxonomic type which is a list of values with a hierarchy (tree), or a scalar type which can be integer or short, real or float, boolean, or string. A composite attribute is a characteristic feature that combines several related attributes.

The similarity in an **expert search** between a new problem and existing cases in the case database is calculated in two steps. Firstly, the computation of the local similarity is operated for each attribute by application of the similarity function, a chosen operator, and the setting of a “must have” criteria. The local similarity is defined as the degree of likeness between the value of an attribute in an end user query and its respective value in the case database. The must-have settings enable users to filter a part of the case database. A must-have similarity threshold Ψ is defined for each attribute and cases whose local similarity for this attribute is strictly lesser than the threshold are eliminated. After this, the global similarity is calculated for each case applying the weighting factor τ and the result is a list of cases ordered by similarity. The global similarity is the weighted average of all the local similarity scores computed for each attribute. The global similarity represents a holistic view of the cases in the casebase. With the weighting factor τ the priorization of certain attributes can be determined.

The pilot uses the identify function, which assigns a local similarity of 1 when the value of an attribute in the casebase exactly matches the value of an attribute in an end user query. If the value of an attribute in the casebase does not exactly match the value of an attribute the local similarity is equal to 0. A library of pre-defined similarity functions is available in the domain model which provides different ways to calculate the similarity. The parameters are set in accordance with characteristics of the attribute in order to influence the similarity calculation, for example by defining a smooth function for the related values. Operators are used to further customize the effects of a similarity function with for example the “=”, “≥”, or “≤” operations.

The **guided search** is based on dynamic induction. Cases are retrieved by selecting the best questions to ask to the user, in order to focus as quickly as possible onto a subset of target cases. In the guided search the most crucial attributes from the case base are searched for. The difference is made by the local similarity derived from the expert search settings. The induction can be categorized into static and dynamic induction. Static induction requires a decision tree which has been previously built. A decision tree contains nodes and leaves, it is built iteratively, and at each step the list of available questions is ordered. The first question is chosen and all the possible values are considered by creating as many branches as possible. When no conditions are defined, the building of the decision tree stops once a unique diagnosis is reached or there are no more questions or cases. Dynamic induction consists of ordering the list of attributes for each users answer dynamically. There are two variants of the dynamic induction: the user-dynamic induction, letting the user choose from the list which attribute to answer, and the system-dynamic induction, instructing users to answer the first attribute of the list. Additionally, a **keyword search** is provided where the words and expressions which best meet the query can also be defined. The different search options are shown in Figure 5.5 in the boxes on the left.

The exchange of information between users and the casebase is performed using **internet or intranet technology**. The casebase is stored on a web server and is connected with a HTTP protocol to the user who uses an internet client, for example Internet Explorer or Mozilla Firefox, to access the casebase. The end user can make queries and is able to modify existing cases and create new ones. The domain model operates multi-lingually and can be adjusted to each specific application. The internet technology enables access to all participants and to provide access to end-users quickly.

5.3.3 Definition of domain-model

The first part of the domain model contains the symptom composite attributes SY which refers to the upper left part of the methodology shown in Figure 5.4. The objective is to integrate the "Voice of Customer" directly from service stations and to gain information about the symptoms experienced by the customer. The **symptom composite attributes** are vehicle details (SY_1), general symptoms (SY_2), driving behavior (SY_3), dashboard information (SY_4), and circumstances/influences (SY_5), which are listed in the first row in the case input client[2] shown in Figure 5.5.

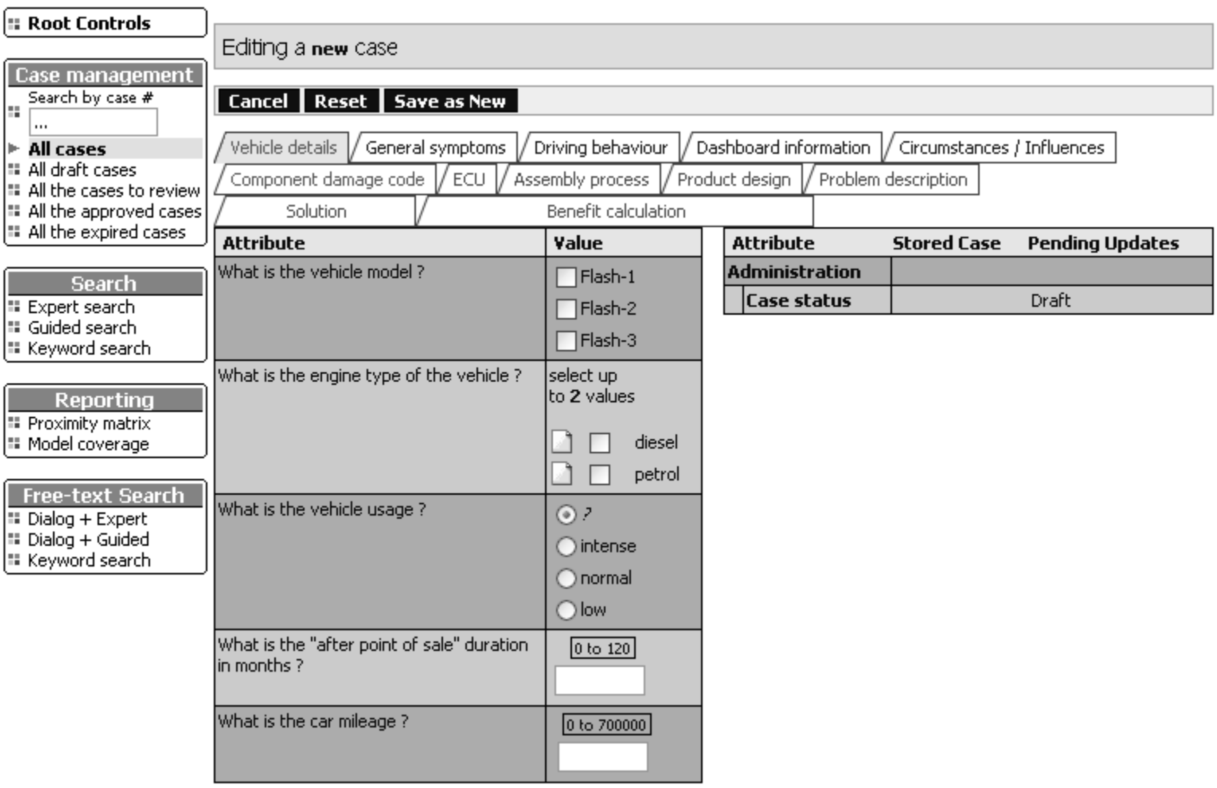


Figure 5.5: The blank case input client

[2]The client-server architecture in this business case is programmed with an official CBR tool

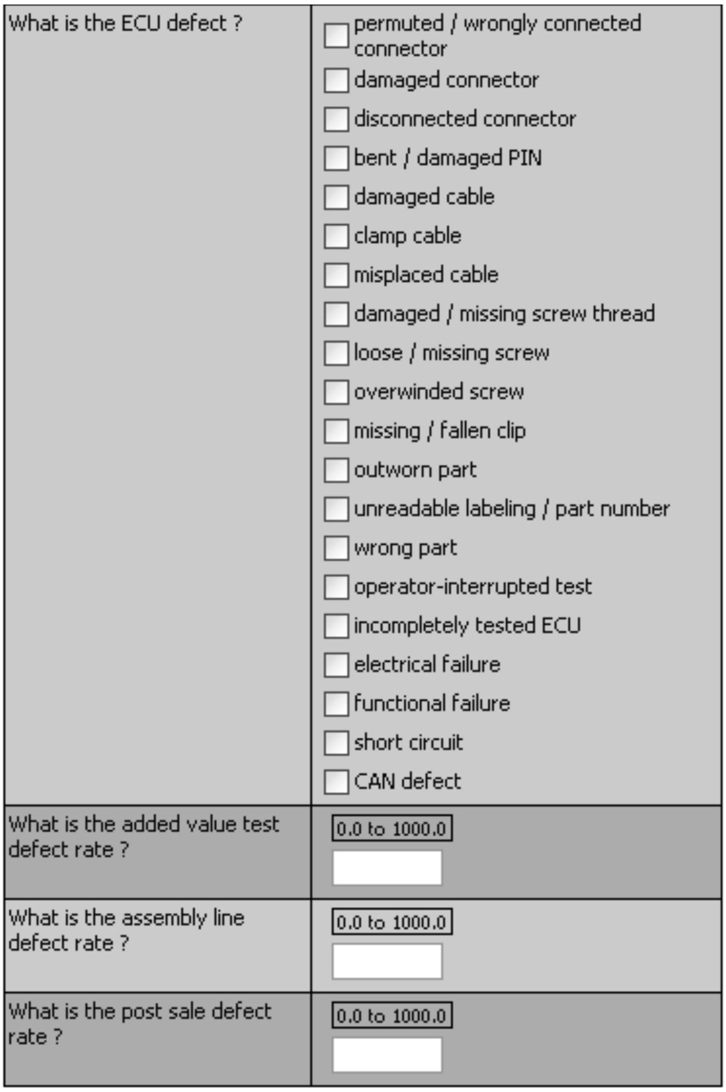
In the *vehicle details* (SY_1) the attribute model is determined with the type series values “Flash-1”, “Flash-2”, and “Flash-3”. Other attributes are the engine type and the vehicle usage as well as the usage duration after Point of Sales including the car mileage. In the composite attribute *general symptoms* SY_2, the first attribute contains the question “Does the vehicle have a fluid problem”, where the values “leak”, “consumption level”, and “air pressure” can be chosen. Additionally, the attributes noise, odour, and smoke with related values can be selected.

