From Build-to-Order to Customize-to-Order
Advancing the Automotive Industry by Collaboration and Modularity

Code of Practice Findings of the EU-FP6-Project AC/DC—Automotive Chassis Development for 5-Days Cars
Edited and Published by the Consortium of the AC/DC Project
From Build-to-Order to Customize-to-Order

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Roland Ericsson • Rolf Becker • Andre Döring • Holger Eckstein
Thomas Kopp • Ismail Poslu • József Vánca (Editors)
on behalf of the consortium of the AC/DC project
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Executive summary

The European automotive industry is facing enormous challenges as a result of the financial crisis, high prices for oil and steel, intensified emission controls and the trend towards electric vehicles. To tackle these challenges, traditional procedures have to be questioned and novel approaches have to be established.

The European Commission-funded project AC/DC supports this transition towards a sustainable automotive economy by means of knowledge-based products and processes introducing innovative approaches.

Smart modular products

The main smart modular product developed in AC/DC is a highly innovative rear axle module enhancing existing safety functions and increasing driving comfort options. The rear axle is equipped with mechatronic actuators, an active stabilizer, a torque vectoring rear axle differential, and semi-active magneto-rheological (MR-) dampers. To handle the increase in variability and flexibility, all the connections of the rear axle have been consolidated in two central connectors, a power and a signal connector. Another developed component is a modular high frequency (HF) sensor for different crash scenarios, as well as for vehicle dynamics control. Due to advanced software, which has also been developed, the HF sensor can be adapted to different vehicle chassis types and also support different add-on functions. The mechatronic actuators are presented and validated on test-benches, which are also used to validate the interoperability of the components inside the rear axle module and within the car. Due to the central connectors and the advanced software, the smart modular products can be featured very late in the production and thus comply well with the Customize-to-Order (CtO) approach of the project.

Collaborative production network management—Dynamic Supply Loops

Although the need for collaborative planning in supply chains is generally recognized, there is still a gap between theoretical proposals and practical requirements. The proposed principles of the Dynamic Supply Loops (DSL) can be treated as a viable compromise for more optimized inter-company respectively inter-project planning: it offers scope for other partners’ options, while keeping communication and decision complexity at bay through a relatively simple information exchange and decision protocol confined to immediate partners in a chain. DSL is open to embed standard planning techniques and novel incentive schemes alike. Simulation results on a multi-echelon model showed that DSL outperforms traditional upstream planning and facilitates channel coordination.
The methods developed by AC/DC ensure better collaboration between the partners in the supply network and enhance speed and flexibility as well as process reliability in the whole supply grid.

Many of the developed methods have been proven in practical best-case implementation showing applications at each level of the supply chain management, like strategic and tactical planning, collaborative forecasting, event handling and simple automatic information messaging.

**Flexible production system**

The automotive industry is continuously increasing the requirements of flexibility in production systems, both at the car manufacturers as well as at the suppliers. Other than the flexibility in production volumes, product variety is increasing from year to year.

The original objective of AC/DC was to make a production system capable of managing ±25% capacity fluctuation per day, without increasing costs. A number of tools has been implemented to achieve this goal. Lean production management has been considered as one important milestone. The Lean philosophy aims at shortening the order-to-delivery lead time by product standardization and late customization of components, aspects developed as smart modular products in the AC/DC project.

Value stream mapping, calculation of the total cost of ownership (TCO), ABC/XYZ analysis of the product range to optimize the inventory and Single Minute Exchange of Die to reduce waste in the process, are attributes for flexible production systems. Benefit balancing has been considered as an important motivator for all supply chain actors to contribute to the common benefits.

Strategic objectives achieved using AC/DC principles in the supply network:

- Lead time reduction up to 85%
- Inventory reduction up to 50%
- Operator reduction up to 8%
- Floor space reduction up to 6%
- Defect reduction up to 50%
- Flexibility per day ±25%

All results could be achieved without increasing the TCO.
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Section 1

Introduction

The situation of automotive companies can be characterized by low and fluctuating demands for the defined products. It has been recent practice to optimize the component supply as well as production systems and networks for operation at maximum utilization without explicitly supporting flexibility.

Therefore, the financial downturn in late 2008 has made serious impacts on the automotive industry. This specifically concerns considerable fluctuations in sales caused by dramatically decreased market demands and the increased pressure on OEMs and suppliers. The lack of flexibility and reactivity of the supply network as well as restricted collaboration and communication between the partners in the network have led to severe planning inconsistencies. It has caused material shortages resulting in high emergency logistic costs and production line breakdowns.

Additionally, cost pressure on the European automotive industry is growing. Automotive companies in newly industrialized countries such as China or India have adjusted to these conditions and try to catch up quickly to the world's leading automotive standards in Europe. However, they produce, deliver and sell their cars at lower prices.

Moreover, the customers become more and more ambitious, which causes a demand for numerous variants and reduced demand for predictability. This leads to even higher capacities, or it requires more flexible and lean production systems. Sub-suppliers, delivering system-relevant parts to the OEMs, must have accurate support tools at hand to fulfill these challenges. Hence, the ability to operate a supply network has become a decisive task for suppliers.
**Introduction**

**Which measures should be taken?**

Firstly, goal-oriented strategies to strengthen the European car industry are branding and differentiation. These strategies help to deal with the increasing individuality, the needed flexibility, and the call for a premium image. Secondly, the reduction of delivery lead times requires fast responses from a highly flexible overall production system and low working capital. Thirdly, the number of variants has to be reduced by means of standardized components, which are configured by software enabling late customization. Other variants which cannot be reduced must be managed using intelligent supply network management systems. Traditional approaches of supply network planning should be questioned, as in recent implementations of collaboration processes and the principles of simply increasing cost pressures in the upstream supply chain.

**Which solutions does this book offer?**

The following sections explain how the European-funded project 5-Days Car AC/DC (Advanced Chassis Development for 5-Days Cars) will implement these required strategies to compensate future challenges of the automotive industry.

These new challenges for the automotive industry and specifically for the suppliers affect the supply grid as a whole and not merely the partners individually. To increase the competitive advantages of one of the leading European industrial areas, there must be more collaboration in the supply network and the industry must implement effective and less restrictive approaches to collaboration.
1.1 The AC/DC Project

The vision behind the project AC/DC is to provide a vehicle production and supply system to deliver a customized vehicle within five days using the experience of leading companies in the European automotive industry. This vision targets not only short order-to-delivery lead times and low stocks but also the overall flexibility of the automotive production grid.

The approach to achieve this vision is a dynamic supply network system for the automotive supply industry which fully supports the “3 Hs”, i.e., to be Highly reactive, Highly reliable, and Highly flexible. The Customize-to-Order (CtO) principle is the enabler for this new supply network system called Dynamic Supply Loops (DSL).

CtO is based on late customization of components and products by utilizing mechatronics.

Section 2 explains what kind of new mechatronic components has been developed within the AC/DC project. They enable late customization of products by using software variant coding. The generation of variants defined by software instead of mechanics also decreases investment costs for new machines and tooling, thus diminishing the financial pressure on automotive companies.

Section 3 describes the novel supply network management approach Dynamic Supply Loops. Based on CtO principles, the DSL leaves hierarchic production concepts behind, cuts down inventory, and assures 100% reliability of delivery to the suppliers’ customers.

To implement a reliable and fast supply network management approach, available flexibility potentials of production capacities must be allocated at each partner of the supply chain. Section 4 introduces concepts and methods to increase flexibility potentials in both highly and lowly automated facilities.

1.2 Definition of BtO and CtO

Traditional approaches, i.e., the stock production of components based on forecasts can be summarized as Build-to-Forecast (BtF). Build-to-Order (BtO, [M1.1]) and Customize-to-Order (CtO, [M1.2]) are both improvements of this traditional approach towards customer-oriented production concepts. These improvements, however, are realized in different manners. While in the case of BtO, the production of parts or components is triggered and “pulled” by orders, in CtO components are prefabricated in accordance to plans and customized by either flashing software and/or parameterization at a late stage.

Product components considered by BtO are typically components which have substantial influence on the production costs [33]. The reason for this is that implementation and operation of a BtO supply chain implies increased process complexity and consequently causes more expensive processes and tuning efforts than the traditional approaches for BtF. To maximize the benefit of high flexibility in a BtO supply chain, a large variety and fluctuating demands are required as additional attributes for components.

In contrast, the application of CtO is appropriate for components, for which the variety can be realized by means of software as well as parameterization and is not a result of their “physical shape”. This means, the respective variant-building feature is not directly “visible” for the end-customer, unlike different fabrics of seat covers or surface finish types of control elements for example.

The portfolio shown in Figure 1.1 can be derived as a consequence of the characterization above. It consists of the two axes visibility and variety. Visibility refers to the aforementioned direct physical perceptibility of the variant-building feature as
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Figure 1.1: Production strategy portfolio

seen by the end-customer which cannot be generated by means of software or parameterization. Variety indicates the overall quantity of variants of the part or component. In the four quadrants, the respective production strategies Build-to-Forecast, Build-to-Order and Customize-to-Order are allocated.

The traditional BtF approach is simple to apply in industrial enterprises but tends to result in large stocks of finished and unfinished goods (work-in-progress). This effect increases if BtF is applied to parts and components with a large variety. Considering the costs for stocks as a consequence, traditional approaches are suitable if the demand is constant or well-predictable, the direct costs for the components are low, or the variety of the parts and components is small. This takes into account the multiplication of costs for inventory with the amount of variants.

As mentioned above, BtO is more appropriate for parts and components, which exist in a large variety, are visible to the end-customer, and are cost-intensive. BtO requires the fulfillment of demand with mass production efficiency but with a short lead time. This may result in fragmented production and probably in inefficient production schedules and high inventories.

CtO-based approaches are also well suited for parts and components which exist in a large variety. However, in contrast to BtO, the variety is defined by means of software or parameterization.

Consequently, we suggest the hybrid strategy shown in Figure 1.2 [M1.3]. BtF, BtO, and CtO may be applied at the suppliers as appropriate for the respective components produced, while the different components are “Assembled-to-Order” (AtO) at the OEM.

1.3 Benefits of CtO

The primary benefit of CtO compared to BtF and BtO lies in the possibility to customize components and systems at a very late stage in the order fulfillment process at low prices.

For the actors in the supply network, additional advantages of the CtO approach and its realization by means of DSL are:

- Small physical variety of components;
- Stable production to forecasts;
- Lower quantity of stocks needed; and
- Reduced efforts for the management of the production of customized components and systems.

To implement BtO, companies have to redesign their internal, technical and organizational processes [21]. Furthermore, they may have to adjust product distribution channels and customer service procedures. Equipment must be available and staff must be trained to handle the new procedures. That is why the efforts involved are quite demanding to achieve a BtO supply chain in traditional companies. In contrast, technical processes
in CtO-based systems are comparable to traditional BtF-based systems, except for the need for late software flashing. Since the CtO approach is rather an incremental innovation of the traditional system than BtO, the efforts for change management and training to implement CtO are noticeable lower as for BtO.

The BtO approach offers great potential for improving organizational competitiveness in a global market but its operation efforts are higher than in traditional approaches as the partners in the supply chain are coupled tighter and internal orders are pulled for each final product sold. These overheads for set-up and operation of a virtual enterprise-like network and for the generation, fulfillment, and monitoring of a large amount of internal network orders are clear disadvantages of BtO in comparison to CtO. The CtO approach results in efforts nearly comparable to those in the traditional BtF approach. On account of the importance of the components suitable for CtO, e.g., the active rear axle, additional efforts are required to properly plan, coordinate, and monitor the supply network, realized in form of the new AC/DC approach DSL (see Section 3). For CtO, extra efforts result from the additional information flow to and from the on-site flashing stations.

### 1.4 Reader’s guide

This book introduces the implementation of new strategies such as CtO by means of innovative technical and organizational approaches as developed by the project AC/DC.

The approaches and methods described are valid for the automotive industry but may be applied to customized series production of complex products in general as well; they enhance adaptivity and flexibility of production systems. In particular, they support the shift from traditional cars to hybrids and electric vehicles.

This book is a practical reference guide with links to the AC/DC website for descriptions in detail—it is not intended to be a scientific textbook. If reading time is limited then please proceed directly to the methods of interest in the following sections. However, more time is needed to fully understand the new approaches. There are a multiple of helpful solutions which can be applicable for your business as well.

Further details can be found on the AC/DC website (see Subsection 1.5).
1.5 The AC/DC website

The website of the AC/DC project, accessible at http://www.acdc-project.org, presents the results of the project in more detail, including descriptions of various methods that were applied in the project but could only be described in a nutshell in this book. On the website, one can look for particular methods according to their names or categorizations, though the book also points to them via direct references in square brackets, like [M3.1] (where the leading “M” stands for methods to distinguish them from citations). For instance, the detailed description of Dynamic Supply Loops (DSL) can immediately be found on the website by using its search-by-method-id service for the method identifier 3.1. Such references to methods are specifically given in Sections 1, 3 and 4.

The idea of the website is therefore to support the reader for implementation of the methods. In addition to the description of many methods, best-practice examples are also given to illustrate their implementation. Each method or example is linked to its author who was the expert responsible for the development of this method in the AC/DC project.
Section 2
Smart Modular Products

The Customize-to-Order (CtO) principle is tailored for components with specific characteristics to maximize planning and cost potential in supply chain operations. CtO is neither suitable for a full vehicle nor for every single component of a car but for those components that can be customized at a late stage during the order fulfillment process, e.g., by means of software. For this reason, the project AC/DC has focused on progress of mechatronic components and modules in the field of product technology.

Requirements from the CtO perspective
An essential feature of the CtO approach introduced by the AC/DC project is the reduction of the variety of components in form and shape. The approach is suitable wherever the differentiating feature of a particular component is not directly perceivable by the end-costumer physically, as the functionality is defined by software and/or parameterization. In fact, it can be applied to essential components of vehicles with major influence on the production costs like the chassis, the engine, the gearbox unit as well as the entertainment and route guidance systems—components that include a control unit, providing the possibility to emulate variety by means of software, and components which are directly computer-based.

The introduced product technologies are centered on a highly innovative rear axle module enhancing existing safety functions and increasing driving comfort options. Technical development in intelligent software and sensor-actuator technology combined with customer-neutral mechatronic axle modules pave the way to the next generation of automotive chassis, which are taken into account when implying new automotive production processes.
2.1 Problem definition

The objective of the AC/DC project is the development of component and system technologies to enable a significant increase in product flexibility and variability while using standardized components. This approach reduces the complexity of the supply chain because parts can be produced customer-neutral throughout almost the entire supply chain. They can be customized at the last instance, i.e., in very late downstream production or assembly process steps or even at the car dealers.

Technical challenges

From a technical point of view, the development of highly individualized, mechatronic automotive chassis modules—in this case an advanced rear axle module—is an enormous challenge. It enables the transfer of a customer-neutral module design methodology to ample applications. Derived from the novel automotive chassis technology, there is numerous potential for new drive trains, electrical drives, and new wheel systems. Existing safety functions will be improved and driving comfort options increased. Technical progress in intelligent software and sensor-actuator technology combined in customer-neutral mechatronic chassis modules leads to innovations of the automotive chassis, which needs to be considered by modern automotive production processes.

The potential and feasibility are exercised on the automotive chassis as a master component and system, which comprises the necessary technology convergence of mechanics and electronics into mechatronics. Mechatronic systems can be featured at a very late stage in the production sequence by means of advanced software.

Rear axle demonstrator

One of the main results is the implementation of a rear axle to demonstrate the feasibility of the developed modularization concept. A sports utility vehicle (SUV, i.e., Volkswagen Touareg) rear axle presents this concept. The rear axle is equipped with mechatronic actuators, an active stabilizer, a torque vectoring rear axle differential, and electronic dampers. In addition, the rear axle has two wheel speed sensors. To handle the increase in variability and flexibility, all the connections of the rear axle will be consolidated in two central connectors, a power and a signal connector.

This section introduces principles necessary to develop modular, mechatronic automotive components for late customization.

2.1.1 Connections to the other sections of the book

The development of smart modular products will simplify the realization of an appropriate collaborative production network management and flexible production systems enabling CTO.

Objective of the project is to postpone the point in time when the features and equipment, which the customer has ordered, are actually implemented into the vehicle. From a production point of view, this marks the change from customer-neutral production to the production of customized components and products. To shift this moment as close as possible to the point of delivery of the vehicle to the customer, the project AC/DC pursues the approach of generating variants by means of software and parameterization. This approach does not lead to a reduction of the number of variants with different functionalities, which can be experienced and selected by customers. In fact, the amount of functionalities and the variability can be increased. However, they result in
a reduced amount of different physical components. The consequences on the production system and the logistics are substantial. This product technology-oriented approach promotes the transition from conventional automotive terms of delivery to a highly reactive production system, as a result of the new dynamic supply network collaboration concept developed by the project AC/DC—the so-called *Dynamic Supply Loops*, which is described in Section 3.

The efforts for a production system can be reduced if it has less different physical parts to provide. Manufacturing and assembly are facilitated and the supply chain of the entire production system is simplified. Inventories throughout the supply network can be decreased. This will directly lead to a reduction of overheads for manufacturing and assembly as well as of handling and inventory costs.

Forecasts of the usage of physically uniform components are improved while the re-activeness of a production system which has to produce fewer physical variants is enhanced at the same time.

However, additional efforts for software logistics must be implied. A second, alternative type of workflow is required from the development to the “assembly” (i.e., flashing) of a non-physical component (software and/or parameterization). This includes installation of necessary flashing stations at the specific site.

Additionally, late customization demands the implementation of a backward-oriented information flow to integrate the monitoring data of the flashing station into the overall quality management system. This enables the traceability of the product, its elements, and features.

### 2.2 Rear axle demonstrator

Generally, every electric actuator located on the chassis needs to be connected to a bus system, either CAN (Controller Area Network) or Flexray, and needs to be connected to the supply voltage. In most cases, the bus cable is separated from the cable of the power supply for the reason of decoupling disturbances from the power to the signal connection. Figure 2.1 shows a box, which holds two connectors at the interface between axle and body. This first integration of two cables is a starting point on the way to further integration of the wiring harness and to a modular rear axle.

#### Modular rear axle

A modular rear axle (Figure 2.2) aims to demonstrate the development of a rear axle in a way so that an additional or omitted electrical component inside the axle will have no influence towards the wiring harness of the rest of the car.
Apart from a central power connector and a gateway (subsection 2.2.5), so-called “smart actuators” (subsection 2.2.1) and “modular sensors” (subsection 2.2.2) are other key components, which help to reduce the time at the axle assembly line and increase the modularization even within the rear axle.

Another key component for a modular rear axle is the so-called “advanced software” (subsection 2.2.4), which can be deployed in smart actuators as well as in modular sensors.

2.2.1 Smart actuators

Technical processes are usually controlled by actuators. These actuators transform specific process inputs with the help of energy. In the past the automotive industry used the rotational energy of the motor as the energy mentioned above (e.g., fuel pump). Today more and more of these actuators are substituted by electronic actuators as these are more efficient and can be controlled much easier. Through electronic control, actuators have more degrees of freedom, which make them so-called smart actuators. All smart actuators have the following points in common:

- Power on demand functionality;
- Controllable; and
- Ready to use systems for a wide range of models.

Some of the latest smart actuators represented in the active axles of modern and future cars will be presented on the following pages.

