Automotive Supply Chain Evaluation with Conventional Model and Integrated Model

Von der Fakultät für Ingenieurwissenschaften, Abteilung Maschinenbau und Verfahrenstechnik der

Universität Duisburg-Essen

zur Erlangung des akademischen Grades

einer

Doktorin der Ingenieurwissenschaften

Dr.-Ing.

genehmigte Dissertation

von

Yuanyuan Tian
aus
Jiyuan, China

Gutachter: Univ.-Prof. Dr.-Ing. Bernd Noche
Univ.-Prof. Dr.-Ing. Ferdinand Dudenhöffer
Tag der mündlichen Prüfung: 28.02.2011

Abstract

Increasing competition due to market globalization, product diversity and technological breakthroughs stimulates independent automotive companies to collaborate in a supply chain that allows them to gain mutual benefits. Especially the events of the past years have shell-shocked even the most ardent industry participants – a crisis and the following hard recovery. Not only the critical challenges in implementing process lean with low cost and high quality, also critical to success is the ability to efficiently meet stricter emissions and fuel economy standards escalating in most jurisdictions.

With all the factors working beneath the waves, supply chain management becomes the core source of a company's competitive advantages and even the trump of the entire automotive industry's success. A proper supply chain strategy provides financial returns and other key factors superior to the old concepts which brought profits before but no longer up to date now. Correctly design and effectively evaluate the supply chains, and improve the supply chain structure dynamically over time, are the key methods for an automotive company to survive and succeed in the volatile and critical automobile industrial environment.

In this research work, based on the real case study in the automotive door system supply, different supply chain scenarios are designed and corresponding performance evaluations are made by applying different methods, namely the conventional model and the integrated model with their corresponding algorithms.

With conventional model, the evaluation is done from different aspects, where the chosen perspectives such as costs, flexibility, stability, and reliability are assessed respectively for the multi-stage international supply chains. The data applied in this model comes from real-case door module supply, and the evaluation results helps in the decision making in localization process of that certain project.

To be able to evaluate more complicated supply chain scenarios in a more accurate and efficient way, an integrated model is designed for the comprehensive performance evaluation. Based on the fuzzy theory, a MDFIE (Multilevel Dynamic Fuzzy Integrated Evaluation) algorithm is developed to assess the automotive supply chain performance. With the real case of vehicle door system supply, a detailed index system is designed based on a profound understanding of the automotive door supply chain. And with this new method, supply chain scenarios with different outsource degree and integration degree are evaluated and analyzed, a positive solution of deeper integration and downstream task shifting in the automotive supply structure is concluded in the end.

In addition to the use in this research work, the integrated model, especially the index system can be flexibly adjusted for other automotive supply chains under their special interest and requirements. And with the MDFIE algorithm or other possible methods, the model can also be further developed into user-friendly software or system for the normal application. This software development is suggested for the further research.

Based on the researches done in this work, a new tier structure is proposed as well. A mega system supplier which is defined as the new Tier 0,5 and other outsourced service companies which are playing as the half tiers (tier 1,5/ 2,5…) are discussed in this work. With all the theoretical researches and practical investigations, this new structure which occupies the niche positions of supply chain is supposed to be benefiting the entire automotive supply chain in many critical aspects, like the long lasting over capacity problem and the coming E-mobility trend. Some other suggestions like the application of RFID technology are also proposed for increasing the productivity and strengthen the information flow along supply chain. In general, improving the entire automotive supply chain performance, is the ultimate goal of supply chain management, which means balancing all participators' maximum profits and offering the highest market service level. The realization of the proposals and concepts, is also supposed to be studied in the further research.

Keyword: Automotive Supply Chain, Performance Evaluation, Automotive Tier structure, MDFIE, Index System

Acknowledgements

The completion of this dissertation would have not been possible without the generous help and valuable advices from many people.

First I would like to express my sincere gratitude to Prof. Dr.-Ing. Bernd Noche for his guidance, expertise, time and patience throughout the course of my studies. His supports helped me tremendously in every stage of the research work.

I am specially grateful to my family – my parents Tian Tiansheng and Deng Chun’e, and my younger brother Tian Shen, whose love and encouragements give me a constant source of inspiration and strength. For years they have been sharing my tears and laughter, and giving me the most loving support in my life, and help me out whenever I felt overwhelmed. Their love and understanding always inspire me to keep going.

I would also like to thank all the researchers, who have done so much amazing work, from which I learnt so much in the field of supply chain and automotive industry.

My deep appreciation is also extended to company “Brose Fahrzeugteile GmbH Co. Kommanditgesellschaft” and “Kirchhoff Automotive GmbH”, who have offered me the valuable chance of working in the team and collecting industry practical experiences. Thanks to the free access to all kinds of data, I am able to complete the dissertation with the real case study. Special thanks to Mr. Hilmar Dohles from Brose, Mr. Arndt Kirchhoff and Mr. Ludger Engels from Kirchhoff, and all my other team colleagues.

I also want to thank my faculty colleagues who spent a lot of precious time with me, and helped me in the literature searching, software studying, and made their efforts in every possible aspect. Special thanks to Mr. Zhu Taobo, Mr. Sun Yongxin and Mr. Weng Weibing, their supports helped me avoiding a lot of mistakes and detours.

Last but not least, I would like to express my great thanks to my dear friends, who have been all the time encouraging me during the long time in Germany. To Mr. Liu Yan, Mrs. Yang Hui, and all my dear friends, I would like to say a sincere Thank You.

Table of Contents

List of Tables

List of Figures

Terminology

ABC	Active-Based Costing
ABS	Anti-lock Braking System
AHP	Analytic Hierarchy Process
ASC	Automotive Supply Chain
BIW	Body In White
BSC	Balanced ScoreCard
BTO	Build to Order
BTS	Build to Stock
CKD	Completely Knocked Down
ESA	Engineering Source Approval
ESI	Early Supplier Involvement
EMM	Equidifferent Marking Method
EVA	Economic Value Analysis
FMEA	Failure Mode Effective Analysis
FSI	Full Supplier Integration
GSCM	Global Supply Chain Model
IMVP	International Motor Vehicle Planning
JIS	Just in Sequence
JIT	Just in Time
LSP	Logistic Service Provider
MDFIE	Multilevel Dynamic Fuzzy Integrated Evaluation
OEM	Original Equipment Manufacture, Auto Maker
PBWE	Partial BullWhip Effect
PD	Product Development
PE	Performance Evaluation
PM	Project Management
PPM	Parts Per Million
QM	Quality Management
QSI	Quasi Supplier Integration
R&D	Research and Development
RFID	Radio Frequency IDentification
ROI	Return On Investment
SC	Supply Chain
SCM	Supply Chain Management
SCOR	Supply Chain Operation Reference
SEM	Strategic Enterprise Management
SKD	Semi Knocked Down
SOP	Start of Production
TBWE	Total BullWhip Effect
VMI	Vendor Managed Inventory

1. Introduction

In the current society, which is characterized by increasing speed, complexity and high information content, the strategical focus of industry companies is undertaking a constant transformation. Since the automotive manufacturing industry is an extremely competitive one, many companies have recognized that the competition is now actually a competition of supply chains and have been focusing on their supply chain management for sources of competitive advantages. The supply chain involved material flow, information flow and financial flow are being taken into full consideration to achieve an optimal situation and thus enhance the companies' competitiveness.

In this paper, I make a review of the automotive supply chain, which shows that the relationships between the supply chain parties are complex and challenging, despite the success of the industry, there are a number of structural weaknesses and for the automotive manufacturing companies, there is still big space to improve. On one hand, the platform and modular strategies of BTO (Build to Order) lead to greater business opportunities with higher margin pressure, and on the other hand the trend towards further consolidation leads to the need for lean management and integration of the manufacture's global supply chain networks.

Currently most of the supply chain performance measurement systems are inadequate because they rely heavily on using cost as a primary measure, they are not inclusive, they are often inconsistent with the strategic goals of the organization, and do not consider the effects of uncertainties. In this work, in addition to industry analysis, two models are offered to evaluate the supply chain, using the conventional method and multilevel dynamic fuzzy integrated method.

This work demonstrates that the proper supply chain strategy provides financial returns and other key aspects superior to each of the other strategies modelled in the work. It proves that a company can design its supply chain to allow itself and other supply chain partners to benefit from the changing environment, not only hedging its downside exposure, but exploiting upside profitability as well. In general, a proper supply chain design in the automotive industry, can benefit all the supply chain participators and improve the overall supply chain performance.

1.1 Research Background

Correctly evaluating the supply chains and dynamically changing the supply chain network structure over time, is the key method for an automotive company to survive and succeed in the volatile and critical automobile industrial environment. Controlling the stability, reliability and flexibility in sourcing, manufacturing and distribution logistics both operationally and managerially is playing a more significant role in the entire industry, and those key supply chain aspects are drawing more and more emphasis of the decision makers. In the real-life world of the global automotive industry, operating an optimal, individual case suitable supply chain, will specifically support the world-wide automotive industry.

Thus, focusing on the analysis of global automotive business and the supply chain design strategies, I choose the case of door system supply based on a Tier 1 supplier's real situation as the research case, for which the research is done under the background of the entire automotive industry characteristics especially under the economic crisis. The trends in the global automotive industry and the corresponding challenges are to be discussed.

1.1.1 Trends in Global Automotive Industry

The environment for the automotive supplier has never been more volatile. To succeed, it's important to understand what they are up against in this shifting industry landscape. A lot of analyses to automotive industry indicate that, for major players in the automotive supply chain, seven current trends are having the greatest impact. Though differences emerge from region to region, it's clear that all apply to the automotive suppliers' business to some degree. It's also clear that these trends are all interrelated, forming a web of both challenges and opportunities. According to the whitepaper published by INFOR [Inf 06] and the research by Schwarz [Sch 08] from Cisco, the automotive industry has the following 7 trends.

1. Following the OEMs (Original Equipment Manufacturer, Auto Marker) Geographically

The base of the automotive industry is regrouping rapidly world wide. The auto makers from U.S. and west Europe are seeking to become competitive in the new economy by finding green fields where land is plentiful and facilities can be built with less worry about hidden environmental dangers or congestion. Even more significant, some of these plants are able to operate as non-union locations, cutting labour costs dramatically and changing the economic equation within the industry.

Besides U.S., the automotive industry is also expanding rapidly in the other European countries, especially Eastern Europe (Slovakia, Hungary, and Romania/Poland), as well as in many areas of Asia-Pacific (including Thailand, Malaysia, and China). The automotive industries in these areas are expected to grow considerably over the next few years.

As original equipment manufacturers (OEMs) move into the new growth areas, the supply chain will grow in that direction. Just-in-time production processes demand shorter transportation routes, requiring supplier locations closer to these new plants. Furthermore, suppliers seeking to serve multiple OEMs will need to be more centrally located within this new community of auto makers.

2. Diversifying the Customer Base

Suppliers are diversifying their base for both survival and revenue growth. No longer can the supplier rely on a single primary customer as a source of growth. The auto industry has become too fluid, and a string of acquisitions, mergers, and restructuring could leave a dedicated supplier in desperate straits before preventive actions can be taken.

Of equal importance, the supplier's growth potential in the years ahead will more likely reside in the ability to provide innovative, integrated, and niche products to a variety of auto makers, rather than in reliance on expansion within an individual OEM's production.

And finally, as suppliers go global to meet the needs of their customers, they will find it increasingly valuable to service not only the companies that they originally followed, but also local manufacturers in the new nations, capitalizing on the security and additional revenue that true globalization can bring.

3. Increasing Revenue through Products with Higher Added Value

OEMs are pushing more responsibility down to their supply base, and successful suppliers will be the ones who can integrate the automakers' needs into value-added modules and systems, going beyond conventional components. Additionally, OEMs will rely more than ever on their suppliers as sources of innovation. Those who generate new products and add a greater intrinsic value to the OEM's assembly process and/or the end user's preferences will have a significant competitive advantage. This need for demonstrating higher added value also will require suppliers to become involved in product development earlier in the vehicle design cycle. Suppliers, as a result of greater collaboration, may well find themselves leading more design and engineering and driving more innovation.

4. Efficiency at Lower Volumes

Paradoxically, the automotive market has become more fractionated and diverse at the same time that it is being subjected to mergers and consolidations. The aggressive expansion of all OEMs on a global basis has created niche markets and entirely new types of vehicles. Also, companies that once with luxury brands are expanding downstream and companies that once with only economy brands are now moving upscale. Consequently, the supplier can be faced with lower order volumes from any particular OEM and must find a way to produce its automotive systems efficiently at these reduced volumes. The emergence of solutions designed to multiply efficiencies throughout the supplier's enterprise is enabling this change in production economics at the supplier level.

5. Forming More Global Alliances

Globalization in the automotive industry is playing out in many ways. Many OEMs and their suppliers are moving operations to new, lower-cost areas. Meanwhile, other regions like China, Russia, and India are emerging as major factors in automotive consumption and production. China is, by far, the most dramatic new player in the automotive industry. It is now the largest car market and production land, and automakers have only scratched the surface of the potential Chinese market. Every major OEM now has established operations in China, and many are pressuring their suppliers to follow them.

Suppliers will be solidifying an increasing number of global alliances throughout their own enterprise and that of the OEMs. To survive the requirement for globalization, suppliers will need to diversify not only their plant locations, but also their customer base. They will form new alliances with companies based in foreign locations, maximizing their revenue but adapting their value-added products for local OEMs as well as for the domestic OEMs they have followed overseas or across borders. They will exploit the new markets by becoming an integral part of the economies in which they operate.

6. Reducing the Cost of Quality and Fixed Costs

In such a highly competitive, fluid, global market, quality must be a “given” for every supplier. Any manufacturer producing less than world-class quality simply is unlikely to survive in a world where OEMs have a wealth of suppliers from which to select. Therefore, suppliers will need to compete by reducing the cost of quality – offering valuable, reliable systems at a lower cost than competitors – and by lowering their fixed costs within their plants. Just as knowledge workers relied on suites of software to achieve these goals in the office, automotive companies will be implementing integrated solutions on a larger scale to keep quality high while the costs of operations diminish. The focus must be on consistently improving productivity over the long term and forming strategic partnerships up and down the supply chain to reduce the total cost of quality.

7. Growing the Service and Aftermarket Business

Not just auto suppliers, but manufacturers of all types of industrial products and equipments, are learning that a future differentiator and real source of revenue growth will develop from expansion of their service and aftermarket businesses. Services such as spare parts, preventive maintenance, testing, field support, repairs, and quality management can help differentiate an automotive company from competitors and earn a loyal revenue stream from OEMs that no longer have the resources to carry out many of these functions in house. As the OEMs extend their warranties, and as the variety of nameplates continues to proliferate to reach niche markets, the ability to obtain service parts from suppliers in a cost effective way will become ever more crucial to auto makers. Suppliers will be setting up highly efficient global solutions for servicing the vehicles they support for many more years beyond the model introduction, whether in house or outsourced.

The aftermarket business has exploded over the last few years and is now a more than $75 billion global industry. Automotive companies can generate significant revenue by offering aftermarket items within their product portfolio.

1.1.2 Times are Challenging for Automotive Companies

These trends across the automotive industry clearly create a daunting array of business challenges for automotive companies. Whether single site or global in scope, automotive companies are trying to implement lean processes in their production facilities to keep inventory costs down and quality high. Globalization of the supply chain has impacted both the manufacturing base and the customer footprint, with the supplier producing a greater variety of higher-added-value products, integrating components into systems, and serving customers in multiple nations, each with multiple locations.

Automotive companies also are seeking a greater foothold in such high-growth areas as environment, energy, safety, personalization, and service. As a result, their product mix continues to grow, material management becomes more complex, and companies often are entering into unfamiliar environments that require increased support from automated systems.

At the same time as they are scaling back on inventories for production, suppliers are expanding production to meet customer-service demand. The approach to warehouse management, production management, and materials is shifting in ways that require re-adaptation, along with much more market insight and anticipation.

The benefits of globalization and of moving facilities to lower cost locations can be realized only if the cost of materials is managed in an effective way. Maintaining large inventories can result in hefty overhead costs for suppliers. To reduce these inventories, suppliers are turning to automated systems that pull materials into production when and as needed, dramatically cutting down on requirements for safety stock and allowing suppliers to apply materials in the way they have traditionally applied labour: at the point and time where it adds value and has a positive impact on the product. The pull strategies that are emerging from these capabilities are serving to better synchronize supply chains and keep suppliers running profitably wherever they operate.

Suppliers are becoming much more collaborative with their customers, material providers, partners, and sister plants in an effort to attain greater predictive capability and to establish methodologies that ensure consistent top quality while meeting operational performance goals.

They are finding the need to produce more, in a more connected fashion, at lower cost with higher quality. Further, the OEMs are demanding that suppliers produce a greater proportion of each vehicle’s systems, becoming, in effect, a primary assembly arm for the OEM. This fact of life is requiring suppliers to outsource portions of their own production to lower tiers and makes the supply chain even more complex.

