

# **Opposites Attract: An Approach to Collaborative Supply Chain Management between Semiconductor and Automotive Companies**

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**Abstract:** This article illustrates the differences between the semiconductor and the automotive industry and the subsequent challenges to their common supply chain. The weak points at the interfaces between the two supply chains will systematically be identified and assessed.

Based on this analysis, a toolkit for collaborative supply chain planning and execution between the automotive and the semiconductor industry is presented. A fit/gap analysis assesses the measures and their potential to solve the supply chain challenges in a systematic manner. The model is built upon existing supply chain management frameworks and defines a set of specific optimization measures for the problem at hand. These are designed to ensure a better alignment of planning and control processes between the automotive and the semiconductor industry.

**Keywords:** supply chain management, semiconductor, automotive, value chain, collaborative supply chain management

## **1. Introduction**

Companies no longer compete with each other; their supply chains do (Christopher, 2012). Christopher's credo gets more and more important as market volatility and the fragmentation of supply networks are on the increase. Managing the risk within supply chains thus becomes a critical success factor in the current business environment.

The work presented in this paper is motivated by two factors: The growing importance of semiconductor supply to the automotive industry and the difficulties in the supply chain, which have already brought production lines to a halt in the past.

The automotive semiconductor supply chain is of critical importance because the share of electronic components in cars is already high and continuously increasing: The share of electronics in the value-added in cars is expected to more than

double between 2010 and 2020 (Krust, 2012). The majority of innovations in cars, such as airbags, ABS brakes, GPS systems, and automotive Ethernet, are owed to microprocessors and chips and thus to semiconductors.

Unexpected events in the last two years, such as the volcanic eruption in Island, the tsunami followed by the nuclear incident in Japan and the flooding in Thailand, have put the automotive semiconductor products and their globally distributed supply chains at risk. The impact of the disaster in Japan extended to material, component and system suppliers in the chain and highlighted the importance of the semiconductor supply to the automotive sector: A shortage in chip manufacturing spilled over to the supplier Hitachi and disrupted production at four of five Japanese Nissan plants (Riemenschneider, 2011).

But even without natural catastrophes, supplying the automotive industry with semiconductor products is a challenge. The real risk lies in the nonaligned supply chains. Increasingly volatile markets, differing manufacturing lead times, innovation and product life cycles, but also the fact that the planning and control processes of both industries are not coordinated, have led to overproduction and underproduction along with overstocking and supply shortages in recent years.

The chip producer Infineon, for example, claims the real challenge is to manage the bullwhip effect between semiconductor and automotive supply chain (Ehm, 2012).

Figure 1 illustrates how the downward trend in 2009 created excessive stock and overproduction throughout the semiconductor supply chain. The subsequent uplift was recognized and mitigated too late, leading to significant bottlenecks in the supply of semiconductor products. This bullwhip effect resulted in repeated bouts of material allocations, line stoppages, and exorbitant logistics costs for the entire supply chain from semiconductor manufacturers to automotive OEMs (Forster & Zapp, 2011a). The material shortage in 2010 was followed by an oversupply in the second quarter of 2011, where the automotive semiconductor stockpiles peaked at 93 Days of Inventory (DOI) – the highest in the last three years (Stiefel, 2011).

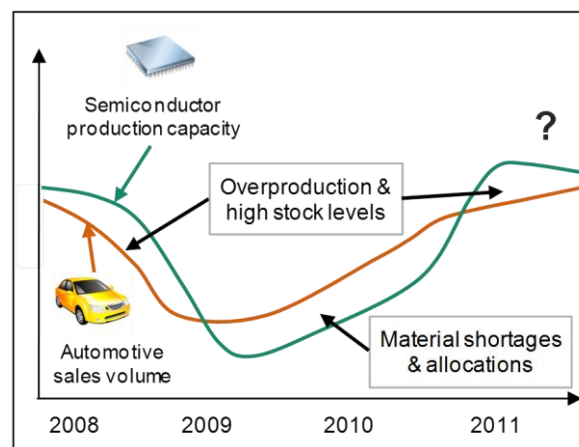


Figure 1: Semiconductor production capacity and automotive sales volume in the years 2008 to 2011  
(Zapp, Forster, Verl, & Bauernhansl, 2012)

This shows that the collaborative management of the supply chains between semiconductor industry and the automotive sector is a must. Sharing costs, risks, intellectual property and talent has become a matter of survival, or, in the plain words of industry experts: Collaborate or die (Myers, 2006). Better collaboration in the automotive supply chain for semiconductor devices can only be achieved by a structured analysis of the weak points in the supply chain. Taking this assessment as a basis, improvement measures can be identified.

## 2. Background

### 2.1 The Supply Chain between Semiconductor and Automotive Industry

The process of semiconductor production is one of the most complicated manufacturing processes, which can require more than eight hundred discrete steps (Huethorst, 2011). The production process can broadly be divided into two main stages: Firstly, the chip manufacturing stage (front end) and secondly, the assembly, packaging and final testing stage (back end). The manufacturing process is usually performed by different parties spread across the globe: the wafer fab focusing on the front end processes and the assembly plants performing the back end operations. Due to the complexity of the

process, the manufacturing lead time can take up to 16 weeks: The manufacturing of dies requires up to twelve weeks in the front end and four weeks for assembly, packaging and final testing in the back end (Huethorst, 2011; Forster & Zapp, 2011a).

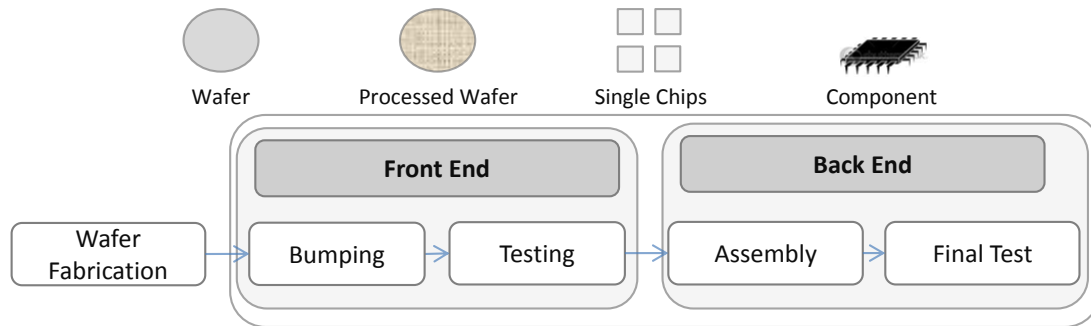


Figure 2: Exemplary semiconductor manufacturing process

Figure 2 illustrates a simplified example of a semiconductor supply chain. It shows the manufacturing process and the outcome of each process step. Chips for the automotive industry are built according to the assemble-to-order principle: The processed wafers are stored in a strategic inventory buffer, the so-called die bank, awaiting customer orders to drive the remaining assembly stages (Ehm, McGinnis, & Rose, 2009).

Unlike the simplified, linear process in Figure 2, Figure 3 shows an example of a semiconductor producer, illustrating the complexity and internationalization of the manufacturing process. The first process step of wafer fabrication, for example, can be performed in fabs in Germany, France, and Taiwan. The fragmentation as well as the internationalization of the semiconductor manufacturing process can thus be best described by the catchphrase: “The global supply chain is the new fab” (Ehm et al., 2009).