Electronic Power Steering

In recent years more and more cars are equipped with an electronic power steering (EPS), instead of a hydraulic power steering. EPS have a lot of advantages compared to a conventional hydraulic steering; it supports the driver and reduces physical and mental stress. EPS is a power on demand system and can save gas respectively oil up to 0.4l/100km, as compared to a hydraulic system. Another advantage is the increased controllability of the car, which allows varying assistance torques, depending on vehicle speed, steering torque, and steering angle. Since EPS is a controlled system, add-on functionalities such as lane departure warning and park assistance can be realized.

EPS consists of several important parts, which enables its functionality in the car. A torque sensor is mounted on the steering column, which measures the torque put into the system by the driver. A steering angle sensor is built in the system close to the steering wheel.

The steering pinion is placed at the end of the steering column, which converts the rotational movement of the steering column into the translational movement of the steering rack. The electric motor is mounted close to the steering rack. The electronic control unit (ECU) is attached to the motor, while the servo pinion is mounted on its other side. All parts can be seen in Figure 2.3.

During normal driving, the main functionality of the EPS shown in Figure 2.4 supports the drivers...
steering procedure as he does not have to counteract to the full force, applied to the steering wheel by the tire forces. One of the main parts of the system is the torque sensor. The measured torque information is transmitted to the EPS control unit. In the control unit, a support torque is computed based on several parameters such as e.g., vehicle speed. The computed torque is generated by the electric motor of the EPS, and applied to the steering rack via the servo pinion. Finally, the sum of the driver torque and assistance torque act on the steering rod.

The main functions of the EPS vary depending on the engine speed, vehicle speed, driver torque, steering wheel angle, and steering wheel angular speed. The level of assistance torque varies in accordance to these signals. For parking the ECU (Electronic Control Unit) computes the highest level of assistance torque and for driving in the city or on a highway the level of assistance torque is reduced.

Due to the fact that the EPS is a smart actuator, driver independent steering torques can be applied to the steering rack and the steering wheel. This way, add-on functionalities like parking assistance can be implemented easily.

Electronic Roll Control

An example for a future electric smart actuator that can be built into a active axles, is an electromechanic roll bar which is also called electronic roll control (ERC). A car with active roll bars allows dynamic driving, with increased comfort and driving safety. On the one hand, the roll angle of a car can be reduced significantly without using very hard springs, as they are used in sports cars, which reduce the comfort. On the other hand, decoupling of both roll bar ends allows you to have good comfort on streets which cause a lot of road-induced roll excitation.

In cars with active roll bars, both passive roll bars of front and rear axle are replaced with a different system. The traditional torsion bar is cut in two halves and an electric motor is placed in between them. This way, the twisting angle of the two roll bar ends can be controlled. The electric drive is a permanent magnetic synchronous motor, which can realize high revolutions but only a small torque. Therefore, a gear unit is needed, which transforms movement into torques necessary to stabilize a car.

The electronic roll control (ERC) realizes three main functionalities:
1. Stabilization of the car. During cornering the body of the car is stabilized, which means that roll angle and roll angular speed of the car are reduced significantly. To stabilize the car, the electronic control unit (ECU) computes a stabilization torque based on several sensor signals (e.g., roll angle speed, lateral acceleration). This stabilization torque is induced into the active axles at front and rear, contrary to the body.

2. Influence the steering tendency of the car, by distributing the computed stabilization torque to the front and rear axle. If the main part of the stabilization torque is induced into the active axles with the active roll bar of the front axle, the car tends to understeer. The more stabilization torque put on the active roll bar of the rear axle, the more the car tends to oversteer.

3. Decoupling of anti roll bars on straight roads with a lot of road-induced roll excitation. With wheel travel sensors on the left and right side of each axle, the ECU computes a torque to decouple the ends of the active anti roll bars. This way, the roll movement of the car on straight roads is inhibited and the comfort increased.

Obviously the electronic roll control is a very good way to solve the conflict between driving dynamics and comfort. In addition to this, the electronic anti roll bars use much less energy than for example hydraulic roll bars. Furthermore, ERC is a power on demand system, which consumes power only when it is active.

Designing magneto-rheological (MR) dampers for automotive applications

Semi-active suspensions based on magneto-rheological (MR) dampers show a great development because of their mechanical simplicity, high dynamic range, low power consumption, high force capacity and robustness. MR fluids are suspensions of micron sized ferromagnetic particles in a carrier liquid (mineral or silicon oil, for example), whose apparent viscosity can change under the influence of an external magnetic field. This ability of the MR fluids to change reversibly their physical properties in a few milliseconds allows their use as controllable systems especially for MR suspension.

Figure 2.6 shows a cross sectional view of an MR damper composed of cylinder housing, piston and MR fluid. A coil inserted into the piston generates the magnetic field. The flux lines passes across the gap $g$ which causes the formation of chains of ferrous particles in order to change the apparent viscosity into the active area increasing the damping force. The Bingham model (2.1) is used to describe the behavior of the MR fluid:
\[ \tau (H, \dot{\gamma}) = \tau_f (H) \text{sign} (\dot{\gamma}) + \eta \dot{\gamma} \] (2.1)

where \( \tau_f \) is the yield stress, \( H \) is the magnetic flux density, \( \dot{\gamma} \) is the shear strain rate and \( \eta \) is the intrinsic viscosity of the MR fluid.

We reduce the damping force by calculating the pressure difference between the two fluid reservoirs, given by:

\[ F_{total} = \frac{3\pi D_p^4 L}{4wg^3} V + \frac{c\pi h D_p^2 \tau_f (H)}{2g} \] (2.2)

where \( D_p, L, g \) and \( w \) are the diameter, length, gap and the average circumference of the annular channel of the piston, \( h \) is the length of the magnetic poles and \( V \) the displacement velocity of the damper.

Figure 2.5 shows a picture of the experimental set-up. The damper is actuated by a linear motor. The damping force is measured using a force sensor placed above the damper. An LVDT (Linear Variable Differential Transformer) linear position sensor is placed at the piston rod level; the velocity and acceleration are obtained by the derivation of position signal.

Figure 2.7 presents force versus velocity graph for values of electrical current from 0A to 1.5A. The amount of damping force increases as the applied current increases.

A skyhook control scheme is applied to the quarter vehicle suspension, the damper is considered connected to an inertial reference in the sky which remains fixed in the vertical direction. By consequence, the damping tends to maintain the mass of the quarter vehicle fixed whatever distur-
Figure 2.8: Experimental results of a Skyhook control strategy

Bounces come from the road. Skyhook control can be written as follows:

\[
\begin{align*}
V_m(V_m - V_r) & \geq 0 \quad \rightarrow \quad I = I_{\text{max}} \\
& \quad \text{(damper on)} \\
V_m(V_m - V_r) & \geq 0 \quad \rightarrow \quad I = 0 \\
& \quad \text{(damper off)}
\end{align*}
\]

(2.3)

To assess the effectiveness of this control, suspension is subjected to a sinusoidal excitation frequency of 7Hz and amplitude of 10mm. Figure 2.8 shows the experimental results. The displacement, velocity and acceleration of the mass were reduced by applying this control.

2.2.2 Modular HF sensor

Today’s vehicles are equipped with sensors for different crash scenarios, like frontal impact, side impact, and pedestrian accident as well as sensors for vehicle dynamics control.

Due to a missing standard these sensors have many different implementations depending on the OEM, vehicle type and sensor mounting position, resulting in a large sensor diversity.

There are variants in electric interfaces, for example open standards such as PSI-5 [35] and company specific interfaces such as DSI, MERAS, MRSA, PAS, PEGASUS, RSU. In addition, there are different functional parameters such as sensing range and frequency band.

This sensor diversity results in extensive development to include the massive array of specific components and provide problems for system development and the logistics. Also for “second source strategies” (i.e., different suppliers for the same component), is extensive development necessary.
2.2.3 Effect of standardization

If standardized, the variety of sensor types will be reduced significantly, in best case to one universal type.

Efforts regarding the standardization of the sensor housing and programmable sensing range are already ongoing in the German automotive industry.

A sensor with free configurable frequency band and sensing range would have the advantages of less standard components instead of many different variants, the reuse of certified parts and also the availability of one part from different suppliers. Due to the resulting standardized high volume production, the part quality is expected to improve.

Other positive effects of standardization are cost reduction by reduced development effort, reduced part cost by volume bundling, less tooling cost and less logistics effort.

The modular high frequency (HF) impact sensor is one step to reduce the variety of sensors for impact detection. Due to the programmable HF frequency band, this sensor can be adapted to different vehicle types and also different types of central electronic control units (ECU).

The table above shows sensor variants, which are available today (green) and the possible variations in frequency band for the HF range (orange).

In the field, there are very different crash scenarios, which are represented by standardized
crash tests in the test facility. For example there is a low speed crash with only 15km/h, called “AZT crash” [5], which must not activate the air bags, while other crash types such as an angular crash (30°) with a speed of 30km/h against a rigid wall must activate the air bag system. Also crashes with 40km/h or even 64km/h against a deformable barrier with offset (“ODB crash” [19]), must activate the air bags within 20–30ms.

The following images show a top view of an AZT crash (Figure 2.13) and an ODB crash (Figure 2.14), in order to determine sensor characteristics and parameters for the deployment algorithm. Differing to standard tests, the motor hood was dismounted. So the deformation and interaction of the components during the crash could be analyzed.

In the following figures, the difference between standard sensor equipment and usage of the modular HF sensor is shown.

With standard deceleration measurement in the central ECU, the discrimination in time will be difficult, as the signals of different crashes are similar until the required time for the airbag deployment decision (see Figure 2.16).

For a safe discrimination, additional sensors mounted in the vehicle front are advantageous (see Figure 2.17). During a crash, structure borne sound is generated at the impact zone. This structure borne sound is transferred through the vehicle's body. The modular HF sensor (Figure 2.15)
can measure the impact noise, in a range up to 15–20kHz, directly in the ECU.

In Figure 2.18, the difference in the signal amplitude can be seen, enabling an early discrimination of fire and non-fire crashes. Thus, and in combination with low frequency signals, the discrimination can be improved. The possibility is given to replace the upfront sensor in this way.

Thus, and in combination with low frequency signals, the discrimination can be improved. The possibility is given to replace the upfront sensor in this way.

With the help of the modular HF sensor, the detection frequency band can be adapted to different vehicle types and could also replace or complement additional sensors, in some cases.

Consequently, the modular HF sensor has advantages such as: less system cost, less logistics for additional sensors, and improved crash discrimination.

### 2.2.4 Advanced software

To enable late customization of features of a car, one of the most flexible approaches uses software modifications at end-of-line production or even at the car dealers. To achieve this goal, several preparations have to be implemented during the development, production, and distribution of the software for an ECU. Additional emphasis has to be
paid not to violate the high safety and security requirements, which are present in an automotive environment, e.g., prevention of undesired modification, which would lead to malfunctions, damage, or personal injury.

The methods and concepts, although presented in the environment of an active axles application, are by no means restricted to this field of application only, but could easily be applied to other fields as well, such as power train or applications inside the car.

At the heart of the advanced software concept lies the modularization of the different software components as addressed within the automotive Open System Architecture (AUTOSAR, [4]) together with the use of standardized processes for the update necessary for add-on functionalities and late customization (see Figure 2.19).

It is also essential to follow a standardized process for the development of the software modules such as the V-model, to guarantee the relevant quality and safety requirements for an automotive application.

It is also worth mentioning that several security goals have to be respected to ensure a correct update and prevent undesired modifications. The ontological analysis proved by mathematics considers all possible attack patterns, which have to be considered (see Figure 2.20).
A three-stage process consisting of an authenticity before the actual download together with a final check of an associated signature has been proven to be a sufficient measure for the ECU-related attack goals (Figure 2.20).

An example for add-on functionality is given in the following, which could be used together with the modular sensors for late customization.

**Add-on functionalities**

Add-on functionalities (AOFs) are special functions and algorithms which can be integrated in a vehicle without the need to introduce additional sensors. Actually, the main objective of the add-on functionalities is to provide more information to vehicle ECUs and to the driver. This can be achieved by elaborating the data available in the vehicle network without additional costs.
There is a very wide variation of road conditions such as smooth or gravel roads, and many other surface types, as well as very bumpy river beds. Besides, the usage of snow chains is of importance, as having additional information about the tire pressure. Knowing these conditions, the suspension system can be adapted accordingly for better comfort and safety.

AC/DC partners BMW and Autoliv equipped a vehicle with the Modular HF sensor and performed a test sequence (approx. 100 test drives) with dif-
The different road surfaces show different signal amplitudes and frequency values, which can be used for a rough discrimination between smooth or rough roads, and severe off-road conditions simply with the root mean square RMS value (Figure 2.28).

The data were also provided to AC/DC partner Unimore, who performed a much more sophisticated signal analysis, based on support vector machines.

The signals from the modular HF impact sensor in addition with the data about “driver stress” provide the possibility of an optimal vehicle set up for the current driving situation. For details please refer to the related section.

The results of the analysis have been interesting for other companies as well, who could take advantage of it for active axles control in the future.

Add-on functionalities have been divided into two main categories, listed below.

- **Driver Behavior**: these AOFs estimate current state of the driver in terms of cognitive effort (workload) spent during the driving task. Driver Behavior AOFs achieve information from driver’s actions hence from a human domain.

- **Driving Behavior**: the aim of these AOFs is to assess the drivers Behavior by estimating potential safety or critical conditions the driver may incur. This estimation is performed by elaborating data related to road conditions, current maneuver and vehicle dynamic detection.

These two macro areas can be considered as complementary. Actually, they cover two different aspects of the driving task.

### Driver behavior

The identification of the driving maneuver is a relevant input for the estimation of driver and driving Behavior hence, a specific AOF has been developed to discriminate several categories of maneuvers.

- **Car Following**: A car following maneuver is detected when the speeds of the vehicle hosting the AOFs and a preceding vehicle are the same and the driver of the preceding car keeps a safety distance, as constant as possible. The identification of this maneuver is an information that can be used to pre-alert safety devices (i.e., by increasing brake sensitivity) in order to prepare the vehicle to unexpected braking events.

- **Lane Change**: When the vehicle moves from the right lane to the left lane and vice versa, the combination of these changes is called a double lane change. As mentioned above, the online detection of the lane change maneuver...
Smart Modular Products

**Environment influences and road conditions**

Examples:
- Road surface condition
- Lane crossing recognition
- Road conditions (snow, ice, rain)
- Use of snow-chains

**Driver stress**

- Steering angle
- Speed
- Brake pedal
- Throttle pedal

**Modular HF sound sensor**

**BMW**

**Autoliv**

- Modular HF sound sensor

**UNIMORE**

- Driver stress signals

**Data evaluation with Support Vector Machine method**

**VW**

- Vehicle model

- Chassis adjustment (example: “damper”)
- Pre-crash detection
- Active safety reactions
- Speed limiter
- Active control and warning

Figure 2.29: Usage of Add-On Functionalities in the AC/DC cooperation

Enables, for instance, to activate driving assistance strategies, such as to pre-alert specific safety devices (i.e., braking system, Electronic Stability Program, etc.), to activate adaptive lights, or to change the configuration of some power steering system parameters.

- **Straight Line Driving:** A straight line driving maneuver is detected when the vehicle is driving on a straight road without traffic congestions.

The structure of the maneuver recognition algorithm is shown in Figure 2.31. First, data coming from the vehicle are processed and then classified by means of several binary machine learning algorithms. Each algorithm is able to detect a specific maneuver and it provides a value between 0 and 1 as output: this corresponds to the probability that the maneuver has been detected correctly. Finally, the estimated maneuver is the maneuver with the highest probability.
The Maneuver Recognition algorithm has been trained and tested on the UNIMORE driving simulator, shown in Figure 2.30. The results are shown in Figure 2.32 and Figure 2.33.

**Driving behavior**

Driving behavior AOFs are strictly related to vehicle dynamics and road conditions information. In particular, real-time identification of the road pattern represents a very challenging task.

Information provided by this feature could be used to refine vehicle dynamics or intervene on smart actuators and control units tuning: for instance, roll compensation and semi-active suspension systems are able to smooth the vibrations transmitted from tires to active axles and then from active axles to the driver.
Table 2.2: Road pattern recognition AOF: correct estimations ratio

<table>
<thead>
<tr>
<th>Road type</th>
<th>Detection performance [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth road</td>
<td>93.47</td>
</tr>
<tr>
<td>Cobbled pavement</td>
<td>72.30</td>
</tr>
<tr>
<td>Fine lateral gutter</td>
<td>83.54</td>
</tr>
<tr>
<td>Concrete slab road</td>
<td>82.28</td>
</tr>
<tr>
<td>River bed</td>
<td>51.90</td>
</tr>
<tr>
<td>Grass paver</td>
<td>73.42</td>
</tr>
<tr>
<td>Pothole road</td>
<td>45.57</td>
</tr>
<tr>
<td>One side on grass</td>
<td>65.82</td>
</tr>
<tr>
<td>Gravelly road (fortified)</td>
<td>75.95</td>
</tr>
<tr>
<td>Unfortified roadside</td>
<td>50.63</td>
</tr>
<tr>
<td>Gravel road / path</td>
<td>78.48</td>
</tr>
<tr>
<td>Lane line</td>
<td>70.89</td>
</tr>
</tbody>
</table>

The structure of this AOF is slightly similar to the Maneuver Recognition (see Figure 2.31), though it deals with different inputs. The algorithm receives data coming from vehicle bus as well as from the Sound Sensor Cluster made by partner Autoliv. Active axle vibrations are treated in order to discriminate among several road patterns. Results on a subset of different road patterns are shown in Table 2.2.

Overall framework

Both Maneuver and Road Pattern Recognition algorithms are intended to be integrated into a modular active axles framework to enable the reconfiguration of other sensors and actuators. Figure 2.36 shows how these AOFs can be implemented in a modular active axle. For instance, a special controller can be implemented to state the damping ratio of semi-active suspensions or to force on electric roll compensators depending on the detected road and maneuver.

Late customization

A standard sensor device gets a universal parameter pre-setting and will be delivered to the OEM. The final parameter coding is done by the manufacturer once, in accordance to the sensor mounting position and the actual vehicle type. Due to a safety analysis by partner BMW, according to the ASIL procedure [3], the best procedure is coding once in the vehicle and then read back the information after power-on.
The implementation of this procedure is already in preparation. There are several possibilities for late customization which range from the selection of preconfigured options such as inside the modular sensors up to the addition of single software blocks for special add-on functionalities or a complete replacement of the software.

The memory layout inside the ECUs has to be structured as shown in the Figure 2.35 in order to perform these multiple variant options.

The boot sectors should contain the software needed to communicate with different users and replace the associated software parts.

Again, it should be mentioned that this is not only restricted to the presented examples or active axles applications. To the contrary, it could easily be used for other functionalities anywhere inside a car as well, as long as the applied software is; clear in respects to the different requirements for the different applications.

As the example with the modular sensors shows, the concept is not limited by the size of the ECU although not all variant options are appropriate for all applications.

To successfully implement the concept, the multiple options have to be defined for each user during the design phase taking into consideration; the amount of resources needed for flexibility in the final application and also the resources needed for a safe development of the components.

A major factor is also the impact on production equipment and time, which will be the main restriction for the variants implemented inside a product, beside the price per piece.

2.2.5 Modular chassis ECU and Gateway

As previously mentioned, one of the aims of a modular rear axle is to provide an independent module,
which has no influence on the wiring harness of the car.