The composite attribute *driving behavior* (SY_3) aims at gathering customer experience about the attributes of starting the vehicle, engine performance, and if the vehicle has a holding problem and/or mobility problem. For automotive electronics in particular, the next composite attribute *dashboard information* (SY_4) is an important symptom source. In the first attribute the various fixed “indicator displays” with the values for example odometer or fuel level are listed, and the second attribute the “multifunctional display” contains the different possible displays such as service relevant information, maintenance calculator, or ABS light.

The last symptom composite attribute *circumstances/influences* (SY_5) contains the attributes “how frequently the problem occurs” with the values being “constant” or “intermittent”. Another attribute is the point of time when the problem occurs with the possible values “after fitting new parts”, “just after ignition”, “during acceleration”, and “during deceleration”. The other attributes of SY_5 are conditions of the engine temperature, the climatic conditions, and the route type at the time when the problem occurs.

The second row contains the **risk-cause composite attributes** (RC) with the objective to identify risks and causes for the gathered symptoms. This input can be done with the client directly in the service station, directly on the assembly line, or in other related departments like production planning and development. The first composite attribute *component damage code* (RC_1) has as first attribute the affected system or component groups. Therefore, all possible components of the type-series are listed in this attribute. The second attribute of RC_1 is the abnormal behavior of a component with possible values such as for example “does not function” or “improperly adjusted”. The last attribute of RC_1 is the question of if a component is damaged with the values for example “broken”, “melted”, or “unscrewed”.

The composite attribute *ECU* (RC_2) puts emphasis only on the ECUs of the affected system or component group. In the first attribute all possible ECU are listed. The second attribute contains the “ECU defect” with possible values such as “permuted” or “wrongly connected connector”, “clamp cable”, or “electrical failure”, demonstrated in Figure 5.6.



What is the ECU defect ?	permuted / wrongly connected connector damaged connector disconnected connector bent / damaged PIN damaged cable clamp cable misplaced cable damaged / missing screw thread loose / missing screw overwinded screw missing / fallen clip outworn part unreadable labeling / part number wrong part operator-interrupted test incompletely tested ECU electrical failure functional failure short circuit CAN defect
What is the added value test defect rate ?	0.0 to 1000.0
What is the assembly line defect rate ?	0.0 to 1000.0
What is the post sale defect rate ?	0.0 to 1000.0

Figure 5.6: The ECU attributes and values

Additionally, the results of the risk analysis have to inserted in RC_2, which are the added-value test defect rate, the assembly line, and after sales defect rate denoted in percent. The next composite attributes *assembly process* (RC_3) and *product design* (RC_4) correspond to the variables in step 3 of IMPROVE which are described in detail in Section 4.3.3 for RC_3 and in Section 4.3.3 for RC_4. In order to realize improvements a detailed problem description is important to be entered. Therefore, the composite attribute *problem description* (RC_5) contains firstly an attribute where a “case title” can be entered and secondly the attribute “problem description” where the detailed problem description can be entered.

After analyzing risk and causes the last input row contains the **composite attribute** *solution* (SO_1), containing a description of the solution for the described problem. For a beneficial IMPROVE process it is necessary to operate an integrated cost calculation which content of the composite attribute *benefit calculation* (SO_2). This composite attribute contains firstly the attributes estimated "rework time and cost" reduction denoted in Euros per vehicle, as can be seen in Figure 5.7.

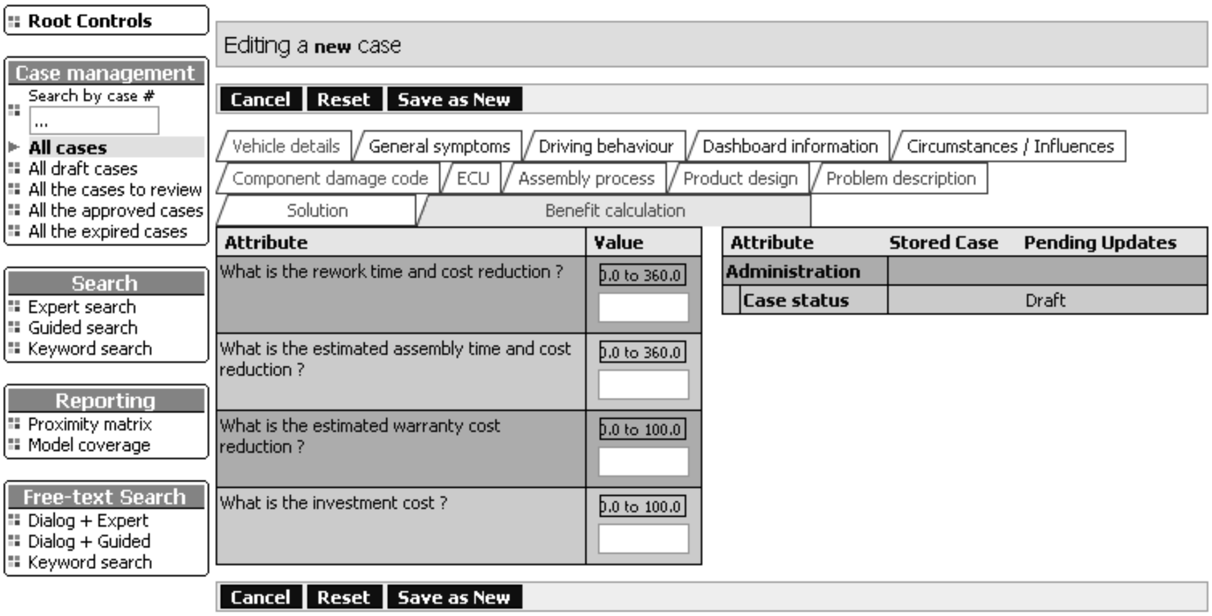


Figure 5.7: The CBR benefit calculation

Secondly, the estimated "assembly time and cost" reduction is inserted as well as the estimated "warranty cost" reduction when implementing this solution. In the next attribute the "investment cost" value is entered, also denoted in Euros per vehicle. After summarizing the savings and subtracting the investment cost, the last attribute contains the benefit of the considered solution denoted in benefit per vehicle.

5.3.4 Industrial application cases

The automotive manufacturer SPEED pursues the objective of significantly improving the electronics quality of type series Flash-1, Flash-2, and Flash-3. Therefore the methodology IMPROVE is used and the domain model with CBR technology and the case database "General knowledge" is implemented. The case database has been already filled up with a basis of useful cases. The similarity threshold Ψ is set to $\Psi = 90$ and the risk threshold Φ is set to $\Phi = 100$, derived from previous iterations.

Wiring harness case

A customer of Flash-2 operates a "dialog reception" with the service worker, as the multifunctional display indicated to go to the service station due to a defect, which can be seen in Figure 5.8.

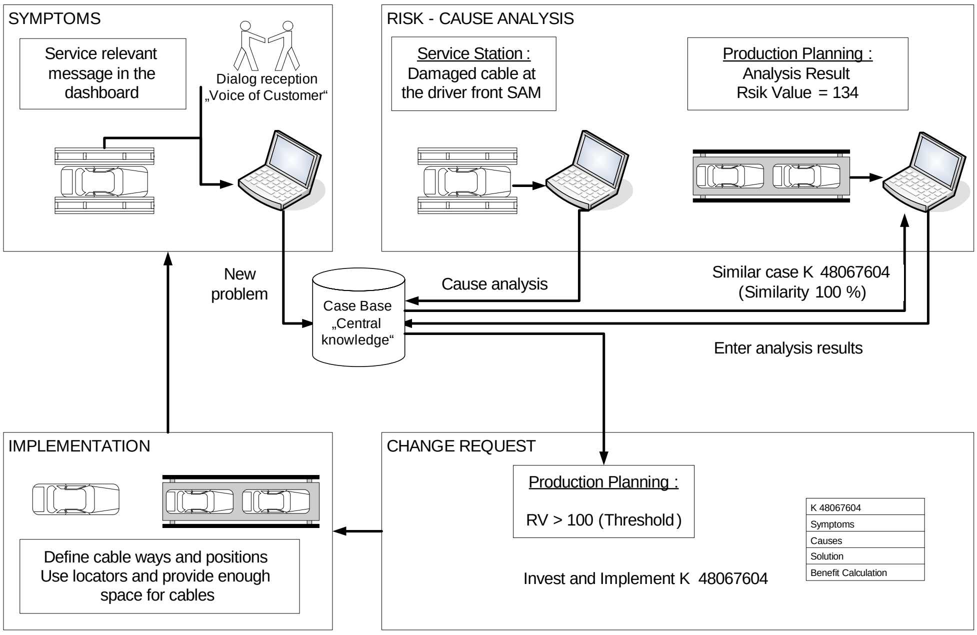


Figure 5.8: Process steps of wiring harness case

The problem has occurred constantly since the customer left the service station after fitting new parts. The service worker identified a damaged cable in the engine compartment to the driver-front Control ECU as the Control ECU was pressed in with power due to insufficient space for cables. The production planner performs an expert query in the case base and receives 3 matches of cases, which are shown in Figure 5.9. The result shows the case **K 48067604** with a **similarity** of 100%, which is over the similarity threshold of 90%. A risk-cause analysis in the assembly process has not been made as the case K 48067604 was entered in another service station. The production planning department performs the risk-cause analysis and identifies a risk value of $RV = 134$. The risk value $RV = 134$ is a relevant risk and is over the risk threshold $\Phi = 100$, as can be derived from Section 5.2.4. Therefore, the automotive manufacturer has to invest definitely in a new solution, which is in best case also beneficial. The solution is set on the improvement list for the next Flash-2 generation.