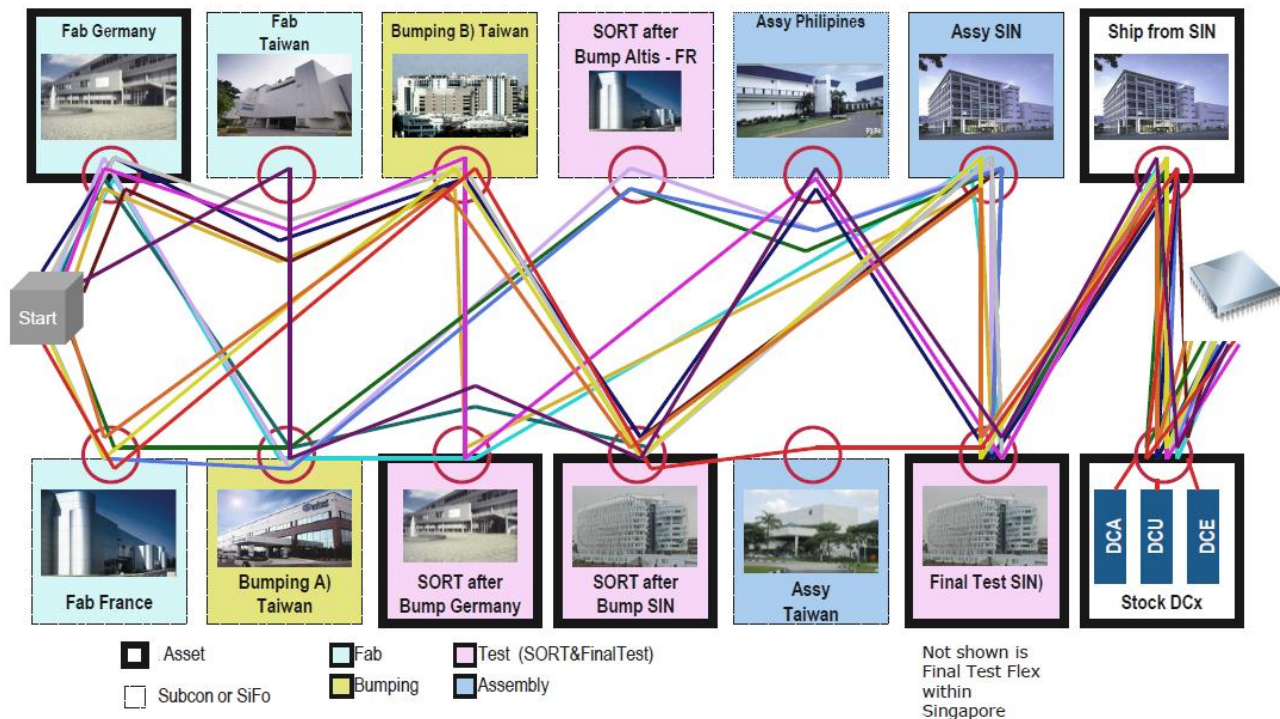


Figure 3: Internationality and complexity of supply chain scenarios (Ehm, 2012)

## 2.2 Differences and Difficulties in Semiconductor and Automotive Industry

The supply chain between the semiconductor and the automotive industry faces not only the challenge of a complex and international network, but is also marked by the clash of two opposing industries.

First of all, it should be pointed out that in this context even the mere complexity of the network between wafer fabrication and OEM – caused by the globalization of the supply chain and the outsourcing trend – poses a challenge to the supply chain (Kersten, Böger, Hohlrath & Späth, 2006). Unlike other industries, suppliers in the automotive industry take on extended responsibilities in the wake of declining production depth. Once just manufacturers of parts, automotive suppliers today offer in-depth knowledge in development and production, along with product expertise, and are heavily intertwined with the OEMs (Diez & Reindl, 2009). Hence, the automotive industry is characterized by a large network of suppliers in which the semiconductor supplier usually takes over a 2<sup>nd</sup> or 3<sup>rd</sup> tier role, contributing a large share of the value added to automobile products.

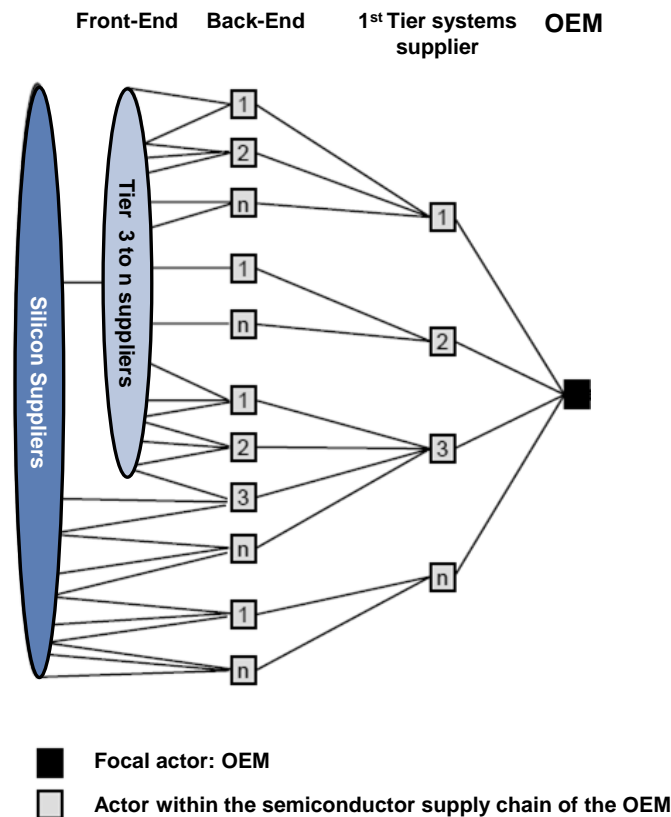


Figure 4: Semiconductor supply network (Lambert, D. M., Cooper, M. C., Pagh, J.D., 1998)

Looking at Figure 4, it becomes clear that the term “supply chain” does not exactly describe the supply situation between semiconductor and automotive industry in its full complexity: Anything but a linear chain, the supply is organized as a large network of suppliers throughout the world. The increasing number of players itself deteriorates transparency across the supply chain and triggers the bullwhip effect. This is further enforced by the distance between semiconductor companies and automotive OEMs, with their interface being the 1<sup>st</sup> Tier supplier.

Further industry differences that pose a challenge to the supply network will be analyzed in the following. The focus is on long-term issues, for example diverging life cycles, and mid-term issues, for example planning horizons. Operational challenges affecting day-to-day business are not taken into account.