**Wiring harness**

This leads directly to different approaches for a gateway, located directly at the interface between axle module and the other electrical components of a car. These architectural approaches are linked with different advantages and disadvantages concerning the variant handling and therefore, the tactical choice of an electric architecture is important for the whole concept.

Figure 2.37 shows a first possible layout scenario of a wiring harness considering the rear axle as a module. The interface towards the vehicle body comprises of a power and a bus connector.

The gateway ECU serves as signal interface and controls the actuation of the semi-active dampers. In this scenario, there is no need for an additional ECU to control the semi-active dampers. Advantages of this scenario are the possibility of pre-testing the assembled axle module as well as time saving aspects at the final assembly line concerning the laying of the wiring harness. Additional actuators or sensors can be covered by a modular arranged ECU which provides the opportunity for plugging on additional components.

In comparison with scenario 2 presented in Figure 2.38, scenario 1 offers an increased variability concerning packaging and the design of the gateway, since the power connectors require much more space compared to the signal connectors.
In scenario 2, there is only one interface (consisting of two sub-connectors) towards the rest of the vehicle and in respect to the modularization thought, this is the most convenient solution. However, since packaging is very tight in modern vehicles, scenario 1 seems more appropriate.

**Design of a signal gateway and a power connector**

The vehicle interface remains the same, while additional actuators and sensors can be directly plugged to the central power connector and the signal gateway. Of course, these variants have to be foreseen in the design of the central power connector and the signal gateway. The laying of the cables in the body as well as the interface between axle and body is not affected in any way.

Figure 2.39 shows a prototype design for the power connector with the capability of connecting three smart actuators. The power connector distributes the supply voltage to the different actuators at the axle. The number of contacts needed depends on the number of actuators connected. One plug serves as power interface for the cable coming from the car body. Hence, the number of actuators plugged can be easily varied for different cars, if needed.

Figure 2.40 shows a possible gateway design for wiring scenario 2, which is pointed out in Figure 2.38. Of course, the design depends on packaging requirements as well as on the numbers of sensors connected to the gateway. For each type series, a different solution may be feasible, the
modularization concept, however, can be applied for different types of car and packaging solutions.

There are also different possibilities for the location of gateway and power connector. Since the packaging is a crucial issue for modern cars, the design and the possible location are very dependent on the package of the car considered. For those cars offering the advantage of mounting the gateway on the axle frame, Figure 2.41 shows one example how a gateway could be mounted at on the axle frame.

The signal gateway provides all sensors and actuators with bus signals and also includes signals of additional sensors which may be required by some actuators. Additionally, supply voltage for sensors and actuators with a current consumption less than 3A is provided by the gateway. The power connector provides supply voltages for actuators with a high current consumption. The preferred mounting position for the power connector is likewise directly on the axle frame. Different spatial requirements for different cars have to be taken into account as well.

**Platform software for a modular chassis ECU**

The goal of the platform software for a modular chassis ECU is to provide a modular concept for a chassis ECU which control magnetic coils in different chassis applications. Possible applications are:
2.3 Implementation guide

2.3.1 Overview of potential methods

For the creation of smart modular products, diverse methods can be applied, depending on the different phases of product creation. These phases include product planning and concept development, the design and testing phase, and eventually result in production planning and production.
Smart modular products are characterized by integrating features into physically uniform modules by means of software and parameterization. During product planning, Quality Function Deployment (QFD) can assist the transformation of customer requirements into features for sub-systems and components.

The design phase could be supported by a method called Design for Customization, which could work similar to well-known approaches such as Design for Assembly, Design for Test, or Design for Recyclability. This could be a collection of design guidelines, which represent an explicit form of procedural knowledge containing information about the modularization of products and integration of features and (mechanical) functionalities into fewer physical modules.

To prevent or reduce the likelihood of failures during production and use, the Failure Mode and Effects Analysis (FMEA) can be applied at an early stage of the product development. A Product- and/or System-FMEA is particularly crucial for complex systems such as mechatronic modules.

Along the later phases of the product development, the resulted new product technologies must be approved or certified by the developing partners. This technical validation can be supported by methods such as remote testing and electrical network simulation. These methods will be described in the following subsections.

Production and supply chain management-related methods are presented in the subsequent main sections.

### 2.3.2 Advanced ECU testing approaches

New approaches for system tests in Extended Enterprise (EE) environment during the development phase are indispensable to shorten time to market for the development of intelligent mechatronic components and their integration in the overall automotive board network system. These approaches are also necessary to ensure the reliability and safety requirements for all potential car variants. In addition, they represent a key prerequisite for reliable production processes in respect to the product variant configurations, assuring the supply of the correct software version at the right time. It also provides an excellent basis for a reduction of efforts for the variant management at the OEM.

In this context, the integration and system tests of ECUs (provided by different suppliers) at OEM sites in the different development life cycle phases (prototype, pre- and production model, etc.) represent cost, time and critical quality processes. Since the electronic components are provided by different suppliers, the integration of the final system and its validation has become more and more difficult and time-consuming. Moreover, the functional range of automotive electrical systems, and therein included ECUs, has strongly increased in recent years. At the same time, the terms and conditions for development and testing are drastically changed by shortening product cycles, development times and overall time to market. Furthermore, practical experiences clearly indicate that identified errors or problems in the scope of the system integration tests may have consequences on all system development steps. All these circumstances, i.e., increased testing requirements and shorter development times, require an even more intensified interaction of all involved partners to speed up the overall development and testing pro-
cesses, also enabling an early elimination of sub-system, interfacing, and interaction errors.

The electronic car-board subsystems are currently developed fairly independently resulting in a late physical integration tests in the overall car-board networks at the OEM site. A crucial issue represents the strong interdependency between the development and system-oriented testing processes and the wide scope of involved participants at the OEM and supplier sites. To overcome this situation, presently preventing a dynamic and reliable supply loop network between OEM and suppliers, the existing interaction obstacles between development and system oriented testing processes need to be eliminated. In this context, the key critical issue to be improved within distributed development and testing processes is the insufficient knowledge and information exchange (e.g., test data and results) between the OEMs and the suppliers, leading to late identification of errors (e.g., regarding interaction of ECUs), among others.

Such situation requires the re-engineering of the actual distributed development and testing processes, by a cooperative execution of integration and system tests of ECUs, enabling an early and reliable identification, analysis, and elimination of errors. Using this approach, a drastic increase of the efficiency and result quality of the distributed testing activities between the OEM and its suppliers can be achieved, leading, among others, to the harmonization of testing steps, scope, and content to avoid test duplication, or missing test coverage between involved partners. Besides the targeted reduction of errors or problems in the scope of dis-
In reference to this situation, ICT support solutions for three operational interaction models of OEM and suppliers ECU testing processes were developed, addressing the following distributed testing modes:

1. Remote diagnosis of ECUs;
2. Remote testing of ECUs; and
3. Online testing of locally distributed ECUs.

Main objective of all three interaction processes is to support collaboration activities between various involved testing and development areas, departments, and groups at the OEM sites as well as at different supplier sites. Therefore, the three distributed testing modes are targeting the achievement of the following key benefits in distributed testing processes:

- Supporting distance testing and analysis of the ECUs, which are not on-site;
- Enabling failure analyzing, or rather having direct access to ECUs in order to execute functional tests, etc.;
- Units can be analyzed locally, thereby saving delivery costs and time; and
- Contributing to an efficient OEM-supplier cooperation, enabling an increase of efficiency and result quality of the development and testing procedures.

Moreover, all distributed testing nodes can be easily integrated in existing tests and analysis environments, enabling a simple and flexible connection to the existing testing configurations and use of existing analysis software, e.g., for failure diagnosis. The specific key characteristics of all three operational interaction scenarios are presented as follows:
Remote diagnosis of ECUs

Key objectives of the remote diagnosis approach are to achieve a direct online access to ECU real-time test data, enabling the presentation and joint analysis of failures, and improvement potentials. Therefore, the remote diagnosis testing mode enables to “record” ECU real-time test data (e.g., from domain testing configurations at the OEM sites or ECUs Hardware-In-the-Loop (HIL) testing environments at the supplier sites), transfer them via TCP/IP to a recipient, as well as to replay and analyze the ECU real-time behavior at the recipient site with less time offset.

By this unidirectional transfer of CAN bus messages via an IP network the remote diagnosis approach will enable the supplier to access, e.g., CAN bus messages of dashboard testing configurations at the OEM site in order to analyze failures, or rather enabling the OEM to have a direct access to ECUs at the supplier site in order to execute functional tests. Existing CAN analysis software can be used for debugging. Just a simple CAN bus connection is needed. The remote diagnosis approach represents an enabling technology to realize the diagnosis of locally distributed ECUs at OEMs and supplier sites.

Remote testing of ECUs

Key objectives of the remote testing approach are to achieve an effective reduction of user interaction in integration and system tests of ECUs. Therefore, the remote testing approach is targeting the automation of currently manual driven testing processes, as e.g., by realization of a centralized control, monitoring, and validation of locally distributed testing configurations. By this, the approach will also promote the harmonization of test cases and procedures to avoid test duplication or missing test coverage between involved partners. Therefore, this approach requires highly automated testing processes, e.g., by the substitution of manually driven testing steps due to robotic-driven activation of user interactions and monitoring of system reaction.

By this approach, the execution of head-unit audio tests can be mostly automated, covering test control, monitoring, and validation of input and output signals. Therefore, the remote testing mode enables the automation of testing procedures for speech interaction of the driver with the ECU including the analysis of system reaction, as well as testing procedures for automating the detailed
sound assessment of the ECU reaction, to test, e.g., the activation of correct CD tracks, volume levels, balance, up to the analysis of the frequency spectrum. This testing mode covers the complete testing cycle: the remote specification of test sets to be executed by a test specification language, the remote activation of the HIL testing environment, the automatic execution of specific tests, as well as the feedback of the assessed test results to the testing application at the remote location.

**Testing of locally distributed ECUs**

Key objective of the distributed testing approach is to test the ECU interactions in a network of locally distributed ECUs at various supplier sites. With this new methodology, functional tests on many vehicle ECUs and electronic components are now easier and faster since the OEM does not need to physically receive all the components before performing tests. A key objective of the distributed testing methodology is to allow testing execution between OEM and suppliers using Ethernet transmission to exchange data. It is virtually possible to transmit data at any distance and with any kind of connection supporting the Ethernet protocol (e.g., LAN, Wifi). Tests can be performed between different suppliers, between OEM and suppliers but it can also speed up the development process between different divisions of the same company.

The distributed testing approach is based on a client-server architecture: typically, the server is located at the OEM plant and supervises the complete testing procedure. Each supplier can join the testing platform with one or more CAN nodes connected to a client. One can perform functional tests and debugging in a network of locally distributed ECUs by using this service, without having hardware and software on-site. This approach speeds up the development phases and reduces development cost and time to market.

**2.3.3 Electrical network simulation**

The number of electrical actuators is increasing constantly in modern vehicles. Most actuators, which were operated hydraulics, are being replaced by components which obtain their energy from the electrical system (e.g., fuel pump). Most of these actuators are located in the active axles of the car and perform add-on functionalities, improve comfort, safety, and the vehicle dynamics. Some important components, which perform the functions mentioned above, are: EPS (Electronic Power System), electric dampers, electric roll bars, and the ESP (Electronic Stabilization Program).

The main advantage of electrical actuators is that they only use power if they are active (unlike hydraulic components). Power on demand systems reduce fuel consumption and are thus energy efficient but they obtain their power and energy from the electrical network.

The electrical network was not originally built to provide high power peaks as they are demanded by an Electronic Stability Control (ESP) and Electronic Power Steering (EPS). In addition to that, the lifespan of lead acid batteries is decreased due to the power consumption caused by high peak currents, which results through high cycle frequency.

**Hardware in the loop (Hil) test bench**

As a result of high current peaks, the voltage level of the electric network can fall below a critical level, at which jitter in headlamps or passenger compartment illumination occurs. Above all, in some situations, ECUs may malfunction and the safety of the car can be jeopardized. Today, lots of emphasis is placed on development to insure stability of the electrical network guaranteeing permanent stability at all times. Stability analysis is done by road tests, which are very time-consuming and
hence cost-intensive. In order to reduce development costs and increase reproducibility of network stability tests, AC/DC partner Volkswagen has built a HiL test bench which reduces time-consuming road tests (Figure 2.46).

The test bench consists of a real-time computer on which a car model is simulated. This car model was extended to accommodate mechanical and electrical models of the high-power consumption components such as EPS, torque vectoring, magneto-rheological dampers, and active roll bars. Various driving manoeuvres can be simulated with the extended car model.

A hardware test bench with a battery and a synchronous motor driven generator (Figure 2.47) has been constructed to test the influences of the high-power peaks on the net power. The motor simulates the combustion engine speed of the vehicle dynamics model on the generator. Load and charging currents can be applied to the battery by an electronic current source and a current sink. The vehicle dynamics model computes the currents needed or produced in accordance to the actual driving condition and voltage level of the battery.

With the help of this test bench, driving manoeuvres and driving conditions can be identified
which lead to unstable electrical network conditions. On the test bench, other components such as ultra-capacitors, DC to DC converters, and Li-ion batteries can be integrated, and their influence on the network stability evaluated.

Besides, an approach for an optimal-power vehicle controller can be implemented which controls the smart actuators of the active axles. In this approach, a control strategy is implemented which is optimized for vehicle dynamic performance and power consumption.

**Powernet simulation**

In the project, the net power of a sports utility vehicle, a car with 4-wheel drive and off-road capabilities, is simulated. This SUV model was equipped with the following smart actuators:

- Torque vectoring on the rear axle;
- EPS;
- MR dampers; and
- Active roll bars.

For simulation, the double lane change at 80km/h was chosen as manoeuvre. In this manoeuvre, all
components are active, and thus consume a lot of current, which results in a high power load for the battery. In addition, a constant load current of 100A was simulated, to represent constant loads such as seat heating for example and other energy consumers. This leads to a high constant load of the generator, and only a small capacity to compensate the power peaks from the actuators.

One possibility to decrease the load on the battery is a double layer capacitor (DLC), connected in parallel to the smart actuators. With a layout like this, the high power peaks from the actuators will be buffered by the DLC.

The simulation (Figure 2.48) clearly shows that, with the help of a DLC, the voltage of the net power is much more stable, and the voltage peaks can be reduced down to 60%. In Figure 2.49 the simulation results for the different battery currents are displayed. The utilization of a DLC confirms that the high current peaks are filtered by the DLC and thus, the current peaks in the battery are reduced to one third.

2.4 . . . And the future

2.4.1 Energy consumption

When the electric network was established in cars, a 12V Pb-acid battery and a generator with an average efficiency were enough for a stable net power because only a few loads were applied. Over the years, the number of devices, with power consumption, increased enormously. A number of loads typical to that of modern cars in an electric network are demonstrated in Figure 2.50, the consumption of all these components can easily sum up to a power demand of 1–2kW. Considering that the generator of a modern middle sized car produces a maximum current of approximately 150A, which equals to a power of 2kW, it is evident that
the electric network in its present form suffices the limits, or even exceeds them, as shown in Figure 2.51.

In recent times most components which were hydraulic powered or mechanical are electronic based or electrical actuators (e.g., electronic power steering). Hence the implementation of the new technique “mechatronic” deriving from “mechanical” and “electronic”, whereby electrical impulses are converted to mechanical actuation.

There is a major focus on electric powered active axles control systems in current research projects. Volkswagen recently conducted research on an ERC (Electronic Range Control) system and an active EBC (Electronic Body Control) system. Both systems improve driving comfort and dynamics. Both systems have the common task to convert previously passive systems into modern active systems such as the damper or the roll bar. Active axles control systems are well-known to the market but are usually actuated by hydraulics. Another advantage is that the reaction times by these systems are in the nano second time frame so road handling errors can be corrected almost simultaneously.

The disadvantages of these hydraulic systems are their continuous energy consumption and their assembly costs. With systems such as ERC and EBC, partner Volkswagen showed that the mentioned disadvantages can be avoided with systems which are electronically based. The challenge of these power on demand components is to compensate their influence on the stability of the electric network.
DLCs now fulfill automotive specifications in recent times. Hence, a number of new net power concepts can now be developed.

Enhanced hardware concepts should be taken into consideration during development in an effort to stabilize the electric network.

The following concepts will help to stabilize the net power with the help of DC to DC converters and DLCs:

- Net power with secondary voltage level, for stability and optimal recuperation;
- Net power with secondary energy storage in a DLC; and
- Net power with free running generator.

Especially the concept with a free running generator (Figure 2.51) will help to stabilize the entire net power. With a free running generator concept,
efficiency of the generator is improved and thus recuperation and net power stability for loads with high current demands.

2.4.2 Modular components in other functions

The concept of modularization, which has been described in subsection 2.2 “rear axle demonstrator”, can also be applied to other parts of a car, for example, a front axle (Figure 2.53) or a driveline module (Figure 2.54).

Beside sensors, a front axle module could connect the following smart actuators:

- EPS;
- ERC; and
- Semi-active dampers.

A driveline module can be used to connect the following actuators to a centralized power plug and a signal gateway:

- Torque converter;
- Transmission;
- Transfer case;
- Front differential gear; and
- Rear differential gear.

The add-on functionalities of advanced software could also be useful in other automotive sensors such as lane departure warning, acceleration, or driver monitoring sensors. Late customization of advanced software could also be used to create non-vehicle specific sensors, e.g., roll over, parking, or rain sensors.

It is also possible that in the future, the modular rear axle could be equipped with propulsion components for electric vehicles. For example, the torque vectoring gear could be replaced by an electric propulsion engine and a rear differential gear. Of course, the voltage level of a propulsion engine would be different to the 12V voltage level, which is used now by the rear axle components. A possible solution for the different voltage levels could be the implementation of a DC to DC converter into the rear axle module. Thus, the central power connector of the rear axle module is connected to the higher electric propulsion voltage level while the standard axle components, which use a lower voltage level, are connected to the DC to DC converter, which supplies them with the necessary voltage level.
One essential effect of the financial downturn in late 2008, is the general lack of cash and financing sources which induced serious impacts on the automobile industry, especially the decline in sales which caused a dramatic decrease on market demands coupled with the upcoming cost pressure on the whole supply chain.

The arising challenge, especially for the sub-suppliers in the automobile industry, is therefore the substantial reduced predictability, which imposes even higher capacity and flexibility demands of the OEM. The ability to operate a supply chain network becomes a decisive role for suppliers. Goal-oriented strategies to strengthen the European Car Industry are firstly, branding and differentiation to deal with the increasing individuality, the needed flexibility and the demand for a high-class image. Secondly, the reduction of delivery times which requires fast responses of a highly flexible overall production system thereby maintaining low working capital. Lastly, the questioning of traditional production strategies by introducing approaches such as build-to-order (BtO).

Enabled by the usage of recently implied customized car parts and modules, the vision behind AC/DC is to provide a vehicle production and supply system to deliver a customer ordered vehicle in five days. This vision not only targets short order-to-delivery times and low stocks, but the overall flexibility of the automobile production grid.
3.1 Problem definition

The present automotive market situation has now forced OEMs who originally built high-tech customized cars using the build-to-order (BtO) network to compete against OEMs who produce models with limited variants using the build-to-forecast (BtF) supply system. The advantage of the build-to-forecast system is the ability to plan the production on low stocks, optimized lot sizes and sequences and avoidance of the bullwhip effect which leads to increased stock upstream of the supply chain. The BtO approach offers the customer the possibility to configure the desired car of their dreams at an extra cost as shown in the recent study “FAST 2015” by VDA, Mercer Management Consultants, and Fraunhofer-Gesellschaft [45].