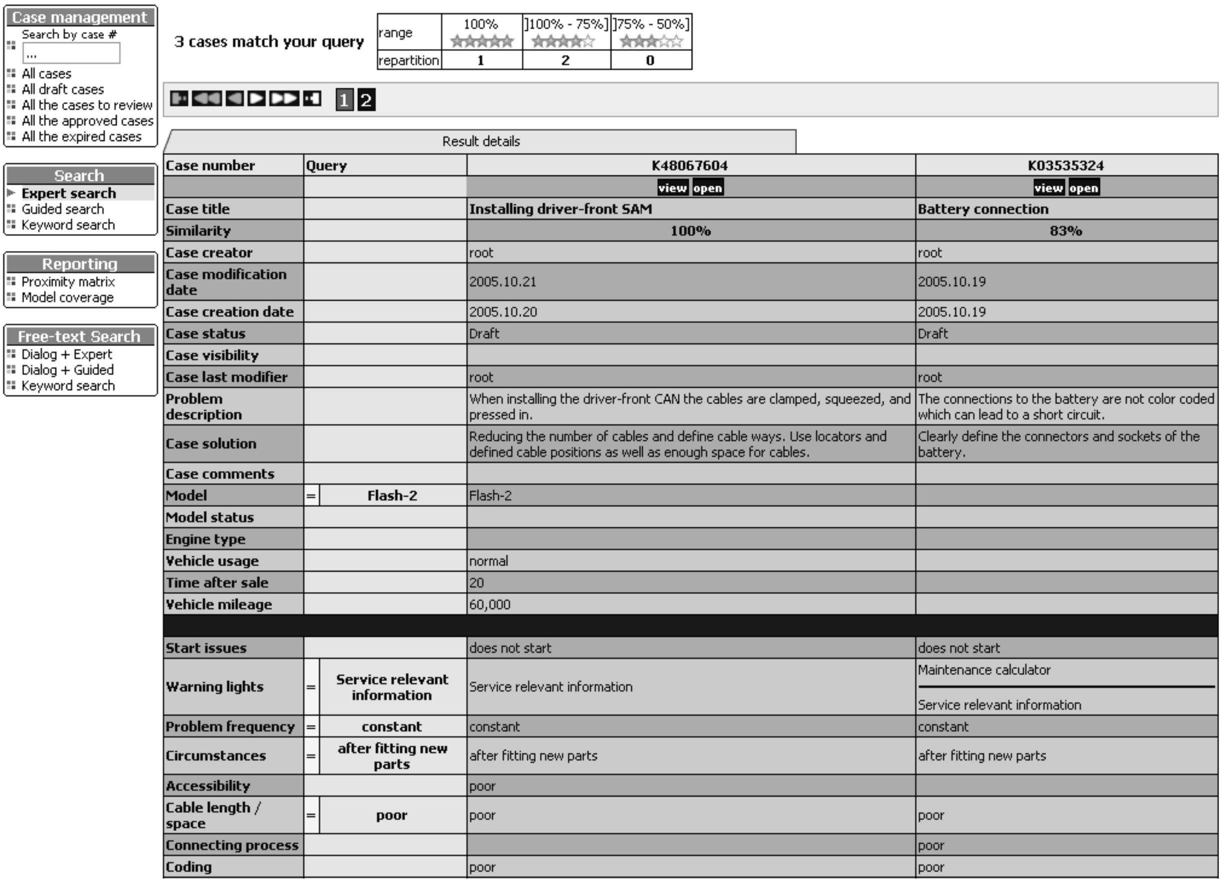


Figure 5.9: Result of the expert query - wiring harness

Control ECU rear case

In one of the company's service stations a dialog reception between a service worker and a registered customer of model Flash-2 took place. The service worker entered the following information into the system: It is the type series Flash-2 with a diesel engine and normal usage; the after POS duration is 1 month with a mileage of 500 kilometers; the driver has received in the multifunctional display the service relevant message to bring in the vehicle for inspection as a lamp is defect; the circumstances are that the message is displayed constantly just after ignition. The service worker changes the electric bulb and identifies a dissolved connector at the ECU Control rear, which can be seen in Figure 5.10. After plugging in the connector after the ignition the message disappears. The production planning department receives a message that a new case is entered in the service station. Therefore an expert query is performed to search for similar cases in the case database. The result show that no cases exist with 100% similarity, but there is a case **K 48067604** with 80% and **K 55129493** with 75% **similarity**, which is shown in Figure 5.11.