### 2.2.1 Product life cycles and pressure for innovation

Traditionally, components for the communications and IT industry account for a large share of turnover in the semiconductor industry, a fact that goes back to the invention of the transistor radio in the 1950s. The communications and IT industry is driven by innovation: According to Moore’s law, the performance of a semiconductor chip doubles every 18 to 24

months, which correlates with the useful life of a cellular phone (see Figure 4). Semiconductors are integrated into products of various industries with sales periods of less than a year. The duration of a chip's life is thus not determined by its functionality, but rather ends when new, more powerful products enter the market (Foj, 2009). Consequently, semiconductor production facilities are in a constant process of steep ramp-ups or ramp-downs. A distinctive characteristic of the semiconductor industry is its cyclical and volatile nature. The demand from the IT and communications industry is highly cyclical with short-term peaks: If a supplier cannot provide the chips for the next generation, another one will. Looking into the future, this trend is even expected to intensify: ever shorter market cycles with rapid growth periods, market slumps, and innovation cycles.

The automotive industry, on the other hand, offers products that have a much longer useful life: One third of the cars on European roads are older than ten years (Association des Constructeurs Européens d'Automobiles, 2010).

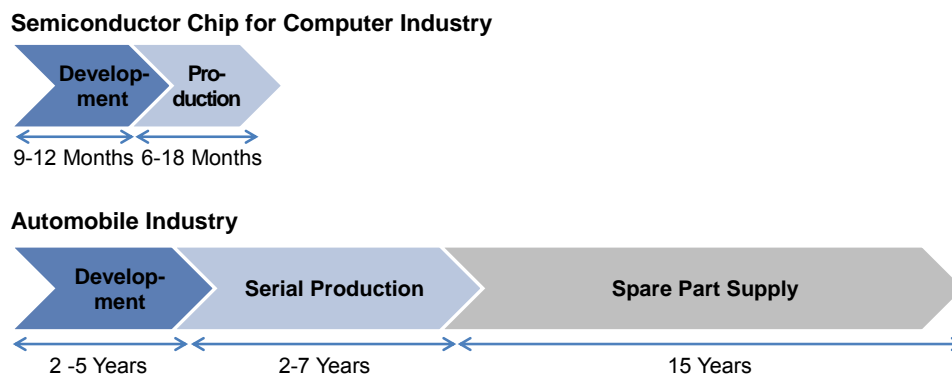


Figure 5: Differing product life cycles (Forster, Zapp, Aelker, Westkämper, & Bauernhansl, 2012)

### 2.2.2 Spare Part Supply

As vehicles have a long useful life, the demand for electronic components in the automotive industry is also long-term and solid. OEMs demand a spare part supply of up to 25 years and ideally even longer to additionally serve the old-timer market (Stoppok, 2002).

A different environment can be found in the IT and communications industry: As consumers are ready for change and demand the latest technologies, the spare part demand is almost inexistent. A defective product will simply be replaced by a follow-up product. Hence, the semiconductor industry is not prepared to provide spare parts on a long-term basis. Unlike chassis parts, electronic components cannot be properly stored for a longer period of time – not even at high costs. Keeping old production technology in operation for the manufacturing of spare parts cannot be done in a cost-efficient way.

### 2.2.3 Quality

Another challenge is the quality of semiconductor devices. The almost inexistent spare part demand from the IT and communications industry is the reason why the quality of the chip only needs to be good enough to survive the life cycle of the electronic product it is built into.

In the automotive industry, best quality and a zero-defect strategy are crucial for passenger safety and therefore have first priority. This importance has recently been demonstrated by Honda: Problems with the airbag had led to a large callback, a massive slump in sales and a persisting degradation of the brand image (Jensen, 2011). The high requirements in terms of quality are also reflected in the qualification process of semiconductor production equipment in the automotive industry. It is a complex, costly and time-consuming process, which can take up to twelve months. Accordingly, it is not amazing that most automotive companies are reluctant to change from existing and already qualified technologies to new products and production lines.

In addition, the performance requirements of the automotive products are often relatively low. As a consequence, chips for the automotive market are fabricated on older semiconductor technologies. Semiconductor manufacturers must therefore retain older production technologies for their automotive customers for many years, even though new process technologies are already used (Forster & Zapp, 2011a).



## 2.2.4 Manufacturing Flexibility

With regard to manufacturing flexibility, the cycle times are shorter and flexibility is greater in both IT and communications industry and in the automotive industry than in the semiconductor industry. The semiconductor industry aims at maximum utilization of its resources through a 24/7 production schedule, and so utilization rates of 95% are typical for the industry (Scheckenbach & Zeier, 2003). High qualification standards, a global division of the manufacturing process as illustrated in Figure 3 and 4, and long lead times further restrict the flexibility on the shop floor (Forster & Zapp 2011a). From a strategic point of view, both the long product life cycles in the car industry as well as the qualification requirements reduce the semiconductor manufacturers' flexibility in reacting to short-term market trends and demand fluctuations in the automotive supply chain.

The automotive industry, on the other hand, can quickly build up extra capacity by resorting to a number of different measures, for instance through additional shifts or the fast ramp-up of additional production resources. Unlike the semiconductor industry, the automotive industry is flexible and highly responsive to demand fluctuations. All manufacturers strive for the "10-day car," which means that the entire order cycle from order entry to customer delivery shall be performed within ten days (Rinza & Boppert, 2007). The automotive lead time is hence a fraction of the cycle time of a semiconductor component.

## 2.2.5 Planning Horizons

The different production lead times are reflected in the differing planning horizons. Due to the long lead times, the semiconductor industry operates on longer planning horizons of up to six months (Forster & Zapp, 2011a).

With customer-driven demand for flexibility, the automotive industry is required to plan on a short-term basis: A few days before assembly starts, the master production schedule is prepared according to the just-in-sequence principle. Another reason for shorter planning horizons as compared to the semiconductor industry is that the automotive sector has achieved a higher level of adaptability and that it can increase capacity at short notice.

It is common practice that semiconductor suppliers only get reliable planning data from their automotive customers for the following two months. Consequently, the only way to compensate for the lack of planning reliability for periods of up to six months is to build up large stocks and thus increase working capital or to compensate the deviations between forecast and actual demand by capacity flexibility. Figure 6 recapitulates the contradictory requirements faced by the semiconductor industry.