The problem of OEMs offering a multiple of variants using BtO are complex logistics, longer lead times and consequently the need for a highly flexible and reliable supply network planning and control approach to deliver the demanded car quickly and on time. Efficient planning of procurement, production and shipment is therefore becoming a more significant complex task throughout the complete supply network. The study FAST 2015 has proven that the ability to plan such a central complex supply network is not possible. The planning and operational complexity in today’s European automotive supply networks results in a lead time of 40 days between the customers order and the final assembly at the OEMs assembly line.

**Customize-to-Order**

Methods developed during the AC/DC project demands a radical reduction of the supply network lead time and increases planning flexibility to overcome the long order lead time mentioned above and to reduce intensive costs. AC/DC developed an approach called **Customize-to-Order** which combines the advantages of the approaches build-to-order and build-to-forecast.

The production system is widely customer-anonymous and based on late customization of parts in the assembly line. The CtO paradigm can be applied for every part of a car which is configurable as late as possible, e.g., using software or through parameterization. The concept implementing the CtO production system is called **Dynamic Supply Loops (DSL)** [M3.1].

**Advantages of the Dynamic Supply Loops**

The Dynamic Supply Loops assure 100% reliability of delivery to the customer (i.e., reliability of delivery by the OEM). The core concept of the
DSL is a flexible readjustment of the supply network structure based on collaborative continuous planning processes in closed loops between tier_\text{n} and tier_{\text{n+1}} mainly on strategic and tactical planning level as well as on operational level focused in event handling processes. All planning processes are based on a one-stage feedback loop to support process reliability and prevent long adjustments of the planning processes and assure the usage of lessons learned principles for a continuous process improvement.

**Collaboration, speed and flexibility**

The Dynamic Supply Loops are based on several core process models:

- **Collaboration in forecasting and planning:** Through utilization of historical data combined with known future changes in the system environment and principles of collaborative data exchange throughout the supply chain, consistent data can be used for planning and forecasting. AC/DC developed principles taking confidentiality of customer demand data while using them to generate collaborative inter-company forecasts.

- **Fast, secure and easy-to-access communication protocols:** The AC/DC messaging service offers services for process automation supporting easier collaboration in the supply network. It implements the feedback principles required for the DSL application and enables SME integration.

- **Event detection and handling:** Processes have been defined, implementing a preemptive and real-time event detection and handling integrated in the Red Adair Toolbox for improved planning flexibility on the shop-floor.

Implementing the principles of the DSL strengthens the advantages of less complex supply network planning. They assure a better utilization of network capacities according to customer demands and increase the flexibility of production system and planning speed at each step (partner) of the supply chain.

**Structure of Section 3**

During problem definition, actual challenges in European automotive industry have been analyzed and linked to specific requirements which are to be tackled by DSL.

Subsection 3.1 discusses the requirements and assumptions regarded during the DSL development process.

Subsection 3.2 gives a summarizing overview of the methods implementing the DSL concept. Additionally, a short overview describes the advantages using the DSL approach is provided.

Subsection 3.3 illustrates the application of selected methods while subsection 3.3.1 presents an outlook for further application of the DSL.

**3.1.1 Planning observations for the automotive supply chain**

Today’s supply chain in the automotive industry is organized as a hierarchical upstream planning system, proceeding top-down from the OEM to its suppliers [17]. The planning process thereby encodes restrictive planning conditions by the OEM. These conditions force the tier_1 suppliers to fulfill the OEM’s specific demands without compromises and to deliver the needed information to generate a robust and reliable plan for a longer time period at tier_1. The same pattern is repeated between tier_\text{n} and tier_{\text{n+1}}. Hence, the tier_{\text{n+1}} supplier loses flexibility in its planning procedures. Instead of
controlling its own material flow and planning cycles, it is compelled to react more and more to tier\textsubscript{n} needs.

Forced by the supply chain, the sub-optimal collaboration of tier\textsubscript{n} and tier\textsubscript{n+1} lead to several problems:

- Loss of optimization potentials in local planning decisions due to restricted information policies;
- Capacity overloads because of uncertainty according to future demand developments and the need of an enhanced event handling system to react quickly to uncertain demand changes; and
- Material shortages occurring.

These circumstances lead to an unstable and nervous system wasting time and money for keeping it stable and therefore increases the product price while reducing the accounts.

Summarizing these problems, the current automotive supply chain is not operated optimally according to cost and benefit issues taking the specific situation of each partner in the supply chain into consideration. E.g., the OEM can optimize its costs while forcing the tier\textsubscript{1} supplier to deliver only just in time.

### 3.1.2 Requirements towards collaborative planning methods

A new planning approach must therefore regard all previously illustrated problems, driving the overall system towards a better performance in terms of lead time (speed), reactivity due to When considering the structure of the automotive supply chain as a competitive environment, the DSL planning approach should guarantee local planning autonomy using decentralized planning and application of local planning systems including multi-criteria decision made at each partner in the supply chain, thereby regarding non-local planning preconditions and information about the tier\textsubscript{n+1} supply chain partner. Details of this problem have also been analyzed by Döring [13].

The DSL should allow competition between partners in the supply network. It should also support cooperation between the partners whilst optimizing the whole supply chain avoiding local minima and using principles for benefit sharing (see subsection 3.2.6) as an incentive for participation in the system.

More information should be shared (see subsection 3.2.2) to consider tier\textsubscript{n+1} supplier's conditions when planning at tier\textsubscript{n} or OEM while avoiding information overflow and unstructured information exchange. A simple protocol is needed for an efficient, bidirectional communication process. This
Dynamic Supply Loops

extends existing standards in automotive industry such as ODETTE and enables smaller suppliers to obtain a simple access to essential network-wide information as well (see subsection 3.2.4). *Elimination of conflicting process chains* will be an additional effect implementing the DSL principles.

To handle the amount of possible variants, the DSL combine push and pull principles in the CtO principle using late customization.

Finally, the DSL must offer a clear improvement compared to the current procedures, and the resulting costs needed to apply the developed approach, methods, and tools have to be substantially lower than the expenditures of existing supply chain planning and control approaches such as build-to-order.

### 3.1.3 Concrete business benefits of DSL supply chain co-ordination

Several problems have been evaluated when summarizing the present situation in the automotive supply chain. The low level of synchronization of demands and capacities due to restrictive information policies implies consequences at the inventory level, communication process efficiency, event handling issues, and shop-floor planning in the whole supply network, leading to:

- Material shortages;
- High inventory levels;
- Unutilized capacities;
- Double marginalization;
- Strong sub-optimization in local optima;
- Lack of communication and information flow;
- Reactive rather than proactive management;
- Slow and not standardized processes;
- Higher costs; and
- Loss of assets.

Using the Dynamic Supply Loops and its methods, the business should be improved tremendously:

- Increasing the production of modules (components knocked down), which are customized later in the process and which naturally support the Customize-to-Order production concept thereby reducing the production process complexity, especially at major tiers and bigger SMEs.
- Reduced planning can be supported by automation, standardized processes—from demand planning to detailed production planning thereby eliminating redundant unnecessary planning processes.
- Usage of reliable forecasting based on optimized methods for Customize-to-Order production systems over long periods (>18 months) leads to proactive event prevention, optimal capacity utilization, less inventory, and controllable replacements.
- Usage of collaborative planning and execution supports the achievement of a globally more optimized supply network in regards to costs and of benefits by better planning results while managing collaboration risks.
- The DSL establish a fail-safe real-time event management for reoccurring events, taking effect on operative or strategic plans by collaboratively re-establishing a globally beneficial plan.

### 3.2 Dynamic Supply Loops

The Dynamic Supply Loops specify a possible coordinated process for planning and controlling supply networks while minimizing planning effort and communication overheads, designed primarily but not exclusively for automotive supply chains [M3.2].

#### 3.2.1 Main principles of the DSL

DSL methods with the four basic principles incorporate faster and more flexible network planning and
operation. These principles could be defined as the significant foundation for the implementation of the DSL method which influences the positive effect of the DSL method in accordance to planning and delivery reliability, planning and operational flexibility as well as to costs and benefits for the partners in the network.

**Decentralized planning**

The DSL planning processes are decentralized. There is no central instance to plan or control the entire or specific segments of the network. This assures the planning and operational autonomy of all partners in the supply network. A frame plan will be instantiated at the launch of the supply network to ensure reliable decentralized planning and control processes. This framework plan will be continuously monitored during the network operation phase and adapted to upcoming demands on a regular basis.

**Only tier-to-tier communication**

All communication will be carried out by tier-to-tier communication channels only. This simplifies the communication processes as there are only bidirectional communication channels needed between two partners and “chaotic” cross-network communication is excluded. Based on this assumption, the complexity of all adjustment processes during planning and network operation can be reduced to a simple force-feedback loop system, the DSL. This simple communication structure supports data visibility (storing, transferring, and retrieval) over the complete network thereby promoting fast reaction time or practically simultaneous response. Consequently, the DSL collaborative planning and operation processes can be executed on a less complex frame.

**Collaboration principles**

Collaboration principles have been defined and established based on the DSL concept. The usage of collaboration concepts facilitates a win-win situation for all involved partners. The planning processes must be synchronized at an inter-organizational level (e.g., planning horizons, etc.) to enable collaboration. Data must be visible in real-time. A major collaboration aspect in supply networks is the inter-organizational alignment of forecasting and event handling processes during supply network execution. The partners must be open-minded towards collaboration activities in order to establish the collaboration processes and enable possible potentials activities. Clear and reliable responsibilities must be defined in the agreement phase during the supply network footprint planning phase to support this process.

**Customize-to-Order using customer-neutral parts**

Mechatronic modules which are customized by flashing or programming software at a very late stage in the production process have been developed using AC/DC concepts. This enables the DSL to set up all planning processes based on a customer-anonymous series production up to the point of customization (see Figure 3.3). This is the essence of Customize-to-Order. A customer-anonymous series production system enables the advantages of economies of scale (cost reduction) and simplifies the adjustment processes from tier-to-tier. Based on this assumption, all methods developed for the DSL can be optimized for this type of network (mainly the forecasting methods!) and stocks can be reduced dependent on the framework plan forecasting data. The result will be a flexible and reliable network planning and control system.
Figure 3.3: Building blocks of the Dynamic Supply Loops
Demand-oriented planning

The Dynamic Supply Loops will be operated based on demand-driven planning. Demands are thereby communicated optimally from tier\(_n\) to tier\(_{n+1}\), using cumulative quantities as net demands. The demands are committed or changed according to the supplier’s demands (e.g., quantities, individual calendars) from tier\(_{n+1}\) to tier\(_n\) and used as feedback. In long-term (5 years) and mid-term (18 months) planning, demands are calculated by collaborative forecasting algorithms. Demands are communicated through the entire network enabling all partners to optimize their internal production schedule. Production control within the plants or for mass production parts (C parts such as screws, etc.), suppliers can also be controlled by consumption-driven approaches such as pull-oriented production systems controlled by KANBAN (see Section 4).

3.2.2 Strategic, tactical and operational planning

The DSL (see Figure 3.4) is operating on two different levels of the supply network, the network level and the plant level. The DSL uses different adjusted planning methods at the two levels implemented by feedback loops for data communication and planning algorithms:

- The strategic loop generates the framework plan for the whole supply network, extrapolating a 5 year period. The plan is used as general planning agreements (e.g., expected demands, needed capacities, and locations on product platform level) and is valid as constraints for generating tactical and operational plans. The generation of framework plans has been described by Timm [43] using a hierarchical optimization model.

Figure 3.4: DSL planning model

[Diagram of DSL planning model]
Dynamic Supply Loops

- The **tactical loop** offers planning methods for generating rolling demand plans with a time span of up to 18 months.
- The **operational loop** processes occurring events based on operational plans and regards shop-floor flexibilities.
- The **real-time event loop** will monitor and process all events in the supply network and is part of the operational loop. The processing of events can be based on intra-company and inter-company processes. The major process steps in event handling are the identification and classification of the event, the analysis of events consequences resulting from events, and the evaluation and assessment of the consequences followed by a suitable initiative to be executed. After finishing the event handling process, feedback from involved partners should help to improve future event handling routines.

**Implementing the DSL**

Implementing the listed requirements, the system should be very robust and less instable because its theory is based on reliable long-term and mid-term plans and it can react to unexpected events by exploiting shop-floor flexibility.

By using the DSL, the traditional hierarchical automotive supply chain planning concept will be modified to establish a one-step feedback planning loop between tier\textsubscript{n} and tier\textsubscript{n+1}, between any OEM and/or supplier as shown in Figure 3.4.

Tier\textsubscript{n} will propose several planning scenarios to its suppliers at tier\textsubscript{n+1} and ask them for specific cost statements. The scenarios implicitly include the knowledge about the plant locations, flexibility, and delivery conditions of the suppliers. The idea is to propose those scenarios only, which could be fulfilled by the supplier according to formerly defined delivery agreements. Tier\textsubscript{n+1} will calculate scenario cost statements using its own planning facilities (e.g., an Enterprise Resource Planning (ERP) system) and communicate those back to tier\textsubscript{n}. This feedback will be used by tier\textsubscript{n} when making a final decision on the distribution of demand figures to the tier\textsubscript{n+1} supplier.

The resulting process is a strictly structured negotiation process, which can be implemented easily and facilitates fast reaction times. Considering implicit information on tier\textsubscript{n+1} during the scenario generation at tier\textsubscript{n}, the accepted plans will be more focused to the actual situation at tier\textsubscript{n+1}, in opposition to the traditional upstream planning procedures in today’s automotive supply chains. This information includes, e.g., the knowledge of capacity capabilities, flexibility agreements, quality issues or specializations as well as the framework plan at tier\textsubscript{n+1}. This implicit information will be gained by collecting information about tier\textsubscript{n+1} at tier\textsubscript{n} and by using new protocols based on EDI standards.

The supplier becomes more flexible, now being able to reduce its costs and stocks as a result of focused and reliable demand plans from its buyer. Furthermore, it can evaluate various alternatives and express its preference in terms of prices. When choosing the final scenario, not only costs but other factors such as lead times or inventory levels must be taken into consideration too [M3.3].

**3.2.3 Collaborative forecasting**

For every business, the starting point for capacity and flexibility decisions is a forecast of the future demand. AC/DC suggests methods and tools to create a reliable demand forecasts and how information is shared amongst partners (collaboration). Decisions about capacity changes can thus be made with reasonable reaction time (speed). Collaborative forecasting also includes methods to
measure the forecast precision, which is necessary to estimate the required flexibility.

**Collaboration in demand prediction**

Figure 3.5 shows the AC/DC model of collaborative demand prediction and how two supply chain partners, e.g., tier\(_n\) and tier\(_{n+1}\), may share demand and forecast information.

The proper level of collaboration must be recognized, when formalizing the collaborative agreement. This will depend on the specific situation, capabilities, planning horizon, etc.

Recent models of collaborative forecasting described by Småros [40] suggest a staircase model, in which more complex information is shared for each step. Step by step, the actors produce and share data obtaining improved quality. The shared data can be raw data (e.g., historical data), adjusted data with qualitative criteria, forecasted data, adjusted forecasted data, etc [M3.4].

There is a risk with supply chain collaboration whereby each actor has to make his detailed information transparent to other actors in the chain. These details may include information on the market and production regions, on the type of customer, etc. In other words, disclosing information to other partners is a very sensitive and critical risk in business. *Statistical disclosure limitation* (SDL) is a method to guarantee the protection of sensitive information before a data set is published. In general, the scope is to provide the data users with useful statistical information, while assuring that a number of individual details are protected [M3.5].

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*Figure 3.5: The AC/DC model for collaborative forecasting*
A forecast is an approximate assumption for the future based on the best available information at the present. The AC/DC model includes a recommendation to measure forecast precision, which facilitates a discussion about the forecast error, based on facts. A measurement model needs to be defined for the specific needs in the collaboration, and has to be agreed by all users and forecasters [M3.6].

Several aspects should be considered before choosing the appropriate level of collaboration. Some of these aspects are: lead time, inventory policy, price variations, planning horizon, product life cycle, reaction time, and flexibility.

**Level 1—Create connectivity and visibility**

First of all, collaborative demand prediction is defined by associating actors in the supply chain and by making demand information transparent along the supply chain. In this section, the prerequisites for the connectivity and visibility are presented.

Beside the required internal integration within each company, a key element in DSL is the collaboration amongst the actors in the chain. The same issue applies to the forecasting phase: enhanced results can be obtained and globally optimized strategies can be devised if the OEM and its tiers are able to cooperate in producing a more accurate vision of the future sales.

**Level 2—Create system generated forecast**

The second level of collaborative demand prediction deals with creating a system generated forecast.

Data parties a vital aspect in forecasting. It is important to know how to analyze and treat data, how many observations to use, etc. Decades of research and development has resulted in a wide range of forecasting methods [M3.7].

In Figure 3.6, we find statistical methods, which analyze data to identify a pattern which is assumed as repetitive. In time series models, one variable is used to detect trends or seasonal patterns. Explanatory methods are used to detect a cause-and-effect relation between two or more variables [M3.8].

Judgmental methods include systematic collection and processing of knowledge from experts in a certain topic in order to predict the future development. The result from judgmental methods should have a forceful impact on the forecast in forecast horizons longer than 12–18 months [M3.9].

The right choice of a forecasting method largely depends on the specific situation. Derived from empirical findings and expert opinions, Arm-
strong [2] created a selection tree for forecasting methods. The selection tree is a flowchart, which consists of different branches and finally leads to a forecasting method depending on the situation [M3.7].

Level 3—Create qualitatively adjusted forecast

At the third level, the system generated forecast is adjusted according to information from qualitative decisions. The monthly sales and operations planning (S&OP) process [14] include input and decisions from many parts of the organization.

The S&OP process will also take more information into account than pure demand data, and will include qualitative adjustments to the forecast. Qualitative adjustments will be necessary if:

- There is not sufficient data to determine the impact of a demand driver; or
- Statistical methods fail to predict future behavior of a demand driver.

Figure 3.8: From demand model to forecasting process

For the latter, it is necessary to have facts about the forecast precision. In a monthly planning process with a planning horizon of 12 months, one month will be forecasted 12 times.

The forecast for one specific month will likely be changed during the planning horizon. The variations in the forecast will be the reason for new capacity decisions in the supply chain and can increase cost for these changes.

Level 4—Compare forecasts and collaborate on exceptions

Level 4 is the most important additional quality in which not only the forecasts themselves are shared but also information about the partner’s forecasting process and the factors upon which the forecasting decisions are based.

The corporate strategy is likely to influence the forecast to a great extent. Figure 3.8 describes how the forecast model includes interpretation of the data for the demand drivers A, B, and C, but finally also the corporate strategy.

Exceptions that are identified when comparing forecasts made by the buyer and the seller can be resolved by going deeper into collaborative comparison of the forecasting processes. This includes comparisons of:
• Demand drivers;
• Interpretations of the demand drivers;
• Corporate strategies; and
• Decisions made, based on forecasts and strategies.

The framework for collaboration level 4 considers a process of comparing both, the result of the forecasted volumes but also the rationality behind this. The rationality is considered to consist of data, interpretations, and the corporate strategy. When exceptions are identified, the forecasting process and assumptions should be revised thus leading to an agreed business plan. Agreement on a business plan opens up great opportunity for strategic synchronization, thereby extraordinarily strengthening the collaborative partners against market pressure. Before achieving this status the first three steps in the collaborative staircase must have been taken.