These new characteristics are the new realities within the automotive industry, as well as the source of many challenges and pains. To expand further:

- Companies are struggling to get lean. They cannot compete successfully unless they drive down waste in materials and effort and keep production inventory levels low.
- Many are having difficulties in getting their supply chain to be agile and flexible. Working globally and for a broader customer base necessitates a level of precision that is a difficult challenge for some. They need to be working in synchronocme and be able to shift their production on a short time frame.
- Meeting regulatory and compliance regulations emerging from customer requirements and mandates requires constant attention. Environmental, safety, financial, and other demands may be difficult to meet consistently unless new assured and validated internal systems are set in place.
- Suppliers continue to find themselves ensnared in OEM pressures to lower costs while simultaneously improving quality.
- The leap in raw material costs and energy prices are squeezing companies’ attempts to grow their business profitably. At the same time, decreasing vehicle

volumes are slicing revenue, making it imperative to find new markets, new products, and new services to offer their customers.
- Improving customer satisfaction remains an often painful objective as market preferences shift more rapidly than ever, as quality demands grow more strident, and as profit margins become thinner.
- Global competition and consolidation among OEMs and within the supplier industry itself are placing new strains on companies. They must find ways to operate within much longer supply chains, in markets that literally are foreign to their conventional customer base, and remain profitable to buck the consolidation trend that itself can add considerable uncertainty to the set of pains that must be diagnosed.
- Globalization means finding ways to manage global supply chains, global manufacturing plants, and global customers. Cultural differences, geographic barriers, and variations in business rules internationally can make management of global operations extremely demanding.
- Companies often experience problems when trying to patent their advanced technology in foreign markets.
- The complexity of vehicles is becoming a serious concern, with so many new models and product launches. Adding to the complexity is the significantly increased electronic content that requires suppliers who once were solely focused on the vehicle's mechanics now to integrate interiors, systems, and under-the-hood systems with electronic devices.
- As OEMs seek to be more responsive to fast-changing consumer preferences, energy requirements and environmental regulations, the pressure to accelerate the supplier's time to market becomes far greater.
- The global economy has left many suppliers with an overcapacity which mirrors that of their customers. Furthermore, the new realities of the marketplace do not tolerate the high legacy labour costs that have been a foundation of the auto industry for many decades. How to shed these costs in light of union contracts, general economic conditions, and shifts in manufacturing locations is a puzzle that confronts companies across the globe.

New opportunities for automotive companies are made possible by lean, flexible, global, and world-class solutions driven by business processes. The world's economies, both established and emerging, have been depending largely on automobile industry for more than 100 years, and will continue for the foreseeable future. The ways we consider, select, build, and use our vehicles, however, are changing rapidly, and the automotive industry remains one of the most competitive and dynamic industries in the world.

In order to enable automotive companies to thrive and grow in this environment, business solutions that focus on the industry's key initiatives and help survival in a turbulent global marketplace are supposed to be provided. Customer management, supply chain management, manufacturing and quality management etc, are about to be applied for the individual automotive companies, and for the entire automotive industry as well.

1.2 Research Motivation and Objectives

The above mentioned trends and challenges have had largely impacted and enriched my personal experiences. Since 2005, I have worked as project engineer and project manager in a Tier 1 supplier, of an alliance effort to win and deliver vehicle systems for some world car platforms that were being developed at the time. This involved designing, costing, quoting and operating a global supply chain that delivered a full vehicle system to the OEMs' factories in Europe, North and South America, and Asia from a supply base and factory network in those areas.

These experiences generated a strong motivation on the part of me, to develop new business tools and practices that would allow a company to better design, structure and operate a global supply chain, and to yield increased competitive advantages for winning new business and delivering exceptional operating results over the full life of a contract. It was this motivation that leads me to explore the advantages and shortcomings of different existing supply chains and optimize them. And the purpose is to create value in existing, or in the case of merging or acquisition activities newly created, in worldwide supply chains, and to exploit this value when establishing and refining corporate and supply chain management strategy.

Based on the observation and experience in the automotive industry and the results presented in the dissertation, a well designed supply chain strategy is supposed to yield exceptional operational, financial and strategical results, in short, create real value, when applied in the automotive and other global manufacturing industries. Further, it is predicted that the application of some new technologies and concepts will become a differentiating success factor in the global industry.

1.3 Problem Description

In this sub chapter, a business problem is posed that often confront the supply chain management team of global manufacturing companies: managing the design of a world wide supply chain while dealing with unknown or unpredictable events. Choosing to go beyond a single company's benefit, but benefiting the overall supply chain participators, by the design of a proper global supply chain, and dynamic evaluation of the supply chain performance which furthermore leads to continuous optimization of the supply chain, is the main task of this work.

1.3.1 Supply Chain Design Challenges

The move by auto makers towards world car production embodies a great challenge for the world's automotive industry suppliers. As they go global, OEMs are increasingly reducing their supply base to include just those Tier 1 companies that offer a worldwide manufacturing presence and partnership capability. For those fortunate supplier companies who have such global capabilities and are chosen as a worldwide source for products or systems, world car platforms present unique, never before experienced opportunities for them. Given that the suppliers master the challenging aspects of this new business problem, they're having now the chances to design the companies' supply chains. And through the design process they are supposed to contain operational and managerial flexibility that allows the companies to minimize risks and to increase profitability and competitiveness.

The large investments in capital equipment and facilities are common in the automotive supplier industry. And this puts a supplier in a difficult position, combined with specific challenges and associated with the quest for winning and delivering a world car contract. More than 3 years prior to the SOP (Start of Production), the suppliers must quote binding prices to an OEM for products that will be sourced and manufactured in multiple territories in the world. And they are supposed to know almost all of the assumptions regarding vehicle volumes, raw material prices, inflation levels, invoice currencies and foreign exchange rates when submitting the quotation, while the OEM has an equally common convention of only focusing on the bottom line prices.

As the vehicle volumes for world car platforms are often ten or more times greater than the volumes associated with regional car platforms, the competitions for such high profile contracts are intense. The prices are regularly quoted in a way that is expected to yield exceedingly tight single-digit profit margins. Further, if one of the suppliers attempts to re-negotiate prices after starting delivery even after clearly defined assumptions, it can be fatal for his future business opportunities. Getting a reputation as a “re-coster” may jeopardize the supplier’s business, since automotive industry is such an industry where all the players know each other, and careers hang in the balance of achieving significant year on year cost reductions through supplier pricing productivity.

There are further unique and complicating facts of life in the automotive supply chain business. Though they only serve to heighten the challenges, the successful suppliers must accept them and work through. The first tier suppliers have vast flexibility and freedom in making different kinds of decisions. The decisions may possibly be regarding contract formulations with suppliers and (to a lesser degree) customers, second tier supplier selection, their own manufacturing facility location selection and capacity installation, and so on. These decisions are supposed to be made in the very early stages of establishing the supply chain specific to a new vehicle program.

As is evident from the example network depiction in Figure 1-1 below, the potential supply chain in question is huge, and with over 50,000 (VDA data) links between second tier, first tier and OEM facilities being a not-unusual starting point for the supply chain designers. This can impress a supply chain designer as a big, difficult, complex and confusing problem, and begs the question where one should begin. This picture proves to be too daunting, and as a result many companies do not question or attempt to effect significant change to their legacy supply chains.

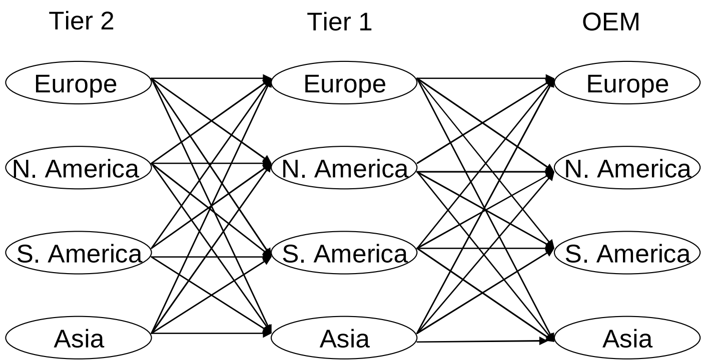

Figure 1-1 Global Automotive Supply Chain

For those supply chain designers that tackle this problem, the vast flexibility and freedom of choices is quickly reduced, or disappears altogether. In the process of establishing the supply chain and completing the product and process development, validation and release process, the Tier 1 supplier together with the OEM have a lot to do. They must test, validate and release every intended element of the supply chain network, which includes each company, factory, product, component, sub-component, machine, process, tool, quality control plan, logistics provider, physical and electronic logistics link, returnable and disposable packaging container and material, so on and so forth. After this validation and release process is completed and volume production has begun, there is minimal flexibility to make unplanned changes to elements of the supply chain network structure. Indeed, once a first tier supplier's supply chain has begun producing hundreds of thousands or millions of components per year on manufacturing lines at 5 to 45 second cycle times and 18 to 21 shifts per week, it will be very committed to the decisions made when designing the supply chain.

There are varying levels of commitment and flexibility. A logistics provider could be changed and the second tier supply base could be modified. The most binding decision is selecting the amount and location for the supplier's own internal manufacturing capacity, since investment levels are usually high, even in the case of simply re-tooling and refurbishing existing equipment and facilities.

However, decision makers cannot seek solace in the false hope that post SOP changes to the supply chain are always possible. And it is even more false to expect a complete remedy for poor or excessively restrictive supply chain configuration decisions that were made at the beginning of a project. These changes are painful and expensive, and they are usually used as a last resort to try to bring the financial performance of a business back to what was promised in the original investment sanction or the business plan. All desired changes must be re-validated and re-released by both the supplier and the OEM, which is quite costly in terms of time and money, even if the corresponding facilities are available. As the OEM must be intimately involved in the validation and release of any changes, adding or deleting elements in a supply chain is only marginally financially rewarding. Because for every supply chain change, the auto maker inevitably demands its perceived fair share (or more) of the cost improvement coming from it.

In essence, the supplier is working within a step-change flexible/fixed business environment. At the beginning of designing a supply chain, every element and indeed the chain itself is in a malleable state. The subsequent validation and release procedure then serves as the hardening process, and produces a rigid supply chain.

A further step-change element in the design and development process is related to a cost comparison, which is the cost of initial validation and release of SC elements versus the cost of any subsequent attempts. All intended SC elements are validated and released together via the prescriptive and comprehensive R&D procedure during the initial validation, which carries very significant fixed costs and time requirements. And these commercial and time requirements are commonly contained in the participating companies' engineering budgets and facility utilization schedules. As such, the cost of including an additional second tier supplier to the supply base, an additional product to those already delivered from an existing supplier, or an additional manufacturing location is strictly marginal in the initial validation. The fact that subsequent validations are generally not budgeted in terms of material, manpower or facility planning explains why post SOP validations are rare and extremely expensive, and why the full cost of including an incremental supply chain element in a subsequent validation is usually prohibitive.

Finally, the first tier suppliers must take as given that during the two to four year design and development process and the four to eight year vehicle life, they will be confronted with fluctuations in foreign exchange rates, and real prices respectively that could not be explicitly predicted at the time the supply chain was designed.

Given those complex and non-proportional constraints, it is not surprising that the design of supply chain is such emphasized within the automotive industry today. In most cases, suppliers are rather using their current supply chain in quoting and delivering new business opportunities than applying new business tools, in spite of taking advantage of the newly found worldwide networks or through consolidation flexibilities. This was one of the central realizations that lead me to look for improvements which would yield more robustness and profit in supply chains. The evaluation models I am about to provide in this dissertation is serving mainly for the first tier system suppliers. They are applied when the suppliers are designing their supply chains at the outset to include additional second tier suppliers or excess manufacturing capacity, and to allow sourcing and production site changes. The changes are expected to be made during the vehicle program life without required validations, therefore, allowing a supplier to keep his options open and to consciously and repeatedly make SCM decisions that optimize profitability.

1.3.2 Real Case to be Studied

An important outcome of the increased quest for competitiveness is globalization with the international distribution of production facilities as well as sourcing of material and labour. However, these decisions must be made with full consideration of the total supply chain in view of the cost and the increasing need for efficiency and associated postponement strategies.

In this dissertation, the auto door system supply chain is taken as the case. The reason for choosing door system, is not only that a door system is considered to be one of the most complicated systems in auto manufacturing, for it includes metal parts, plastic parts, glass and electronic parts etc, but also a door supply chain is representative, and it reflects the characteristics of the entire auto supply chain. So here I firstly take the example from a global door system Tier 1 supplier, which supplies its door modules to almost all of the auto brands. The supply chain scenarios refined from the China part of a global project reflected the supply chain concept development during the localization process. Whether to supply the customer with ready made German products, or with the parts from experienced original suppliers globally, or to develop brand new local supplier in China and make local assembly, is a question to be considered. Using the “made in Germany” products, an investment for local assembly line could be reduced, but logistic-wise is it economic? Using the existing suppliers, the quality and price can be maintained on a certain level, but isn’t the supplier management and the on-time supply too complicated and challenging? And developing new suppliers locally and make the local assembly, is it really a safe way out? Those question need to be answered in the real situation supply chain design.

Then another example from the vehicle door system supply is taken as well. Scenarios with different integration degrees are investigated, whether the door system should be supplied by parts, modules or entire systems to the OEMs is to be decided. The general performances are to be evaluated for each scenario based on the real case data, thus using an integrated model to asses them comprehensively is supposed to be a good solution.

So the different scenarios are analyzed, evaluated, and optimized step by step, these scenarios are compared in details and extracted for getting the advantageous aspects of every supply chain, the goal is to have in general a most profitable, stable, reliable and flexible supply chain in the end.

1.4 Roadmap

The dissertation is organized as follows: Chapter 1 presents a general introduction of the thesis, automotive background, including the trends and corresponding challenges to the automotive companies, the motivation of the research work, and the problem description.

In chapter 2 the state of art is studied, where the literatures about supply chain and automotive industry are reviewed. 3 sections regarding the supply chain management, supply chain simulation and supply chain performance evaluation are investigated respectively. In sub chapter 2.3, the literatures about automotive supply chain are reviewed mainly concerning the supplier classification and supply chain tier structure. Afterwards the roles of the supplier tiers are individually introduced and the special automotive supply chain character - modularity is discussed in detail. At last, automotive BTO (Build to Order) strategy and collaborative strategies are investigated.

In chapter 3 the supply chain evaluation theory background is studied, 4 aspects are discussed, which are respectively the transportation, stability, flexibility and reliability of the supply chain.

Then in the next two chapters two models to evaluate the automotive supply chain performance are built up. With the conventional model, the door module supply chain scenarios are evaluated in chapter 4 from different single aspects, and in chapter 5, an integrated model is developed to evaluate the supply chain generally by MDFIE (Multilevel Dynamic Fuzzy Integrated Evaluation) method based on the real case vehicle door system supply, where the supply chains with different integration degree are investigated.

In Chapter 6, the evaluation methodologies are discussed and the two evaluation models are analyzed with their own characteristics and the evaluation results. Based on the studies before, especially the evaluation results presented, the application of RFID technique and the reorganization of supply tier structure are proposed and considered to be the new important changes for the future automotive supply chain.

Then in Chapter 7, a conclusion of the entire thesis work is summarized, and recommendations for future researches are proposed as well to enhance the usefulness of this research work.

In the end, the references for this thesis are listed in chapter 8.

2. State of the Art

2.1 Introduction

Increasing competition due to market globalization, product diversity and technological breakthroughs stimulates independent automotive companies to collaborate in a supply chain that allows them to gain mutual benefits. This requires the collective know-how of the supply chain characteristics, profound understanding of automotive industry, the mode of coordination and integration, including the ability to synchronize interdependent processes, to integrate information systems and to cope with diverting unpredictable uncertainties.

A large body of literature exists on different aspects and problems related to supply chain management, system static and dynamic characteristics, evaluation models, optimization methods, and so on. Also plenty of researches have been done within the automotive industry, automotive supply chains have been studied under great emphasis since auto manufacturing is almost the largest industry in present era. However, the researches regarding the automotive supply chain are mainly focusing on the final car maker's point of view, so our work from the viewpoint of a Tier 1 supplier should be somehow unique, and in addition, I will be also dealing with the entire supply chain including car markers' interest.

This chapter is organized as follows, in sub chapter 2.2 and 2.3 I make a review of the study of general supply chain and automotive industry. Further introduction of the automotive supply tiers are given in 2.4 and the modularity is discussed as a special characteristic in sub chapter 2.5. In the end, automotive supply chain design strategies are introduced from 2 aspects: BTO strategy and collaboration strategy.

2.2 Literature about Supply Chain Management

In this subchapter I am going to review the existing literatures about supply chain management, the review is done from 3 aspects as the general supply chain management introduction, supply chain simulation methods, and the study of supply chain performance evaluation.

2.2.1 Supply Chain Management in General

Supply chain management is not a strange topic since half century ago. Giving continuity to the evolution of productive sectors and the increasing competitive level, one may say that today there is no existence of competition among companies, simply, but a competition among supply chains. This again leads to the conclusion that good supply chain management will define who will stay and who will leave the market [VCJ 05]. In this section, the multidisciplinary origin of the concept "supply chain management" will be discussed, we find not only the definition of supply chain and supply chain management, but also the tons of work done for supply chain functions.

2.2.1.1 SCM as a Field of Research and of Practical Endeavours

The term “supply chain management (SCM)” was originally coined in 1982 by the two consultants Oliver and Webber who pointed out that businesses could potentially derive benefits from integrating the internal business functions of purchasing, manufacturing, sales, and distribution [Har 96]. Today, the term is almost omnipresent in both academia and industry.