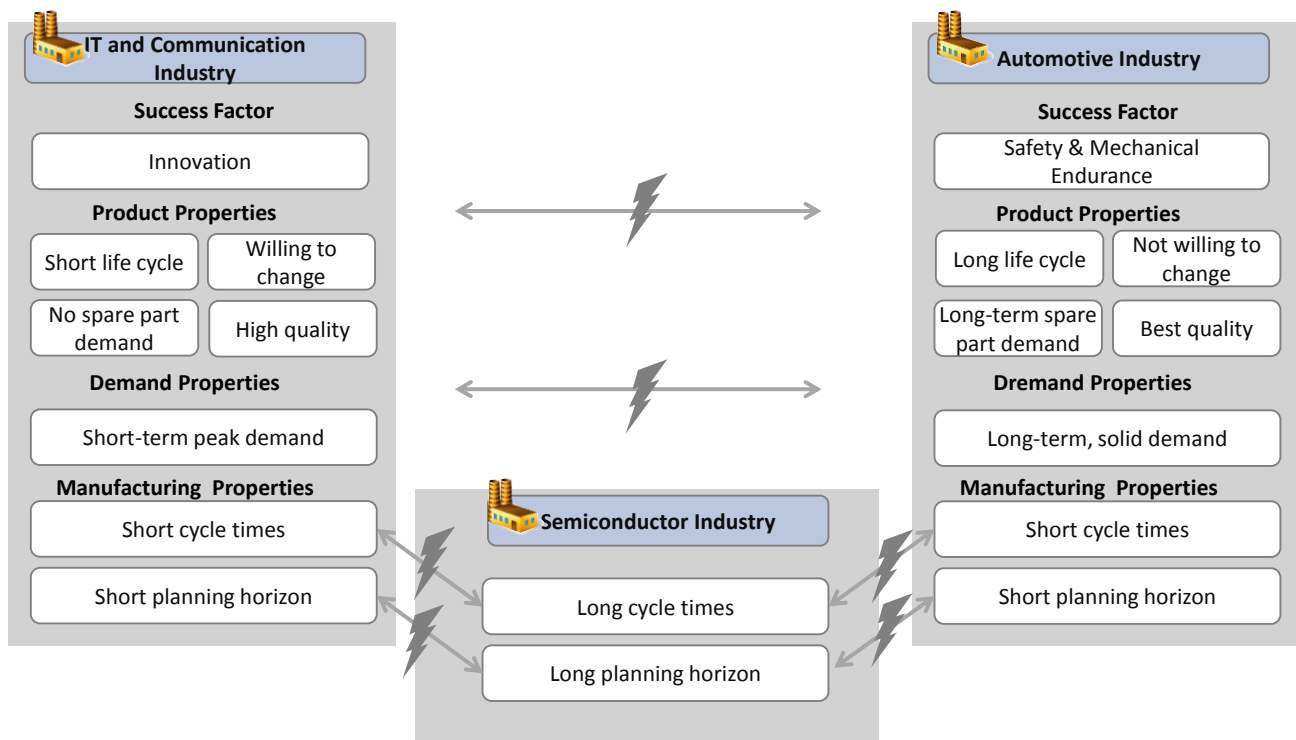


Figure 6: Differences and challenges between the automotive, the IT and the semiconductor industry

The bottom line is that the problems associated with the automotive semiconductor supply chain, for instance the diverging innovation and product cycles, cannot be resolved in the medium term. However, weak points such as the diverging planning horizons resulting in the bullwhip effect can be approached with collaborative supply chain measures.

### **3. Supply Chain Management and Collaborative Approaches**

According to the Council of Supply Chain Management Professionals, supply chain management “encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.” (Council of Supply Chain Management Professionals, 2011). A rather practical definition that better caters to the globally fragmented semiconductor supply chain comes from the Gartner Group, comparing supply chain management to “orchestrating a concert of resources to manage the process of creating and fulfilling the market’s demand for goods and services” (Gartner Group, 2011).

#### **3.1 Approaches to Collaborative Supply Chain Management**

A core element of Supply Chain Management is the collaborative planning, coordination and control of information, material and value flows between customers and their suppliers throughout the value chain (Kuhn & Hellingrath, 2002). In order to identify measures to optimize the collaboration between semiconductor and automotive companies, the existing strategies will be outlined in the following. In literature, a wide variety of industry-independent as well as industry-specific initiatives, models and approaches on this issue are discussed (Min, Roath, Daugherty, Genchev & Chen, 2005; Kuhn & Hellingrath, 2002; Werner, 2008; Sennheiser & Schnetzer, 2008). The relevant strategies for the supply chain at hand were identified by following a funnellike procedure.

In terms of width, supply chain management encompasses the processes of supply, recycling and disposal (Schupp & Baumgarten, 2004). This work focuses on the supply process including procurement, supply logistics as well as the integrated fields of production logistics, such as planning and identification of demand. In general, the supply function of a value chain is supported by cooperative strategies. These cooperative strategies can be further divided into vertical and horizontal strategies, depending on whether they focus on the same stage of the value added chain (horizontal) or on upstream or downstream stages (vertical). Here, the emphasis is placed on vertical cooperation strategies as the interaction between players of different up- and downstream stages is taken into consideration.

In terms of depth, supply chain management can be divided into a strategic, tactical and operational level (Sennheiser & Schnetzer, 2008). In this regard, the focus is on mid-term measures between one and five years aiming at specific goals, a period that applies to the tactical level. Out of the tactical measures focusing on vertical cooperation, those approaches were selected that can organizationally and technically be applied in the supply chain between semiconductor and automotive industry.

The selected approaches and their relevance for the topic at hand are described in the following sections.

##### **3.1.1 Supply Chain Operations Reference (SCOR) Model**

The SCOR model provides a hierarchical model decomposed into four levels. At the top level, it consists of five elementary types of business process: plan, source, make, deliver and return. The next level offers best practice configurations for different supply chain approaches, for instance make-to-order. The lower levels need to be tailored to the company implementing the model (Bolstorff, Rosenbaum, & Poluha, 2008).

SCOR offers a general framework for supply chain management and can help companies to standardize their supply chain terminology and processes as well as to apply best practice approaches (Supply Chain Council, 2012). Thereby, the model can facilitate cross-company communication and collaboration. However, SCOR does not offer operational process models for the collaboration between two particular industries like the automotive and the semiconductor industry. Therefore, the help it offers for the problem at hand is limited.

##### **3.1.2. Efficient Consumer Response (ECR)**

The ECR approach aims at the complete integration of information and supply chains to be able to efficiently respond to current customer demand (Birtwistle, 2006). This effort leads to the logistical objectives of responsiveness, cooperation, and customer-orientation. Marketing objectives are also included in the ECR approach but will not be considered in the following. The ECR approach should be understood as an umbrella serving as a superstructure for

numerous operational approaches (Wheatley, 1997). These include Cross Docking, Synchronized Production, and Continuous Replenishment.

Cross Docking builds on the establishment of central storage facilities in conurbations. Accordingly, its objective is not to supply a limited number of industrial customers, as in the semiconductor industry.

With Synchronized Production, the sales data are automatically sent from point of sale (POS) to the manufacturer to better control production. This approach is designed for highly flexible supply chains, which do not exist in the semiconductor industry. Moreover, semiconductor manufacturers often do not know what parts their chips are used for, so they are not able to interpret the POS data.

Continuous Replenishment (CR) itself provides a superstructure for improved supplier integration. The aim of CR is a continuous supply of goods along the entire supply chain from manufacturer to dealer, either through the actual demand at the point of sale or the forecasted demand of the storage locations of the retailer (Petzinna, 2007).

To ensure the supply of goods along the supply chain, three types of continuous replenishment programs are distinguished, each of which differs in the extent of integration and information exchange (Werner, 2008):

- Vendor Managed Inventory (VMI)
- Co-Managed Inventory (CMI)
- Buyer Managed Inventory (BMI)

Out of these, Vendor Managed Inventory is the pure form and means transferring the responsibility for part or even the complete inventory to the vendor. The supplier gains insight into the consumption figures as well as into sales and production planning and is responsible for managing the customer inventory (Werner, 2008).

Another approach associated with ECR is Collaborative Planning, Forecasting and Replenishment (CPFR), which will be explained in the following section.

### **3.1.3. Collaborative Planning, Forecasting, and Replenishment (CPFR)**

The Collaborative Planning, Forecasting and Replenishment approach aims to build collaboration between manufacturers and retailers to improve the sales forecasts. It is an initiative of the consumer goods industry and was first applied by Walmart in 1995. Demand forecasts shall be optimized by developing close cooperation between manufacturers and retailers. CPFR differs from process models such as SCOR by having the operational steps for implementing the joint cooperation processes defined by a CPFR process model (Kuhn & Hellingrath, 2002).