3.2.4 Messaging service in Dynamic Supply Loops

In order to assure a reliable and consistent plan at all tiers of the supply network, the communication between OEMs, suppliers, and further partners must be organized in an efficient and transparent manner (collaboration). Whenever possible in a DSL, data communication should be established within the loop i.e., between tier\textsubscript{n} and tier\textsubscript{n+1}. A simultaneous update should guarantee consistent and coherent data sets at all tiers (speed). The dynamic planning and execution loops should also support the combination of central and decentralized planning. All these requirements call for novel standards and interfaces of the planning and coordination processes. This includes in particular the standardized exchange of information simultaneously, reliability, and a security communication network as well as a common understanding of the communicated terminology (flexibility). Following these drives, the AC/DC messaging service and ontology were developed to ensure interoperability between enterprises on three levels:

1. The infrastructure;
2. The protocol which determines what and when to communicate; and
3. The conceptual level which defines a common dictionary.

Technical details of the messaging service

The AC/DC messaging service was conceived upon the following assumptions [M3.10]: First, the communication between partners in a given supply chain is realized by sequential exchange of messages through direct point to point links in the Internet respectively Intranet. This means, a message originated by a partner (company A) to a given supplier (company B) does not go to any intermediate element but instead is delivered by means of a reliable and secure protocol (see Figure 3.9).

Secondly, a state of the art survey revealed two potential candidates: the traditional EDIFACT (Electronic Data Interchange For Administration And Commerce and Transport) solution already in place at AC/DC partner Continental and involving some of their suppliers, as well as a more recent technological solution based on the usage of the ebXML (Electronic Business using eXtensible Markup Language) messaging service (ebMS).
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Figure 3.10: AC/DC messaging service API

Hence, the messaging service had to support both, legacy EDI (Electronic Data Interchange) and EDIFACT standards as well as OASIS/ISO ebXML messages (see Figure 3.10). The message can be sent directly from a company’s ERP system or from an email application supported by a graphical user interface for message creation, editing, and tracking (see also subsection 3.3.3).

Specifically, the EDI AS2 protocol is used when the destination partner has an EDIFACT-based system: EDIFACT messages can be sent directly by the AC/DC messaging service. In contrast, ebMS is applied when the destination party is not supported by the EDIFACT standard or the message is not an EDIFACT but an AC/DC specific message. Thanks to party profiles, the AC/DC messaging service can distinguish between the standards used in bilateral communication.

The messages refer to framework plans, supply and demand information on long-, medium- and short-term horizons, call-offs, cost estimations, inventory reports, shipping notifications, etc. A so-called application programming interface (API) is coupled to the company’s ERP system as an automatic communication system. This API can transmit and receive messages. Figure 3.11 illustrates the connection between an ERP system (e.g., OOPUS AC/DC in subsection 3.3.3) and the AC/DC messaging service.

Finally, a common dictionary was defined. This application makes software systems at different locations compatible. This knowledge management task called for a methodology of collaborative domain conceptualization. Attention was given to some existing general e-commerce ontologies like UNSPSC [44], eCl@ss [15], RosettaNet [36], and in particular to the existing ILIPT ontology [23]. An analysis of as-is forecasting processes at partner Continental led to the development of a sample ontology. Next, the AC/DC ontology was built which provided a common understanding and a formal representation of the concepts specifically related to DSL. Technical support for ontology development was given by the CMap Tools software [25] as well as by a bottom-up concept mining process which generated the most frequent concepts and their relationships arising from the documents on DSL [M3.11]. The formally specified ontology is focused, unambiguous, user-friendly, simple, and linked to relevant documents.
Beyond providing a common platform for communication despite different in-house terms and vocabularies, the ontology is of great assistance when it comes to company mergers, which happened during the project, to achieve common understanding and expected synergies more efficiently. It also allows future users of AC/DC results to comprehend the knowledge behind the DSL processes and extend it with formal inference methods, if necessary.

### 3.2.5 Collaborative event handling

Any production system holds risks based on forecasted demands either because the forecasted demands are not in accordance with reality or because of various influencing disturbances with a diversified severity. This may happen every day in the production as well as in logistics, quality management and other company processes. In any case, this can lead to a disruption of the company’s steady-state and by that of the whole situation within the supply network in a worst case scenario. In order to deal with these events and to return fast and reliable to a steady-state, real-time event handling methods were developed, which can identify these disturbances and deduce handling alternatives on plant level as well as on network level. As a consequence, by the use of these new mechanisms by all partners in the network (collaboration), the overall process of adoption is enhanced to work spontaneously (speed), is more reliable and flexible (flexibility), and works with reduced cost for all participants in the supply network.

### Event effects

Due to occurrence of events, the validity and consistency of production schedules can change tremendously during supply chain execution. These changes can be, for example:

- Short-term changes of demand or supply values;
- Blackout of capacities caused by machine breakdowns; and
- Material-based loss of supplies caused by logistical delays.
These events are handled by a supply chain event management processor, who executes event-corresponding clearing actions. However, today’s existing event handling software systems are only aligned to application in simple supply chains, not in complex collaborative process environments (supply networks).

The efficient and reliable management of events in denser and inter-company automotive manufacturing networks demands for a new consideration of this topic regarding the influence of network-based factors. It is obvious that only more cooperation and collaboration will lead to an efficient event management in the supply networks, implemented by efficient overhead minimization and robust processes.

**Red Adair Reaction Toolkit**

As it is shown in Figure 3.12, a general Collaborative Event Handling process has been set up. By regarding the Real-Time Event Management processes, the intended solution can be solved by the *Red Adair Reaction Toolkit*, which bundles a set of methods and processes used for the handling of predictable as well as unpredictable events, occurring in the objective of AC/DC. One of its main elements is the *Triple-i-Rescue Tool*, which performs the immediate Event Handling and acts therefore as a sort of fire extinguisher, limited to those partners only, who are directly affected by the event (Figure 3.13). As a basis for event classification, the supply network is modeled using MFERT (MFERT is described in detail in [43]). Based on this model, an event classification scheme for supply network event management was defined as described in [37].

An example for such an event classification is shown on the left hand side of Figure 3.14. It shows an event classified as an out-of-stock situation demanding a specific planning task. In this case we increase as a global backward planning process the netto demand of the tier\textsubscript{n-1} partner to increase our stock as soon as possible. Each event can be mapped to a change in value (of either positive or negative nature) at a certain point in the model. The point in the model can be either before, behind, or at a node (two types of nodes exist in MFERT, capacity nodes and object nodes) [M3.13].

**Practical proof**

The proof for the classification scheme of events is based on an informal collection of possible events performed with the AC/DC industry representatives. Gathered events have been mapped successfully into the event classification scheme and thereby demonstrate the relevance of practice.

**Triple-i-Rescue Tool**

In a first step, the Triple-i-Rescue Tool has to identify and classify the locally monitored derivations...
of the basic production schedule, the intended demands, or supplies. Enriched by additional events from either supplier’s or customer’s side, this will lead to a total view on the arising events, which can or already affects the intended production. Beside a monitoring mechanism, a basic communication structure is needed, which provides the interchange of necessary information between the partners of the supply chain. As a main focus, solutions for the classified events need to be found, which is based on a set of possible handling alternatives, enriched by further information regarding historic decisions and their success in comparable system states. This self-learning aspect of the event eval-
ation, the Real-Time Reaction Schemes (RTRS), leads to the best possible selection of a handling alternative, which is, in most cases, triggered by an expert's decision.

By this, the event clearing process is started, which covers the information and initiative part of the event handling (the decision is distributed to the affected partners and implemented internally). It also includes the collection of feedbacks in order to close the entire Event Handling process and it provides the needed information for an improvement of the knowledge base of the RTRS. In some cases, a restart of the DSL and, by this, a re-planning at operational level may be necessary. The gathered information, needed for conclusion as well as judging the selected alternative, is additionally used to identify presumable events, which arises from the decision or the actual system state (Pre-emptive Event Management).

The entire event handling process is triggered by an observed derivation of the actual production plan. User input as well as an automatically transmitted information from the company's ERP system could be the source of this derivation. In addition, information from any of the connected supply chain partners could be the source.

With the general approach of an automated collection of necessary data, the overall handling process becomes faster. The measurement of the handling action will lead to a more reliable recommendation for the next event. After a short period of time, the RTRS should offer an excellent rating of possible handling actions, which will in return improve the handling process itself, because the necessary decision can be made faster.

**Real-time reaction schemes**

It can be summarized that using simulation for process coverage will increase the reliability of production plan scenarios but decrease the reaction time far from being real-time event handling. Additionally, the process starts with scenario selection, simulation model generation, and at last simulation. However, it is interrupted by manual processes done by a production planner or simulation expert. To improve the reaction times for event handling, it would be helpful to optimize this manual process by using process automation and to integrate the whole clearing process into a force-feedback loop for processing events and covering changed plans as fast as possible. Several problems arise in an effort to fulfill this task:

1. A set of change planning algorithms or strategies (→ 8D, Lessons Learned) is needed and can be applied on the production plan [M3.16].
2. A measure is needed to reduce the possible scenarios for simulation to a workable number covering the most promising scenarios for event handling generated by the change planning strategies.
3. A simulation environment (software or production management team) is needed to generate simulation models according to those scenarios which are dynamically configurable, in regards to the time horizon offered for simulation. The level of detail of the simulation model must be adaptable to speed (rough model, fast processing, and short time horizon for simulation) or reliability (detailed model, accurate processing, and longer time horizon for simulation).
4. A foresighted event handling module to increase the time period usable for scenario generation and process coverage by simulation.
5. A real-time event detection system connected to the change planning system.
6. A production control center as an umbrella integrating all modules.

To enable real-time reaction to events by applying changed planning strategies, the used change plan-
ning algorithms must be designed lean and highly effective. The number of scenarios to be assessed depends on the number of applied changed planning strategies as every change planning strategy will generate a new alternative scenario, which has to be covered by simulation.

The measure assessing the scenarios for selecting the most effective change planning algorithm could be implemented by a machine learning system such as reinforcement learning (RL) [42]. RL is a good means for learning rule-based decisions in complex models. However, in the case of production network plans as the state model, the RL must handle a large number of states which leads to extremely long processing times. Thus, the state space must be reduced effectively by abstraction while preserving the characteristic features which enables assessing those abstracted states for applying change planning strategies.

**Correct event handling: emergency management**

It is very important to make a distinction between the event (i.e., the cause of the critical incident) and the material shortage. It is not the goal of the material shortage management process to solve the critical incident but to handle material shortage until supply situation return to normal.

The emergency management process is composed of two processes: the Material Shortage Management (MSM) process and the escalation process. These two processes are strongly interconnected. The material shortage management describes what actions should be taken to face a material shortage efficiently. The escalation process describes the way the different levels of the organization should interact and communicate with each other in case of critical incidents.

Any type of event can eventually lead to a material shortage, and the material shortage is the first effect of a critical incident, which needs to be handled by the emergency management.

The focus of this process is to describe the various actions a plant should perform in case of material shortage: what information should be gathered; how the event should be processed and by whom?

Material shortage may be identified internally or externally. Internally, it may be identified by anyone within the organization as well as from information automatically transmitted by the company’s ERP system. Externally, it may come from any partner of the supply chain.

### 3.2.6 Benefit balancing

Decentralized decision making in supply networks leads to suboptimal performance. Hence, extended coordination and cooperation are necessary between the companies in order to dampen the disadvantageous effects of distributed decisions. Long-term strategic partnerships, clear regulation of responsibilities, and vertically integrated supply chains can help to improve the operational efficiency but only if all partners share in the achieved benefits. Declaring a common mission statement, together with sharing technology and facilitating mutual growth, can prevent serious supply problems caused by weaker links in the chain. In the AC/DC project, the partners investigated both, the theoretical background [16] as well as some practical possibilities for guaranteeing mutual benefit from improved supply processes.

**Practical methods of benefit balancing**

Three practical methods related to benefit balancing have been initiated by one of the core industrial partners of the AC/DC project [M3.17]. They represent three basic principles of benefit balancing:
(i) the measurement of the performance, (ii) the cooperative evaluation from a set of alternatives, and (iii) the optimization of the total cost instead of considering separate local objectives of the logistics. A short overview is given here; for more details see subsection 3.3.5.

An essential task is the measurement of supply performance, which can be used as a basis for benefit balancing amongst supply chain partners. In the AC/DC project, a commercial software system has been chosen to rate the delivery performance of the suppliers. In the second method, a company can compare its own logistics with those of the supplier in order to resolve the cheapest price and to redefine the trade conditions (so-called Inco terms). Finally, Total Cost of Ownership (TCO) is an initiative to measure and compare the full costs of competing business alternatives. When properly applied, suboptimal replenishment processes caused by disparate local objectives can be avoided.

**Benefit balancing in the Dynamic Supply Loops**

The planning processes in supply chains are usually done hierarchically: in tier \( n \) demand information arrives from downstream and is then processed, transformed into part or material demand, and sent further upstream. In this way, tier \( n \) company optimizes its own production without considering the consequences at the subsequent tiers.

The DSL process changes this practice by involving the supplier into the decision making: instead of propagating new constraints automatically, tier \( n \) and tier \( n+1 \) partners can harmonize their plans. Since this means deviating from the (local) optimum of the tier \( n \) company, it works only if the supplier can achieve higher gains and uses part of it for compensating the buyer. Specifically, the DSL concept proposes replacing the hierarchical planning processes with the following approach:

1. The tier \( n \) company generates and prioritizes different alternative plan scenarios, instead of submitting only one “optimal” plan.
2. In tier \( n+1 \), these scenarios are evaluated and priced by the supplier. If the supplier has savings on an alternative compared to the most preferred plan of the tier \( n \) company then it decreases the price appropriately.
3. The tier \( n \) company chooses the best alternative (here not only prices but other factors like lead times or inventory levels may matter, too). Hence, instead of considering only the production cost, the total production, logistic, and purchasing costs can be optimized this way.

Both companies involved profit using benefit balancing. Figure 3.16 shows an example.

Note that when applying this method bilaterally along a supply chain, there is no guarantee that in
the end, the partners will find the overall optimal scenario for the whole chain. Though, as a series of simulation tests on a multi-echelon model with de facto standard planning methods have shown, DSL achieved better performance (smaller logistics cost and inventories) than the traditional hierarchical planning scheme. All in all, the proposed benefit balancing approach may sometimes fail to achieve the globally optimal plan but it has several advantages:

- It is simple, easy to understand and to implement.
- It can be realized automatically, with existing planning systems, by means of the AC/DC messaging system.
- Sensitive private information (e.g., on costs) does not have to be shared.
- It can possibly improve supply chain performance.

**Theoretical aspects of benefit balancing: mechanism design**

Collaborative planning on a medium-term can also help long-term sustainability: improved production anywhere in the process entails lower prices, which causes better competitiveness of the whole supply chain. It also decreases system sensitivity and the need for event handling (see subsection 3.2.5).

It is possible to investigate cooperative networked production also from a more general, theoretical aspect, by using the apparatus of mechanism design (MD) theory [31][M3.18]. By mapping basic concepts of MD and supply chain coordination, we could analyze a variety of typical supply chain relations in an abstract method, directly focusing on issues of disparate utilities and private, asymmetric information. While the common occurrence of some expected properties such as global efficiency, individual rationality, and budget balance make a fair balancing of benefits and risks between the partners impossible, it could also be shown that
one can find appropriate ways for practical and fair coordination by relaxing some assumptions. Overall, mechanism design theory is a promising instrument for designing and analyzing novel and innovative business relations.

3.3 Best Practices in the automotive industry

3.3.1 Collaborative planning using the DSL

As AC/DC partner Continental is using SAP for years and this system lays the foundation for all future processes, the advanced planning capabilities are supported by a SAP tool. A key component of the mySAP.com Supply Chain Management solution, the SAP Advanced Planner and Optimizer (SAP APO), provides the complete toolset needed to plan and optimize supply chain processes at the strategic, tactical, and operational planning levels, as needed for the DSL process set-up.

Partner Continental Automotive installed the modules DP (Demand Planning), SNP (Supply Network Planning), CMDS (Collaborative Management of Delivery Schedules), and PP/DS (Production Planning and Detailed Sequencing). These modules are the given standard modules by SAP. It has been necessary to customize the existing modules, sometimes even to modify them, to cover the needs of automotive business and to fit into Continental’s environment.

Demand Planning (DP)

In particular, partner Continental creates a forecast in APO DP based on the characteristics of configurable end products, for example, based on the characteristics color, engine, and air conditioning of the end product: the car. Moreover, one can forecast the demand for a combination of several characteristics, thus taking into account the mutual interdependency of the demand for these characteristics. Characteristic-based forecasting allows anticipating demand for many different variants of the same product and reacting swiftly to encounter market demands.

APO DP is used to create a forecast of market demands for all Continental Automotive products taking the many different causal factors that affect demands into consideration. The customer demand plan is the result of APO DP, which is the basis for all downstream planning processes to suffice customer demands where needed.
DP is a powerful and flexible tool which supports the demand planning process at partner Continental. Planning method specific layouts and interactive planning books enable employees’ integration from different departments into the forecasting process. Using the DP library of statistical forecasting and advanced macro techniques, forecasts are created based on demand history for spare parts business (AM and OES) analogous to the OEM business.

Supply Network Planning (SNP)

Two aspects are used in the first step at partner Continental. One is the regular plant spanning bill of materials (BOM) explosion based on sales planning for budget and strategic planning once per year, and the other for customer demand planning updated monthly. These planning results are published in Business Information Warehouse for further use and analysis.

The second implemented aspect is simulation possibilities, which enables to plan “what-if-scenarios” as a decision basis.

Collaborative Management of Delivery Schedules (CMDS)

For partner Continental, the CMDS processes and tools were highly modified to the specific needs of monitoring and adaptation of customer call-offs. Possibilities of confirmation are not used, as OEM customers do not apply such feedback messages today. The only information is sent together with the outbound delivery to inform about goods in transit.

Two functions are performed online in the APO, which is the monitoring and the adaptation of customer call-offs. This guarantees a timely availability of the corrected demand data for planning processes.

The analysis presents data for a longer time period to judge customer fluctuation, and it compares the customer call-offs regarding specific criteria. Consequently, this information is provided only offline once per day, which is sufficient for the needs.

Production Planning Detailed Sequencing (PP/DS)

Production scheduling and sequencing at partner Continental strives to optimize production planning processes within Continental Automotive Systems plants. Focus is a decision support for production planning which takes the capacities available into account. Furthermore, simulation functionality enables the planners to test the effects of variation for future demand. Being able to understand and anticipate these effects will lead to more effective production plans while, at the same time, the decision support system will integrate and help the planner to coordinate production plans more efficiently.

The use at Continental concentrates on implementation of heuristics to handle constrains and on optimizing the capacity usage, regarding available stocks and monitored by the business ratio overall equipment efficiency (OEE). Hence, customer order fulfillment has highest priority.

3.3.2 Collaborative forecasting

Test of statistical disclosure limitation

Statistical disclosure limitation methods (SDL) can be used to mask data using a specific mapping algorithm and keep the real data confidential while processing without losing their semantics [M3.5].

Original data appearing in cells can be seen in Table 3.1, and marginal cells are added to contain summary information (e.g., row and column sums).
Categories can be of several types. In the following example, they correspond to time periods (T1–T6) and geographical regions (A–C).

SDL methodologies mask sensitive cells giving a guarantee that the user cannot reconstruct the masked data within a certain approximation fixed by the owner of the data.