SCM has already been an en vogue topic in the 1990s and the assumption that its popularity has risen to even higher levels by now does not seem too farfetched. However, it has to be pointed out that - despite the entire buzz that is being raised about SCM - there is only a “relative poor supply of empirically validated models explaining the scope and form of SCM, it’s cost and benefits” [CRG 00]. It is probably not too daring to state that SCM as a field of research is still in its infancy. Not only seem the number of empirically validated SCM models to be relatively limited; but even more elementarily, there is neither a uniform definition of the term, nor a common understanding of SCM as a concept [Har 96]. Moreover, a confusing plethora of labels refers to both the supply chain and its management, for example: integrated purchasing strategy [CE 93], supplier integration [PHR 04], buyer-supplier partnership [LSG 02], strategic supplier alliances [EK 01], supply chain synchronization [TLW 02], value added chain [Bea 99], lean chain approach [Mcl 01], supply pipeline management [SL 03], supply networks [Rom 03], and value stream management [HRBT 98].

Despite the extensive body of academic and popular literature on the topic, there are very few examples of successful SCM implementations; and as a matter of fact, in many companies SCM is either non-existing or still in the infancy stage [FM 02]. In other words, there seems to be a gap between discussion led in the world of academia and world of practice: Apparently, the academic discussion surges ahead, and the practical implementation leaps behind.

The fact that neither a universal definition nor a clear understanding of the concept exists could possibly be explained with the multidisciplinary of the concept of SCM. As such, it draws from many different bodies of research, “which, to date, have remained largely unconnected” [Har 96]. Consequently, SCM has been viewed and considered from many different perspectives, and it can be characterized as multi-faceted and complex. Table 2-1 lists selected streams of research that have contributed to the field of SCM.

Table 2-1 Streams of Research Contributing to the Field of Supply Chain Management

Streams of research	**Sample of source**
Industry dynamics	Towill, [Tow 96]
dynamic theory of strategy and competitive strategy	Porter, [Por 07]; [EP 08]
Network theory	Carey Hill, [Hil 02]
Market channel theory	Coughlan, [Cou 85]; Achrol et al., [ARS 83]
Business logistics	Persson, [Per 97]; Mentzel et al., [MK 91]
Strategic management	Teece et al., [TPS98]; Burgelman et al., [BCW 08]

Inter-organizational behaviour	Ebers, [Ebe 99]; Lu, [Lu 02]
Operations management	Chary, [Cha 95]
Information management	Picot et al., [PRW 08]

2.2.1.2 Definition Supply Chain Management

As noted in the previous sub section, a single, generally accepted definition of SCM does not exist. The abundance of definitions begins already with the term "supply chain" as shows in the table below:

Table 2-2 Sample Definitions for "Supply Chain"

Author	**Definition**
Cavinato, 1991	"Supply chains …. are popular interfirm linkages to attain joint cost savings, product enhancements, and competitive services"
Ellram, 1991	"A network of firms interacting to deliver product or service to the end customer, linking flows from raw material supply to final delivery."
Lee and Billington, 1992	"Networks of manufacturing and distribution sites that procure raw materials, transform them into intermediate and finished products, and distribute the finished products to customers"
Saunders, 1995	"External Chain is the total chain of exchange from original source of raw material, through the various firms involved in extracting and processing raw materials, manufacturing, assembling, distributing and retailing to ultimate end customers."
Kopczak, 1997	"The set of entities, including suppliers, logistics service providers, manufacturers, distributors and resellers, through which materials, products and information flow."
Mabert and Venkataramanan, 1998	"Supply Chain is the network of facilities and activities that performs the functions of product development, procurement of material from vendors, the movement of materials between facilities, the manufacturing of products, the distribution of finished goods to customers, and after-market support for sustainment."

(Source: Based on Diaz, 2006, [Dia 06])

The term "Supply Chain Management" has numerous definitions differing in various aspects such as, for instance, the scope of the concept as well as the emphasis on certain involved functions and processes (see table 2-3).

Table 2-3 Sample Definitions for "Supply Chain Management"

Author	**Definition**
Houlihan, 1985	"Supply Chain Management covers the flow of goods from supplier through manufacturing and distribution chains to the end user […]. It views the supply chain as a single entity rather than relegating fragmented responsibility for various segments in the supply chain to functional areas […]".

Jones and Riley, 1985	"Supply Chain Management deals with the total flow of materials from suppliers through end-users".
Stevens, 1989	SCM is "a connected series of activities which is concerned with planning, coordinating and controlling materials, parts, and finished goods from supplier to customer. It is concerned with two distinct flows (material and information) through the organization".
Ellram and Cooper, 1990	SCM is "an integrative philosophy to manage the total flow of a distribution channel from supplier to the ultimate user".
Christopher, 1998a	"The management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole."
Ellram and Cooper, 1993	"Supply Chain Management has been characterized as a cross between traditional, open market relationships and full vertical integration. As such, supply chain management represents an innovative way to compete in today's ever changing global economy."
La Londe and Masters, 1994	"Supply chain strategy includes: 'two or more firms in a supply chain entering into a long-term agreement; […] the development of trust and commitment to the relationship; […] the integration of logistics activities involving the sharing of demand and sales data; […] the potential for a shift in the locus of control of the logistics process'"
Carter and Ferrin, 1995	"Supply chain management (SCM) is an integrative approach for planning and controlling the flow of materials from supplier to end users."
Bowersox and Closs, 1996	"The basic notion of supply chain management is grounded on the belief that efficiency can be improved by sharing information and by joint planning […] an overall supply chain focusing on integrated management of all logistical operations from original supplier procurement to final consumer acceptance."
Bowersox, 1997	"Supply Chain Management is a collaborative – based strategy to link cross – enterprise business operations to achieve a shared vision of market opportunity"
Cooper et al., 1997b	"The integration of all key business processes across the supply chain is what we are calling supply chain management"
Metz, 1997	"Integrated supply chain management is a process – oriented, integrated approach to procuring, producing and delivering products and services to customers."
Tan et al., 1998	"encompasses materials/ supply management from the supply of basic raw materials to final product (and possible recycling or re-use)."

(Source: Based on Diaz, 2006, [Dia 06])

In order to master this abundance of definitions, various authors try to group definitions that can be found in literature. A widely accepted classification scheme is presented by Harland [Har 96], who distinguishes four main use of the term as presented in table 2-4:

Table 2-4 Four Main Use of the Term "Supply Chain"

#	Use of the term "Supply Chain"
1st	"First, the internal supply chain that integrated business functions involved in the flow of materials and information from inbound to outbound ends of the business"
2nd	"Secondly, the management of dyadic or two party relationship with immediate

	suppliers”
3rd	“Thirdly, the management of a chain of businesses including a supplier, a supplier’s supplier, a customer, a customer’s customer, and so on”
4th	“Fourthly, the management of a network of interconnected businesses involved in the ultimate provision of product and service package required by the customers”

(Source: Based on Harland, 1996, [Har 96])

2.2.1.3 The Objectives of Supply Chain Management

Now, that SCM has been defined and its background has been outlined, the question remains as to what the objectives of SCM are. The objectives of a company are “designate the ends sought through the actual operating procedures of the organization and explain what the organization is actually trying to do” [Geo 73].

Table 2-5 Objectives of Supply Chain Management

Objective	**Sources**
Improving customer satisfaction and service	Cooper et al., 1997, [CLP 97]
Lowering costs and resources required for value creation	Giunipero and Brand, 1996, [GB 96]
Reducing inventory levels and respective costs	Cooper and Ellram, 1993, [CE 93]
Improving efficiency and effectiveness	Giunipero and Brand, 1996, [GB96]
Increasing profits and profitability	Tan, 2006, [Tan 06]
Increasing competitiveness and competitive advantage	Cooper et al., 1997, [CLP 97]
Improvement of cooperation	Christopher and Jüttner, 2000, [CJ 00]

As presented in the above table, one objective of SCM is to improve customer satisfaction whereby Spreng et al. [SMO 96] argue that overall customer satisfaction is influenced by a customer’s assessment of the degree to which a product’s performance is perceived to have met or exceeded his or her desires and expectations. Customer satisfaction could be improved by the application of SCM since, among other things, SCM might contribute to reducing the number of stock-outs, and it might help to minimize the time span between order placement and delivery because the value creation process is streamlined by SCM. For example, customers of a car manufacture will most likely be unsatisfied with the brand if they get the product later than promised; and they will most likely be satisfied if they get their new car on the promised day. Customers of this car manufacture are probably even happier if the OEM is able to deliver the car faster than competitors in terms of the time span between order placement and delivery. SCM would help to achieve this goal.

Another objective of SCM is to lower costs and resources required for value creation. This objective might be achieved if, for example, participants of a supply chain share resources such as their fleet of trucks which might result in improved capacity utilization and, thus, lower unit costs for transportation leading to lower total cost. The reduction of transportation costs, production costs and purchasing costs [SHK 05] play a key role in this objective of SCM.

The third objective mentioned in the above table, reducing inventory levels and respective costs, might be attained by the reduced need for holding safety stocks when

SCM is implemented. Reducing inventories might be one factor contributing to the achievement of another goal, namely increasing (organizational) efficiency and (organizational) effectiveness. According to Ostroff and Schmitt [OS 93], efficiency is the ratio of outputs produced by an organization to the inputs needed for making those outputs. “Efficiency is improved either by reducing the costs while holding outputs constant, by increasing outputs with the same amount of inputs, or by simultaneously reducing costs and increasing outputs” [GO 04]. By conducting SCM, organizational efficiency might be increased because the members of a supply chain might be able to acquire needed inputs at a lower cost whereby “cost” can be understood as the sum total of all acquisition costs which is product price plus other costs such as those for transportation and installation, and transaction costs related to making that purchase. Transaction costs, for instance, will decrease if a company maintains long-term relationships with its suppliers because it is not necessary to search for a new source each time a good is needed. Hence, by cooperating, i.e. conducting SCM, companies increase their own utility level, but also make a contribution to improving, i.e. to increasing, the efficiency of the entire value creation process. Markland (cited by Chung [CH 99]) for example, describe the reduction of lead times as an improvement of efficiency.

Concerning organizational effectiveness, there is no universal agreement on what this term means. Cameron [Cam 86] distinguishes eight different models of organizational effectiveness, each of which features a different definition.

Which model and, thus which definition of organizational effectiveness is appropriate depend on the circumstances (c.f. the right column of Table 6). For example, if goals are clear, measurable and time bound, the goal attainment model seems appropriate to determine organizational effectiveness. Within this model, the effectiveness of an organization is appraised in terms of the degree to which it achieves its goals. This model focuses on the output an organization produces; however, under certain circumstances, it might be more suitable to judge an organization by its capability to acquire input and to transform it into output as well as its ability to maintain itself internally as a social organism and to interact with its environment (Robbins, 1990, cited by Denison and Mishra [DM 95]). If this applies, the systems approach might be more suitable. Within the context of SCM, this might be an appropriate model to assess organizational effectiveness: by implementing SCM in a joint effort with other companies each participant might be able to increase its ability to source input made according to certain specifications, i.e. non-standardized products or products that are not commodities, because it can work together closely with the preceding echelon to develop such specific input.

Organizational effectiveness is appraised in terms of the degree to which an organization achieves its goals (Koschnick, 1995, cited by Diaz [Dia 06]). In other words, an organization is effective if it is “producing, or capable of producing, a decided, decisive, or desired effect” (Webster’s dictionary, cited by Dia [Dia 06]). For example, a company has raised its effectiveness in achieving the objective of increased customer satisfaction if it is able to reduce the number of stock-outs through the implementation of SCM practices.

Improving efficiency and/or effectiveness as well as attaining the other objectives described so far might be helpful in achieving the objective of increasing profits and profitability. Profit is defined as “the surplus of revenues over costs” [Gra 02] and profitability is “the quality or state of being profitable [and] […] the capacity to make a profit” (Oxford English Dictionary, cited by Grant, [Gra 02]). That means, a company can increase its profitability and its profit either by reducing costs (e.g. by lowering inventory levels through SCM), or by increasing revenues (e.g. by increasing customer satisfaction through SCM, assuming that a satisfied customer generates more revenue).

All of the objectives described so far might contribute to achieving the last objective mentioned in Table 2-6: Increasing competitiveness and competitive advantage. Competitiveness “usually refers to characteristics that permit a firm to compete effectively with other firms due to low cost or superior technology, perhaps internationally” (Deardorff, 2001, cited by Guerrieri and Meliciani [GM 05]) and competitive advantage can be defined as follows: “When two or more firms compete within the same market, one firm possesses a competitive advantage over its rivals when it earns a persistently higher rate of profit (or has the potential to earn a persistently high rate of profit)” [Gra 02]. A company might attain this objective if it is able to achieve at least one of the other objectives of SCM, e.g. lowering costs through decreasing inventory levels and, thus increasing profits.

The discussion in this section showed that several different objectives can potentially be achieved through the implementation of SCM practices. Additionally, it has been shown that the goals are not independent of each other, but correlated, that is, achieving one objective might help attain another.

2.2.2 Supply Chain Simulation

Specialists in manufacture technology recognize the importance of simulation. Modelling and simulation of systems have been identified as the two great discoveries that will accelerate the resolution of great challenges to be found by manufacture industries [CFMK 07]. A simulation study enables among other possibilities, to perform the analysis of a system which is not yet existent, obtaining important information for the objective of the study performed. This is done by the preparation of a logical mathematical model that represents the real system in a satisfactory form.

According to Retzlaff-Roberts and Nichols [RRN 97], simulation offers an effective analytical tool for organizations that need to measure the performance of supply chains. In these models, individual plans are modelled as being units of restricted production capacities, or, these are simplified, for the purpose is to check how these perform in the supply chains as a whole. So supply chain simulation can be understood as a process of creating a supply chain model and testing it until finding an acceptable configuration, as being a dynamic process [CBS 02].

Arntzen et al. [ABHT 95] discussed the development of a global supply chain model (GSCM) using mixed-integer linear programming to investigate issues related to the location of customers and suppliers, transit time, and cost of various transportation modes. Archibald et al. studied a hypothetical global food manufacturing organization with facilities and suppliers spread all over North America considering transportation options, continuous replenishment of inventories, and collaborative planning. Cachon and Zipkin [CZ 99] investigated a two-stage serial supply chain with stochastic demand and developed a mathematical model to investigate competitive and cooperative inventory policies. A framework to minimize the global cost of supply chain of a manufacturer and two-level hierarchy of suppliers was developed by Novak and Eppinger [NE 01], which addressed the choices of internal production and external sourcing for components in the auto industry focusing on the connection between product complexity and vertical integration using empirical evidence. Tang et al. [TYW 04] developed heuristics for integrating decisions regarding production assignment, lot sizing, transportation, and order quantity for multiple suppliers/multiple destinations logistic network in a global manufacturing system.

Graves and Willems [GW 05] focused on configuration of the supply chain for a new product with different sourcing options and cost at each stage of the supply chain with no split in customer demands using a dynamic programming formulation to minimize the total supply chain cost. Kim et al. [KYK 08] developed a single-period mathematical model to analyze how much of each raw material and/or component part to order from which supplier when given capacity limits of suppliers and the manufacturer. Joines et al. [JLT 01] focused on the impact of sourcing decisions, like “how much to order” and/or “how often to order”, on the performance (i.e., Gross Margin Return on Investment) of the supply chain and Muralidharan et al. [MAD 01] identified supplier quality; cost and on-time delivery as the three most important criteria in supplier selection and developed a practical methodology for rating them. Zsidisin [Zsi 06] studied characteristics of inbound supply that affect perceptions of risk and created a classification of supply risk sources. Nagurney et al. [NCDZ 05] developed a three-tier (manufacturers, distributors, and retailers) global supply chain network model with both physical and electronic transactions to optimize the behaviour of multi-criteria decision-making by manufacturers and distributors concerned with both profit maximization and risk minimization. Lee et al. [LHK 01] developed a mathematical model for selecting suppliers according to their quality management factors (i.e., quality management audit, product testing, engineering work force, capability index, and training time), their price, and production and delivery lead time. Chiang and Russell [CR 04] studied the optimal integration of purchasing and routing in a propane gas supply chain with rigorous solution methods using both set partitioning and tabu search. Wang et al. [WYRX 04] proposed a quantitative method total assessment at the microeconomic decision making level that analyzes all of the quantitative and qualitative factors with regard to the supplier selection using TOCO (total cost of ownership) concept. Cakravastia and Takahashi [CT 04] developed a multi-objective non-linear model to study the supplier selection and negotiation process for multiple parts/materials procurement. Sevkli et al. [SKZDT 08] presented a decision-based methodology for supply chain design to select suppliers, which utilizes the analytic hierarchy process technique and pre-emptive goal programming.

In the following table, I summarize and organize the literature based on the methods and approaches used for solutions.