CPFR is based on agreements between the partners to define the financial and organizational framework and joint business models through shared objectives. From an operational perspective, demand figures from different distribution channels are electronically transferred, aggregated and made available to all supply chain partners via an online platform (Werner, 2008). Instead of working with historical data, sales forecasts can be made by using current sales figures.

Thereby, sales planning is no longer an activity done separately by each supply chain partner but instead becomes a cooperative effort: Forecasts are shared between supply chain partners and deviations can be discussed in a defined process.

### **3.1.4. Mass Customization**

Mass Customization unites the economies of scale of mass production („Mass“) with the individual satisfaction of customer needs („Customization“). Depending on whether interventions in the production process are necessary or not, a distinction is made between hard and soft customization (Werner, 2008). Three of the measures associated with mass customization are relevant for the supply chain at hand and will be discussed in the following.

One hard customization method is modularization, i.e. the assembly of customized products from a toolkit of standardized, compatible elements. Volkswagen, for instance, uses this strategy in its modular transverse matrix (MQB). Modularization offers great potential in the automotive semiconductor chain: Defining industry-wide standardized interfaces and architectures could facilitate the handling of opposing innovation cycles and provide a solution to the spare part supply, but it also requires great efforts for standardizing the existing heterogeneous architecture.

Another strategy is postponement, where the product remains as long as possible in a generic status and is only customized at the later stages of the supply chain. It thus includes an intelligent management of the decoupling point (Werner, 2008). This strategy can already be observed in the semiconductor industry: an assembly-to-order strategy divides the generic products from the customized products at the die bank.

Self-customization is a principle of soft customization and therefore does not affect the manufacturing process; it rather enables the customer himself to personalize the product. This can be done, for instance, with semiconductor chips by means of software configuration.



### 3.1.5. Conclusion

The approaches to improve collaborative supply chain management are as diverse as the challenges that can be identified for semiconductor companies and automotive OEMs. The presented models offer many opportunities for collaborating in supply chains, with each approach aiming at a different goal. The CPFR approach, in particular, allows for harmonizing both the forecasting and the resulting capacity planning procedure and can hence improve transparency and compensate for the diverging planning horizons. The existing approaches, however, were either developed without industry specification or are tailored to the specific needs of other industries. So, it needs to be investigated if and how these approaches can be applied to the challenges of the automotive and semiconductor industry before they can be adapted to the specific circumstances.

## 4. Approach to Collaborative Supply Chain Management between Semiconductor and Automotive Companies

### 4.1 Method for the Evaluation of Strategies

At an expert workshop held at the Fraunhofer Institute for Manufacturing Engineering and Automation IPA, a fit/gap analysis was used to identify the relevance of the identified collaborative strategies for the identified weak points. A “gap” in this context reflects a challenge within the supply chain and can thus be interpreted as a requirement. If a fit exists, it means there is a measure to solve this supply chain challenge. Accordingly, the ability and effectiveness of various strategies to compensate supply chain weak points were analyzed.

As quantitative data about the effectiveness of measures in regard to supply chain challenges is rare, the Analytic Hierarchy Process (AHP) is used to enable the quantification of qualitative judgments. Even more important is that the judgments, either by a single or more persons, can be checked on consistency. To know about the consistency of a decision is of great importance. Low consistency is equivalent to an arbitrary or incorrect judgment (Meixner, 2002). In case of significant inconsistencies, additional information has to be gathered, the data has to be reviewed and the decision process has to be reconsidered (Saaty, 1995). Based on consistent assessments, a profound decision can be made in favor of a supply chain strategy, while considering the respective importance of all challenges.

The American mathematician Thomas L. Saaty developed AHP in the 1970s (Wasil & Golden, 2003). AHP is a method for multi-criteria decision-making. It is a hierarchical additive weighting procedure in which alternatives and evaluation criteria are weighed up and assessed by pairwise comparisons (von Nitzsch, 1993). This helps to structure complex decisions and validate the consistency of the judgments (Saaty, 1994). As a result, rational, systematic and optimal decisions can be made (Meixner, 2002). The basic procedure is as follows:

- (1) *Problem definition:* The first step of the decision-making process is to define the problem. This is the basis for the definition of the overall decision goal (Saaty, 1994).
- (2) *Decision hierarchy:* To structure the decision problem, a hierarchy is built. It contains the overall goal, the alternatives to reach it, and the evaluation criteria (Haedrich, Kuss, & Keilkramp, 1986).
- (3) *Criteria weighting:* Elements of the same hierarchy level are pairwise compared to each other with respect to the element in the upper level. Qualitative judgments are quantified with the help of a fundamental scale (see Figure 7) (Saaty, 1994).

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgment slightly favor one activity over another.
5	Strong importance	Experience and judgment strongly favor one activity over another.
7	Very strong or demonstrated importance	An activity is favored very strongly over another, its dominance demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it.

Figure 7: Fundamental scale (Saaty, 1994)

The results are recorded in evaluation matrices (see Figure 8) and the eigenvector method is used to calculate, relative weights for the decision elements  $i$  and  $j$  ( $1, \dots, n$ ) through pairwise comparisons  $a_{ij}$ . The column sum  $c_i$  and the row sum  $r_i$  are of importance for the following proof of consistency (Saaty, 1994).

Evaluation matrix					Normalization				Row sum $r_i$	Weight $w_i$
$i/j$	$a_1$	$a_2$	...	$a_n$	$a_1$	$a_2$	...	$a_n$	$r_i = \sum a_{ij}/c_j$	$w_i = r_i/n$
$a_1$	$a_{11}=1$	$a_{12}$		$a_{1n}$	$a_{11}/c_1$	$a_{12}/c_2$	...	$a_{1n}/c_n$	$r_1$	$w_1=r_1/n$
$a_2$	$a_{21}=1/a_{12}$	$a_{22}=1$	...	$a_{2n}$	$a_{21}/c_1$	$a_{22}/c_2$	...	$a_{2n}/c_n$	$r_2$	$w_2=r_2/n$
$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$	$\vdots$
$a_n$	$a_{n1}=1/a_{1n}$	$a_{n2}=1/a_{2n}$	...	$a_{nn}=1$	$a_{n1}/c_1$	$a_{n2}/c_2$	...	$a_{nn}/c_n$	$r_n$	$w_n=r_n/n$
	$c_1=\sum a_{i1}$	$c_2=\sum a_{i2}$	...	$c_n$	1	1	...	1	$n$	1

Figure 8: Criteria weighing with the eigenvector method (Weber, 1995; Jonen, Lingnau, & Sagawe, 2007)

- (4) *Alternative weighting*: The decision maker's preference for one alternative over another with respect to a criterion is being questioned. Subsequently, the weights are calculated by the eigenvector method (Meixner, 2002).
- (5) *Proof of consistency*: The weights are checked for inconsistencies due to randomly or improperly executed judgments (Saaty, 1994). For this, the eigenvalue method is applied. The inconsistency of the judgments is higher, the higher the maximal eigenvalue  $\lambda_{\max}$  is compared to the number of elements  $n$ . That means the greater the inconsistency, the higher the consistency index CI (Saaty, 1994).