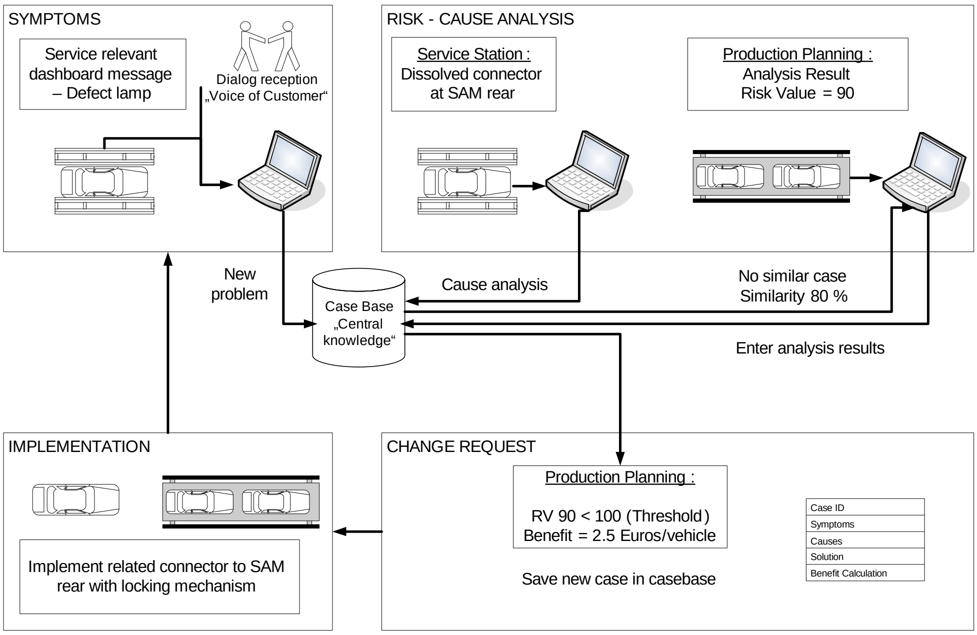


Figure 5.10: Process steps of Control ECU rear case

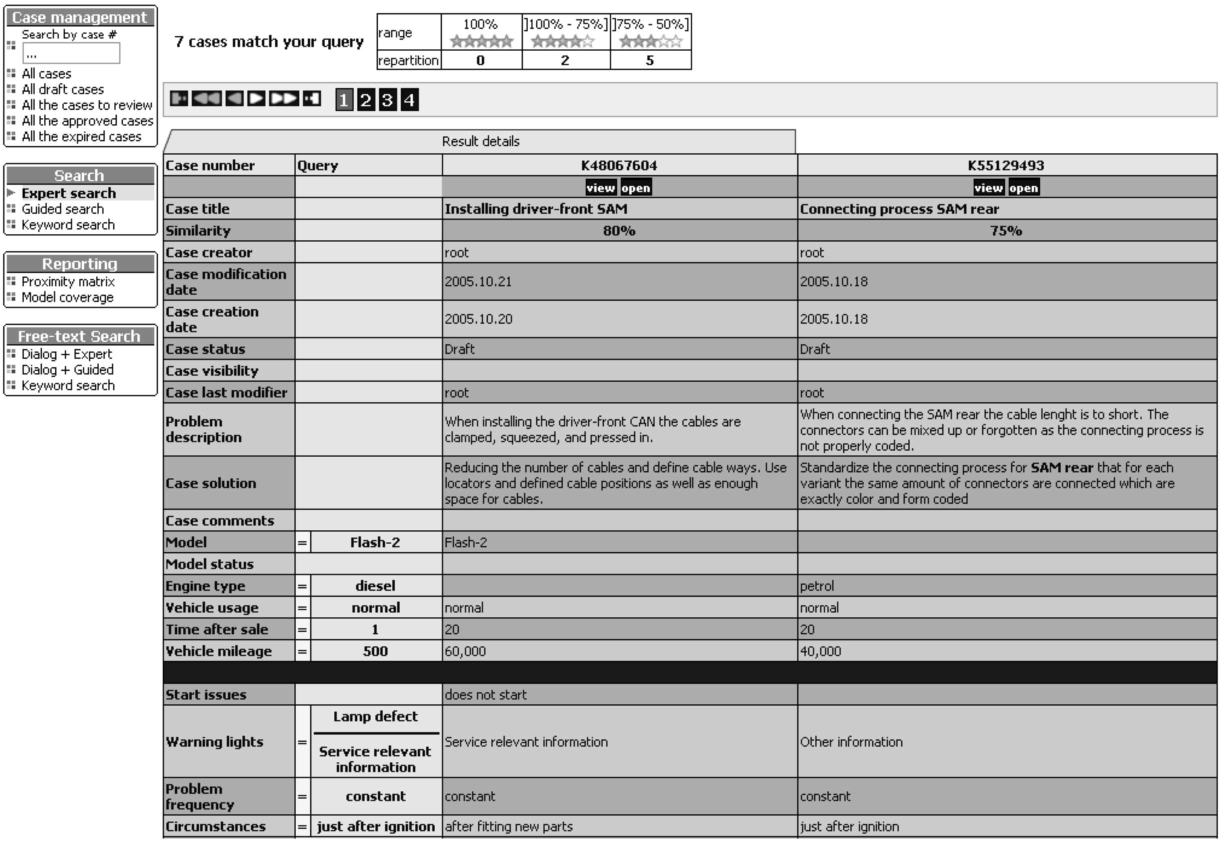


Figure 5.11: Results of the expert query - Control ECU rear

As the similarity threshold is set to $\Psi = 90\%$, there cannot be used any existing solution. The production planning department performs the risk-cause analysis and creates a new solution for the new case for the described problem. In the composite attributes RC_1 and RC_2 the information is entered related to the problem. The results of the risk analysis for type series Flash-2 show a current added-value test defect rate of 2.0%, an assembly defect rate of 1.5 %, and an after sales defect rate of 2.0%. This adds up together with the product and assembly process analysis to a **risk value of** $RV = 90$. This is a value in the low risk range $[50 \leq RV \leq 100]$ a reason to invest only in case of creating a beneficial solution.

As is identified in the assembly process analysis, the locking mechanism of the affected connector and the color coding for the Control ECU rear is not process safe. In the problem description is explained that connectors can be dissolved after a certain time of usage as the locking mechanism does not provide feedback to the worker, whether the connector is properly connected. Therefore, a new connector for improving the connecting process of the Control ECU rear is provided as a new solution. The following benefit calculation shows a rework time and cost rate of the ECU Control rear of 2.0 Euros per vehicle, of the assembly time of 1.5 Euros per vehicle, and a warranty cost reduction of 2.0 Euros per vehicle. In order to improve the locking mechanism of all Control ECU rear connectors and the connecting process an investment of 3.0 Euros per vehicle is necessary. This results in a benefit of 2.5 Euros per vehicle. The new case is saved in the case database “General knowledge”, and the solution is implemented in the new generation of Flash-2.

Production planning case

The production planner of SPEED identifies in a risk-cause analysis the increase of **not or wrong connected connectors**. The following analysis is focused on the assembly process without integrating feedback information from the market and customer. Therefore, an expert query is performed over all type series Flash-1, Flash-2, and Flash-3. In the composite attribute *circumstances/influences* (SY_5), the attribute *problem frequency* is set to “constant”. In the risk-cause analysis are marked in the *ECU defect* attribute of the composite attribute *ECU* the following values: “Permuted/wrongly connected connector” and “Disconnected connector”, as can be seen in Figure 5.12. In the composite attribute *product design* causes for the high defect rate of the connecting process are analyzed, which are the values “Coding”, “Color coding”, and “Joining process”. After performing the expert query, the cases **K53277673** with the **similarity of** 100% and **K00734742** with a **similarity of** 90% are displayed which are both over the similarity threshold, as shown in Figure 5.13. The two cases are related to the component driver-front Control ECU. The risk analysis of this component shows the result of $RV = 95$. This is less than

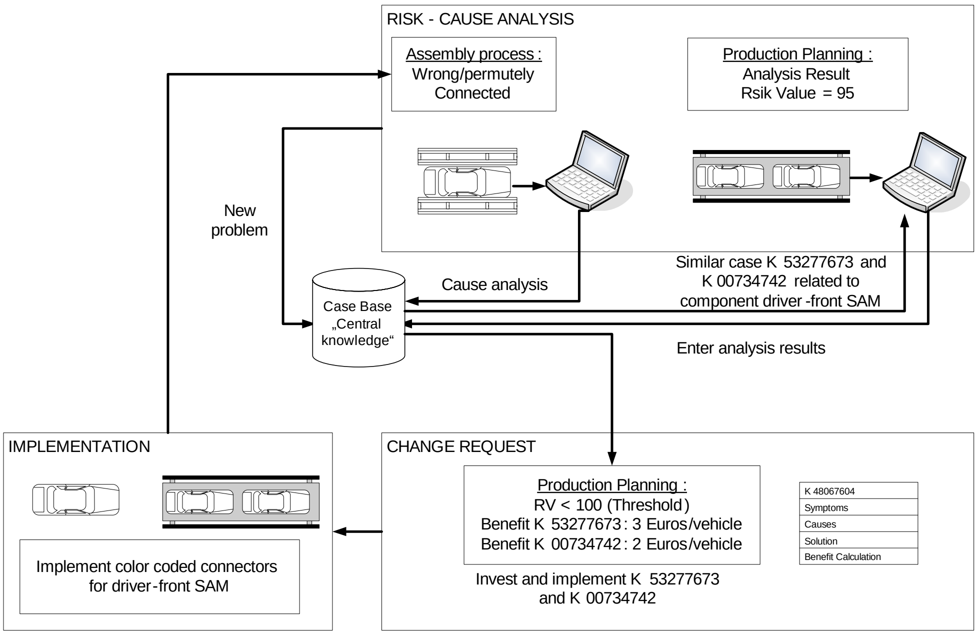


Figure 5.12: Process steps PP case

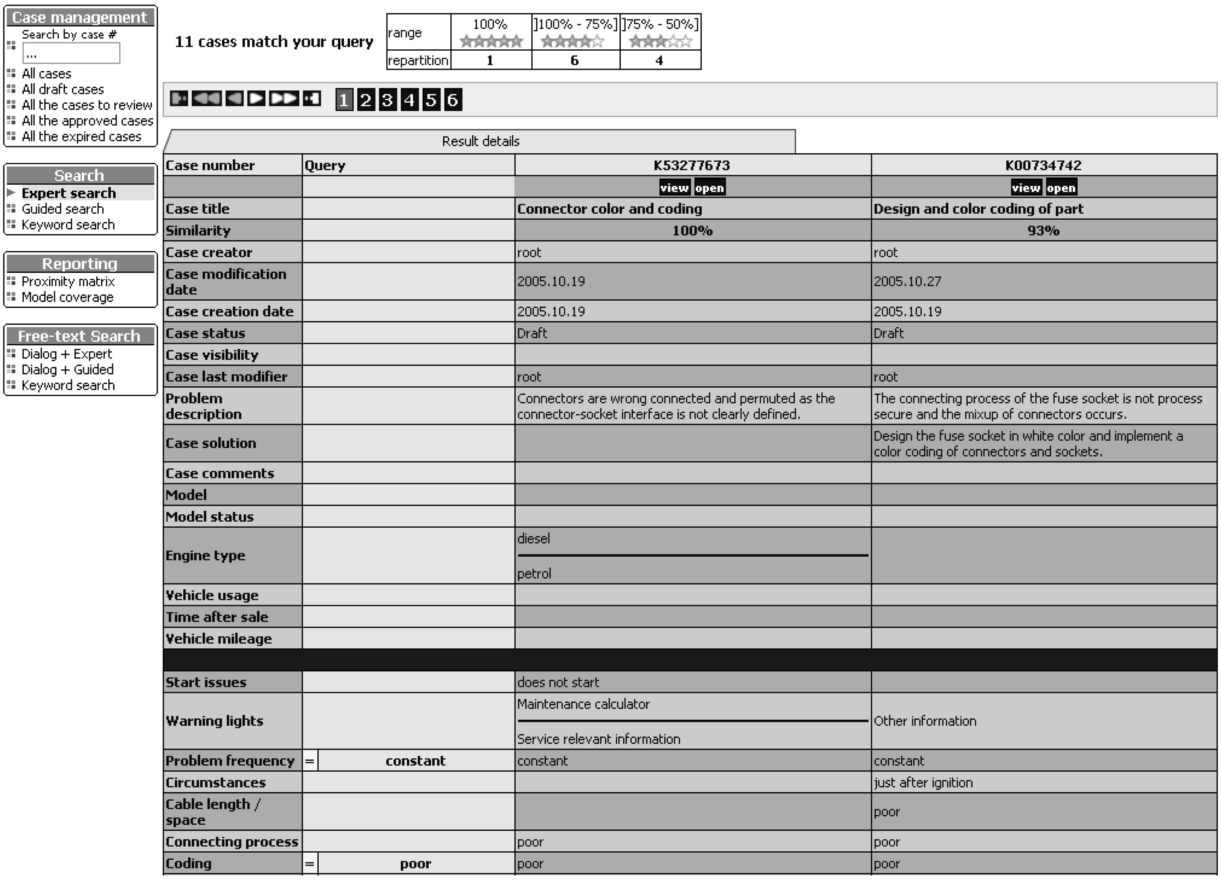


Figure 5.13: Results of the expert query - PP case

the risk threshold $\Phi = 100$ wherefore the economic efficiency is the decisive factor for implementation. The two cases included a benefit of 3 Euros per vehicle respectively 2 Euros per vehicle. The production planning team therefore decides to start integrating these two cases in its improve process.