Table 2-7 Summary of Literature Review Based on the Methods and Approaches

Authors	**Work Done**	**Methods/Approach**
Looman et al. 2002, [LRB 02]	Investigate designing, ordering and inventory management practices for purchased parts from the perspective of integrating purchasing and logistics functions	Quantitative evaluations using AHP
Muralidharan et al. 2006, [MAD 06]	Literature survey on multi criteria group decision making identify supplier quality, cost and on-time delivery as three most important criteria in supplier	AHP for multi criteria decision making

	selection	
Sean Willems, 1999, [Wil 99]	Supply Chain Design focuses on configuration of the supply chain for a new product program. Different sourcing options at each stage of the supply chain along with the associated costs are considered	Dynamic programming formulation
Benton and Maloni, 2005, [BM 05]	Test the influence of supply chain power on supplier satisfaction	Empirical methods
Zsidisin et al., 2007, [ZSMK 07]	Study of journal evaluation criteria, purchasing and supply chain management, survey research	Literature survey
Cachon and Zipkin, 1999, [CZ 99]	Inventory policies in supply chain investigate a two-stage serial supply chain with stochastic demand and fixed transportation times. Inventory holding costs are charged at each stage with optional backorder penalty costs	Develop a mathematical formulation to investigate competitive and cooperative inventory policies
Moon et al. 2002, [MKH 02]	Configuring manufacturing firm's supply network with development of a single-period mathematical model and algorithms to determine how much of a raw material/component should be ordered from which supplier given capacity limits of suppliers and manufacturers. Real-world case study from computer industry demonstrated	Mathematical models
Tang et al., 2004, [TYW 04]	Develop heuristics for integrated decisions for production assignment, lot sizing, transportation and order quantity for multiple supplier/destinations logistics network in a global manufacturing system	Heuristics-based Mathematical models
Arntzen et al. 1995, [ABHT 95]	Development of global supply chain model (GSCM) to investigate issues relating to location of customers and suppliers, transit time and cost of various transportation times, significance of tax havens, offset trades and export regulations. Included multiple criteria	Mixed Integer Program
Chandra and Grabis, 2007, [CG 07]	General framework for supply chain modeling and optimization, supply chain is made up of a manufacturer and two level hierarchy of suppliers, ordering and holding costs considered and have quadratic relationship, delay for procurement activity, demand for final product and raw material is already known. The model seeks to optimize the global cost of the supply chain	Mixed Integer Program
Swaminathan et al. 1998, [SSS 98]	Modeling supply chain dynamics, factors considered in their model were BOM, demand, leadtime, transportation time and costs	Simulation-based framework for developing customized supply chain models from a library of software components
Archibald et al. 1999, [AKK 99]	Distribution and collaborative planning of inventory in a multi-plant hypothetical food processing organization, output measures include return on investment, inventory turns and stock out delays	Simulation modeling

Jain and Ervin, 2005, [JE 05]	Modelling and simulation for evaluating the improvements in business processes and systems	Simulation Model
Reiner and Trcka, 2004, [RT 04]	Studied product specific supply chain in the Food Industry	Discrete Event Simulation
Chan et al. 2002, [CTL 02]	Investigate single channel logistic network and examine the applicability of order release mechanisms for monitoring the performance of supply chains	Simulation Approach
Karabakal et al. 2000, [KGR 00]	Work at Volkswagen, investigate vehicle distribution system with two major objectives: reduce total distribution and inventory holding costs; improve delivery lead times and market responsiveness	Simulation-based mixed integer optimization approach
Novak and Eppinger, 2001, [NE 01]	Study supply sourcing by design by investigating the connection between product complexity and vertical integration	Simultaneous Equations Mathematical model
Wang et al. 2003, [WHD 03]	Robust analytical models and design tools; performance metrics for decision making process	AHP, SCOR

2.2.3 Supply Chain Performance Evaluation (PE)

Based on the supply chain simulation methods investigated before, the supply chain evaluation is currently an increasingly important topic that is being studied. Since the previous researches focused mainly on the SC evaluation criteria selection, evaluation system construction, and evaluation algorithms, up to now the supply chain performance evaluation status is summarized in following 2 sub sections.

2.2.3.1 Supply Chain Performance Evaluation Criteria Selection and System Construction

During the construction of a PE (Performance Evaluation) system, selecting the proper evaluation criteria and indices is playing a key role. For different industries and different organizations the PE system varies from each other greatly. Some specialists have given their opinions in the supply chain PE research.

Main PE criteria from 4 aspects were listed in the previous literatures. From supply point of view, the supply reliability and lead time are considered; from process management point of view, the process reliability, cycle time and order fulfilment are considered; in regards to delivery aspect, transportation, supplementary lead time, ect, are considered; and as to the demand management, total cycle time and risk management are investigated. However, the exact criteria definition and algorithums were not offered, instead, the criteria were only qualitatively described.

Beamon [Bea 99] evaluated the supply chain from resources, outcome and flexibility aspects. Regarding the resources, he considered the following criteria: total cost, production cost, inventory cost, and profitability; regarding the outcome aspect, sales revenue, on time delivery, respond time, and order fulfilment rate, ect, are considred; at last in regard to the flexibility, time, quantity, product and mix flexibilities are investigated. The resource and outcome evaluation is quite well applied, but the flexibility evaluation is limited.

The evaluation system which can generally reflect the performance of the entire supply chain is still under investigation, scholars like Xu et al. [XMC 00] have offered a system with 7 indices regarding to this topic. The indices are sales, sales deviation, demand, cycle time, total cost, core product, and quality. Ma [Ma 04] proposed also some general indices, like customer service, production and quality, capital management and cost control, and in addition, he also suggested some auxiliary indices, like the supply chain efficiency, and so on.

PRTM (PRTM Management Consultants) proposed 11 indices in their SCOR model evaluation, and they are: delivery condition, order fulfilment, perfect order fulfilment, supply chain response time, production flexibility, total logistic cost, added value productivity, guarantee cost, cash turnover time, inventory turnover time, and capital turnover. Currently there are over 170 member organizations of PRTM applying this evaluation system. The SCOR model constructed a system from reliability, responsibility, flexibility, cost and capital aspects, with a detailed index system defined [HSK 05]. Some of the algorithms are given, but most are not.

A system based on the satisfaction degree was also built from the product quality, service level, pricing aspects [GPM 04]. And according to logistic coordination, information coordination, capital coordination and work coordination, Chen [Che 04] established another evaluation system. Zheng and Lai [ZL 08] also proposed a balance scoring system for supply chain, from customer, internal supply chain process, future development and financial value points of view individually. But the limitation of all those systems is that they didn’t propose the corresponding quantification methods and algorithms.

2.2.3.2 Supply Chain Performance Evaluation Methods

The PE analytical methods have been studied also by many research organizations or companies. Basically, the following listed methods are currently being applied:

1. Benchmark Selection, by which the excellent companies’ performances are set up as benchmark and investigated and afterwards learnt to make improvement [HT 02]. The benchmark selection method was developed by Xerox, and was used to quantitatively compare the company situation with the best performed companies.
2. Expert Evaluation, by which the evaluation result is quite based on the integration of experts’ subjective opinions [Yi 07]. It is applied in the forms of: plus evaluation, multiply evaluation, weighting evaluation, and efficiency coefficient evaluation. The advantage is easy of using, but the disadvantage is its subjectivity, and not suitable for complicated system.
3. Mathematical Statistics method, whose principal component analysis, factorial analysis, cluster analysis and discriminatory analysis are applied to categorize and evaluate some objects [TF 07]. The advantage is the avoidance of human influence, and being suitable for large complex system, however, it has very high requirement in data processing, which makes it not proper for supply chain integrated evaluation.
4. Fuzzy Comprehensive Evaluation, which is developed based on the fuzzy factor related object evaluation [FX 99]. The advantage of this method is the possibility of evaluating the fuzzy related objects, and it is quite suitable to use this method for multi-factor, multi-agent system. However, this method cannot solve the information duplication problem, and needs to be further studied.

5. AHP- the Analytic Hierarchy Process. By applying AHP the complicated problem is divided into different components, and these components are organized into different hierarchies. Through the comparison between each component, the item importance is fixed and the decisions are to be made based on the comparison results. [CLH 02]
6. Gray Correlation Analysis method, which is a branch of the Grey System Theory. It is a theory of research based on the incompleteness of information. With this method, researches analyze the closeness degree of the reference model and compared model, and evaluate the closeness of development trend. By using this method, the best option is normally applied as reference, the closer the other options to it, the better the options are. [LSW 89]

The implementation of the supply chain performance evaluation is limited because of the lack of intelligent tools. By Matlab and other tools it is possible to make some evaluation calculation, but for integrated system, it is relative limited in the tool choice. Oracle [Oracle Company] developed some supply chain software to evaluate the performance sub-systems, they defined some key indices, and made automatic calculation through the information aggregate. The weightings are also calculated by the given weight platform, which is based on the internal algorithm store. Besides, a PE system was developed based on web, by which the customers are allowed to define the evaluation systems on their own. However, for automotive supply chain, there hasn't been a proper tool to evaluate the performance.

2.3 Literature about Automobile Supply Chain

Automotive supply chain is a very complicated type of a supply chain system for its special industrial characteristics, thus there are many special norms and concepts that differ from the normal supply chain theory. In this sub chapter, the automotive supply chain studies up to now are about to be discussed in detail.

2.3.1 Taxonomy for Supplier Classification

Different organizations defined different classification for automotive suppliers, in this section, the suppliers will be classified according to the McKinsey (McKinsey&Company) report and the IMVP (International Motor Vehicle Program) definition, since these are the two leading classification standards used until now.

2.3.1.1 Supplier Classification McKinsey

According to McKinsey report, the participating suppliers have been classified into four groups based on their relative evolution along three axes of differentiation:

1. level of contribution to R&D (primarily application engineering and joint product development support to OEMs) involved in producing the parts they supply;
2. level of contribution to assembly (primarily spatial integration of parts and components into ready-to-install modules); and
3. level of contribution to integration (involving full-blown functional integration of components into systems or solutions that provide higher customer value).

Table 2-8 Supplier Classification McKinsey

System developers	A system developer: with significant integration, assembly and R&D contribution; designs and develops entire systems with unique functionality, such as the vehicle's brake system, navigation system or locking system.
Module assemblers	A module assembler: with significant assembly contribution; performs "blue-print" assembly without detailed component R&D contribution, such as the assembly of wiring harnesses or corner modules.
Component specialists	A component specialist: with high R&D contribution; uses superior product R&D to develop functionally differentiated, stand-alone components that may be integrated into systems or modules, such as compressors, chassis components or piston rings.
Commodity suppliers	A commodity supplier: with low integration, R&D and assembly contribution; is the traditional parts supplier, with no differentiation in product R&D because its supplies, such as screws, fittings, castings and sheet metal parts, are mature and standardized.

(Source: Based on McKinsey Report, 2006)

As shown in table 2-7, the automotive suppliers are classified into system developers, module assemblers, component specialists and commodity suppliers by McKinsey Consulting. This classification is more from the supplier capability point of view instead of the functionality and contributions, and it doesn't fit well to the study of actual tier structure, therefore another kind of classification by IMVP (International Motor Vehicle Program) is introduced.

2.3.1.2 Supplier Classification IMVP

IMVP (International Motor Vehicle Program) and some other analyst suggest dividing the automobile supplier industry as follow:

1. System integrator
2. Global standardizer – system manufacturer
3. Component specialist
4. Raw material supplier

And the corresponding concentrations and characters are summarized below in table 2-8.

Table 2-9 Supplier Classification IMVP

	Raw material supplier	Component specialist	Standardizer	System integrator
Focus	A company that supplies raw materials to the OEM or their suppliers	A company that designs and manufactures a component tailored to a platform or vehicle	A company that sets the standard on a global basis for a specific component or system	A company that designs and assembles a whole module or system for a car
Market Presence	Local Regional Global	Global for 1st tier Regional or local for 2nd , 3rd tiers	Global	Global

Critical Capability	Material science process engineering	Research, design, and process engineering; manufacturing capabilities in varied technologies; brand image	Research, design and engineering; assembly and supply chain management capabilities	Product design and engineering; assembly and supply chain management capabilities
Types of components or systems	Steel banks; aluminium ingots; polymer pellets	Stampings; Injection moulding; engine components	Tires; ABS; electrical control unit	Interiors; doors; chassis

Studies within IMVP and other outside analysts [Vel 00] [VK 02] suggest a new configuration that will probably involve a division along the following lines:

1. *Systems Integrator*: Supplier capable of designing and integrating components, subassemblies, and systems into modules that are shipped or placed directly by the supplier in the automakers' assembly plants.

2. *Global Standardizer – Systems Manufacturer*: Company that sets the standard on a global basis for a component or system. These firms are capable of design, development and manufacturing of complex systems ("black-box" design). Systems manufacturers may supply motor vehicle manufacturers directly or indirectly through Systems Integrators.

3. *Component Specialist*: A company that designs and manufactures a specific component or subsystem for a given car or platform. These can include "process" specialists, such as a metal stamper, die caster, injection moulder, or forging shop that builds parts to print. They might also have additional capabilities such as machining and assembly, supplying components such as a steering column or the pedal system. These firms will increasingly work as suppliers to system integrators and standardizers.

4. *Raw Material Supplier*: A company that supplies raw materials to the OEMs or their suppliers. This includes products ranging from steel coils or blanks, to aluminium ingots or polymer pellets. The presence and competitive structure of the specific marker varies, with steel and polymers mostly a regional business, and aluminium or magnesium a global market. Some of the raw material suppliers are also moving into component specialists to add value to their products.

This configuration of the industry also means an important restructuring, with firms actively engaged at some of the levels identified above, and others leaving the industry, the important aspect is focus. Companies must identify a clear positioning strategy and derive a consistent set of actions along the critical development and manufacturing dimensions. For example, the low cost producer is probably not the most flexible one; and the manufacturer of low value added components should not be the one with more resources devoted to product innovation.

This IMVP configuration is suitable for some researches especially the ones for supplier functionality analysis and purchasing strategy identification, but to the objectives of this work, it is still not satisfying enough to be considered as the base of this research.

2.2.3 Automotive Supply Chain Tier System

The growing importance of suppliers in the automotive industry is affecting their structure. Traditionally, the industry supply chain was organized in tiers. As Tier 0, OEMs would design and assemble the car. First tiers would manufacture and supply modules or systems directly to the automaker. Second tiers would produce some of the simpler individual components that would be included in a system manufactured by a first tier, and third and fourth tiers would mostly supply simple single parts and raw materials.

Below is a tier system developed by Schonert [Sch 08], which is also in my opinion the most reasonable classification among all the existing researches, though it still can not generally reflect the current automotive supply chain structure. And later in this work, the Schonert model will be used as the base of automotive supply chains for the discussion of this research.

.

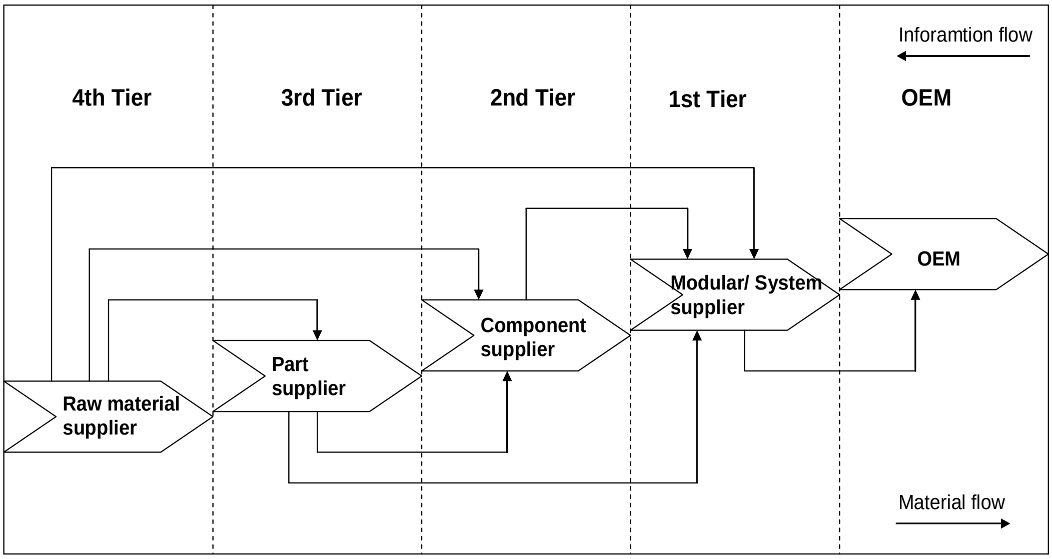

Figure 2-1 Automotive Supplier Chain Tier System
(Source: Based on Schonert, 2008, [Sch 08])

This model is relatively complete and most of the suppliers can be categorized into one of the tiers. However, as mentioned before, this is anyway still not the perfect one, since the new OEM direct suppliers are becoming large global companies, which are specialized either in complex systems, or integrators of several simpler subsystems. New suppliers which are mainly outsourced and offer services instead of concrete products start to appear as well. Based on this model, the automotive supply chain will be investigated with new methods developed in this work, and finally in the end of this dissertation, a newly structured model which is more complete and better reflecting the reality will be developed.

2.4 Role of the Automobile Supply Chain Tiers

Based on the tier system introduced in the previous section, the roles that every single tier plays are to be discussed in detail in this sub chapter.

2.4.1 OEM: the Auto Manufacture (Tier 0)

OEM (Original Equipment Manufacture) is sometimes also called Tier 0. The OEMs acknowledge that the critical issue in subcontracting is research and development cost. Manufacturing cost of modules and systems is often as high or higher in suppliers than in OEMs. Therefore, cost-wise, outsourcing becomes worth doing only if the supplier does all the engineering work. This is particularly relevant for complex systems or modules such as an ABS (Anti-lock Braking System), where it is assumed that the supplier is able to spread its development cost across several clients (OEMs).