	Average matrix				row sum $\hat{r}_i$ $\hat{r}_i = \sum w_i * a_{ij}$	Eigenvalue $\lambda$ of the average matrix $\lambda_i = \hat{r}_i / (w_i * a_{ii})$	Consistency index CI $CI = (\lambda_{\max} - n) / (n-1)$	Consistency ratio CR $CR = CI/R$
	$a_1$	$a_2$	...	$a_n$				
$a_1$	$w_1 * a_{11}$	$w_2 * a_{12}$	...	$w_n * a_{1n}$	$\hat{r}_1$	$\lambda_1 = \hat{r}_1 / (w_1 * a_{11})$		
$a_2$	$w_1 * a_{21}$	$w_2 * a_{22}$	...	$w_n * a_{2n}$	$\hat{r}_2$	$\lambda_2 = \hat{r}_2 / (w_2 * a_{22})$		
$\vdots$	$\vdots$	$\vdots$		$\vdots$		...		
$a_n$	$w_1 * a_{n1}$	$w_2 * a_{n2}$	...	$w_n * a_{nn}$	$\hat{r}_n$	$\lambda_n = \hat{r}_n / (w_n * a_{nn})$		
						$\lambda_{\max}$		
						$\sum \lambda_i / n$		

Figure 9: Proof of consistency (Meixner, 2002; Saaty & Vargas, 2001)

To assess the acceptability of the consistency variation, the consistency ratio CR is calculated, which results from the division of the CI by the random index (RI). RI results from a randomized matrix of the same size as the matrix which has to be reviewed (Akomode, 1999; Noble, 1990). The consistency ratio illustrates the probability of a random assessment (Harker, 1989; Noble, 1990; Rommelfanger & Eickemeier, 2002). The consistency depends on the number of pairwise comparisons. Generally, the consistency is greater, the more pairwise comparisons are made (Meixner, 2002). Consistency ratios lower than 10% are considered as acceptable (Harker, 1989; Rommelfanger & Eickemeier, 2002). In exceptional cases, a CR of 20% is tolerated (Saaty, 1994).

To know about the consistency of a decision is very important. Low consistency is equivalent to an arbitrary decision. Inconsistency can be coincidental or through incorrect assessments (Meixner, 2002). Inconsistency does not necessarily state a problem (Haedrich et al., 1986). In case of significant inconsistencies, additional information has to be gathered, the data has to be reviewed and the decision process has to be reconsidered (Saaty, 1995).

- (6) *Synthesis of weights*: These weights express the element's relative importance in relation to the element on the level directly above (Saaty & Kearns, 1985). To determine the global weights, the relative weights have to be converted, relatively to the importance of the elements within the hierarchy. The global weight represents the importance of the element in relation to the overall hierarchy (Saaty, 1994).
- (7) *Analysis of Sensitivity*: Based on a sensitivity analysis, the stability of the findings can be checked by altering the weighting of attributes (Meixner, 2002).
- (8) *Interpretation of results*: If stability is sufficient, one alternative can be chosen as the solution of the decision problem (Saaty, 1994).

AHP allows structuring challenges and potential supply chain strategies. Before recommending a supply chain strategy, a first impulse to evaluate the current status is given. Hence, active cooperation is encouraged. The model is adjustable to new circumstances and can be repeated.

In this paper, AHP is primarily used to proof the consistency of judgments in terms of the fit/gap analysis performed in the expert workshop. Therefore, the process applied in this case study is reduced by the decision hierarchy and the conversion of relative weights into global weights is not adopted. AHP leads to a clear hierarchy of measures concerning a particular conflicting field.

As illustrated in Figure 10, the supply chain strategies were evaluated in terms of their effectiveness with an AHP-based tool, while the mathematical model ensured the consistency of data. The consistency ratios of the judgments were below 10% and thus the evaluation is within the acceptable tolerance.

UserForm25

Evaluate the effectiveness of the following supply chain strategies with respect to the challenge of a lack of transparency.

Collaborative Planning, Forecasting and Replenishment (CPFR) ... is compared with ... Vendor Managed Inventory (VMI) of ...

9 8 7 6 5 4 3 2 1 1/2 1/3 1/4 1/5 1/6 1/7 1/8 1/9

Extreme importance  
Very strong importance  
Strong importance  
Moderate importance  
Equal importance

9 8 7 6 5 4 3 2 1

Figure 10: Evaluation of alternative supply chain strategies based on AHP

## 4.2 Fit/Gap Analysis

The fit/gap analysis resulted in a reference toolkit of measures instead of a generalist solution. As the diverse challenges in the supply chain are caused by various circumstances, an overall solution that caters to all requirements cannot be identified. The analysis shows how different strategies address different challenges, with the filling level of the bullets being retrieved from the weights calculated with AHP. The filling level is thus related to the effectiveness of the strategies. The various measures of the toolkit can be combined to create a case-specific toolkit (see Figure 11).

Challenges	Strategies	SCOR	VMI	CPFR	Post-ponement	Modular-ization	Self-Customization
Lack of transparency							
High cyclicality and volatility							
Differing product life and innovation cycles							
Opposing demands on spare parts supply							
Diverging quality requirements							
Differing lead times							
High inventory levels							

Figure 11: Toolkit based on fit/gap analysis

In the following, the main strengths of the measures related to the supply chain between semiconductor and automotive industry will briefly be pointed out. The measures included in the presented reference toolkit can be customized to suit the needs of practical application.

SCOR, VMI and CPFR are all models that facilitate cooperation and the exchange of information.

SCOR offers a general framework for supply chain management and supports companies in standardizing their supply chain terminology and processes. Both VMI and CPFR focus on collaboration and visibility into the supply chain to

increase responsiveness to volatile markets. Taking care of direct and undistorted information flows counteracts fluctuations in demand along the supply chain and thereby reduces the bullwhip effect. While VMI promotes the exchange of data from daily operations, CPFR adds to it the coordination of long-term forecasts to improve medium and long-term capacity and investment planning.

The Mass Customization approaches – postponement, modularization and self-customization – support more flexible product designs and the strategic management of the customer order decoupling point. Therefore, they allow for efficiently controlling the differing product life cycles and innovation cycles. Due to late product differentiation in the value-added process, there are fewer variants, less in-process parts and the stock levels are lower, while lot sizes increase and the planning and control effort is reduced. As a result, manufacturing flexibility under stable manufacturing conditions is increased and the complexity of production planning is reduced.

Especially modularization strategies address the remaining unsolved problem of spare parts supply. Standardized architecture and interfaces make it possible to replace discontinued modules. Thus, modules can be integrated into the existing vehicle architecture, while original functionality is maintained. Moreover, a modularization strategy has the potential to reduce the complexity of the qualification process for production lines as single modules can be qualified separately.

The concept of self-individualization of semiconductor devices through software configuration also reduces the number of product variants, enabling a more streamlined production flow with lower stock levels, larger lot sizes and a higher responsiveness to the market.

However, the strategies of mass customization do not directly aim at increasing transparency within the supply chain, although they may have an indirect impact by reducing the complexity of parts.