5.4 Chapter Summary

5.4.1 Evaluation of business cases

Business case I shows with the example of the BCS the usability of the new methodology IMPROVE.

Statement 5.4.1 *It is verified that the theoretical concept can be applied in the automotive industry for electronic systems and components.*

Advantages of this business case are that with the focus on one electronic system, a risk-cause analysis as well as an assembly process and product analysis can be perfectly operated. The objective of creating an effective defect-stoppage process is shown, as direct solutions which are beneficial for the automotive manufacturer are created. The CBR technology can be applied by creating a similarity function based on the analyzed risk values.

A disadvantage of this business case is that the "Voice of Customer" is not integrated directly in order to perform the symptom analysis based on direct customer feedback. Moreover, the effective knowledge management with the CBR technology is only indicated in this business case and the solution case management, data flow and involved participants and users are not clearly defined in business case I.

Therefore, **business case II takes on the shortcomings of business case I** and defines and integrates users along the entire value added creation chain. Another advantage is that the knowledge sharing between service stations, the production planning, and development and engineering departments is verified. The real time operation of improve cases between after sales and production planning in particular is a crucial benefit as it increases customer satisfaction. The usability and feasibility is demonstrated with the software prototype and it is shown that the new methodology can be integrated into existing business processes.

The possibility of **editing and updating existing cases** as well as creating new cases is an essential benefit for the integration of different process involved departments. Another benefit is the keyword query for searching for single components, defects, or other attributes. The expert and guided search provides the possibility for detailed improvements to specific components or systems and the type series. The **traceability of changed or new cases** of the users enables the efficient tracing of changes and improvements.

Another advantage is that the information is stored and can be retrieved centrally. The prototype also contains an authorizing workflow with the definition of different users and roles. This role can be categorized with different authorities for drafting, approving, and implementing cases. A further advantage for industrial applications is the **rapid deployment** and **quick implementation** in an industrial environment.

A possible critical question is whether the information out of the case database is appropriate for the solution. Therefore, the case database is only a support tool which can not replace the engineering knowledge of a human being. In oder to realize quick benefits, the case database can be used for new vehicle generations and model upgrating at the same time.

5.4.2 Continuative questions

Considering the business cases some continuative questions occur which vary between organizations, companies, and applications. One question is how existing data sources and data bases can be attached and integrated in the prototype to have an automatic data transfer. Additionally, if applying the methodology for several type series for all systems a procedure has to be defined on how to use and handle this huge amount of information and how to save and store the data. A procedure for managing the access and update of cases between different users has to be defined. Another continuative question for the prototype is how it can be integrated into an existing PLM system and digital tools.

Chapter 6

Summary and Outlook

This chapter aims at reviewing and summarizing the work and provides an outlook for further developments. **Section 6.1 contains a summary** of the work and an evaluation of the essential results and conclusions.

Section 6.2 provides an outlook, starting with possible further developments and extensions of IMPROVE. This provides related recommendations and proposals on how the topics can be extended and on what can be built on. Possible new and innovative research areas are derived, and related academic and industrial action fields are recommended. Additionally, Section 6.2 contains the future change of basic parameters for the automotive industry, future trends of automotive electronics, future production and assembly trends, and future production planning challenges. The chapter ends with a conclusion of the research topic and the discussed new methodology.

6.1 Summary

This dissertation work introduces a new scientific methodology approach for the efficient and beneficial operation of assembly process and product changes based on a feedback data and technical risk analysis. The overview of this new methodology IMPROVE is shown in Figure 4.2 in Chapter 4. The essential results are discussed in the following:

Result 6.1.1 *A novel conceptional approach is developed to realize and drive the Design for Manufacturing of automotive electronics with the Case Bases Reasoning approach.*

With this new approach the implementation of an effective defect-stoppage process is achieved in order to realize improvement potentials for the vehicle quality due to an early influence on the vehicle creation process. This is performed by analyzing vehicle symptoms in the assembly process and after sales organizations as an input for a risk-cause analysis, which is used to generate solutions for assembly process and product improvements.

Demonstrated in the state of technology in Chapter 3 is the necessity for technical risk management for automotive electronics and the efficient and sustainable management of DFM solutions for assembly process and product changes.

Result 6.1.2 *The technical risk analysis in IMPROVE is an innovative approach to master and reduce risks of automotive electronics and to achieve a new risk understanding across the entire value creation chain. Risk is given a positive dimension as the risk prevention approach in IMPROVE provides the chance to gain additional benefits by reducing or eliminating risks.*

This new risk understanding result in a new cost understanding integrated across development, production planning, production, and after sales divisions. With this new approach an increase of the First-Time-Capability on the assembly line and a reduction of assembly time and cost is achieved. This is accomplished by implementing new DFM and Poka Yoke solutions and methodologies to increase the reliability of automotive electronics. Thereby the share of rework time and additional investments in rework human resources and facilities is reduced. The new cost understanding contains the balancing of additional investments in DFM solutions with saved assembly and warranty and goodwill cost, which provides additional benefits for the automotive manufacturer. This is extended and deepened in [GeBF-06].

Currently in the automotive industry there are an increasing number of vehicle variants and increasing demands of electronic innovations and functions. This leads to an increasing complexity of automotive electronics.

Result 6.1.3 *The new approach helps to master the complexity of automotive electronics and to increase the vehicle quality by efficiently integrating assembly process and product improvements.*

The new approach also addresses the knowledge management of the improvements using CBR technology. This approach enables to compare new problems with existing solution cases using a certain similarity function. Solution cases which are over a certain similarity threshold can be reused otherwise a new solution has to be created.

Result 6.1.4 *The integration of various feedback information in one system is achieved and an efficient knowledge sharing and update process for the solution cases is provided.*

This contains huge potential to reduce and prevent redundancies and to provide a common risk-cause and solution management in real time for all involved participants. The approach provides also the decision making process on how to decide about the implementation of solution.

Result 6.1.5 *An innovative aspect of IMPROVE is that decision criteria for implementing solutions are both a high risk value and economic efficiency.*

For this process a concrete workflow and case solution management is realized. In order to integrate the new approach in existing business processes and to master an efficient interface management, a Strategy Map is developed for a successful implementation process in Section 4.4. The crucial success factors are analyzed and defined. With this Strategy Map, the challenge can be mastered to come from an internal perspective, to a customer perspective, and finally to the financial perspective, as shown in Figure 4.13.

Demonstrated in the state of research and technology in **Chapter 3** is the necessity and potentials for the new methodology. Based on this, the new theoretical methodology IMPROVE is developed in **Chapter 4**, which is successfully verified in business cases in **Chapter 5**. Business case I deals with the Brake Control System. With this example, the feasibility of the theoretical concept is shown. In business case II, the feasibility and practicability of the new methodology approach in an industrial environment and existing business processes is demonstrated. A domain model and a related software prototype is programmed and applied with application cases of automotive electronics.

Statement 6.1.1 *Both for scientific and industry, the new methodology approach is a substantial step forward to increase the quality of automotive electronics and to efficiently implement and integrate innovative DFM solutions for assembly process and product improvements.*

6.2 Outlook

6.2.1 Future developments and extension of IMPROVE

This section is aimed at providing recommendations for further developments and extensions of the new methodology IMPROVE and the related research topic. The new conceptional approach can be revised applying a **functional vehicle view**. Due to new legislations and an increasing vehicle complexity, the functional view, vehicle development, and modelling will be required in the future.

The new approach is focused on automotive electronics and could be extended by integrating an innovation management for the creation of assembly process and product solutions to reduce risk. This issue could be improved by **Computer Aided Innovation** tools in order to increase the creativity to find innovative solutions [GeMO-05].

In the context of Virtual Engineering the new approach can be integrated in digital tools. The requirement therefore is the display of “folding flabby” elements which is currently not possible in an extent to simulate the complete installation process of automotive electronics. Another extension would be the integration of an ergonomics analysis and ergonomy evaluation tool. This could include the quantification of ergonomy which could be used to argue for investments in better manufacturability in order to reduce defects.

One further development would be to use the **Bayesian approach for technical risk identification**. In this context the treatment of the number of assumptions has to be clarified. IMPROVE could be also extended by a follow risk calculation, integrating for example liability risk measures as well as direct financing and investment controlling. New liability regulations require the documentation over 30 years of electronic components, functions, tests, and quality conditions which results in high investments. Therefore, new projects have been initiated recently in the automotive industry in order to face this challenge of efficiently organizing the documentation process. Therefore, the new methodology could be further developed by taking up and integrating this issue.

The software prototype could be extended by additional users and features, such as integrating suppliers in the improvement process. The new methodology approach is in fact an innovative vehicle life cycle management for automotive electronics and supports the learning and knowledge process between type series generations. Therefore it could be further developed and integrated into **existing PLM tools** in order to further improve the integration of involved participants and the data management.

For the implementation as well as for the extension and new development of IMPROVE, the following changes, trends, and challenges in the automotive industry and global economy have to be considered.

6.2.2 Change of basic parameters

In the context of socio-economic trends in the future, an increasing **individualization** will drive the need for customized cars with a multitude of special features more than today. The **aging of populations** means that bigger shares of drivers will have special needs with respect for example to comfort and support of eyesight.