Given the importance of the systems being subcontracted by OEMs, there is a clear strategic goal of these firms toward working with a smaller number of large suppliers. And this is a general tendency that can be found in all automakers. Despite being an overall strategy, OEMs are following it to different extents. Some companies have a more conservative policy strategy toward supplier reduction, while some other companies are being more aggressive. According to the research of CSM Auto：

The strategy of Volkswagen and Renault could be described as the 2+1 suppliers:

- For each major module, the OEM forms a partnership with key suppliers;
- In each region, two suppliers are considered privileged partners, with involvement in the early stages of the development process. A third follows closely, being given less responsibility, but enough for it to be ready to replace any of the existing suppliers.
- Because the same cars are being sold in several regions of the globe, this strategy is generating a tendency to have the same suppliers around the world for a given module in a particular car. Since OEMs demand car parts to have the same characteristics in any given plant around the globe, suppliers are often faced with the options of either investing near new plants to supply the module, or transferring their knowledge to a local supplier. They often prefer the first option.

The Ford supplier strategy is considered more aggressive:

- There is a clear drive toward increased use of large modules rather than individual components or even subsystems.
- The ultimate (theoretical) goal is to have a single firm supplying modules like the complete interior for a given car across the world.
- The company is also pushing for the supplier to own the tools, another way of pushing the risk associated with volume fluctuation onto the supplier rather than Ford. Suppliers will have to be concerned with their amortization schedule when quoting prices because payback for the investment in tools must now be included in price.

This policy is inevitably going to lead to a drastic reduction in Ford’s direct supplier count, with most previous first tier suppliers likely to become current second or third tier. Ford admits that their supply strategy is not the industry standard. Their strategy is not without pitfalls. By outsourcing more and more parts, and worse still, moving toward a single, very large system integrator (like Lear or Magna), Ford will be giving up a lot of power over their supply chain, and knowledge of the supplier industries. At the moment Ford has an extensive databank of "benchmark" cost of supply for many parts. Therefore, it is able to understand what the cost of assembled modules containing these parts should be. In the future, they may only know about the cost of the entire system, and not its individual components, and thus will have relative little knowledge to use during negotiations with the major systems integrators. But the benefits that OEMs enjoy are reduced assets intensity, reduced supply chain management cost, as well as improved quality and productivity.

Given what was described above, choosing partners that are able to work with the auto makers in the development and manufacturing of the systems becomes crucial. Major criteria for choice of supplier to be a strategic partner include:

- Cost and quality competitiveness;
- R&D capacity;
- Closeness to development center;
- For parts with substantial logistics costs, location is also an issue;
- Absolutely no nationality criteria.

More responsibility has often come with strings attached. In the first place, OEMs require suppliers of modules to have quality performance above their own, and with continuous improvement. This has meant that suppliers may need to improve rejects, scrap, and rework by as much as 5-7 percent a year. Second, all OEMs are including price reduction objectives in the contract (see Figure 2-2). The key features of this concern are:

- Contract length and overall value are related to price reduction targets that the supplier is able to commit to.
- For some of the assemblers, suppliers can also propose alternative designs that have the same economy results.
- Magnitude of reduction per year varies from 2 to 8 percent.

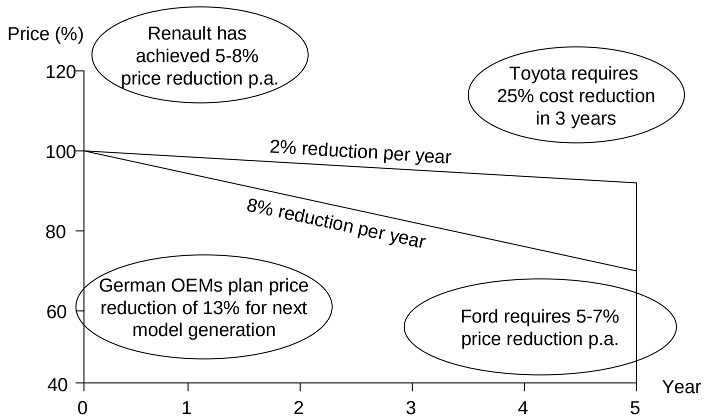

Figure 2-2 Price Reductions Demanded from OEM
(Source: Based on The Economist Intelligence Unit, Mckinsey, 2005, Wards)

2.4.2 Tier 1: Modular & System Supplier

Module and system suppliers, namely the Tier 1 suppliers will need to provide a wide assortment of products and services for automakers. They also need to have a global presence, supplying OEMs wherever they have plants. These aspects, combined with the automakers' desire to reduce their number of firms with which they have a direct relationship with will make the supplier industry more streamlined. It has generated the recent wave of consolidation in the industry, and some firms are expected to leave the industry altogether. Until 2007, the U.S. market had 30 to 50 Tier 1 system suppliers; 150 to 250 Tier 2 component suppliers; and 2,000 to 3,000 other small suppliers (IMVP data).

The current capabilities and position in the industry, available resources, and profitability will largely determine the development paths of each supplier. Moving up the hierarchy by buying other business or merging with another supplier is probably an option to meet the strict requirements that OEMs place to first tiers, and if this is an available option, then crucial considerations to think about are: success in long-standing relationships, manufacturing and assembly capabilities, ability to react quickly to OEM customers' needs, design and development capabilities, program management capabilities and global presence.

Evolving to be a major supplier has important implications:

1. Developing a whole system and manufacturing it for an automaker requires important engineering maturity, proprietary technology, an extended network of suppliers, and presence in key production regions. System manufacturers supply core products and technologies. Because of this, development costs easily reach 10 percent of sales, with three to five years between starting to work in a program and starting to produce revenues. Therefore, any firm wishing to move in this direction has to be able to cope with this challenge.

2. These companies need to strengthen systems' engineering and integrated supply chain management capabilities. They should also place plants where automakers expand.

Because of size, expertise, and presence, the Tier 1 suppliers are generating a new focal point in terms of industry aggregation and rebalancing the relative weights in the auto supply chain. Most existing suppliers were not equipped to respond to the challenges associated with these new supply responsibilities. They were mostly regional, focusing on particular components and had limited resources to withstand financial outlays on product development for several years before actually seeing returns on investment. As a result, a wave of foreign investments and consolidation has swamped the supplier industry during the past few years.

Despite the dynamics of the market and the growing importance of these players, their financial results are still uncertain. According to the research of McKinsey, both the return on equity and the discounted earnings expectation projection has been larger for component supplier than for system supplier. The figures demonstrate that companies should carefully assess whether moving from being a component supplier into a system supplier is in their best interest. If their strongest capabilities and competences are associated with particular components, they may be able to do as well or better than systems manufacturers, even if that means working as a second tier company. Despite some uncertainty in the level of financial results, having a clear strategy has a clear financial return.

Teaching and learning in the supply chain is being redefined by the emergence of suppliers. In the past, OEMs were concerned with transferring best practices in manufacturing and design to their suppliers. Nowadays, they are actually hoping to learn from suppliers. These new large Tier 1 suppliers are taking on this role of teaching the smaller lower tier companies.

In addition to traditional first tiers that deliver some physical product to the OEM, new roles are also emerging. The growing system complexity, either at an OEM or first tier supplier, is inducing the development of a new type of supplier. These do not supply physical products, but rather services, in particular design and engineering. Response to strict deadlines and product proliferation in both OEMs and suppliers requires the ability to rapidly develop and test new concepts and solutions. Given the cyclical nature of these processes, it often does not pay to have all the design and engineering capability in-house. Therefore, as noted in Table 2-9, many companies are emerging as providers of these services for the overall industry, whether OEMs, first tiers, or even smaller firms with particular needs.

Table 2-10 The Emergence of Design and Engineering Suppliers

Role	Focus
Global design company	A company that would design vehicle systems or bodies for OEM and/or Tier 1 suppliers
Global engineering company	A company that will provide engineering resources for OEM/ Tier 1 suppliers for detailed design

(Source: Based on McKinsey Report, 2005)

Another service role that is emerging is aggregator and intermediator. Information technology, in particular the Internet, is enabling the possibility for firms to do an electronic mediation of supply relationships, either on a one to one basis, or by aggregate demand for particular goods or services. This new role is still on its early stages and important change may happen in the next couple of years before an established business model emerges.

2.4.3 Tier 2 and Tier 3: Subassembly and Component/ Part Supplier

The majority of the suppliers that participate in the automotive supply chain are neither system/module suppliers, nor even raw material suppliers. Most of the companies, often smaller and working at a second or third tier level, are component/ part suppliers. Those suppliers can be further divided into Component/ Part manufacturer and Subassembly manufacturer, which are already introduced in sub-chapter 2.3. Here in this section, the definitions and general introduction of these two tiers will not be repeated, instead, the Tier 2 and Tier 3 company poisoning and evolving in the automotive supply chain structure will be more discussed.

The actual position and objectives of a supplier company, illustrated in Figure 2-3, determine the strategy it ought to pursue. The situation of a large number of national companies in virtually any country is that of a small process-focused company.

Moreover, their objective is often to remain as such. If this is the case, then they should focus on a broad array of lower value products, small facilities in few locations, very efficient manufacturing, with a lean business structure and limited engineering.

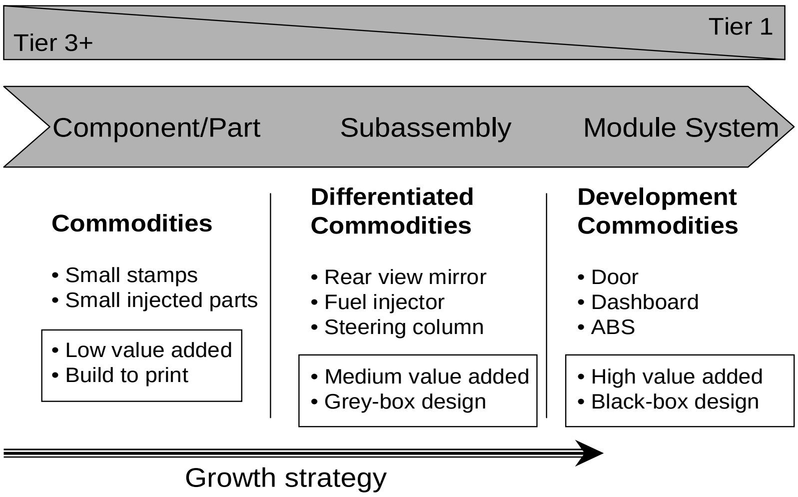

Figure 2-3 Company Positioning in the Supply Chain
(Source: Based on Veloso, 2000, [Vel 00])

As suppliers begin to move from Component to Subassembly Manufacturer, it is important to have capabilities in several manufacturing processes needed to produce the component, the ability to manage its own supply chain, and an improved presence in regions where OEMs are assembling the vehicle and where subassembly will be incorporated. Nevertheless, it is the enhancement of engineering capabilities that often becomes the crucial (costliest) issue. Design, test, validation, and prototyping have to be part of these firms' capabilities. Therefore, to work at a subassembly level, suppliers need, not only to be able to supply at low prices, but also to demonstrate significant engineering capabilities and enough financial resources to withstand financial outlays on product development for several years before having any revenues. Overall, it is estimated that the best subassembly manufacturers consistently spend about 3 percent of sales on engineering, mostly on product development [Vel 00].

Given the requirements associated with being a subassembly supplier, how do new firms get accepted to work at this level? OEMs claim that the process is rather open, with virtually any supplier with the necessary cost, quality, and development capabilities being admitted in the chain. The critical step is the so called ESA (Engineering Source Approval). For most components, the OEM has to approve both component specifications and overall company engineering capabilities. The problem is that OEMs often hold newcomers to a higher standard than they do with suppliers whom they have had joint engineering history, demanding important commitments in development capabilities without any real certainty of a contract.

Therefore, the current conditions are such that only companies with a certain minimum critical size can play an active role in the supply chain. Size is important particularly because of development capability. Gaining size to be able to free enough resources for development may actually benefit regions with labour cost advantages. Traditionally, low wages have been seen as an advantage for tasks and processes where labour costs matter, in particular manufacturing. However, labour cost advantage has often been overlooked at the level of human capital. Companies located in some regions with low cost of highly qualified labour, may eventually have a potential advantage in comparison with a rival from one of these developed countries when developing similar products.

But these firms need to gain size if they wish to enter the development of products with more complexity and higher value added. The same holds true for their presence abroad. Successful companies working at the component and subsystem level have been changing financial resources to endogenous growth, partnerships, mergers or simply acquisition of other companies abroad.

2.4.4 Tier 4: Raw Material Supplier

Raw material suppliers are also using automotive supply chain restructuring to reposition themselves (see Figure 2-4). Although their volumes of steel or aluminium devoted to the auto are small, their products used to be with greater margins. They have felt severe price pressures in the last decade, and they have been concerned that they may suffer a “commoditization”. To counter this tendency they are using supply chain disaggregation and innovative material use to become suppliers of formed parts and components.

Goal: Explore new global opportunities generated in the auto supply chain through the development of innovative material-based solutions that can generate increased value added for the OEMs and the supplier	
From	**To**
Supplier of steel coils or blanks; Global supplier of aluminum ingots	Supplier of fully formed body parts to the assembly line; Global supplier of aluminium castings

Figure 2-4 Repositioning Strategies of Raw Material Suppliers

2.5 Modularity in Auto Manufacture

Stagnating or partly declining sales figures, growing overcapacity and costs due to increasing model variety and individualisation of the products, as well as the development of new markets in the boom regions of the world characterise the challenges of the automotive industry at the beginning of the 21st century. Rising regulatory requirements in the areas of safety and environmental protection further increase pressure on automotive manufacturers and suppliers. Modular product design is intended to make the advancing variety of options controllable for companies and affordable for the customers. New collaborative planning methods are being developed to deal with the complexity of the multistage supply chains of the industry and to maintain its capacity to act. The proper approaches should be used to achieve BTO and enable companies to meet these challenges.

The saturation of the automotive market requires OEMs to differentiate and individualize their products. The auto makers have, in recent years, reacted with a massive expansion of their model range and equipment options. For example, the optional equipment in vehicle manufacturing in the last 20 years has posted an increase of more than 200%, while product variety in the past decade has actually increased by more than 400% (CSM Data).

According to the research of Shamsuzzoha et al. [SH 09], producing a new vehicle contributes 39% to the business volume, but only 8% to the profit of the auto maker. On the other hand, financing and insurance contributes 46% of the total profit and 30% of the business volume. Besides the car-fleet corporate customers, a major part of these earnings is contributed by recent strong growth in the leasing sector, with an increasingly large percentage of private customers. In future, individualized leasing offers could further enhance the importance of the leasing sector.

2.5.1 Product and Process Modularization

The increasing variety of brands and models created by the automotive groups induces vast numbers of variants, vehicle parts and components. This is added to by the companies' presence in more and more foreign markets, for which both regulatory issues and those of local taste must be considered. The automotive industry must master a balancing act, not only to maintain product differentiation for the customer, but also, as far as possible, to standardize parts required for their entire model range.

Standardization has made possible the configuration of different products using a large set of common components. The modularity proposed to group components of products in a module for practical production objectives. Today, modularisation and standardization are promising tools in product family development because they allow to design a variety of products using the same modules of components called "platforms". Using platforms allows important family design savings and easy manufacturing. In contrast to the old-fashioned "platform" which was usually only limited to the standardization of vehicle components that are rarely noticed by the customer, such as the use of the same chassis for two or more models of the same size class, current modularized platform concepts strive to build also more complex modules or entire systems, which can be used in their basic forms in many vehicles. Innovative modularization concepts address the design of a standard base frame module that can be used in a large variety of vehicle derivatives of a size class and are enhanced with additional frame modules depending on the type.

Great savings in assembly costs are potentially available to the auto makers when they can limit the majority of the final assembly work to preassembled connected modules or systems. In recent years more and more production and development work has been assigned to the suppliers. This initially moved costs and risks to the weaker, mid-sized suppliers and it seemed to worsen their relative market position. However, the end effect was a core of suppliers who mastered these difficult circumstances and were able to establish themselves as a direct system or module supplier. The assignment of customer-specific orders to develop and produce systems or modules almost reversed the power ratio, because although the smaller suppliers often only served one major customer, this purchaser now completely depends on the quality of the development, production and on-time delivery from these first-tier suppliers.

The choice between efficiency and flexibility regarding production capacities is now often made for the higher cost flexible production choice. If different car models can be produced at one location with the same assembly lines, such flexibility contributes to increased efficiency in production. This is in spite of higher initial investment, because the variance in demand for the individual segments can be balanced out, without incurring large overcapacities. Capacity is partially reserved for increases in demand and because these are not utilized most of the time, they represent as dead capital. The investment behaviour of most manufacturers, with the expansion of the model selections, does not usually balance beyond this uneconomic, planned under-utilization of product capacities. Exogenous specified market volumes must currently lead to structural overcapacities worldwide. The figure below shows an estimate of capacity utilization in the manufacturing sector and in the manufacturing of motor vehicles and parts.