One of the most frequently used methods is cell suppression. This involves replacing the value in a cell by a missing symbol whenever that cell is considered as sensitive.

A different methodology is controlled rounding which aims at reducing the level of detail (accuracy) of the information provided to the user. All the cells are involved in this methodology. Each cell value is replaced by the closest multiple of a given base number. The rounding pattern must be chosen in order to keep consistency with marginal cells.

In the AC/DC project, tests have been made with sales data for the Hydraulic/Electronic Control Unit HECU, as input to a forecasting model.

Results on the cell suppression method with up to 6 deleted cells, out of 72, show a good reliability.

Results on controlled rounding present a different behavior. Due to the way the output data are obtained, there are not relevant differences among the original and the output values. It is important to note that up to a certain approximation, the results remain very close to the input data and represent a good starting point for demand prediction.

As a conclusion, both methods can be efficiently applied to communicate data to partners by hiding some private information but still helping partners in developing their demand predictions.

Table 3.1: Original data

<table>
<thead>
<tr>
<th>Region</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
<th>Total</th>
</tr>
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<td>40</td>
<td>10</td>
<td>30</td>
<td>5</td>
<td>20</td>
<td>125</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
<td>19</td>
<td>22</td>
<td>19</td>
<td>21</td>
<td>22</td>
<td>111</td>
</tr>
<tr>
<td>C</td>
<td>17</td>
<td>32</td>
<td>12</td>
<td>27</td>
<td>11</td>
<td>43</td>
<td>142</td>
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<tr>
<td>Total</td>
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<td>91</td>
<td>44</td>
<td>76</td>
<td>37</td>
<td>85</td>
<td>378</td>
</tr>
</tbody>
</table>

Table 3.2: Data after controlled rounding

<table>
<thead>
<tr>
<th>Region</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
<th>Total</th>
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<td>B</td>
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<td>20</td>
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<td>110</td>
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<tr>
<td>C</td>
<td>15</td>
<td>30</td>
<td>10</td>
<td>30</td>
<td>10</td>
<td>40</td>
<td>135</td>
</tr>
<tr>
<td>Total</td>
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<td>40</td>
<td>80</td>
<td>35</td>
<td>80</td>
<td>370</td>
</tr>
</tbody>
</table>

Test of forecasting models

Statistical methods use historic (quantitative) data to predict the future. They can be divided into univariate and multivariate methods.

Univariate methods use only data of the variable of interest and do not attempt to discover the factors that affect these data. Hence, they do not make any statement about causality [M3.19].

Multivariate methods go beyond the variable of interest and ask why the time series behaved like it did. They assume that the forecast is highly correlated with certain factors in the environment [M3.8].

Cause-and-effect models

In cause-and-effect models, there is a cause, also called driver or independent variable, and there is an effect, also called dependent variable. One determines the average relationships between the cause and effect, and then uses them to make a forecast for the future [M3.8].
These models are used when there is a strong relationship between the cause-and-effect variables, and when the relationship between them does not change significantly over time, at least not during the forecast period. Cause-and-effect models include regression, econometrics, and neural networks [M3.20, M3.21, M3.22].

In the AC/DC project, a cause-and-effect model was tested with the forecasting tool SPSS Expert Modeler [24].

**Collection of indicators**

It was the approach to test both, economic indicators and customer specific indicators to improve the forecasting results. Economic indicators were collected from online databases such as Eurostat [20], while the customer specific indicators, such as the factory working calendar, are available as a result of collaboration.

The data is either applicable worldwide or confined to European countries such as the national unemployment rates or the harmonized consumer price index.

The Expert Modeler chooses the best indicators for the prediction autonomously, but first tests showed that the best results are not achieved with all indicators included and that it is often better to use smaller groups of indicators.

**Forecast precision measurement**

It is important to measure the forecast error and the magnitude of changes in the forecast with an indicator which reflects the precision and stability in the rolling forecasts. This indicator can give important information both, about patterns in the forecast error and it can indicate systematic over- or underestimations over time.

It is the assumption that there is a great value to document the reasons for changing the fore-
casted volume when updating the forecast and the forecast error documentation. In this way, a knowledge database can be built and systematic forecast errors can be identified.

One can consider the tactical loop which has already been set to span from 6 months to 18 months. If the tactical forecast is updated every month by forecasting monthly demands, there will be 12 updates for every forecasted period (see Figure 3.20).

These updates should be compared against previous forecasts for the same periods. If there is a gap larger than a set value, a warning signal should be sent to the forecaster to acknowledge and document the reason for the gap. In addition, when moving from a tactical forecast to an operational forecast, the same tracking should be used (see Figure 3.21).

The AC/DC calculation model for forecast precision measurement is under development in the data warehouse at partner Continental. The definition of the model is a result of comparisons with other models [46] and discussions between the Logistics and the Sales Planning departments. A critical success factor for a measurement model is that both, the forecaster and the user of the forecast agree on the definition.

### 3.3.3 Messaging demonstrator in OOPUS

One basic idea of AC/DC to get improved results depends on a better cooperation of all partners in the supply network. To achieve this, two different methods have been developed. SMEs without a comprehensive IT infrastructure (e.g., a sophisticated ERP system) can use a graphical user interface (GUI) for messages creation, edition, and tracking.

Another method is to participate in the AC/DC network is the integration of the AC/DC Messaging Service in a system [M3.23]. This alternative will be described in more detail, in the following. The
objective is to explain one ideal type of usage of the AC/DC methods. Due to the high potential of the collaborative forecasting, this will be described on the basis of a particular scenario. Hence, implications of different data types on the forecasting result will also be analyzed. This includes the actual process of data transmission and the used forecasting methods. The complete scenario is described in Figure 3.22.

One may suppose a supply chain, in which company A is a customer of company B. Furthermore, due to the economic crisis, reducing costs and staying competitive becomes more important than ever. Thus, company B has to optimize its production facilities and especially avoid an overproduction with high inventory costs. In contrast, it is necessary to fulfill the requirements of the customers in the right time and to avoid backorders. One way to handle this dilemma is an intelligent forecasting. In the past, this was done in each enterprise separately. This means that the basis were mostly own historical data and perhaps external public indicators (e.g., gross domestic product). However, as the current crisis has shown, especially customer behavior influences the own production. Hence, a lot of companies have launched short time production without a direct propagation of this information to their customers and the reduced customer call-offs could not be included in their forecasts.

Because of these problems, information about the customer's shift calendar should be integrated in a forecasting model. To keep this data consistent, it is necessary to communicate it regularly. For this purpose, appropriate communication mechanisms are necessary. After generating a forecast on basis of representative data, the results can be compared with the local forecasting results. Figure 3.22 presents aggregated numbers of this process.

Step 1: In this scenario enterprise B runs a system called OOPUS AC/DC (German for Objekt-Orientiertes Planungs- und Steuerungssystem). This is a web-based production planning and control software with the main objective to support a production planner of an enterprise by the creation of a production plan. OOPUS AC/DC is
Collaborative Production Network Management—Dynamic Supply Loops

entirely implemented in Java, making use of open source packages and frameworks.

This system has possibilities to administrate typical elements of an ERP system. These are products and their BOM, customer requests with due dates, the structure of the production systems with the individual capacities, historical data, external public data, stocks and calendar information. In addition, this system should facilitate the use of different forecasting methods and the exchange of appropriate data between the partners (for more information about the used API see subsection 3.2.4). For the latter one customer profiles have to be generated giving information about the type of messages. Dependent of this a message will be sent with the help of EDI AS2 or ebXML.

The subscription concept guarantees the consistency of the planning process in one way or another. In one case data at one enterprise is adjusted (e.g., the capacity), the system automatically sends the requisite information to the network partners.

Figure 3.24 depicts a subscription request of capacity information. Besides the determination of the receiver, the granularity (e.g., days or minutes) and the time horizon have also to be chosen. Before transmitting the data to the receiver—if necessary—it is transformed from the sender enterprise’s internal understanding to the agreed understanding of the network (e.g., special data format such as 02. April 2009, 02/04/2009, 04/02/2009, 2/4/09, 4/2/09)). This assures a consistent understanding of the communicated terms.

Steps 2 & 5: Different messages are compiled before transmitting the data. Besides the messages and the answers with the request of enterprise B to enterprise A and the answer other messages are required. These messages are more
technical and assure the conflict free transmission (such as a check if the server is available or if a message with the transmission was successful or failed). To keep the consistency of the system during the execution of the messages a relational database management system is used (see Figure 3.23) [M3.24]. The messages sent and received by applications at each business partner are kept in this database, together with their causal sequence.

**Step 3:** Enterprise A runs OOPUS AC/DC also. If the understanding of received terms differentiates from the enterprise’s internal understanding it has to be translated. After this the message can be opened from an inbox (see Figure 3.25).

**Step 4:** An information request can be answered with the full requested information, it can be answered with a part of the requested information or it can be refused. For all of these three possibilities appropriate mechanisms are necessary. To answer a capacity request the internal working calendar has to be translated into an appropriate message type.

**Step 6:** After receiving the message it has—if necessary—to be transformed in the enterprise internal understanding. In OOPUS AC/DC the forecasting takes place with the integrated open source component OpenForecast. Advantages of this component are already integrated forecast models that alleviate the integration of the new developed forecasting methods (see subsection 3.2.3). The component also supports the visualization of the forecast results created. OOPUS AC/DC offers a broad catalogue of forecasting methods such as methods from the time series analysis (moving averages, exponential smoothing), the local multiple regression (on basis of its own historical data and on basis of public data (economic data: oil price)) and the collaborative multiple regression (e.g., with the integration of the customer time information).

A collection of various information is necessary for forecasting. Firstly the substantiation of the forecasting problem has to be considered. For this a selection of the planning area, the production stage, the time horizon the consumption factor are necessary. Besides this general information a selection of the forecasting methods of interest will be necessary. With the help of this an analysis of the impact of the different methods is much easier. In an appropriate chart (see Figure 3.26) the results of the forecasting are illustrated. Content of this is the trend of the historical data and trends of resulting forecasts. To allow a better graphical analysis it is possible to change the zoom level of the chart.

**Step 7:** To analyze a forecast a special benchmark mode was implemented. With the help of this a comparison of a formerly generated forecast and real data can be derived. This allows an analysis of the quality of a chosen method and the chosen parameters. Figure 3.27 shows the benchmark mode.
Various information is necessary for a benchmark. Analogously to the forecasting methods GUI, details of the forecasting problem, the selection of the planning area, the production stage, the time horizon and the consumption factor can be presented. Besides the comparison of the graphical trends the average variance can also be computed. This describes how much a forecast result differs from the real data in percent for a specific time horizon.

Step 8: In case of an adaption of relevant data for the partners in the AC/DC network OOPUS AC/DC has different methods which updates the formerly sent data through a new distribution. This assures that the data set is always consistent at all enterprises.
3.3.4 Collaborative event handling

Continental has adapted the Red Adair reaction toolkit [M3.14] to its event handling activity and organization. Processes, methods and tools necessary to bring this development to reality have been identified and implementation plan defined.

Figure 3.28 shows the Red Adair reaction toolkit adapted to the Continental development. It contains elements of the non-adapted Red Adair reaction toolkit, and two blocks defined by Continental: the emergency management block and the problem solving block.

The emergency management block is a set of processes and tools, which aims to support efficient handling of any material shortage (global or local) and escalate it within the right level of the organization.

The problem solving block is primarily a set of processes, methods and tools, which aim to solve a defined problem in a rational and systematic method. Further on, it also facilitates learning from other plants or organizations which have developed successful projects or approaches for their own problems. The two elements are necessary because it is not enough to find the right solution to a specific problem, but it is also necessary to ensure the whole organization can benefit from it and apply it wherever it is relevant. Therefore, the next step is to identify which part of the organization could potentially be affected with same issue, provide the best known solution and collect feedbacks.

The overall goal is to ensure that the same issue is not repetitive and implementing the best known solutions which can eventually be standardized.

Material Shortage Management (MSM) process

Any kind of event can eventually lead to a material shortage, and this is the first effect of a critical incident which needs to be handled under emergency management.

The focus of the MSM process is to describe the various actions a plant should perform in case of material shortage, what information should be gathered; in which format they should be collected and escalated to the rest of the organization.

Escalation process

A material shortage can affect different levels of the organization both horizontally or vertically.

Within Continental, there are three vertical and three horizontal levels which are involved in the escalation process.

- Vertical levels: plant, Business Unit (BU) and cluster.
- Horizontal levels: logistics, quality and purchasing.

These 3×3 levels of the organization need to interact spontaneously and efficiently to encounter any kind of emergency. Each level of the organization needs to get the decisive information and understand what is its role and responsibility in a supply crisis.

Continental has created a global escalation matrix to estimate the level of emergency of a material shortage.

Each step on the matrix is called Emergency Level Material Shortage (ELMS). Continental has identified 4 critical stages. These steps are focused on the customer. The degree of emergency is determined according to the impact of the material shortage on customer’s production planning.
### Red Adair reaction toolkit

<table>
<thead>
<tr>
<th>Triple-i rescue tool</th>
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<tr>
<td>Identification and classification</td>
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<td>Evaluating and judging action activities</td>
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<tr>
<td>Information and initiative</td>
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<tr>
<td>Feedback, consequences and closing</td>
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</tbody>
</table>

#### Emergency management
- Problem identified, classified, escalated with the appropriate tool; task force defined. Material shortage monitored within the right level of the organization.

#### Problem solving
- Method available to handle a problem in a rational way; solution available and usable for the rest of the organization; experts diffuse solution and implement process whenever applicable.

#### Communication (T2300)

### Monitoring

<table>
<thead>
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<th>Emergency management</th>
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<td>Material shortage management process</td>
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<td>SQM escalation toolbox</td>
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<td>Allocation tool</td>
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### RTRS

<table>
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<td>Problem solver tool / 8D</td>
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<td>Preemptive EM (included in SQM escalation toolbox)</td>
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<tr>
<td>Replanning (T2100)</td>
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</table>

Figure 3.28: Red Adair reaction Toolkit adapted to Continental’s vision [M3.14]

#### SQM (Supplier Quality Management) escalation toolbox

The purpose of the SQM escalation tool box is to establish immediate and direct information to the management and organization about all critical incidents via “Red Alerts” and to trigger the necessary measures for actions.

#### Lessons Learned

Lessons Learned is a process which aims at collecting knowledge from experience, spread it internally and reuse it. The integration of Lessons Learned into the business processes is the condition for Continental to establish an effective Lessons Learned program.
The main aspect of Lessons Learned is to give possibilities to all employees to benefit from the experience of their colleagues. This is why, to get the full benefit of this collection of knowledge, it is necessary to store the lessons learned in a mutual accessible platform for the whole organization.

The Lessons Learned Process is supported by a worldwide database with access for all employees. A Lessons Learned statement is stored in the form of a structured document. The main components of a Lessons Learned document are the description text, solution text, keywords, classification, and the title. The title follows the design rule “Result + Object + Approach” (e.g., “Increase product quality by using certified supplier”) in order to reflect the subject matter of the Lessons Learned. The description and solution texts are written as detailed as necessary and as short as possible [M3.16].

The benefit of a common repository for Lessons Learned is the possibility to reuse Lessons Learned in the context of new projects by all employees via different push and pull services, searching and browsing.
Danger for Continental plant(s)'s production to shut down. Customer call-off can still be fulfilled

1 Location logistics  
2 Local logistics management  
3 Quality department if applicable  
4 Location management  

Escalation to supplier  
1 Local supplier customer service  
2 Key account manager

Delinquency situation towards customer

5 Category management  

Escalation to supplier  
1 Middle management

Danger for customer's production plant to shut down. Less than one day on hand at customer.

6 LA cluster organization / BU logistics manager  
7 BU management  
8 Global category management  

Escalation to supplier  
1 Upper management

Red alert team see no possibility to avoid customer shutdown. Shutdown will last for more than one day.

9 LA manager  
10 Conti Top management  
11 Purchasing management  
12 Key account to customer  

Escalation to supplier  
1 Top management

Figure 3.30: Escalation process—Escalation Level Material Shortage [M3.26]

The final target is the reuse of Lessons Learned by automatic integration into standard documents and processes (design guidelines, Failure Mode and Effects Analysis FMEA, etc.).

LOG.net—TECH.net—PROD.net

Basic idea of the network approach is the concept of decentralized network teams being responsible or supporting the standardization of manufacturing and logistics related processes, methods or technologies based on best practices. Extended scope is to improve competence, to share knowledge, good practices and lessons learned. The mentioned networks are the Continental Automotive (Electronics) way to reach world class manufacturing and Supply Chain Management performance by using team excellence.

This approach and all its contents are fully supported by the Plant management and the BU manufacturing leaders. The relevant managers have committed themselves to follow these principles and actions in detail.
The work of the Networks is based on the Continental Automotive Production System principles and methods.

Basic tasks of each Continental Automotive Network team are for example:

- Standardization of the basic elements such as processes, equipment, Production System methods on Best in Class level regarding quality, cost etc.
- Process/Production Systems Method optimization by means of process performance indicators such as process quality, cost and productivity.
- Knowledge transfer (lessons learned, good practice transfer, plant-to-plant training support).

For LOG.net, the standardization scope is SCM processes.

For TECH.net, the standardization scope comprises technology processes (including inspection and test), equipment and material.

For PROD.net—also referred to as Continental Automotive Production System Network—the standardization scope are production processes.

**Problem solver tool/8D-tool**

The 8D process, which is an important method at Continental for problem solving, is a concept to solve known, existing, serious problems but root causes are not known. The solution is significantly characterized by solving the root cause and not
only symptoms. The process describes the requirements for one of the most efficient and fastest methods to finally solve a problem. Using this process will avoid recurrences of problems. As a standard documentation tool the 8D method is used to monitor the progress. Single process steps can be finalized only if the required information is provided. Therefore, the 8D Report is equivalently used as a plan of action, visualizing open action items.

To fasten the complete 8D process, Continental developed the "8D Tool" which is an electronic platform acting as a knowledge and monitoring database where all occurring 8D reports will be managed, processed and stored.

### 3.3.5 Benefit balancing

For realization of the benefit balancing idea Continental has on the one hand implemented the Bensberg tool for Supplier Evaluation and, on the other hand, developed an own Total Cost of Ownership (TCO) approach.

The idea behind the Bensberg tool is to establish a tool, which standardize a Supplier Ranking System as well as to harmonize the Supplier Evaluation Process. Aim of this project is to build up stabilized processes between suppliers and Continental.

The Supplier Evaluation provides a basis for sourcing decisions and will support local Logistics departments with Supplier Comparison Factors (SCF). It is part of Supplier Development illustrating performance results and critical areas by using a scorecard. Furthermore it forms part of the yearly Profile Evaluation.

By means of continuous improvements the customer satisfaction can be assured.

The procedure of implementing a Supplier Ranking System is based on the following concept. If the performance result of a supplier needs to be overhauled, the supplier gets additional support to the effect of improving its performance (collaboration). If it turns out that after an advanced evaluation there has been no improvement occurred, the supplier will not be considered during the next projects. This concept facilitates the improvement of supplier's performance as well as Continental's performance. Moreover it is possible to compare two parties with each other and to indicate further progresses.

The TCO approach at Continental is described in Section 4.
Section 4
Flexible Production System

Requirements from the CtO perspective

Today, existing manufacturing technologies are building up their customer variants mostly in an early stage of their production processes at a plant. This can lead to inflexibility of the manufacturing process by having established expected variants much earlier than necessary. Consequently, proper capacity utilization and order fulfillment can become impaired, which invariably impact manufacturing excellence and efficiency.