It is obvious that oil resources are of special concern for the automotive industry and the number of oil consumers is increasing due to more drivers in China and India. According estimates of the Organisation for Economic Co-operation and Development (OECD), the total number of vehicles in OECD countries is expected to grow by 32% from 1997 to 2020 and, on a global scale, by 74% in the same time period. The European Commission estimates in its White Paper "European Transport Policy for 2010: Time to decide", that the demand for the transport of goods within the European Union will increase by 38%, and the demand for passenger transport by 24% between 1998 and 2010 [WeWa-03]. The anticipation of future scarcity of conventional fuels is a major driver for several technological developments. **Environmental legislation** is one of the major drivers of developments in the automotive sector. This holds especially true for the take-back regulations, recycling, and emissions standards. The automotive industry is a prime sector in driving new technological developments. Because of its high R&D expenses, this industry is determining the directions of research in several areas.

In a survey of Unigraphics Solutions Incorporation [UGS], about the innovation propensity, German car drivers were asked in which **technology field increasing intelligent technology** is desired. In the field of driving safety 67% of luxury car drivers and 41 % of economy cars driver would like to have more innovative technology. Whereas 68% of luxury car drivers would prefer more communication and entertainment technology, only 19% of the economy car drivers said the same. The second question asked for a risk estimation that more complex technology leads to more extensive problems in the vehicle usage. The answer was that 58% of luxury car drivers estimate a mean risk, 27% a high and 8% a very high risk. Meanwhile, 19% of economy car drivers are worried about a very high risk, 38% about a high, 39% of a mean, and only 4% about a low risk.

One global trend in the automotive industry until 2015 is that the **BRIC states** (Brasilia, Russia, India, and China) will have the **greatest growth potentials** caused by a reorientation of the global production strategies. Reasons for this are the increased cost pressure of OEMs in the saturated domestic market, and increased location advantages of salary, low tax, and less regulation in the BRIC states [Beck-05]. The competition in the automotive industry will increase as **Chinese automotive manufacturers** for example will provide simple vehicles at cheap prices. Even though safety standards are not fulfilled today, this issue will be also solved in the future and will change the competition in the global automotive market.

6.2.3 Future trends of automotive electronics

Considering **automotive innovations in the future**, it is forecast that 90% will be based on electronics development and 80% of that amount will be based on software development [LeFH-03]. Today, telematic and multimedia applications are in the forefront and mechanically actuated components are being replaces with electrically actuated ones. Accordingly, the transformation has occured over the last two decades in the automotive industry from mechanically oriented companies to electronically, mechatronically, or software oriented companies which will be further accelerated in the future. It is forecasted that the software in vehicles will increase by a factor of four during the period from 2000 to 2010 up to an estimated value of 100 billion Euros worldwide [LeFH-03]. The challenge lies in the drastically **increasing complexity** of the vehicle electronics system, which is a challenge both for engineering and the management.

Driver assistance systems are also receiving increasing importance in the future automotive industry. ESP and ABS are mostly standard, however night view assistance is gaining in importance having 2 infrared light sources in the front headlight cases. At crossways 60% of all accidents occur where the technology can be efficiently used. Together with the camera in the windshield a picture of the traffic is generated on the dashboard in order to display possible hindrances [IAA]. New approaches connect active and passive safety in a vehicle. The idea of the project **PRE-SAFE** [VDIr-03] is to increase the passive safety as the vehicle prepares for an impending accident. Therefore an accident probability has to be determined which is done by the ESP sensors. If a certain value is crossed, reversible actors are activated. The ACC is the first driver assistant system which not only alerts the driver but also interferes actively in the vehicle's dynamics. **"Car-2-Car"-communication** is the next huge innovation step in order to realize active saftey when cars exchange information about hazards and traffic jam precociously for example. The "Car-2-Car" is a system which is able to communicate locally around the vehicle for approximately 300 meters and uses therefore WLAN technology [VDI-3705].

Due to more electronic functions such as assistance and comfort systems, an optimized energy management is required in a vehicle. This will require larger generators and batteries which will lead step by step to the hybrid drivetrain generation. One trend is for example the usage of the Intelligent Battery Sensor which increases the accuracy of the battery parameters and the availability of power, and reduces production and service cost [Baek-05].

Another trend is the **X-by-Wire technology** in the automotive industry. The X-by-Wire concepts Steer-by-Wire, Brake-by-Wire, Throttle-by-Wire, and Shift-by-Wire can be realized by replacing some of the conventional electrical, mechanical, or hydraulic connections. Advantages are lower weight, less required space, easier service and in the long run, lower cost. This concept leads to the closer networking and interfaces of functions. This step to a fully integrated electronics architecture puts high demands on safety, availability, and defect tolerance. With this increasing system complexity the testability, safety, and simple updates of components as well as the diagnostic ability have to be increased in order to balance the high cost pressure. Liability and legal questions, and technological maturity are still a challenge for automotive companies.

Future automotive electronic architectures are in the competition of the **functionality-complexity-quality triangle**. The objective is to generate a basic infrastructure for the management of functions within both future applications and standard software modules. The goals include the standardization of basic system functions and functional interfaces, the ability to integrate and transfer functions and to substantial improve software updates and upgrades over the vehicle lifetime [Heid-04]. One innovation is the **FlexRay protocol** which has the advantages of a one or two channel usage, small latencies, and the support of different topologies. This arouses high interest and is one current trend in the automotive industry [Baek-05].

Additionally, self organizing, self reparable and (semi-) autonomous systems which support human beings gain in importance. Other trends are that web service technology provides the basis for process oriented integration and automatization of IT bases business processes, that networked smart labels provide the basis for embedded internet services, and that grid computing gains in importance for applications to be economically usable. Another future trend is the new communication paradigm **"Peer-to-Peer" (P2P)**, which is an innovative internet concept for the direct communication between computers and the end device (peers) on the user view [WaWe-05].

The complexity of automotive electronics will be increasing in the future by other innovations such as biometric system for the keyless car entry, or DirectTV in the vehicle with other communication and entertainment innovations [VDI-4005]. In fact, this increasing electronic complexity will also affect the production and assembly process time and cost which is discussed next.

6.2.4 Future production trends

At some point, automotive manufacturers will reach the limits for installing electronic components into the vehicle due to increasing components but limited space in the vehicle. Another limit is related to the testing process. For driving assistance functionalities for example a test in the assembly process is difficult to realize which requires new testing concepts. In order to manage the increasing complexity of automotive electronics, future innovations will be required especially in the field of Design for Manufacturing. A special focus should be laid on the very complex wiring harness, for example the creation of a several part wiring harness, or a wiring harness following new structures such as the neuroanatomy principles. A reduction or limitation of the number of ECUs will be indispensable when weight and consumption restrictions are adhered. Another innovation could be the application of the **"Plug-and-Play" concept** on the assembly line which means that a direct response is given when the ECU is connected, which could be a light or a sound. Another innovation for the assembly process would be the creation of always identical sockets for connectors using a sensible connecting order or the usage of plug racks for all ECUs to be assembled similarly, such as the standard **Universal Serial Bus (USB)** socket in PCs.

Further industry trend is the usage of the **Radio Frequency Identification (RFID)** technology which is interesting to be used where the digital process chain can be intelligently designed with radio chips. RFID chips are part of electronic labels and save information without using power over many years. They can be read out with special sending and receiving antennas, and can be written and deleted. Important information can be stored such as article numbers, series number, or the date of manufacturing which enables consistent tracing and relocation of the product. The market for the RFID labels until 2008 is estimated to be 4.6 billion US $ [VDI-2105]. Whether this technology will be also used in an automotive manufacturing process as an innovative vehicle identification and information medium will become an important question.

Another development in the automotive industry is that **three different life cycles** of a car exist: the **chassis** life cycle, the **engine** life cycle, and the life cycle of **electronic components**. In fact, the life cycle of electronic components is the shortest one and thus the question occurs whether automotive manufacturers should be able to replace the electronic components or systems after for example 4-5 years, to extend the life cycle of the entire car and to further use the chassis and engine. If customers put emphasis on having the recent electronic features in their vehicle, this could be provided to the customer by exchanging for example ECUs and other devices. The crucial requirement for this would be the creation of standard components in order to perform an intelligent ECU and software change. This would create a new service business area which additionally enforces customer loyalty.

The future production planning will face the challenge to integrate and use **digital planning tools** which will optimize and shorten the entire planning process. The main future production trends are increased flexibility, growing individualism, speedy innovation, and continuous cost reduction. The creation of standards, system integration, and the simultaneous development of hardware and software are the main future challenges for automotive electronics production planning [WeWa-03]. OEMs have to intensify the concentration on all steps of the added value creation chain in the future. That means outsourcing of up-stream activities to suppliers and insourcing of high profitable down-stream activities such as sales and customer orientation. This means that automotive manufacturers will be more like **high-tech brand managers** whereas brand management will be the decisive success factor in a close network of OEMs and suppliers. Automotive manufacturers increasingly play the role of system integrators. The car has to be considered in the future not as an addition of several single systems or subsystem but rather as one system in a functional view.

6.3 Conclusion

The automotive industry will also be in the future a driver for innovations and new technologies. The increasing individual customer demands and further change of basic economical conditions will be a challenge for automotive manufacturers. In the field of automotive electronics in particular, the increasing complexity of function and system integration will require new concepts and solutions such as technical risk management and an efficient and sustainable Design for Manufacturing. Therefore, the new introduced methodology IMPROVE is making a useful and significant contribution. The business cases show that this new methodology is feasible and can be applied in the automotive industry. Automotive manufacturers which are reacting flexibly and consistently to the described challenges will also provide highly qualitative and innovative products in the future.