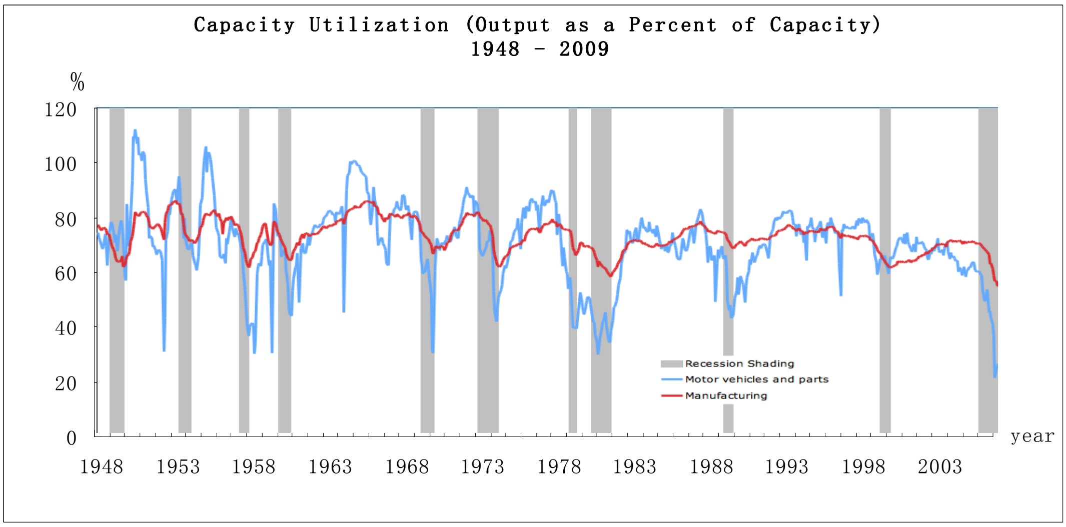

Figure 2-5: Estimated Capacity Utilization 1948 – 2009 (U.S. auto)

(Source: Lynch, 2009, [Lyn 09])

These estimates, which are constructed by the Federal Reserve of United States, are designed to measure output (seasonally adjusted) as a percent of capacity. Capacity, in turn, is an estimate of the greatest level of output a plant can maintain within the framework of a realistic work schedule, after allowing for such factors as normal downtime. As can be seen from the figure, the rate of capacity utilization for the overall manufacturing sector is clearly cyclical, and the rate has declined sharply since 2008 when the recession began. The down time in the motor vehicle and parts industry is even more striking. As represented by the blue line, the capacity utilization rate was 70% when the recession began at the end of year 2007, and in 2009 it drops to once 42%, which are the lowest levels on record. Another way of looking at this is the idle capacity in the auto industry, which is at a record high.

Therefore it can be concluded that the increased demand is generally addressed too far ahead of time and an expensive over-capacity "buffer" is created, which has been even worse for the recession reason. In order to keep the automotive industry not too much affected and meantime have the overall market capacities not reduced, the automotive companies have to address this problem as soon as possible.

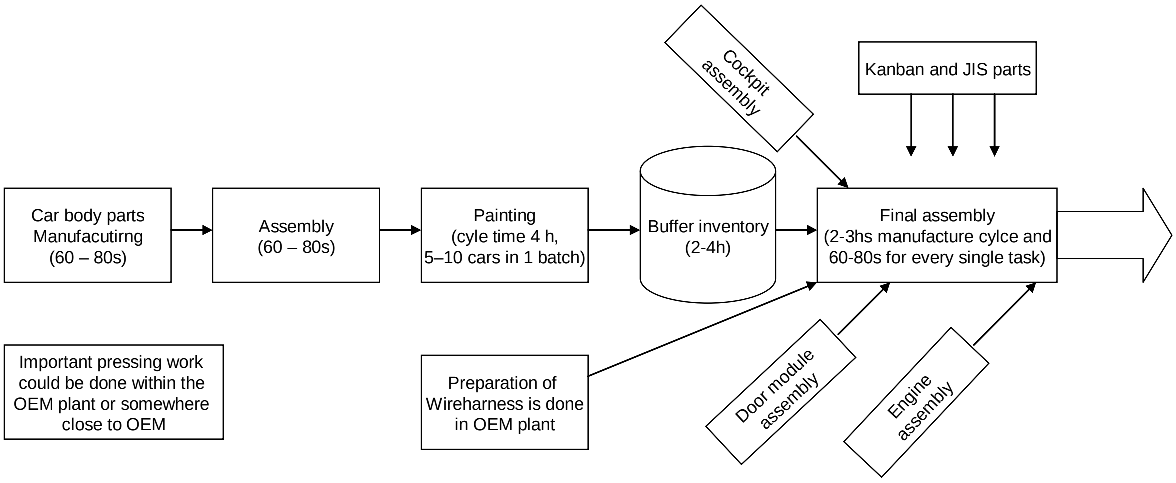

Figure 2-6 Assembly Line Design for Flexible Production in OEM

Today, most of the auto makers have already designed their production line targeting bigger flexibility. Above the Figure 2-6 illustrates a general process in the OEM assembly line, as we can see, most of the key process are already quite clear.

Modularization concepts can also be applied at the process level. It makes sense that with the product orientated direction of the entire company, product related development, production and manufacturing processes will be modularized. Although the creation of clear customer-orientated process modules within flat hierarchies increases the number of organizational interfaces, it contributes to the transparency of value-adding activity and reduces the overall need for coordination through the implementation of stable processes.

In addition to cost savings and reduced complexity with administrative tasks, modularity also delivers a direct customer benefit because the buyer of a new car can quickly and easily configure his car, make late changes due to flexible production and receive his car within a few days thanks to the short processing times. In the future, it may even be possible for customers to replace or exchange individual new modules, only because they offer different functions or because they have been updated.

2.5.2 Efforts and Advantageous Characteristics in Modular Methods/ Modular Design Methodologies

Modularization is an approach to organize complex designs and process operations more efficiently by decomposing complex systems into simpler portions. It allows the designer to play with combinations of groups of components to develop and customize a larger quantity of products.

The selection of a platform needs a comprehensive balance of “the number of special modules vs. number of common modules”. The dilemma in this sense is translated to the trade-off “product differentiation vs. standardization”. The use of different modules allows realizing a greater number of combinations, which result in more diversity of products and also increasing the costs. The principal advantages and disadvantages of these aspects are exhibited in Figure 2-7, and we could consider “modularity” in the matrix as a synonym for the use of more different modules and "standardization" as the use of more common modules. The high standardization degree is followed by low cost and low diversity, while high modularization means high diversity but also high cost. Finding a balance degree of standardisation and modularization is important for achieving the proper cost and diversity.

Standadization	+	Low cost Low diversity	Low cost High diversity
	-	High cost Low diversity	High cost High diversity
		-	Modularization +

Figure 2-7 Impact of Cost and Diversity by Different Levels of Modularization and Standardization
(Source: Based on Jose and Tollenaere, 2005, [JT 05])

2.5.2.1 Modular Architectures: Modular Design vs. Integral Design

A special interest in the modular products is the product architecture design. Mikkola [Mik 00] says that the product architecture is the arrangement of functional elements in building blocks and it could be developed by defining a mapping of functional and physical elements considering interface specification between components or modules. Ulrich [Ulr 95] distinguishes two types of architectures: The modular design and integral design. Some benefits of these two architectures are listed in Table 2-10.

Table 2-11 Trade offs between Modular Product Design and Integral Product Design

Benefits of Modular Designs	Benefits of Integral Designs
• Module task specialization • Increased number of product variants • Economies of scale in component commonality • Costs savings in inventory and logistics • Lower life cycle costs through easy maintenance • Shorter product life cycle through incremental improvements such as upgrade, add-on and adaptations • Flexibility in component reuse • Outsourcing • System reliability due to high production volume and experience curve • Faster assembly and less production time • Postponement of operations of differentiation for fast reaction of the market • Parallel manufacture of modules • Fast development of products	• Interactive learning • High levels of performance through special technologies • Systematic innovations • Superior access to information • Protection of innovation from imitation • High entry barriers for component and module suppliers • Craftsmanship

(Source: Based on Nevins and Whitney [NW 89][Whi 90], Mikkola [Mik 00], and Boutellier and Wagner [BW 03])

Above in the table we see that in the modular architecture, a relationship “one to one” exists between functional and physical elements, determining loose coupled interfaces between components in such a way that architectural changes on one component do not lead to changes in other components. Meantime, the integral design is fixed architecture oriented and leads to an optimized product. It is the classical product design where changes to one component cannot be made without interfering with others. Its design includes complex relationships (not one to one) between components and functions, and complex interfaces connecting components.

2.5.2.2 Module Evaluation: Standard or Special

There are different versions of modules to be assembled, whether to be a standard module or special module should be evaluated somehow based on a certain criterion.

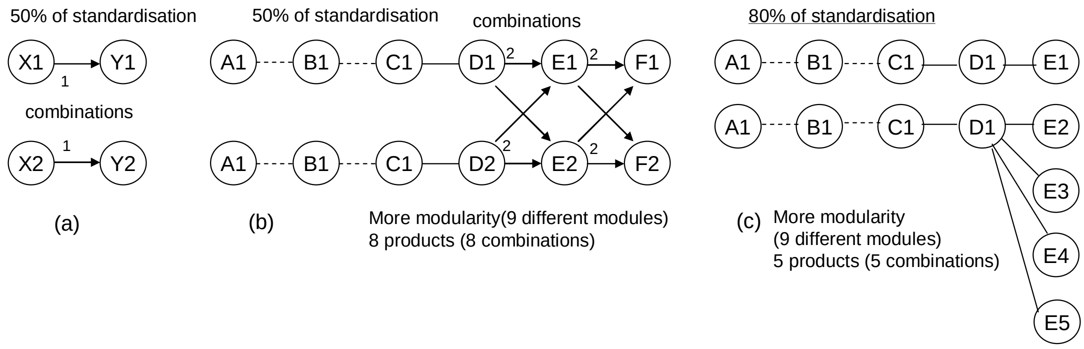

Figure 2-8 Assembly of Versions of Modules
(Source: Jose and Tollenaere, 2005, [JT 05])

According to example in Figure 2-8, the level of standardization and modularization can be manipulated without affecting one or another. Thus the level of modularity and the level of standardization could be independent. In relation to this, the trade-off evaluation should be focused to finding a maximum of standard components without affecting the ability to develop the necessary products.

The matrix mentioned in Figure. 2-9 could be used as a guide to evaluate and identify a module as standard or differentiation module.

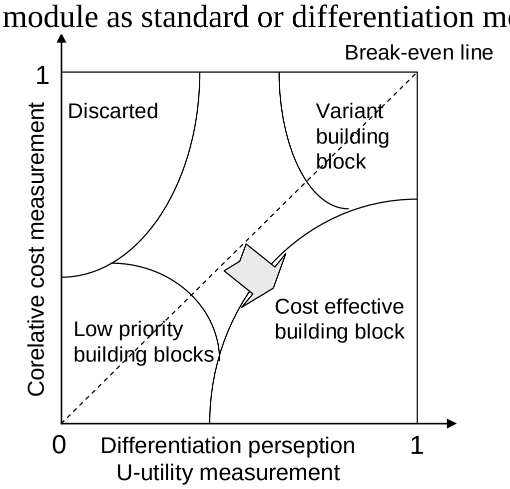

Figure 2-9 Module Evaluation as Standard or Differentiation Module
(Source: Jiao and Tseng, 1999, cited by Shamsuzzoha et al., [SHK 08])

According to Jiao and Tseng, the selection of a module as standard or differentiation, depends on its utility to product distinctiveness and on its cost. Where the relative cost measurement of the module can be based on the facility that is obtained by using the module to adapt other modular products and the utility measurement could be considered as the influence of the components on the product performance and their aesthetic characteristics.

2.5.2.3 Organizational Aspect

In addition to the conception aspects, working with modules requires to consider several implications about the organization. Managing modules to design other products needs a careful analysis because any update or design choice have an influence on future manufacture and management activities, thus affecting the company performance criteria, for example as listed by Sanchez [San 00]:

- The number and type of assembly requirements in the production line;
- The way the modules are supplied;
- Stock costs;
- Components and material savings;
- Operational reprocessing;
- Transport costs;
- The way the product is repaired, bundled, packed, recycled, etc.

Designing modular products requires more commitment by the key members of the company and product life cycle actors, since it needs more expertise, coordination, efforts, time and is more expensive than the design of classical products because it considers the conception of several products at the same time. The efforts and costs are concentrated at the initial period as illustrated in Figure 2-10.

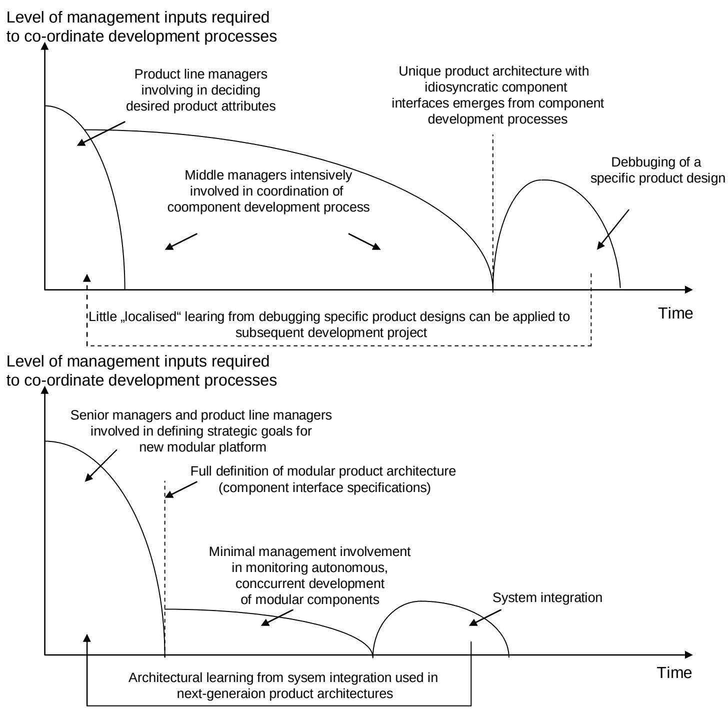

Figure 2-10 Module Comparison of Management Effort and Organizational Learning in Traditional vs. Modular Product Development Processes

(Source: Based on Sanchez and Collins, [SC 01][San 00])

According to this figure, there is more time spent to develop a product family in a classical way than to develop a product family with modules. This allows to consider that if the variety of product is low it may not be necessary to spent time and great efforts to match modules to develop different products. Optimizing and designing products in the individual form (integral design) could be faster and a better option. If there is a great variety of products in the family, it would then be faster and cheaper to design different products with a set of modules.

A modular design can be justified for a faster product development for subsequent derivative products. The company can develop families not only because the use of the same modules saves time, but also because specialized discipline groups can work more efficiently on modules related to their discipline.

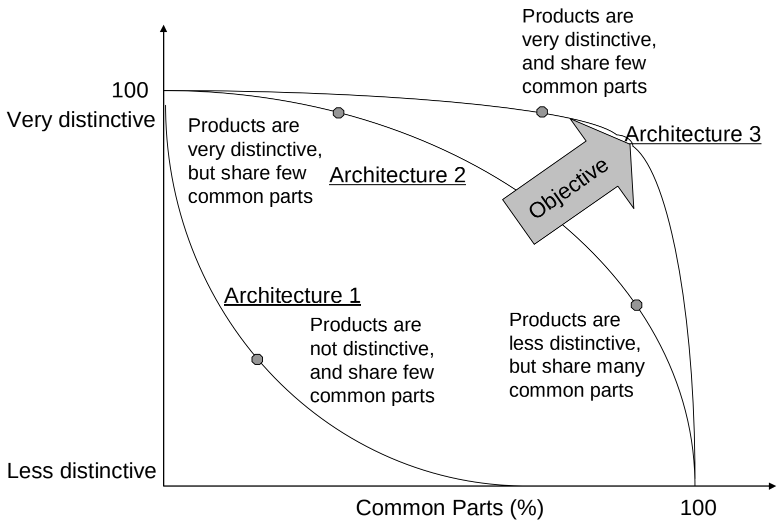

Figure 2-11 The Trade-off Distinctiveness vs. Commonality Depends on the Architecture Characteristics
(Source: Based on Robertson and Ulrich, 1998, [RU 98])

The modular methodology should consider an efficient analysis of component parameters to meet each product family requirement. The modular and platform development allows several advantages, therefore standard and differentiation components should be carefully balanced inside a modular architecture. An analysis of the previous research about this aspect is to observe the interest of maximizing the use of common components in the architecture while allowing a maximum of distinctiveness between products as shown in Figure 2-11. One of the principal interests may be to develop a family of products using a maximum number of standard components which, along with minimal architecture changes, allows developing different products. In this sense a special objective is to find “less sensible architectures” to the tendencies of the market. In other words, to find which components could be re-used between products in a way to have the flexibility to respond to future market needs.

2.6 Automotive Supply Chain Strategy

There are different strategies serving the supply chain design, considering the special characteristics of automotive industry, there are also some special strategies correspondingly.

2.6.1 SC Design Supporting BTO Automotive Production

Build-To-Order (BTO) is a production strategy that aligns to the demands of the 21st century where the industry is challenged to achieve flexibility from elongated supply chains that cross the globe and yet reply on inaccurate demand forecasts.