#### **4.3 Practical Example: Increasing Supply Chain Transparency with SCOR, VMI and CPFR**

To put theory into practice, the following example will demonstrate in detail how the gaps identified in the automotive semiconductor supply chain and the supply chain strategies are interrelated and affect each other. One of the greatest risks in the automotive semiconductor supply chain is the lack of transparency caused by opposing planning horizons and the complexity throughout the supply chain (Forster & Zapp, 2011b). The reference model lists measures to increase transparency along the supply chain and ranks them according to their effectiveness: CPFR, VMI and SCOR (see Figure 10). The aforementioned measures and their customization for practical application in the semiconductor supply chain will be discussed in the following.

Firstly, the SCOR model has been identified as a measure that positively affects supply chain transparency. SCOR offers a general framework and enables users to address, improve, and communicate supply chain management practices within and between all interested players. By standardizing the supply chain terminology through a common set of definitions and by describing supply chains using process modeling building blocks, all parties involved can discuss the supply chain in depth and breadth. It can thus be interpreted as the common basis required for efficient communication.

SCOR has the potential to bring agility and flexibility to the complex semiconductor chain, as it enables to discuss in appropriate detail the divergent data structure from both production and sales point of view, while considering both views. Multiple stock keeping units (SKUs), for instance, can be aggregated to fewer planning items. This allows for planning production, confirming orders, reserving supply, adjusting capacities and tracking distribution in sufficient detail.

Secondly, Vendor Managed Inventory (VMI) is a partnership between supplier and customer, where the supplying organization makes inventory replenishment decisions on behalf of the buyer. VMI has its roots in the retail industry, but is also applied in the automotive industry, where it is used by some automotive suppliers and semiconductor suppliers. However, today's practical implementation of the model and the extent of its application leave room for improvement.

With the traditional Buyer Managed Inventory (BMI), material planning is particularly problematic for the global production networks of the automotive industry. This is because the automotive supplier's plants trying to improve material sourcing are neither considering the global demand trend for all plants nor necessarily using standardized planning principles. Especially if a shortage of material is anticipated, the local plant logistics experts of the automotive suppliers tend to build up higher safety stocks or to combine demands to larger lots. However, from a company-wide perspective and from the semiconductor suppliers' point of view, these planning-related interventions lead to unclear planning figures. This increases the risk of planning errors, creating additional demand fluctuations so that demand in the supply chain builds up and leads to the bullwhip effect (Schönsleben, 2007).

After the traditional disposition processes (call-offs, individual orders) are transferred to VMI, the semiconductor suppliers can directly view the production demand of their customers and have to ensure that the agreed minimum and

maximum limits are complied with. Apart from gaining visibility into the plant inventories, the semiconductor suppliers can also view the demand figures that are based on the production schedules of the individual plants of the automotive suppliers.

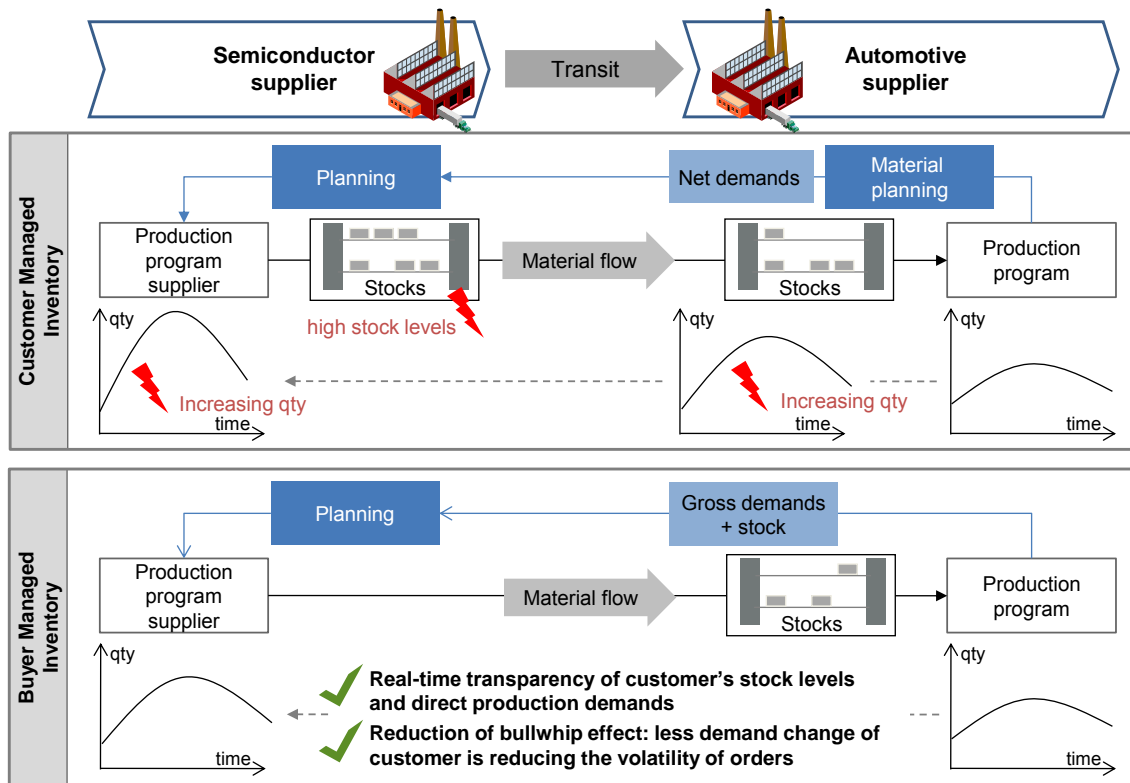


Figure 12: Effect of Vendor Managed Inventory (Zapp et al., 2012)

This makes the global production demands of the automotive manufacturers more transparent to the semiconductor suppliers, enabling them to optimize their stock levels accordingly. In addition, the semiconductor suppliers can align their production with the needs of their automotive customers. As Figure 12 illustrates, introducing the VMI model eliminates the planning stage between production planning in the automotive supplier plants and production planning of the semiconductor suppliers. It thus reduces the bullwhip effects in the supply chain (Disney, 2003). Especially when material shortages occur, material allocations can be managed more easily. Responsibility for material supply clearly lies with the semiconductor supplier and so significantly reduces the need for communication between automotive and semiconductor supplier. However, the benefit of VMI is limited by the fact that the semiconductor lead times exceed the automotive supplier's lead times.

While VMI suggests the exchange of current data, Collaborative Planning, Forecasting and Replenishment (CPFR) also focuses on mid-term and long-term forecasts. In accordance with the performed evaluation, CPFR can be a highly effective measure to harmonize the current capacity planning processes of both industries. This covers, for example, the organization of regular coordination meetings to produce joint forecasts as a basis for capacity planning (see Figure 13). Production and supply chain parties are brought together in order to identify current topics and to discuss alternatives and solutions. These meetings need to be backed by a standardized procedure and jointly defined performance indicators.