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Appendix A

Mathematical Reliability Calculation

In a mathematical approach, Reliability Re is defined as the probability that the item will perform its required function under given conditions for a stated time interval. For the duration of an operation or mission, the parameter t is recorded, and the reliability function is then defined by $Re(t)$. A failure occurs when a person or item stops performing its required task or function. The failure-free operating time is generally a random variable [Biro-97]. The failure rate provides important aspects of reliability analysis and the occurrence of a breakdown can be described by the failure probability $F(t)$. The breakdown density is then

$$f(t) = \frac{dF(t)}{dt} \tag{A.1}$$

Reliability can also be described as the survival probability as the complement of $F(t)$, that is

$$Re(t) = 1 - F(t). \tag{A.2}$$

$Re(t)$ describes the probability that a system is in a functional condition after a time t. The formula for continuous $Re(t)$ is generally (Assumed that the system is correct at starting point t_0)

$$Re(t) = e^{-\int_0^1 \delta(t)dt} \tag{A.3}$$

The variable δ is defined as the failure rate and describes the volume of failures in a time interval dt, related to the amount of correct entities at time t. In general, δ is the rate of failure density to survival probability

$$\delta(t) = \frac{f(t)}{Re(t)} \tag{A.4}$$

$$= \frac{dF(t)}{dt} \cdot \frac{1}{1 - F(t)} \tag{A.5}$$

$$= \frac{d}{dt}F(t) \cdot \frac{1}{e^{-\int \delta(t)}} \tag{A.6}$$

$$= \frac{d}{dt} \cdot \frac{F(t)}{1 - F(t)} = \frac{d}{dt} \cdot \frac{1}{\frac{1}{F(t)} - 1)} \tag{A.7}$$

$$\Rightarrow \int \delta(t)dt = \frac{1}{\frac{1}{F(t)} - 1} \tag{A.8}$$

$$\Rightarrow \frac{1}{F(t)} = \frac{1}{\int \delta(t)dt} + 1 \tag{A.9}$$

$$\Rightarrow F(t) = \frac{1}{\frac{1}{\int \delta(t)dt} + 1} \tag{A.10}$$

From this it follows that the probability of failure depends on the sum of the failure rate over time.

Appendix B

DIN 61508

The International Standard [IEC-61508] and the German version of the standard [DIN-61508] contain the functional safety of electrical/electronic/programmable (E/E/PE) safety-related systems. Systems comprised of electrical and/or electronic components have been used for many years to perform safety functions in most application sectors. Computer-based systems (generally referred to as programmable electronic systems (PESs)) are being used in all application sectors to perform non-safety functions and, increasingly, to perform safety functions. If computer system technology is to be effectively and safely exploited, it is essential that those responsible for making decisions have sufficient guidance on the safety aspects on which to make those decisions

The international standard IEC/DIN 61508 sets out a generic approach for all lifecycle activities for systems comprised of electrical and/or electronic and/or programmable electronic components (electrical/ electronic/ programmable electronic systems (E/E/PESs)) that are used to perform safety functions. This unified approach has been adopted in order that a rational and consistent technical policy be developed for all electrically based safety-related systems. A major objective is to facilitate the development of application sector standards.

In most situations, safety is achieved by a number of protective systems which rely on many technologies, for example mechanical, hydraulic, pneumatic, electrical, electronic, programmable electronic. Any safety strategy must therefore consider not only all the elements within an individual system, for example sensors, controlling devices, and actuators, but also all the safety-related systems making up the total combination of safety-related systems. Therefore, while this international standard is concerned with electrical/ electronic/ programmable electronic (E/E/PE) safety-related systems, it may also provide a framework in which safety-related systems based on other technologies may be considered.

Beside other issues, this International Standard

- considers all relevant overall, E/E/PES and software safety life cycle phases when E/E/PESs are used to perform safety functions;
- provides a method for the development of the safety requirements specification necessary to achieve the required functional safety for E/E/PE safety related systems;
- uses safety integrity levels for specifying the target level of safety integrity for the safety functions to be implemented by the E/E/PE safety-related systems;
- adopts a risk-based approach for the determination of the safety integrity level requirements;
- sets numerical target failure measures for E/E/PE safety-related systems which are linked to the safety integrity levels;
- sets lower limit on the target failure measures, in a dangerous mode of failure, that can be claimed for a single E/E/PE safety-related system;
- adopts a broad range of principles, techniques, and measures to achieve functional safety for E/E/PE safety-related systems, but does not rely on the concept of fail-safe, which may be of value when the failure modes are well-defined and the level of complexity is relatively low.

In Figure B.1 is shown the overall framework for parts 1 to 7 of this standard and indicates the role that IEC 61508-6 plays in the achievement of functional safety for E/E/PE safety-related systems.