BTO has been described as a production strategy that fits the demands of the 21st century, fulfilling customer orders in short lead times through responsive manufacturing and information exchange [GN 05]. Yet, a considerable challenge is how to achieve flexibility from extended supply chains that retain elements of the destructive cycle of make-to-forecast [PH 04]. Today, automotive supply chains hold weeks of component stocks, driven by a combination of vehicle manufacturer forecasts and supplier concerns over “stock-out” arising from quality or delivery issues. Globalisation of the industry has meant that low value vehicle parts are now shipped from all corners of the world. For instance, to complete a door module in China, the ECUs (Electronic Control Unit) take 6 weeks to arrive from Germany, which represents a 1,5 months worth of inventory, and travels over 8000 nautical miles. One way to achieve the increased level of flexibility demanded by BTO in recent years is to build new network for the automotive production, through module sourcing, and through cluster of suppliers located in close proximity to production, which is defined as Supplier Park.

2.6.1.1 Characteristics of BTO Automotive Production System

Value creation networks in the automotive industry have grown over years and consist of a large number of related companies. As is mentioned in the previous chapters, supply chains are structured in tiers with raw material suppliers at the lowest level and first-tier component, module, and systems suppliers directly connected to the OEM. The first tier suppliers locate themselves mostly not far away from the customers because of the JIT or JIS requirements.

In order to overcome the high costs of large finished vehicle stock and establish a pure BTO system in the automotive industry, product structures, planning and execution processes and supply chain design have to be examined. Regarding supply chain design, a large number of publications have evaluated differences between BTO and BTS network structures ([BS 08]). The main results are that BTO supply chains have to be agile and responsive, with a focus on low lead times to the final customer [LCK 04]. On the contrary, BTS network structures focus on leanness and efficiency in production and component supply. Lead time and responsiveness are less important in this field as customers can be served from the finished product inventory.

Even though lead times have been identified as a critical factor in BTO networks, costs are still an important criterion. This leads to the fact that BTO automotive networks have to be lean and responsive at the same time. Apart from time and cost measures environmental impact will be a third dimension for the evaluation of automotive value creation networks. In the context of rising political and social interest in environmental issues, this dimension has to be kept in mind when alternatives for the design of automotive value creation networks are developed.

2.6.1.2 Alternative Designs for Automotive Supply Chain

According to Brauer and Seidel [BS 08], the automotive supply chain was divided into three areas: component supply, vehicle assembly and distribution. For each area, a number of alternative designs can be utilised. The alternative sourcing strategy in the supply chain design is then about to be discussed.

Regarding component supply, two alternatives are compared here. The first option is the conventional strategy of sourcing of parts, components and minor subassemblies, which results in a rather large number of suppliers directly connected to the OEM. In Figure 2-12 it becomes clear that the conventional sourcing strategy leads to relatively greater effort for the OEM, as many suppliers and parts have to be coordinated at the vehicle plant.

The second option is to decrease effort in final assembly and source large preassembled modules from a smaller number of module suppliers. This role could be taken up by former first-tier suppliers or supplier parks. The applicability of modular sourcing concepts depends on the product structure of the car that is to be built. Imperatives for modularity are agreed architecture, detailed interfaces and standardisation [BC 06].

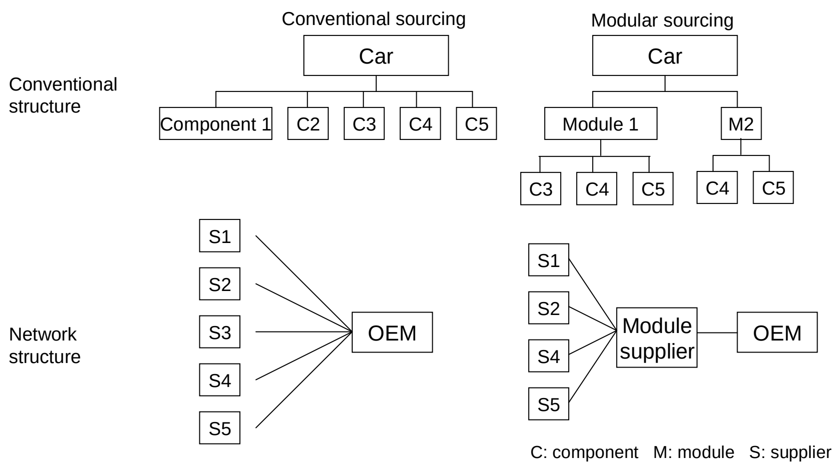

Figure 2-12 Alternative Sourcing Strategy
(Source: Based on Brauer and Seidel, 2005, [BS 05])

The possibility of independently developing, designing and producing the modules is one of the great benefits of this approach, along with the decrease in internal variety and complexity. Additional advantages are time-saving and reduced effort in final assembly, as well as the outsourcing potential that is created [GD 08].

While these facts support the application of modular sourcing in the automotive industry, the issue of whether or not the transport and handling of those modules lead to a disproportionate increase in overall logistic costs has to be examined.

2.6.1.3 Construction of a Flexible Production Network

The current trend for automotive suppliers and manufacturers to concentrate on their own brand specific or customer oriented core competences has resulted in more intensive mutual dependencies. Market participants need to reduce uncertainty and increase their use of external capability to respond to the cost of their internal flexibility. One consideration is to decide to join an alliance or a network. The advanced development level of automotive networks requires demand-orientated planning and logistic methods to design value-added networks that are flexible, adaptive and cost efficient. At the same time, the key to success is the overall view of networks as a unit of development, acquisition, production and distribution processes. The network participants have a common goal of becoming a customer-oriented, value-added chain, simultaneously optimising cost potential [MH 08].

Complexity is then increasing within supplier networks driven by increased dependability and interaction levels between companies and the variety and flexibility in production that is demanded by car buyers. Auto makers generally hold control dominance over the supplier network and must therefore be as familiar as possible with the structures and processes of the network. As the central consumers, they should be able to recognize any potential delivery bottlenecks early on and they want to be informed about current product movements using performance monitoring. The demand information for Tier 1 suppliers must be updated frequently to be able to proactively advise of problems and avoid short term delivery bottlenecks. In addition, first tier suppliers strive for optimal utilization of their critical and expensive resources in terms of supply security and cost relevance and forward the bundled information of the planning system to their network partners. The n-th tier suppliers, which are often small and mid-sized companies, must also be provided with information about partners' planning activities, and be able to optimize the utilization of their resources and ensures their ability to deliver [HMG 06].

The collaborative demand and capacity planning process integrates mid- and long-term planning and optimizes forwarding of demand forecasts. It also handles shipment planning and processing in the short term for a supplier up to receipt by the customer. Simulations are used to play through different planning scenarios, to generate demand forecasts and to determine how the network partners must respond to different, potentially critical, situations [MH08].

As a result of the global structure of automotive networks and intensified cooperation of network companies on different levels, competition in the global automotive industry will become more and more a competition among these networks. In the future, the complete performance and quality of the network will be the deciding factor in the ability of an automobile brand to compete, not only the success of an automotive group at the top of a supplier pyramid.

2.6.2 Collaborative Supply Chain

A substantial degree of uncertainty exists in most supply chains. To create and sustain competitive advantages for a supply chain, this operational uncertainty must be reduced and dealt with explicitly by all supply chain partners. Current strategic and tactical paradigms employed in supply chain decision support systems are not well suited to handling decision making in the presence of substantial amounts of uncertainty. This leads to a poor overall utilization of the company's assets in capacity and inventory while not necessarily providing a high and reliable level of customer service. Therefore, collaborative supply chain design is pursued to avoid the problems.

2.6.2.1 SC Relationship Management and Cooperation Fields

In order to remedy the underutilization of resources, five principles of supply chain management excellence are proposed for the effective design and execution of supply chain systems. And according to Muckstadt et al. [MMRC 01], the five guiding principles are:

- Know the customer;
- Construct a lean supply chain organization that eliminates waste, variability, and uncertainty;
- Build tightly coupled information infrastructures;
- Build tightly coupled business processes;
- Construct tightly coupled decision support systems.

By actively pursuing only one subset of the principles, companies will not likely succeed in achieving their expected improvements in supply chain performance. Only installing advanced information systems and streamlining business processes will not overcome a poorly designed physical operating environment, and vice versa. Business processes and rules must be tailored to the specific nature of the operating environments and to the objectives of the supply chain. Lastly, decision support systems and business processes must be capable of dealing with uncertainty explicitly. Therefore, those five principles must be applied together, so that companies can achieve their expected supply chain performance.

Similarly, to demonstrate the complex supply chain participator relationships, Figure 2 - 13 and 2-14 are developed based on the research of Croxton et al. [CGLR 01]. Supply chain internal relationships are then investigated with different process interfaces: Customer relationship management, customer service, demand management, order fulfilment, manufacturing flow management, product development and commercialization, and return management. The interfaces connect both the strategic sub-processes and operational sub-processes through different links. Below in the two figures, supplier relationships and customer relationships are illustrated.

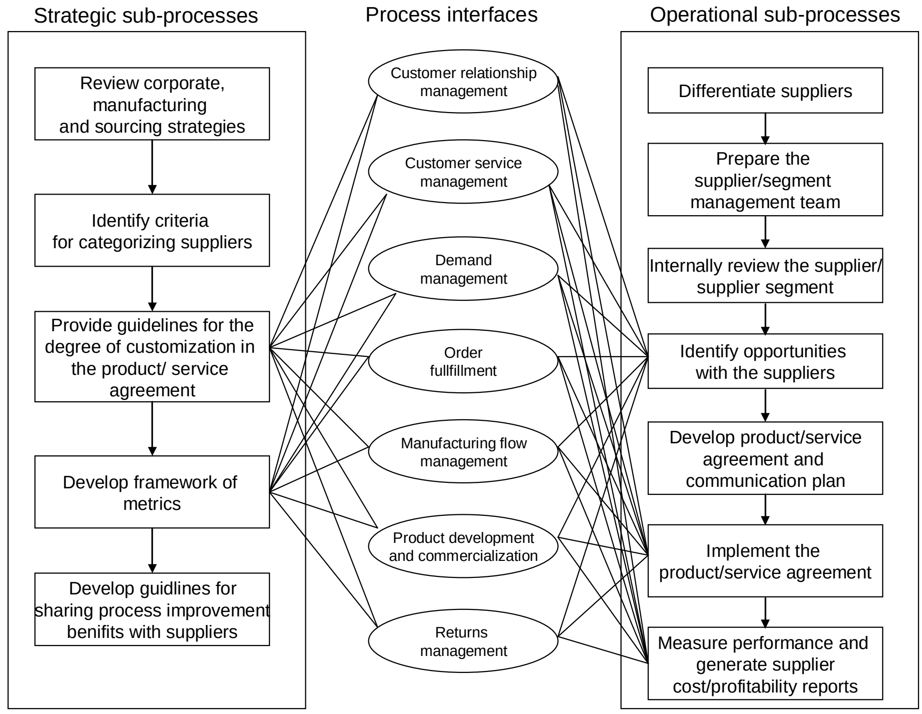

Figure 2-13 Supplier Relationship Management

Supplier Relationship Management provides the structure for how relationships with suppliers are developed and maintained. According to the explanation by Croxton et al., strategic sub-processes like product/service agreement guidelines and metrics framework are connected to operational sub-processes like opportunity identification, product/service agreement implementation and supplier performance report though the process interfaces, so as to realize the supplier relationship management.

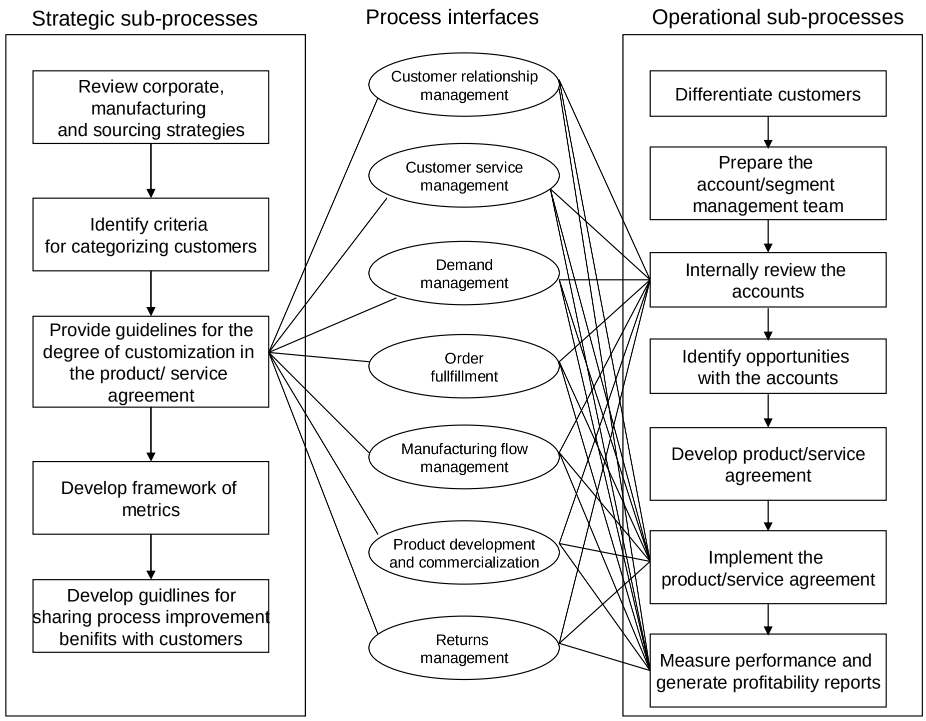

Figure 2-14 Customer Relationship Management

Customer Relationship Management provides the structure for how relationships with customers are developed and maintained. According to the explanation by Croxton et al., strategic sub-processes like providing product/service agreement guidelines is connected to operational sub-processes like internal account review, product/service agreement implementation and supplier performance report though the process interfaces, so as to realize the customer relationship management.

Based on the above illustrated complex SC participator relationships, it is essential to think of a supply chain in terms of five interconnected business systems [MMRC 01].

- *Engineering systems*: In order to create the products desired by customers, both the product, and its manufacturing and delivery process, must be designed and *engineered* properly;
- *Marketing system:* The market for products must be understood and the needs for the products must be created and nurtured. In creating needs in the mind of the customer for the firm’s products, the marketing function also creates expectations of a reliable delivery mechanism and good customer service;
- *Manufacturing systems*: Manufacturing processes must be aligned and maintained to produce products in a reliable and cost effective manner;
- *Logistics systems*: Logistics systems must be capable of providing raw materials and components to supply chain partners, and finished goods to customers, in a timely and cost effective way;
- *Management systems*: Management planning, control, and reward systems must ensure that the operations are designed and executed properly.

Most of the companies are part of more than one supply chain. This indicates that co-opetition [NB 97] appears to be a real issue, and problems such as conflicting priorities and trust which can disturb the flow of information for cooperative activities have to be addressed. From this point of view, it is very sensitive that supply chain partners deal with the topic co-operation and its effects. The problem of co-opetition is highlighted from many different aspects as a palpable issue in the automotive industry.

In theory, a supply chain should be an extremely cooperative environment since business partners share common goals and use similar performance measures. In this context, the term cooperation can, for example, describe either a single project or a long-term collaboration in the fields of R&D, e-commerce/e-business, and development of standards as well as manufacturing, inventory and the consolidation of transportation [BGM 00].

2.6.2.2 Supplier Integration

As is mentioned before, the mutual dependencies are becoming more intensive since not one company along can maintain the competences required to serve the markets. Therefore, integration of suppliers is quite a proper way out for the competitive demands.

1. Trends of Supplier Integration

Due to the increasing innovation pressure to meet different needs of customers, the automotive industry is seen to adopt the supplier involvement into the development process or outsource a higher percentage of the product development to suppliers [PHR 04]. Actually, it has been found from contemporary research in the fields of concurrent engineering and supply chain management that significant benefits can be achieved if suppliers are integrated or involved in product development processes as early as possible, which is called ESI (Early Supplier Involvement). The reason is that suppliers frequently possess the greater depth of domain expertise that can lead to improvements in product design and development. The traditional OEM-supplier relationship is characterized by a sequential, two-step interaction. In the first step, the OEM gives clear product and production requirements to the supplier. And in the second step, the supplier delivers the product or service to the OEM. Both parties tend to optimize their own positions instead of looking at the cooperative gain, and this behaviour is not based on complementary strengths. Supplier integration/involvement is a new method for integrating supplier creativity and innovativeness in the product development process. Supplier integration/involvement strives to create synergy through mutually interacting deliverables and decisions between OEM and supplier. Both sides take advantages of each other's capability to develop the product as well as to obtain feedback from the other party to improve the product development. To decrease development cycle as short as possible, the OEMs, try to focus its time and cost on core competency areas such as styling, BIW (Body in White), engine, and transmission, while shifts other portions of auxiliary system development to suppliers, which can lead to a win-win situation to both the automotive OEM and suppliers. Meanwhile, automotive suppliers are seeking new ways to strictly contain costs without sacrificing innovative, feature rich products and platforms. With the demands for faster innovation, higher quality and increased regulation, it becomes apparent that the winning automotive suppliers will be those that leverage product innovations to rapidly developing new platforms and winning new programs.