Especially very long lead times from more than 150 days are quite normal in today’s supply chain starting from the car driver down to the 3rd-tier supplier. The challenge here is to come down to approximately 5 days in the entire supply chain without increasing the total cost of ownership.

Standard production systems allow to increase additional flexibility only by higher investment in people, equipment and inventory.

More speed and flexibility—challenges

In addition to the general supply management methods integrated into the Dynamic Supply Loops concept, AC/DC developed and evaluated several methods to increase speed and flexibility. This section introduces those methods and illustrates their industrial application at Continental facilities and the advancement which have been achieved.
4.1 Problem definition

Building up highly flexible production systems needs the redesign of both: shop-floor layout redesign and the reduction of wastes in the supply chain, e.g., stock, long lead time and complex planning and control procedures. Actual production systems in the automotive industry require a demand handling flexibility of ±25% per day.

Subsection 4.1 shows the use-case. Subsection 4.2 describes the implementation steps that have been made. While subsection 4.3 gives an overview of the implemented tools and methods, subsection 4.4 offers an outlook about future implications.

4.1.1 Case description

One example of the AC/DC use-case is the manufacturing of electronic components called SMD (Surface Mounted Device). In electronic manufacturing technology the variant building takes place during the Surface Mounting Technology (SMT) process. The back end assembly process is running on an automatic assembly line based on one-piece flow. The process is shown in Figure 4.2.

In order to meet the daily customer sequence of product variants, a complex production planning process is needed which leads to long production lead time, high inventory levels, and inefficient material and information flow in the supplier plants as well. This is because of long setup times in the SMT process fulfilling capacity utilization needs out of high investment for the production equipment.

Furthermore, the quantity of variants for automotive suppliers is expected to increase by the actual European market situation. OEMs are building more and more customized car designs based on their product range in order to secure their sales figures in a saturated market. Unfortunately, the OEM is unable to accurately quantify the increasing number of variants necessary.

Discussion with production planning experts at OEMs like BMW has shown that they expect an increasing number of car variants in the future and therefore SMD variants are very high and increasing continuously.

During the last 10 years the number of car models increased from 5 to 20 for nearly all major OEMs (see Table 4.1). One can imagine that with such variable figures, production planning of the suppliers in the automotive supply chain will further increase and become quite complex. And these figures are not even quantified to date.

For the European industry to survive and suffice future market demands, today's production
systems need more flexibility to react immediately—say, an order-to-delivery lead time of 24 hours per partner in the Automotive Chassis Development for a 5-Days Car—to cover customer expectations and needs.

Flexibility definitions for the supply chain partners will be addressed first. Workshop results as discussed with the partners of the project in cooperation with BMW—one of the leading OEM concerning flexibility in their global production network—are shown in Figure 4.3

The definition of flexibility needs in the supply chain for this project was initialized with ±25% capacity fluctuation per day, without increasing individual costs in the entire supply chain!

In contrast, price reduction for the delivered products are requested by the OEM in order to stabilize the market demand in Europe by integrating increasing functionality in future cars in considerably short time and practically simultaneously.

4.1.2 Connections to the other sections

This price reduction can be problematic for the entire supply chain in the automotive industry. So as to increase functionality and reduce lot sizes by constant total volume of end-customer demands in the European car market, a benefit balancing pro-
cess can be used to share the price reduction and satisfy all supply chain partners.

Even more, there is a need for evaluating any changing manufacturing process and technology. This enables a design to manufacturing approach by calculating always the total cost of ownership (TCO) for the complete sequence of all production processes in a plant as well as in the entire supply chain. To date, such a tool does not exist in the entire automotive industry and needs to be developed based on integrated scientific research.

The challenge of today’s manufacturing processes is to use a highly flexible and modular production system similar to Toyota’s, incorporating additional methods such as zero defect planning in order to avoid customer recall campaigns as seen today.

Thus, we need to integrate the same flexible production system in all companies of the entire supply chain in order to get sustainable and robust production processes along the whole supply chain.

4.2 Code of practice: implementation guide

4.2.1 Lean production management

The aim of a lean production system is to shorten the order-to-delivery lead time of a product by incorporating standardization and late customization of the components, optimizing the production processes, and significantly reducing stocks, thereby increasing flexibility and savings.

Targets and benefits

The main target is to increase efficiency in all processes and to obtain more transparency within the entire supply chain. Therefore, a continuous flow of material is necessary and production stations have to be highly flexible and reactive to volume and variant changes by the downstream customer in the supply chain. The entire supply chain would be oriented to become a pull system according to the original takt time. Stocks used by the downstream partner will be produced and replenished just in time in less than 24 hours. This collaborative design of the supply chain makes it possible to achieve the following benefits:

- Avoidance of overproduction;
- Optimized inventory buffers;
- Shorter lead time;
- Reduced inventories;
- Harmonization of material flow; and
- Simplified and fast processes.

Cost reduction

Costs can be reduced due to:

- Reduced lead time and inventories;
- Implementation with reduced investment; and
- Minimized planning and scheduling efforts.
Implementation approach

The following pre-conditions have to be fulfilled before starting the implementation steps:

- Detailed knowledge about takt time, shift model and delivery terms;
- Reduced set-up times for increased flexibility; and
- Reliable and stable processes along the complete supply chain.

Implementation steps

The following guide shows the implementation steps starting with:

- Installing a supply chain manager to train workers and process owners in lean production principles and methodology.
- Analyzing current manufacturing processes with a door-to-door value stream mapping (VSM) at each partner of the supply chain.
- Analyzing customer demands and fluctuation of products.
- Implying the VSM into the entire supply chain.
- Developing the value stream design over the supply chain and the future state of the partners hereafter in accordance to lean principles.

It is very important to imply the customization processes of the products as late as possible downstream into the supply chain. From this point on, one can organize the pull principle along the supply chain starting with a finished supermarket where it is possible to place any variant to fulfill the daily demands according to the takt time.

- Design a highly flexible production cell first, which is able to react to customer demands within 24 hours.
- Use standardized manufacturing technologies in order to assure efficient and robust production processes with zero defects.
- Implement an efficient road map which responds to all “7 wastes” topics found during the VSM and reduce them.

The “7 wastes” in the lean production management are defined as:

- Transportation;
- Inventory;
- Movement;
- Waiting;
- Overproduction;
- Overprocessing;
- Defects.
Stabilization and control process

One has to go through the following steps first when implementing a lean production system:

- Start with a pilot implementation at one production line/process and control efficiency by different operational ratios.
- Take corrective measures if needed and control the efficiency again.
- Plan a roll-out concept for the entire plant, imply, re-check and react if necessary.
- Plan a roll-out concept for the entire supply chain, imply, re-check, and react if necessary.

The following Key Performance Indicators help to set up and measure the efficiency of the optimized production system:

- **Takt Time**: This is the time measured from the first car to the second car leaving the final production line at the customer plant; in this case, it was 60 seconds.
- **Lead time**: This is the time measured from changing the variant in the call off by the customer until the required product is produced by the supplier and delivered to the customer line; in this case, the target was 24 hours.
- **Throughput time**: This is the time measured for a production process; in this case, it was the final assembly process at the BMW line which actually took 9 hours.
- **Turn rate**: This is the amount of actual inventory in € divided by the sales turnover for the same year; in this case, a good turn rate was 42 days.
- **Scrap rate**: This is the value of material scrapped in € as a result of defects divided by the sales in the related period; in this case, the target was <0.4%.
- **Floor space**: This is the area in square meters needed for the production line/station.
Figure 4.7: Value Stream Design (VSD) is the design of the future state.

- **Total transportation distance**: This is the distance the handled material was transported during the complete supply chain; in this case, it is measured in kilometers and the target was <500 km.

### 4.3 Methods and tools

#### 4.3.1 Value stream mapping (VSM) and design

VSM is a lean technique [M4.1] used to analyze the flow of materials and information a product undergoes until completion. It is intended to understand flows and to recognize and eliminate weak points. VSM is mapping all processes and flows from the supplier to the customer. It uses simple icons easy to visualize and should be performed by a competent and well trained team and should be documented on paper.

The main focus is to avoid the “7 wastes”. A supply chain manager leading the team is mandatory. The manager must have the competence to make decisions immediately.

The purpose of mapping and design is to increase the flow factor and to decrease total lead time by implementing an A3-sized action-plan to be followed.

VSM has to be done regularly (yearly) by a cross-functional team with the following functional departments: Production, Quality, Logistics, Industrial Engineering as a minimum, other functions such as Purchasing/Controlling and Sales can be an improvement. The time needed for a door-to-door VSM/VSD of one product family in a plant was approximately 4 days in this case.

#### 4.3.2 ABC/XYZ analysis

ABC/XYZ is a tool [M4.2] which shows each part on a graph with the classic ABC inventory categorization on one axis and the XYZ fluctuation of volumes on the other.

ABC analysis is a business term used to define an inventory categorization technique often applied in material management.
ABC analysis provides a mechanism for identifying items which will have a significant impact on overall inventory cost whilst also providing a mechanism for identifying different categories of stock which will require different management and control methods.

When carrying out an ABC analysis, the inventory items are valued (item cost multiplied by quantity consumed in a period) by the results and ranked afterwards. The results are then grouped typically into three sets. These bands are called ABC codes:

1. “A class” inventory will typically contain items which account for 60% to 80% of total value.
2. “B class” inventory will consist of the next 15% to 20% of total value.
3. “C class” inventory will account for the remaining 5% to 20%.

For XYZ analysis, the fluctuation is calculated with the standard deviation divided by the average level in %:

1. “X class” fluctuation will contain items which have a variation of a monthly consumption <50% and variation of a weekly consumption <75%.
2. “Y class” fluctuation will contain items which have a variation of a monthly consumption <100% and variation of a weekly consumption <125%.
3. “Z class” fluctuation will contain items which have a variation of a monthly consumption >100% and variation of a weekly consumption >125%.

The following typical decisions are shown and can be made in accordance to the ABC/XYZ results:

1. XC, YC and XB can be managed by KANBAN
2. YC, ZC, YB, ZB can be managed by Material requirement planning (MRP)
3. XA, YA can be managed by JIT

ABC/XYZ analysis has to be done regularly (monthly) by Logistics (see Table 4.2). The time needed for a complete portfolio of a plant was approximately 1 day in this case.

4.3.3 Quick changeover

Single Minute Exchange of Die (SMED) is a method [M4.3] to reduce waste in a manufacturing process. It provides a rapid and efficient way of converting a manufacturing process from running the current product to running the next product. The idea is to reduce non-value-added set-up time such as changing tools or die, clamping and releasing procedure. The simple steps of the SMED system are:

1. Observe and document all set-up and changeover activities.
2. Separate the external steps (all the preparation which can be done while the machine is still operating) from the internal steps (when the machine is stopped).
3. Convert internal steps to external steps.
4. Streamline all external and internal steps.

Benefits are the increased up-time and productivity of machines which have experienced the results of efficient set-up reduction routines. The greatest benefit of quick changeovers is the manufacturing flexibility and enhanced response time which allows the production of smaller lots and a larger variety which runs on the same machine.

SMED has to be done in case of lot size reduction by a cross-functional team with the following functional departments: Production, Maintenance, Logistics, and Industrial Engineering. The time needed for a complete improvement session of one production process step was a minimum of 3 days in this case, depending on the complexity of the production equipment.
4.3.4 KANBAN

KANBAN ("Kan" means "visual", "Ban" means "card" or "board") is a concept related to lean and just-in-time (JIT) production. It is a system of continuous supply of components, parts, and supplies, to insure that workers have what they need, where and when they need it. This is called a "pull" type of production system.

KANBAN is a signaling system to trigger action. As its name suggests, KANBAN historically uses cards to signal the need for an item. However, other devices such as plastic markers (KANBAN squares) or balls (often golf balls) or an empty part-transport trolley or floor location can also be used to trigger the movement, production, or supply of a unit in a factory. The number of parts made depends on the customer demand represented by the number of cards received by the downstream manufacturing area.

4.3.5 Leveling

Leveling ("Heijunka" in Japanese) refers to a system of production smoothing designed to achieve a more even and consistent flow of work [M4.5]. It is the leveling or smoothing out of the production schedule by averaging out both the volume and model mix of products. Production leveling allows
a consistent workflow, which makes it possible to set standards and identify abnormalities. Heijunka as a concept is closely related to lean production and just-in-time manufacturing.

Leveling has to be reviewed regularly in accordance to ABC/XYZ analysis results from Production and Logistics.

4.3.6 Just-in-time / Just-in-sequence

It is based on producing only the necessary units in the necessary quantity and sequence at the necessary time by bringing production values exactly in line with market demand [M4.6]. It is essential that equipment, resources and human resources are made available only for the amount required and at the time required to do the job. Just-in-time production can only be done with small lot sizes, for just-in-sequence production a one piece flow is mandatory nearby or in the customer plant.

Planning of just-in-time / just-in-sequence depends either on customer needs or on results out of VSM/VSD: for the needed resources, see above.

4.3.7 Results

AC/DC principles of lean production management have been adapted and implemented to increase the production system flexibility and to react to \( \pm 25\% \) demand changes from the customer per day. Lead time has been reduced down to 85\% in the production, rejects and inventory have been cut by 50\% and the layout usage could have been downsized by 6\%. Due to less multi-module production lines the needed human resources were reduced by 8\%.

4.4 . . . And the future

Scalable production systems

Nowadays, the manufacturing of diverse customized products requires many technological instances in terms of processes and material. The development and introduction of this new manufacturing platform to produce micro-electronic and micro-mechanic products implies a completely new approach which is comparable to the introduction of SMT processes within industrial production. It will replace complex product-specific manufacturing processes by one multi-purpose production line facilitating easy to imply and fast down- and up-scalable manufacturing of customer processes and product requirements on an industrial level.

Multi-module production lines (LCA)

Lean Clever Automation (LCA) is a system for effective manual production, where manual stages, simple control systems and clever tools are integrated into a flexible, productive and high quality method of assembly [M4.7].

Small, simple and dedicated equipments support the flexibility of production and logistics.

Design for flexible manufacturing

Manufacturing of the product will be ensured by application of standardized manufacturing processes during the design phase [M4.8]. Simultaneous Engineering in accordance to the Product Life Cycle will reduce time-to-market. Targets / benefits are:

- Strengthen feedback of production to R&D (Simultaneous Engineering);
- Enhance product design for robust, safe and simple production processes;
- Safe, rapid and reliable product launch;
a) Serial engineering

b) Simultaneous engineering

Figure 4.13: Simultaneous Engineering approach to reduce time-to-market

- Reduce time-to-market;
- Reduced complexity and variants in production by late customization;
- Reduce non-conformance costs before delivery; and
- Reduce total cost of ownership.

**Zero defect planning**

This method [M4.9] uses Predictive Quality Planning during product development prior to start of production, focusing on defect prevention. Targets/benefits are:
• Get the zero defect quality right from the beginning;
• Prevent passing defects from internal and external customers in the chain;
• Zero repair / zero rework;
• Ensure quality of product;
• Avoid customer returns, rejects or complaints;
• Ensure safe launch;
• Ensure on time delivery; and
• Reduce additional cost.

Production according to customer takt

Takt time sets the pace of production to match the rate of customer demand. Implemented consequently, this will result in minimum inventories throughout the supply chain, JIT production and the avoidance of over-production [M4.10].

Pre-condition is a detailed knowledge about customer shift models and flexibilities in order to install the same condition in all upstream processes of the entire supply chain.

Normally this will lead to a one-piece flow just-in-sequence to suffice final customer demand.

Best solution is to locate the last production process nearby or at the customer plant if there is only a single customer for the product.

For delivery to more than one customer, suppliers should be located within a 500km radius maximum, with daily delivery to all customers as shown in the use case of AC/DC.

Total Cost of Ownership

Total Cost of Ownership (TCO) evaluates cost of all processes such as design, production, and logistics over the complete supply chain. TCO is strongly related to financial reporting and includes all variable and fixed costs of a company [M4.11].

The contribution of this project is the development of a TCO model which determines the true costs of a given supply chain. In doing so, we have designed a model which is able to provide a more extended view up- and downstream of the value chain. The model supports the more strategic perspective of TCO and can thereby serve as a starting point to redesign a given supply chain in a more cost efficient way.

Elements of the supply chain for TCO analysis

Logistics
• Freight bill, import taxes, duties, and customs;
• Value added taxes;
• Packaging;
• Air freight to meet schedules;

Quality Assurance
• Qualification, validation and audit costs;
• Incoming inspection;
Flexible Production System

Risks
- Demand changes;
- Possibility of missing product/service necessary for production;
- Currency and political environment;
- Lead-times, union vs. non-union environments, delivery performance, formal supply agreements, expediting and obsolescence;

Maintenance and Repair
- Costs of acquisition, depreciation and maintenance;
- Cost for capital equipment in outsourcing;

Administrative and Financing
- Payment terms and currency fluctuations;
- Extra inventory because of outsourcing;

Lean Production
- Cost of flexible production;
- Variable shift models;
- Reduced investment;
- Late customizing.

Benefit balancing
Benefits arising from collaboration in a supply chain belong to the participants, namely the suppliers and the buyers involved. Total benefit from all collaborations in a supply chain can be substantial and the collaborative partners expect to gain their individual shares. Therefore, as a strong incentive for initiating or sustaining favorable changes in a collaborative environment, total benefit should ideally be balanced or shared amongst the active participants. In fact, equitable sharing or balancing of this resultant benefit has been the hallmark of various supplier development programs in many companies.

A supply chain can thrive on business success and active collaboration of the participants. However, much collaboration fails because of unacceptable benefit sharing: Participants often feel that they do not benefit sufficiently for the contributions they make [9]. Therefore, proper benefit balancing in collaborative environments is an increasingly important concern.

In order to balance the benefit in a supply chain, it is not only imperative to measure the resultant total but also to assess accurately the individual contributions of the participants. Nature of their collaborations and value generators must be carefully evaluated alongside potentially conflicting goals. Comprehensive analysis is important because key cost drivers, value generators, and multiple costs associated with procurement of goods as well as services have significant bearing.

4.5 Reference to other methods

Collaborative design of supply chain

Collaborative Design is a method of joint design and optimization of the supply chain and processes together with customers and suppliers in order to reduce inventories, costs, lead time and to increase efficiency. Targets / benefits are:
- Common optimization of the supply chain process flow;
- Synchronization of activities between the business partners;
- Early detection of supply bottlenecks;
- Exchanges of most effective practices;
- Utilization of synergies;
- Generation of win/win situations;
Before After

Figure 4.15: U-shaped production cell

- Faster reaction to changes and problems due to a common understanding;
- Cost reduction due to reduced lead time and inventories;
- Maximal utilization of available resources at production and logistics; and
- Joint leveling of demand fluctuations.

Continuous flow

Continuous Flow is the link of manual and machine operations in a most efficient way by minimizing movement, transport and handling for a material flow without interruption, detours, back-flow and stand time. Targets / benefits are:

- Reduced inventory;
- Reduced lead time;
- Optimized material flow;
- Quick problem detection;
- Minimized resources;
- Reduced quality risks;
- Smoothed production;
- Reduced space; and
- Improved/reduced response time to customer call-offs.

Best practice is a one-piece flow in accordance to the takt time. In all other cases follow the principle [7]: “Flow when you can, pull when you can’t!”