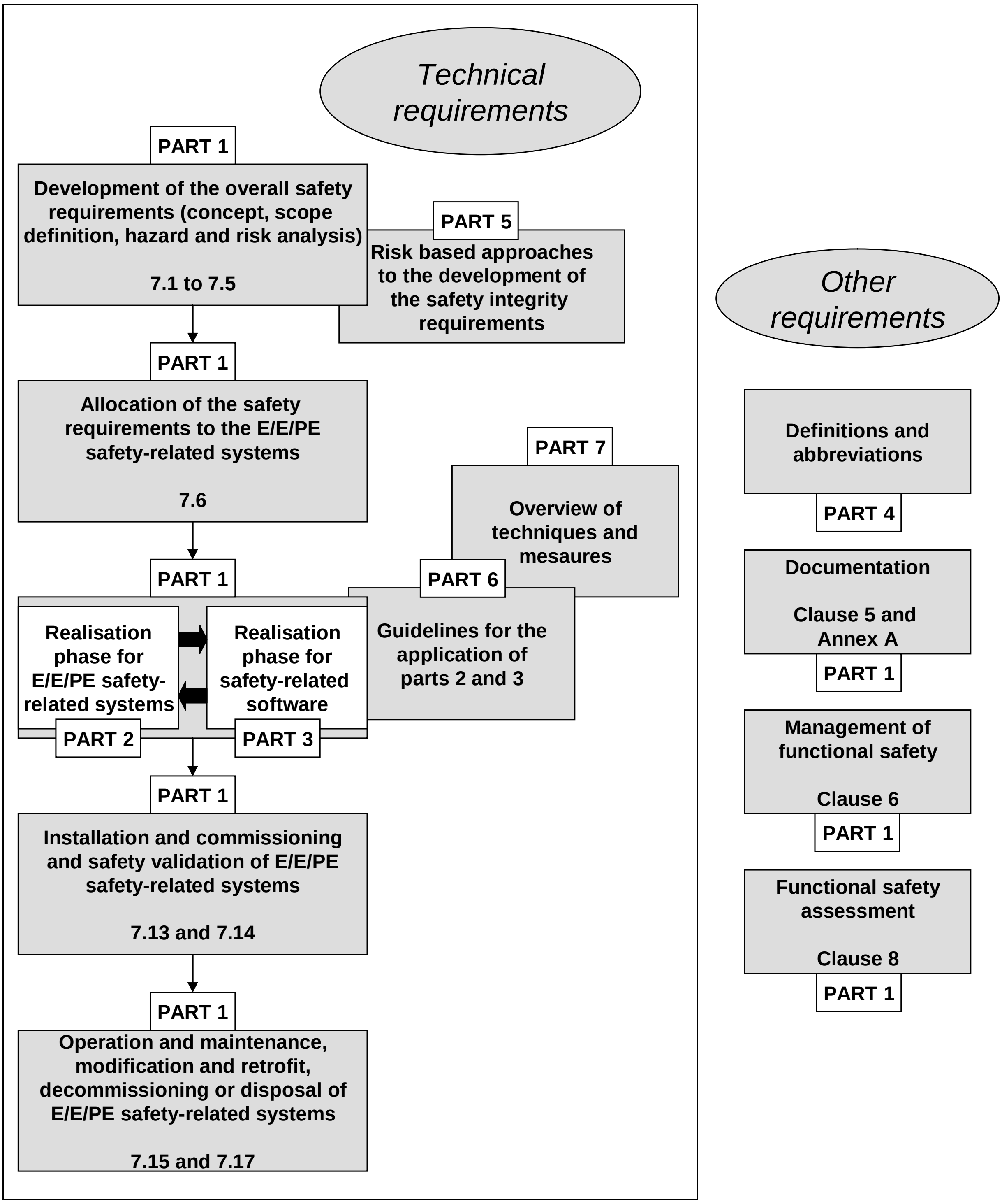

Figure B.1: The overall framework of DIN 61508

Appendix C

JD Power Criteria

1.	**Ride, Handling and Braking**	**2.**	**Features and Controls**
1.1	Vehicle pulls	2.1	Windshield wipers
1.2	Brakes pull	2.2	Rear window wiper
1.3	Brakes are noisy	2.3	Windshield washers
1.4	Brake pedal requires too much effort	2.4	Turn signals
1.5	Brake Pedal feels mushy/soft	2.5	Exterior lights
1.6	Brakes vibrate/shudder	2.6	Sunroof
1.7	Ride is too stiff/soft	2.7	Side window
1.8	Steering system is too stiff/heavy	2.8	Door locks
1.9	Steering system has too much play	2.9	Dome/map lights
1.10	Steering system leaks	2.10	Remote keyless entry sytem
1.11	Steering system noises	2.11	Security system
1.12	Steering wheel is not centered	2.12	Cruise control system
1.13	Steering wheel vibrates excessively at idle	2.13	Trip computer/navigation system
1.14	Str wheel vibrates when driving	2.14	Mirrors
1.15	ABS light indicated a problem	2.15	Cupholders
1.16	Parking brake problem	2.16	Cigarette lighter/power outlet
1.17	Excessive tire road noise	2.17	Sonstige Ausstattung und Bedienung
1.18	Unusual suspension noises		
1.19	Traction control system problem		
1.20	Brakes don´t have enough stopping power		
1.21	Poor handling stability		
1.22	Other Ride, Handling and Braking problems		
3.	**Seats**		
3.1	Forward/backward adjustment problem	3.7	Seat belt doesn't retract
3.2	Recliner adjustment problem	3.8	Seat squeaks or rattles
3.3	Poor/uncomfortable lumbar support	3.9	Material sags/loose/parting seams
3.4	Height adjustment doesn't work	3.10	Seat dirty/damaged at delivery
3.5	Headrest not working properly	3.11	Folding rear seat does not work properly
3.6	Seat belt buckle won't latch/difficult to latch	3.12	Other seat problems

Table C.1: JD Power criteria category 1-3

4.	**Sound System**	**7.**	**Vehicle Interior**
4.1	Radio won't stay on station/poor reception. . .	7.1	Instrument panel/dashboard
4.2	Casette drags/skips	7.2	Glove box
4.3	Casette won´t eject	7.3	Airbag cover
4.4	Casette eats tapes	7.4	Door panel
4.5	CD Player won´t load CD	7.5	Headliner
4.6	CD Player jumps/skips	7.6	Carpet
4.7	CD Player won´t eject	7.7	Center console
4.8	Static or popping noise in speakers. . .	7.8	Overhead console
4.9	Speakers vibrate/rattle	7.9	Rear parcel shelf/cargo cover
4.10	Speakers cut in/out	7.10	Rear compartment floor cover
4.11	CD changer doesn't work properly	7.11	Fuel gauge inaccurate/doesn't work properly
4.12	Controls hard to operate	7.12	Other gauges/instruments don't work properly
4.13	Other sound system problems	7.13	Instrument panel lights don't work properly
5.	**Heating, Ventilation and Cooling (HVAC)**	7.14	Distortion/blemish in windshield
5.1	Air conditioner not working properly	7.15	Distortion/blemish in rear window
5.2	Air conditioner noisy	7.16	Other interior problems
5.3	Air conditioner doesn´t get cold enough	**8.**	**Transmission**
5.4	Heater not working properly	8.1	Shifts roughly
5.5	Heater doesn´t get hot enough	8.2	Slips/shifts erratically
5.6	Fan/blower not working properly	8.3	Shifts up/down too often
5.7	Fan/blower noisy	8.4	Gearshift hard to operate
5.8	Front defroster problem	8.5	Clutch chatter
5.9	Rear defroster problem	8.6	Gears grind when shifting
5.10	Heater/air conditioner smells moldy/stale	8.7	Clutch pedal problem
5.11	Windows fog up a lot	8.8	Gearshift hard to operate
5.12	Can't maintain desired temperature	8.9	Difficult to shift in/out of 4WD
5.13	Controls hard to operate	8.10	Unusual transmission noises
5.14	Other heating/cooling/ventilation problems	8.11	Transmission fluid leaks
6.	**Vehicle Exterior**	8.12	Other transmission problems
6.1	Wind noise	**9.**	**Engine**
6.2	Water leaks	9.1	Hard to start
6.3	Molding loose	9.2	Won't start at all
6.4	Gaps/poor fit	9.3	Stumbles/hesitates/dies
6.5	Hard to open/close	9.4	"Check Engine Light" indicated a problem
6.6	Paint chip/scratch at delivery	9.5	Idles rough/too fast
6.7	Paint blemish at delivery	9.6	Unusual engine noises
6.8	Dents/dings at delivery	9.7	Engine lacks power
6.9	Fog/condensation in lenses	9.8	Excessive oil consumption
6.10	Fuel door problem	9.9	Exhaust system problems
6.11	Headlights not aimed properly	9.10	Oil leaks
6.12	Cracked windshield	9.11	Excessive fuel consumption
6.13	Spare tire rattles	9.12	Engine required unscheduled repairs for emissions
6.14	Other exterior problems	9.13	Engine required unscheduled repairs for computer
		9.14	Engine required unscheduled repairs for other
		9.15	Other engine problems

Table C.2: JD Power criteria category 4-9

Appendix D

Brake Control System (BCS)

The BCS improves the starting and accelerating ability increased traction, particularly favourably on different road surfaces and in curves. It adapts the engine torque to the related transfer options of the wheels automatically to the road, if the driver gives too much gas.

Additionally, it reduces the centrifuge danger on all roadway conditions by automatic stabilization when braking, with accelerating, or in the case of free roll.

It also improves the trace stability of the vehicle clearly when driving along curves in the frontier, shortens the braking distance in curves or on roadways with smooth surfaces. Another feature of the system is that a flashing warning lamp in the instrument cluster is provided which signals to the driver the BCS usage and informs about the fact the driving physical limits are reached. The BCS can be switched off over the switch "BCS Off" when a constantly lighting up of the warning lamp in the instrument cluster occurs in case of deep show for example.

Basically all forces, which affect a vehicle from the outside, want to turn the vehicle around its emphasis, indifferently whether there are one side affecting braking or driving powers or side forces. The BCS seizes the vehicle behavior and steers the correction by focused braking forces at individual wheels. In a situation A, the vehicle is under steered in a left curve which can be seen in Figure D.1 on the next page. The vehicle pushes over the front wheels outward. It takes place an exactly computed brake interference at the left rear wheel. In the figure the identifier **a** is defined as the desired driving direction, **b** as the braked wheel, **c** as the produced correction moment of the vehicle, **d** as the under-steering vehicle movement, and **e** as the overriding vehicle movement. In situation B the overriding vehicle in a left curve is shown where the vehicle breaks out with the tail. It takes place an exactly computed brake interference at the right front wheel. The BCS regulates when

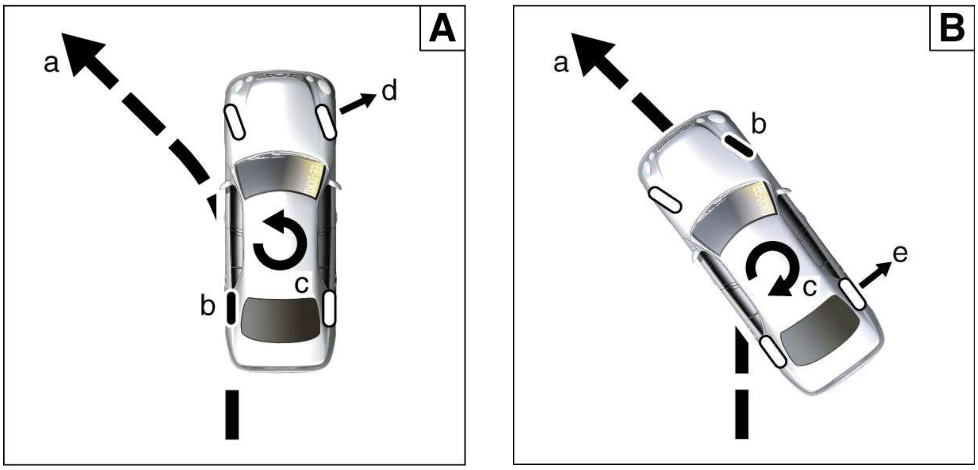

Figure D.1: BCS interference in curves

driving along curves the vehicle is then under or overridden and when traveling straight due to different road conditions or friction values [Baue-03].

In order to enable these regulatory interventions, an extended sensor technology is necessary. These are firstly sensors which recognize the driver desire like the steering angle sensor and driving pedal position. Secondly sensors which measure the actual vehicle behavior such as the micromechanical torsion rate sensor, the brake pedal sensors in the brake booster, and the four rotational speed sensors at each wheel. The information of the rotational speed senors, steering angle sensor, micromechanical torsion rate sensor, and the brake pressure of the individual wheels are collected and processed in the BCS ECU.

The BCS ECU is connected over the CAN C with the ECUs engine electronics and transmission. The ECU BCS is supplied constantly with the current data of the ECU engine electronics and transmission. Over the micromechanical torsion rate sensor the forces are recognized, which want to turn the vehicle around the emphasis. With the specified value registration the forces along and transverse at the wheels can be computed. If these values exceed certain thresholds, the ECU BCS steers the appropriate regulating valves in order to in-regulate defined brake pressures at one or at several wheels. At the same time instructions are passed over the CAN C to the ECUs engine electronics and transmission. For the drive moment reduction the ECU engine electronics receives an engine-moment set value, and via the transmission ECU if necessary a resetting is prevented [BrBP-04]. The purposeful and exactly proportioned interference is performed within fewer fractions of a second. This active brake interference and the drive moment reduction of BCS provides an optimal vehicle stability [LiMS-04].