These monthly or quarterly coordination meetings should not be confined to the discussion of general market trends but also focus on the forecasts for several preselected high priority and high risk product groups and semiconductor technologies. Planning errors, potential capacity bottlenecks, and investment needs for certain semiconductor technologies can thus be recognized and fixed in time (Zapp et al., 2012). Major deviations in the supply and demand of semiconductor components are prevented, and a faster adaptation of production capacity and stock levels to changing market conditions is ensured. Consequently, a high flexibility in the face of short-term disruptions, better usage of production and supply chain capacity, as well as higher customer demand fulfillment can be achieved (Infineon, 2010).



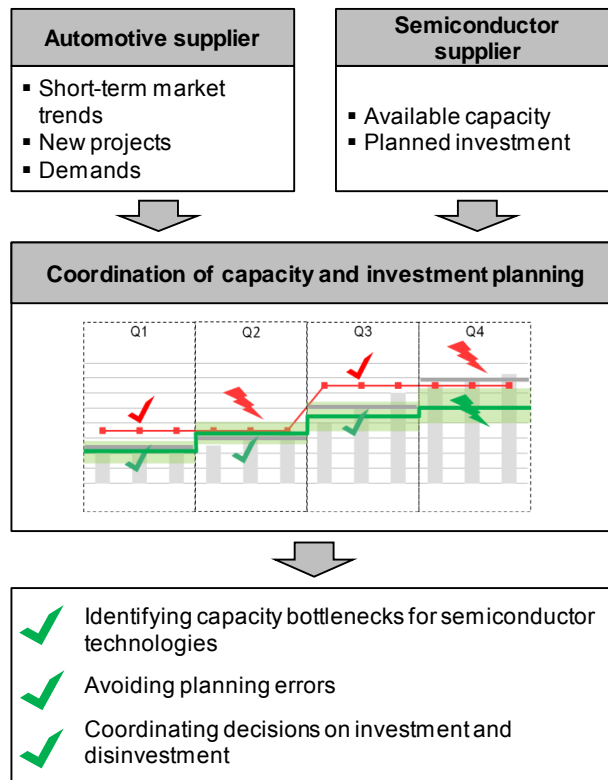


Figure 13: CPFR meetings between automotive and semiconductor supplier (Zapp et al., 2012)

CPFR can be used without much initial expenditure in virtually any company and for every product, making it a very simple but highly effective strategy that promotes the flow of information and thus fosters cooperation and transparency.

As pointed out before, the strategies do not exclude each other. Quite the contrary: The highest effectiveness can be achieved, for instance, by using the SCOR model as the basis for discussion in CPFR meetings, while at the same time deploying VMI with the automotive customers.

#### 4.4 Evaluating the Measures of the Fit/Gap Analysis

At the expert workshop, the identified measures of the reference toolkit were evaluated in regard to the overall problem of non-aligned supply chains. The criteria taken into consideration are benefit, effort and practicability. The results are presented in the bubble chart of Figure 14.

The benefit refers to the effectiveness of the strategy and answers the question: “To what extent does the strategy help to meet the requirements?” Practicability assesses whether a strategy can be used for the different products and the collaboration models in both industries or if their implementation is only possible under certain, restricted conditions. The third criterion quantifies the effort invested in implementing a measure and answers the question: „How much work is ahead for semiconductor companies and automotive suppliers to implement a measure? “

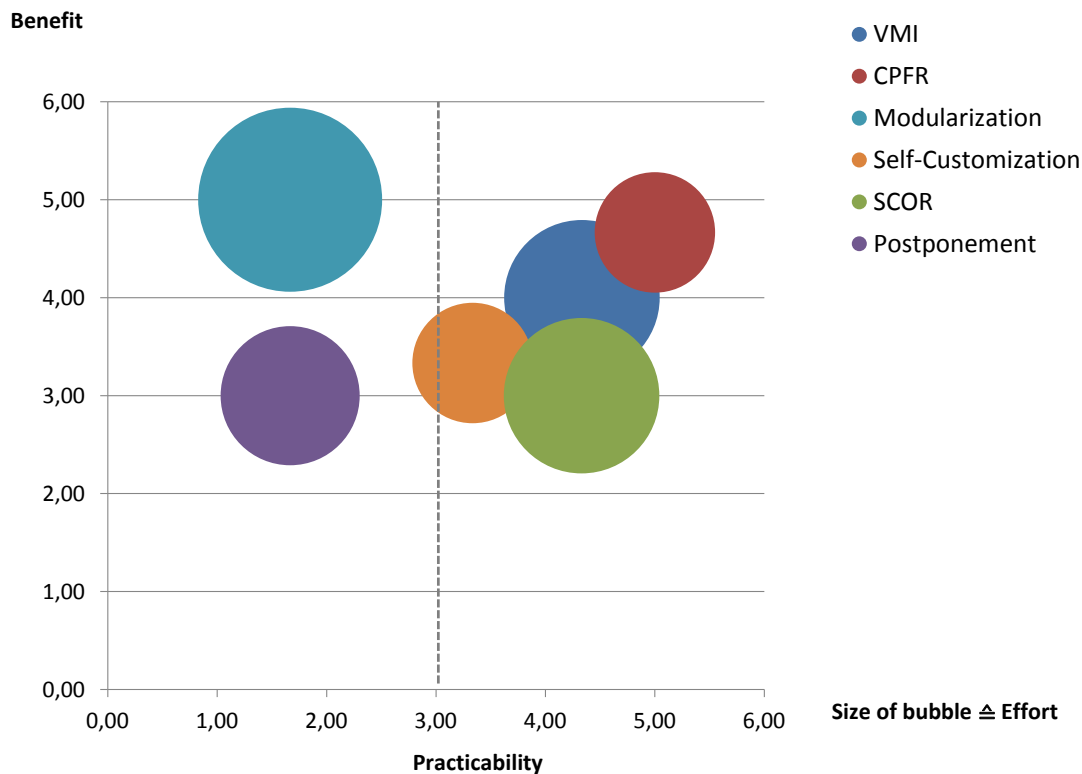


Figure 14: Evaluation of the measures of the toolkit

The evaluated reference toolkit measures are split up into two groups: The measures on the left side of the bubble chart provide a high level of benefit but are difficult to implement, while measures on the right side of the chart provide a high level of benefit while being easy to implement. CPFR, for example, is an efficient method to improve the value chain and can promptly be implemented with little effort by two partners in the value chain. By contrast, modularization – as shown above – offers great potential for minimizing inventories, reducing lead times and solving the spare parts problem, but it requires the collaboration of all companies involved in the value chain for introducing an industry standard to achieve maximum efficiency.

## 5. Conclusion and Outlook

This paper discusses the differences between the semiconductor and the automotive industry and the subsequent challenges to their common supply chain.

The heterogenous and even opposing industry characteristics along with the lack of synchronization increases the complexity of supply chain management between semiconductor and automotive industry. A better coordination of both supply chains cannot be achieved by a single, global strategy. It rather requires the combination of several measures. The presented toolkit of measures and its AHP-proved consistency creates transparency over the existing challenges and the effectiveness of the individual improvement measures. The toolkit of measures for collaborative supply chain management between automotive and semiconductor industry aims at a more efficient coordination of production capacity and a better response to market fluctuations in the supply chain.

However, it presents only a first step into collaborative supply chain management between semiconductor and automotive industry. The identified measures, their application and their interrelation need to be discussed in further detail.

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