Pull principle

The aim of the pull orientation is to keep material flowing on a permanent, continuous basis without interruptions in order that all workstations in the flow just produce the quantity which is required from the next workstations. Targets / benefits are:

- Avoidance of overproduction;
- Optimized inventory buffers with decreased lead time;
- Cost reduction due to reduced lead time and inventories;
- Transparency within entire supply chain;
- Simplified processes;
- Minimize planning and scheduling effort;
- Increase of production flexibility;
- Controlled inventories on shop floor;
- Shorter reaction times;
- Implementation with reduced investment; and
- Harmonization of the material flow.

Supplier management

This is the systematic approach to develop and maintain the performance of the suppliers with the objective to establish a world class supplier base. Targets / benefits are:

- Ensure high quality, timely delivery, and cost reduction;
- Long-term partnerships;
- Clear, common strategy for logistics supplier development;
- Overall management-driven process;
- Clear performance measurements of logistics and quality KPIs;
- Strategic contract management;
- Total cost of ownership approach;
- Fast response on complaints;
- Agreement on responsibilities;
- Knowledge transfer; and
- Reduced effort for qualification.
**Standardization of manufacturing technologies**

The aim is to use worldwide standardized manufacturing technologies in terms of processes, equipment and material. Targets/benefits are:

- Same process quality worldwide;
- Common equipment specifications;
- Standardized production procedures;
- Preferred processes, suppliers and materials;
- Standardized implementation of new process, equipment, material before starting a product development;
- Systematic knowledge transfer;
- Use of proven and best technologies;
- Central technology information database;
- Re-usability of equipment;
- Reduce implementation time, effort and costs for new/existing technology;
- Reduction of maintenance and support costs;

For detailed information regarding methods and tools, please refer to the AC/DC website at http://www.acdc-project.org.
Section 5

Conclusion and Summary

5.1 Summary

The European automotive industry is facing enormous challenges as a result of the financial crisis, the high prices for oil, steel and as well as emission control. To tackle these challenges, traditional approaches have to be questioned and novel solutions have to be developed and applied. The European-funded project AC/DC supports this transition towards a sustainable automotive economy by implying knowledge-based products and processes with innovative approaches.

For the product side, the shift from traditional mechanics towards the combination of mechanics, electronics and software, i.e., mechatronics, has been researched and further developed using the active suspension as a model application. Mechatronics supports the customization of neutral components by means of software and parameterization at low costs and at a very late stage of product realization, or even at the car dealer.

This transformation enables the application of Customize-to-Order (CtO) as a lean complement to complex Build-to-Order approaches. A basic instrument to exploit the accompanying advantages is the Dynamic Supply Loop as an iterative but fast, network-based planning and operations approach.

Smart modular products

The main smart modular product developed in AC/DC is a highly innovative active rear axle module enhancing existing safety functions and increasing driving comfort options. The rear axle is equipped with mechatronic actuators, an active stabilizer, a torque vectoring rear axle differential, and semi-active MR-dampers. To handle the increase in variability and flexibility, all the connections of the rear axle will be consolidated in two central connectors, a power and a signal connector. Another developed component is a modular HF sensor for different crash scenarios, as well as
for vehicle dynamics control. Due to the advanced software, which was also developed, this sensor can be adapted to different vehicle chassis types and also support different add-on functions. The mechatronic actuators are presented and validated on test-benches, which are also used to validate the interoperability of the components inside the rear axle demonstrator. Due to the central connectors and the advanced software the mechatronic systems can be implemented very late in the production to support the CtO approach of the project.

**Collaborative production network management—Dynamic Supply Loops**

Although the need for collaborative planning in supply chains is generally recognized, there is still a gap between theoretic proposals and practical requirements. The proposed principles of the Dynamic Supply Loop can be treated as a viable compromise for more optimized inter-company planning: it offers a platform for other partners’ options, while keeping communication and decision complexity at bay through a relatively simple information exchange and decision protocol confined to immediate partners in a chain. DSL is accessibly to embed standard planning techniques and novel incentive schemes alike. Simulation results on a multi-echelon model showed that DSL outperforms traditional upstream planning and facilitates channel coordination.

The methods developed by AC/DC show possibilities which improve collaboration between the partners in the supply network, offer fast response and flexibility as well as process reliability over the complete supply grid.

Many of the developed methods have been proven in practical best-case implementations showing applications at each level of the supply chain management, strategic and tactical planning, collaborative forecasting, event handling and simple automatic information messaging.

**Flexible production system**

The automotive industry is continuously increasing the requirements of flexibility in production systems, both at the OEM as well as at the suppliers. In addition to flexibility in production volumes, product variety is increasing every year.

Objective of AC/DC is to make a production system able to manage ±25% capacity fluctuation per day, without increasing cost. A number of tools have been implemented to achieve this target. *Lean* production management has been used as one important foundation stone. The Lean philosophy aims at shortening the order-to-delivery lead time by product standardization and late customization of components, aspects which have been developed as smart modular products in the AC/DC project.

The tool box for flexible production systems also include *value stream mapping*, calculation of the *total cost of ownership*, *ABC/XYZ analysis* of the product range to optimize the inventory and *Single Minute Exchange of Die* to reduce waste in the process. *Benefit balancing* has already been mentioned as an important motivator for all supply chain participants to contribute to the common benefits.

The following results were evaluated as being possible:

- Lead time reduction down to 85%;
- Inventory reduction down to 50%;
- Operator reduction down to 8%;
- Floor space reduction by 6%;
- Defect/rejects reduction by 50%; and
- Flexibility per day ±25%.

All results could be achieved without increasing the Total Cost of Ownership (TCO).
5.2 Contributors

The work presented in this book was funded by the European Commission in the thematic priority “Sustainable development, global change and ecosystems” of the Sixth Framework Programme for Research and Technological Development (contract number FP6-SST-031520).

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- BMW AG, Germany
- Centre for Research and Technology Hellas, Greece
- Commissariat à l’Energie Atomique, France
- ERPC GmbH, Germany
- Fraunhofer IAO, Germany
- Fujitsu Services AB, Sweden
- Fundacion CARTIF, Spain
- INESC Porto, Portugal
- MTA SZTAKI, Hungary
- University of Modena and Reggio Emilia, Italy
- University of Paderborn, Germany
- VDI/VDE-IT GmbH, Germany
- Volkswagen AG, Germany
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- Christian Müller, Jürgen Hoffmann
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- José Lozada, CEA
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**T1200 Advanced Software**
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- Jörn Stuphorn, UPB
- Bernd Sieker

**T1300 Technologies Validation**
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- Thomas Kopp, Horst Krimmel, ZF
- Egon Auer
- Francesco Lolli, Stefano Marzani, Roberto Montanari, UNIMORE
- Paul Hochrein, VW
- Christian Müller, Jürgen Hoffmann
- José Lozada, CEA
### T2100 Dynamic Planning Loops

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<tbody>
<tr>
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<td>Jurij Menz</td>
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<td>Andre Döring, Thorsten Timm</td>
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<td>MTA SZTAKI</td>
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<tr>
<td>Jorge Pinho de Sousa, Cristóvão Dinis, Abdur Rais, César Toscano</td>
<td>INESC Porto</td>
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<tr>
<td>Joachim Lentes, Holger Eckstein</td>
<td>Fraunhofer IAO</td>
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<tr>
<td>Marian Gallego, Roland Ericsson, Levi Siljemyr</td>
<td>Fujitsu</td>
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### T2200 Collaborative Demand Prediction

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<tr>
<td>Marian Gallego</td>
<td>CARTIF</td>
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<tr>
<td>Mauro Dell’Amico, Daniele Pretolani, Manuel Iori</td>
<td>UNIMORE</td>
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### T2300 Planning Consistency

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<td>Daniel Brüggeman</td>
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<td>Thorsten Timm</td>
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<tr>
<td>Ismail Poslu, Bernd Schäfer, Bettina Deinhard</td>
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<td>Péter Egri, MTA SZTAKI</td>
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<td>Balázs Csanád Csáji, András Pfeiffer, József Váncza</td>
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<tr>
<td>Jorge Pinho de Sousa, Cristóvão Dinis, César Toscano, Carla Pereira</td>
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### T2400 Real-Time Event Handling

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<td>Claire Diertl, Ismail Poslu, Katja Brühne, Markus Mathieu</td>
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<tr>
<td>Gloria Pellischek, Christoph Laroque, Thorsten Timm</td>
<td>ERPC</td>
</tr>
<tr>
<td>Jorge Pinho de Sousa, Cristóvão Dinis, Abdur Rais, César Toscano</td>
<td>INESC Porto</td>
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</table>
## Conclusion and Summary

<table>
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<tr>
<th><strong>T2500 Modular Production Technology Processes</strong></th>
<th><strong>T2600 Distributed Development and Testing</strong></th>
</tr>
</thead>
</table>
| *Rolf Becker,*  
Melanie Assenmacher,  
Doris Landsammer,  
Ruth Meier,  
Andreas Büchele,  
Robert Keszte,  
Geert Spelier,  
Walter Robbe,  
Markus Schneider,  
Heinrich Sieber,  
Markus Zimmermann,  
Ismail Poslu,  
Francesco del Polito  
Abdur Rais,  
Jorge Pinho de Sousa  
Marian Gallego  
Péter Egri,  
József Váncca | *Uwe Kirchhoff,*  
*Christian Wolff,*  
*Ana Teresa Correia* |
| Continental | ATB |
| Rolf Becker,  
Holger Pietsch,  
Tomasz Augustyniak  
Andrea Pavesi,  
Lorenzo Fantesini  
Mukayil Kilic | Continental |
| Walter Robbe,  
Markus Schneider,  
Heinrich Sieber,  
Markus Zimmermann,  
Ismail Poslu,  
Francesco del Polito  
Abdur Rais,  
Jorge Pinho de Sousa  
Marian Gallego  
Péter Egri,  
József Váncca | INESC Porto |
| Holger Pietsch,  
Tomasz Augustyniak  
Andrea Pavesi,  
Lorenzo Fantesini  
Mukayil Kilic | CARTIF |
| Holger Pietsch,  
Tomasz Augustyniak  
Andrea Pavesi,  
Lorenzo Fantesini  
Mukayil Kilic | MTA SZTAKI |
| Holger Pietsch,  
Tomasz Augustyniak  
Andrea Pavesi,  
Lorenzo Fantesini  
Mukayil Kilic | VW |
### List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>5DayCar</td>
<td>EU initiative to enable delivery of a customer specified car within 5 days</td>
</tr>
<tr>
<td>8D</td>
<td>Eight Disciplines Problem Solving</td>
</tr>
<tr>
<td>AC/DC</td>
<td>Automotive Chassis Development for 5-Days Cars</td>
</tr>
<tr>
<td>AOF</td>
<td>Add-On Functionality</td>
</tr>
<tr>
<td>API</td>
<td>Application Programming Interface</td>
</tr>
<tr>
<td>APO</td>
<td>Advanced Planner and Optimizer (module in SAP)</td>
</tr>
<tr>
<td>AS2</td>
<td>Applicability Statement 2</td>
</tr>
<tr>
<td>ASIL</td>
<td>Automotive Integrity Safety Level</td>
</tr>
<tr>
<td>AtO</td>
<td>Assemble-to-Order</td>
</tr>
<tr>
<td>AUTOSAR</td>
<td>AUTomotive Open System ARchitecture</td>
</tr>
<tr>
<td>AZT</td>
<td>Allianz Zentrum für Technik</td>
</tr>
<tr>
<td>BOM</td>
<td>Bill of Materials</td>
</tr>
<tr>
<td>BtF</td>
<td>Build-to-Forecast</td>
</tr>
<tr>
<td>BtO</td>
<td>Build-to-Order</td>
</tr>
<tr>
<td>BU</td>
<td>Business Unit</td>
</tr>
<tr>
<td>CAN</td>
<td>Controller Area Network</td>
</tr>
<tr>
<td>CAN</td>
<td>Compact Disc</td>
</tr>
<tr>
<td>CMap</td>
<td>Concept Maps (in generic programming)</td>
</tr>
<tr>
<td>CMDS</td>
<td>Collaborative Management of Delivery Schedules</td>
</tr>
<tr>
<td>CtO</td>
<td>Customize-to-Order</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DLC</td>
<td>Double Layer Capacitor</td>
</tr>
<tr>
<td>DP</td>
<td>Demand Planning</td>
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<tr>
<td>DSL</td>
<td>Dynamic Supply Loop</td>
</tr>
<tr>
<td>EBC</td>
<td>Electronic Body Control</td>
</tr>
<tr>
<td>ebMS</td>
<td>ebXML messaging service</td>
</tr>
<tr>
<td>ebXML</td>
<td>Electronic Business using eXtensible Markup Language</td>
</tr>
<tr>
<td>eCl@ss</td>
<td>International Standard for Classification and Description of Products and Services</td>
</tr>
<tr>
<td>ECU</td>
<td>Electronic Control Unit</td>
</tr>
<tr>
<td>EDI</td>
<td>Electronic Data Interchange</td>
</tr>
<tr>
<td>EDIFACT</td>
<td>Electronic Data Interchange For Administration, Commerce and Transport</td>
</tr>
<tr>
<td>EE</td>
<td>Extended Enterprise</td>
</tr>
<tr>
<td>ELMS</td>
<td>Emergency Level Material Shortage</td>
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<tr>
<td>EPS</td>
<td>Electronic Power Steering</td>
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<tr>
<td>ERC</td>
<td>Electronic Roll Control</td>
</tr>
<tr>
<td>ERP</td>
<td>Enterprise Resource Planning</td>
</tr>
<tr>
<td>ESP</td>
<td>Electronic Stability Program</td>
</tr>
<tr>
<td>FIFO</td>
<td>First-In-First-Out</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Mode and Effects Analysis</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
<tr>
<td>HECU</td>
<td>Hydraulic/Electronic Control Unit</td>
</tr>
<tr>
<td>HF</td>
<td>High Frequency (in acceleration measurements HF range is 5–20kHz)</td>
</tr>
<tr>
<td>HiL</td>
<td>Hardware-In-the-Loop</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communication Technology</td>
</tr>
<tr>
<td>ID</td>
<td>Identifier</td>
</tr>
<tr>
<td>ILIPT</td>
<td>Intelligent Logistics for Innovative Product Technologies</td>
</tr>
<tr>
<td>I/O</td>
<td>Input / Output</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>Acronym</td>
<td>Abbreviation</td>
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<tr>
<td>JIT</td>
<td>Just-In-Time</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
</tr>
<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>LCA</td>
<td>Lean Clever Automation</td>
</tr>
<tr>
<td>LVDT</td>
<td>Linear Variable Differential Trans-</td>
</tr>
<tr>
<td>MD</td>
<td>Mechanism Design</td>
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<td>MFERT</td>
<td>Modell der Fertigung (Production</td>
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<tr>
<td>MP</td>
<td>Material Planner</td>
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<tr>
<td>MR</td>
<td>Magneto-Rheological</td>
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<td>MRP</td>
<td>Material Requirement Planning</td>
</tr>
<tr>
<td>MS</td>
<td>Material Shortage</td>
</tr>
<tr>
<td>MSF</td>
<td>Material Shortage Form</td>
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<tr>
<td>MSM</td>
<td>Material Shortage Management</td>
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<tr>
<td>mySAP</td>
<td>Suite of SAP systems</td>
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<tr>
<td>OASIS</td>
<td>Organization for the Advancement of</td>
</tr>
<tr>
<td></td>
<td>Structured Information Standards</td>
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<tr>
<td>ODB</td>
<td>Offset Deformable Barrier, a</td>
</tr>
<tr>
<td></td>
<td>deformable barrier for crash tests,</td>
</tr>
<tr>
<td></td>
<td>representing a second vehicle</td>
</tr>
<tr>
<td>ODETTÉ</td>
<td>Organisation for Data Exchange by</td>
</tr>
<tr>
<td></td>
<td>Tele Transmission in Europe</td>
</tr>
<tr>
<td>OEE</td>
<td>Overall Equipment Efficiency</td>
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<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer, e.g.,</td>
</tr>
<tr>
<td></td>
<td>car manufacturer</td>
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<tr>
<td>OOPUS</td>
<td>Objekt-Orientiertes Planungs- und</td>
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<tr>
<td></td>
<td>Steuerungssystem</td>
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<tr>
<td>PM</td>
<td>Project Manager</td>
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<tr>
<td>PP/DS</td>
<td>Production Planning and Detailed</td>
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<tr>
<td>ppm</td>
<td>parts per million</td>
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<td>PSI-5</td>
<td>Peripheral Sensor Interface 5</td>
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<tr>
<td>Q</td>
<td>Quality</td>
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<td>QFD</td>
<td>Quality Function Deployment</td>
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<td>RA</td>
<td>Red Alert</td>
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<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
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<tr>
<td>RL</td>
<td>Reinforcement Learning</td>
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<tr>
<td>RMS</td>
<td>Root Mean Square, the effective</td>
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<tr>
<td></td>
<td>value of a signal; mathematically</td>
</tr>
<tr>
<td></td>
<td>the statistical mean value</td>
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<tr>
<td>ROM</td>
<td>Read Only Memory</td>
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<tr>
<td>RTE</td>
<td>Run-Time Environment</td>
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<td>RTRS</td>
<td>Real-Time Reaction Schemes</td>
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<td>S&amp;OP</td>
<td>Sales and Operations Planning</td>
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<td>SCF</td>
<td>Supplier Comparison Factors</td>
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<tr>
<td>SCM</td>
<td>Supply Chain Management</td>
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<tr>
<td>SDL</td>
<td>Statistical Disclosure Limitation</td>
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<td>SME</td>
<td>Small and Medium Enterprises</td>
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<td>SMED</td>
<td>Single Minute Exchange of Die</td>
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<td>SMT</td>
<td>Surface Mounting Technology</td>
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<td>Supply Network Planning</td>
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<td>SPSS</td>
<td>Statistical Package for the Social</td>
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<td></td>
<td>Sciences</td>
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<td>SQM</td>
<td>Supplier Quality Management</td>
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<td>SUV</td>
<td>Sport Utility Vehicle</td>
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<tr>
<td>TCO</td>
<td>Total Cost of Ownership</td>
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<td>TCP</td>
<td>Transmission Control Protocol</td>
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<td>UNSPSC</td>
<td>United Nations Standard Products</td>
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<tr>
<td></td>
<td>and Services Code</td>
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<td>VDA</td>
<td>Verband der Automobilindustrie</td>
</tr>
<tr>
<td></td>
<td>(Union of the automobile industry)</td>
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<tr>
<td>Wifi</td>
<td>Wireless fidelity</td>
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<td>VSD</td>
<td>Value Stream Design</td>
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<tr>
<td>VSM</td>
<td>Value Stream Mapping</td>
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Conclusion and Summary


Conclusion and Summary


The European automotive industry is facing enormous challenges as a result of the financial crisis, high prices for oil and steel, intensified emission controls and the trend towards electric vehicles. To tackle these challenges, traditional procedures have to be questioned and novel approaches have to be established. The European Commission-funded project AC/DC (TIP5-CT-2006-031520) supports this transition towards a sustainable automotive economy by means of knowledge-based products and processes introducing innovative approaches.

This handbook, “From Build-to-Order to Customize-to-Order”, represents a Code of Practice based on the results of the AC/DC project.

The key topics include:
- Smart modular products customized at a late stage during the order fulfillment process
- Collaborative production network management by dynamic supply loops
- Flexible production systems able to manage ±25% capacity fluctuation per day