2. Different Ways of Supplier Integration

It has to be considered, that the more active the involvement of suppliers into the automotive development process chain is supposed to happen, the more complex the coordination process will be [Tab 07]. The early integration of suppliers into the automotive development process chain does not only lead to an earlier start of the supplier's usual activities but also to a shift in the focus on activities to be processed. This will cause new challenges for the collaboration between the automotive OEM and the suppliers. In the current global manufacturing context, each geographical location focusing on certain area of the automotive product lifecycle, is based on resource strengths and cost effectiveness. For example, as the auto market is expanding very fast in current China, some big automotive companies (such as VW, Ford and GM) put the final assembly in China where manpower is cost-effective, while keep the design and research residing with the automotive OEMs. To facilitate supplier integration/involvement in the automotive product development, not only technology integration but also process and organization integration are needed to be considered. The automotive OEM needs to make the evolving product definition and development process available to their suppliers, while protecting everyone's private data and private process and managing everyone's role. The collaboration between the automotive OEM and the integrated supplier can be defined at different levels according to the collaboration depth and different types of partnership.

Regarding the depth of collaboration, the supplier integration/involvement is defined in different ways. According to Tang and Qian [TQ 08], here the integration of supplier into OEM process chain can be defined in two ways (see Figure 2-15): quasi supplier integration (QSI) and full supplier integration (FSI).

The QSI means joint development efforts with supplier interaction taking place only at certain times. The development processes of both OEM and supplier remain half-connected and essential know-how and information stays with each party's operation, either side only takes advantage of the other side's input and feedback. In the FSI way, OEM and supplier contribute and share resources to a much larger extent. During the whole product development life cycle, know-how and information get exchanged freely. The boundaries between their development processes begin to diminish.

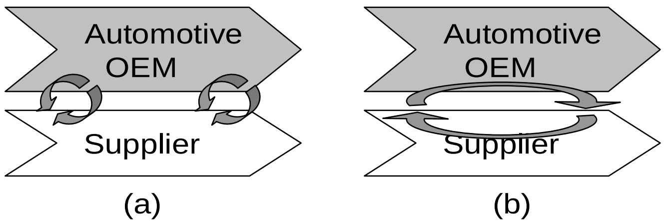

Figure 2-15 Quasi Supplier Integration (QSI) and Full Supplier Integration (FSI)

To enable the success of the supplier integration, one of the project tasks is to control the collaboration between the automotive OEM and associated suppliers, through deciding an appropriate supplier integration way at the beginning of the product development project. The decision needs to be refined so that the degree of collaboration effort by both the automotive OEM and suppliers is effectively and efficiently managed, and their needs to be a clear designation and agreement of the responsibilities for collaborative development between both sides. The preferable way of supplier integration is determined by two dimensions: the development capability comparison between automotive OEM and supplier, and the maturity degree of the product (from very old product to very new product). Based on both dimensions, how to specify the way of supplier integration is explained as follows.

Regarding the comparison of the development capability between the supplier and automotive OEM, the required development capabilities for a product development may be distributed either one-sided or split between the supplier and automotive OEM. One-sided means that the supplier has sufficient capabilities to develop a special type of product, namely, the supplier's capability is higher than the automotive OEM's. For example, the door producers as suppliers to provide automotive doors, have the greater depth of knowledge and expertise within this given product domain whereas the automotive OEM is actually a door system integrator. Thus, the door development could be shifted to suppliers. In this context, the quasi supplier integration is more preferable. Split means that both the automotive OEM and associated suppliers should team up their development capabilities to meet the needs of the product development, and the full supplier integration way is more likely to be selected.

The other factor affecting the way of supplier integration is the maturity degree of product: From very old product to very new product. The old product means that supplier or automotive OEM already has enough experiences on the current product development, and QSI is more likely to occur in this case. In contrast, the newer product development is, more cooperation between the automotive OEM and suppliers is needed in order to be successful, thus follows the FSI.

It is noted that both factors above should be considered together when deciding the way of supplier integration. And combining both factors, Figure 2-16 illustrates which type of supplier integration is more preferable in different contexts. In Figure 2-16, the space above the dash line means Quasi Supplier Integration, while the space below the dash line refers to full supplier integration. For example, for the case A, as the developed product is very old, quasi supplier integration is selected. For the case B, although the product to be developed is moderately new, FSI is selected because the capability of the associated supplier is not very strong. For the case C, quasi supplier integration is selected on account of the higher capability of supplier compared with the automotive OEM. For the case D, the full supplier integration is chosen because the product to be developed is very new, and the tight cooperation between the automotive OEM and associated suppliers is necessary.

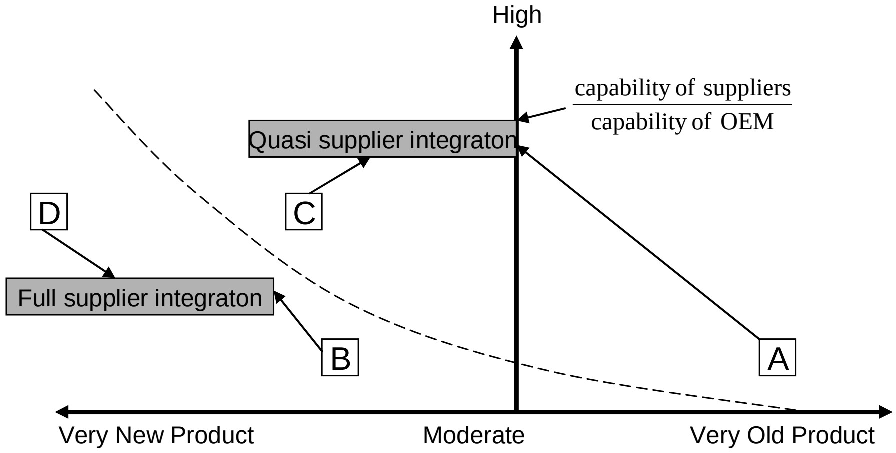

Figure 2-16 Supplier Integration Type in Different Contexts
(Source: Based on Tang and Qian, [TQ 08])

3. Theory Background for Conventional Supply Chain Evaluation

The various processes within supply chain have been investigated since years, and there has been an increasing attention placed on design, analysis and performance evaluation of supply chain. However, the supply chain is such a complex model that it is difficult to analyze the performance of a supply chain philosophically. To evaluate the control mechanism for a supply chain, one of the effective methods is to analyse the SC individually from different key aspects. There are basically 5 aspects being discussed in the subsequent model investigated in Chapter 4, namely the cost, transportation design, stability, flexibility, and reliability.

In this chapter, the theory background of the evaluation methods applied in chapter 4 is going to be discussed, based on the previous study and our own investigation. The supply chain cost calculation will be directly introduced with the model when making the evaluation analysis, so here it will be started with the transportation routing design.

3.1 Collaborative Transportation Design

Transportation is a highly important decision category in business logistics because it accounts for a large proportion of total logistics costs. There are huge amount of researches dealing with the routing plan, location choice, and so on. Here in this sub chapter, we will be focusing on a collaborative transportation design, by which the scenarios introduced might help members of a supply chain to collaborate with each other, thus reduce transportation associated factors, such as cost, transportation distance, time, and pollutant emission etc. By cooperating with other supply chain participants, certain advantages will be gained. The scenarios considered in this analysis are depicted basically in four aspects.

1. Supply Chain Wide Container Management

Different modes of transportation are used to deliver parts or finished goods to their final destination and/or to different parties involved in the delivery. In such situation one problem which might arise is the necessity to repack and/or to reload the freight when switching modes or when transferring the freight from one party to another. Repacking and reloading require material handling capacities and create extra costs and take time. These costs associated with repacking and reloading could be lowered by introducing a supply chain wide container management system which would include two aspects: First, standardizing repacking requirements throughout the system; and second, letting containers circulate throughout the system instead of repacking the cargo each time as they are transferred from one party to another.

Heskett [Hes 77] points out two possible benefits of this scenario: It is no longer necessary to provide resources for repacking and, moreover, only one type of unloading equipment is required for the entire system.

2. Selling Excess Transportation Capacity to Other Companies

One drawback of in-sourcing transportation is that optimal utilization of one's fleet cannot be guaranteed at all times. Underutilization instantly results in an undesirable rise in unit costs because overhead costs need to be covered regardless of the utilization. This problem could possibly be resolved by selling excess capacity to other companies.

By selling transportation capacity, partial truckloads can be consolidated into one truckload and thus, items can be transported at a lower unit cost because the total cost of transportation can be distributed over a large number of items. The amount saved by transporting freight in truckloads can be invested, if desired, in more expensive, but faster modes of transportation, e.g. air instead of truck. By choosing this option, participating companies do not actually cut transportation related costs; but instead, they might be able to increase their competitiveness because today companies often do not compete solely based on price or quality but also on time. Furthermore, by using faster modes of transportation, transit time and, thus, inventory in-transit is reduced which results in a reduction of inventory carrying costs. A transit time reduction also results in shorter lead time which is the time between placing an order and having the product available. This might contribute to eliminating the bullwhip effect in a supply chain.

Other advantages derived from such a cooperation are the ability to set up regular delivery schedule as well as the ability to improve customer service by faster delivery times and by an increased frequency of deliveries because the company does not have to wait until it can fill an entire truck – instead, it sells excess capacity to others. Different cooperation constellations are feasible:

- Cooperation between suppliers and manufacturers (vertical cooperation): For example, a door supplier and an auto maker;
- Cooperation between suppliers (horizontal cooperation): For example, a door supplier and a seat supplier, or even two door suppliers under some circumstances;
- Cooperation between competing manufactures (horizontal cooperation): For example, two auto makers;
- Cooperation between non-competing companies: For example, an automobile company and a computer company.

Of course, implementing this scenario should only be done if the company's competitive advantage is not based on transportation skills [GRD 98] - or the company runs the risk of loosing its competitive edge.

3. Joint Ownership of Transportation Capacity

Joint ownership of transportation capacity, e.g. a fleet of trucks, takes the idea of selling excess capacity one step further: whereas selling excess capacity is a one-time occurrence, joint ownership of transportation capacities requires a long-term relationship between participating companies. Cooperation is possible between the same parties as in the case of selling excess capacities, and the pay-offs of such cooperation are the same as well. However, just like selling excess capacity, joint ownership (and joint use) should only be an option if transportation is not the basis for the company's competitive advantage, or it runs the risk of loosing this advantage.

4. Multi-Stop Shipping (Milk Run) and Sequenced Loading

When multi-stop shipping is practiced, one truck (analogous for the other transportation modes) makes multiple stops at various suppliers on its way to the OEM and consolidates from partial loads into full loads. The combined shipments are then delivered to the OEM as one large shipment.

Transportation can be done by the OEM, by one of its suppliers, by a LSP (Logistic Service Provider) hired by the OEM, or by a LSP hired by one of the suppliers. Which solution is chosen depends on the contract between the supplier and the manufacturer because this document probably specifies who is responsible for transportation. Moreover, it depends on whether the company responsible for transportation out-sources this function or not. If the suppliers are responsible for transportation, and if one of them (or LSP acting on its behalf) carries out the multiple-stop shipping, this company needs to be reimbursed by the other suppliers because it renders a service to them. The advantage of multi-stop shipping is that congestion at the manufacturer’s receiving dock is cleared up since only one truck arrives instead of several.

Sequenced loading means that parts from several suppliers are loaded on the truck in reverse sequence to the sequence used on the assembly line. This concept differs from sequenced delivery inasmuch as when sequenced delivery is practiced, the freight loaded on the truck is from only one supplier; whereas when sequenced loading is carried out, the freight is from multiple suppliers [JHW 10]. Sequenced arrival of parts (regardless of whether the truck contains freight from one supplier or from several) is advantageous to the OEM because the OEM does not need to internally commission the parts, i.e. it is not necessary to put them in the right order anymore. Therefore, parts do not need to be stocked out but can be assembled right away and, thus, inventory levels as well as respective costs are reduced.

In addition to these two advantages - fewer arrivals at the OEM’s receiving dock and no need for internal commissioning, savings in transportation costs for the entire chain are another benefit possible gained from the implementation of this cooperation scenario. Transportation costs are possibly lower because partial loads are consolidated into full loads and the total amount of kilometres driven by all supply chain members is lower: Instead of everyone transporting their parts individually to OEM, one truck picks up and delivers all freight at once. However, the implementation of this scenario is only reasonable if the suppliers are located relatively close to each other; otherwise, transportation costs will actually increase instead of decrease.

3.2 Automotive Supply Chain Stability – Bullwhip Effect Analysis

Whether a supply chain is stable or not, directly influences the service level and customer satisfaction. There are a lot of relative research works done that deal with the supply chain stability, among which the bullwhip effect is considered to be the key factor. Therefore in this work, when I talk about the stability of the supply chain, I am dealing actually the bullwhip effect of it. In the following 2 sections I’ll be introducing the bullwhip effect definition and calculation.

3.2.1 Bullwhip Effect Definition

A common problem to the supply chain management is the so-called Bullwhip Effect. According to Lee et al. [LPW 97], this effect occurs when there is a lack of coordination among the elements of the supply chain at the moment when there is a variation in the quantity demanded by the final client, with the reactions of suppliers tending to be amplified at each passage upstream through the chain. All of them react increasing or diminishing the orders differently from what is really necessary, seeking to protect themselves. For long chains, the results may be extremely negative, as distortions, which accumulate in the client to supplier direction, amplify in a non-linear way. This effect is caused by the lack of an adequate and coherent supply chain management as a whole. Each link in a traditional arrangement, looks only to the demand generated by it’s immediate client and seeks to maximize the financial performance, even though for such, the performance of other links is strongly deteriorated, which will affect the performance of the chain to the eyes of the only link that injects money and sustains the network: the final customer.

According to Chopra and Meindl (2001, cited by Bayraktar et al. [BKGST 08]), the lack of coordination felt by the bullwhip effect is caused by two reasons: The different stages of the supply chain have conflicting objectives, and the information sent among the different stages suffers delays and distortions.

Collaborative management envisages the reduction of negative consequences of the bullwhip effect or the lack of coordination in supply chains. It can be said that the main objective of collaborative management is to obtain, by means of shared planning, a greater precision in sales forecasts and replenishment for all in the chain (not for one or two chain members). As a result, it is possible to decrease the inventory along the supply chain and obtain better service levels that in turn tend to result in sales increases and cost reductions.

3.2.2 Bullwhip Effect Calculation

In the last couple of decades, the bullwhip effect has increasingly become popular for SCM researchers and practitioners as it negatively influences cost, inventory, reliability and other important business processes. In the previous section the existence of the phenomenon is demonstrated and its possible causes are identified. In this section, a quantified model of supply chain Bullwhip Effect is going to be discussed.

Wangphanich et al. [WKK 10] divide variables influencing the bullwhip effect in three groups including:

- Supply chain configuration (such as two-product and three-stage supply chain);
- Supply chain contributions (demand processing technique, ordering policy or production policy in regular situations or when a supplier have a promotion or shortage gaming);
- Supply chain performances (the number of defect and ordering lead time).

The main output of the proposed model is a bullwhip effect which can be measured in two dimensions: Total Bullwhip Effect (TBWE) and Partial Bullwhip Effect (PBWE), as shown in equation 3.1 and 3.2 respectively.

$$\mathrm{TBWE}_k = \frac{\mathrm{Var}(q_k)/\mathrm{Mean}(q_k)}{\mathrm{Var}(\sum_{i=1}^{n} C_i)/\mathrm{Mean}(\sum_{i=1}^{n} C_i)} \tag{3.1}$$

$$\mathrm{PBWE}_k = \frac{\mathrm{Var}(q_k)/\mathrm{Mean}(q_k)}{\mathrm{Var}(D_k)/\mathrm{Mean}(\sum_{i=1}^{n} D_k)} \tag{3.2}$$

where

$q_k =$ Order placed at SC unit k

$C_i =$ Customer demand i

$k =$ SC unit in a supply chain ($k = 1,2,...,n$)

$i =$ SC Number of end customer in the same chain

$D_k =$ Demand from downstream partner at SC unit k

Both equations quantify the bullwhip effect in term of a ratio of order variance. The first equation aims to quantify the bullwhip effect in term of variation ratio of end customer demand (C_i) while the second equation quantify the bullwhip effect in term of variation ratio of local demand (D_k). However, the average of inventory level and the average number of shortage can also be measured form the model.

This model is going to be used in Chapter 4 for calculating the bullwhip effect of our supply chain scenario cases.

3.3 Automotive Supply Chain Flexibility Assessment

Flexibility has been considered as a major determinant of competitiveness in an increasingly intense competition in the marketplace. Effective control of supply chain flexibility can improve the supply chain and business performance. Thus, it is necessary to assess supply chain flexibility precisely and systematically. This sub chapter gives a considerable comprehensive analysis of automotive supply chain flexibility and identifies 5 elements of supply chain flexibility. Next chapter in the conventional evaluation model, the supply chain flexibility is about to be evaluated based on these 5 elements with the evaluation indices.

3.3.1 Definition of Supply Chain Flexibility

According to the characteristics of supply chain, three natures of flexibility in supply chain are identified:

- Robustness;
- Self-adaptability;
- Network alignment and re-configuration.

The definition of supply chain flexibility by Li and Qi [LQ 08] is “the robust ability of supply chain network to restructure their operations, align their strategies, and share the responsibility to respond rapidly to the uncertainty of internal and external environment, to produce a variety of products in the quantities, costs, and qualities that customers expect, while still maintaining high performance”.

In order to provide a comprehensive assessment of supply chain flexibility, a framework of supply chain flexibility is presented below in the figure.

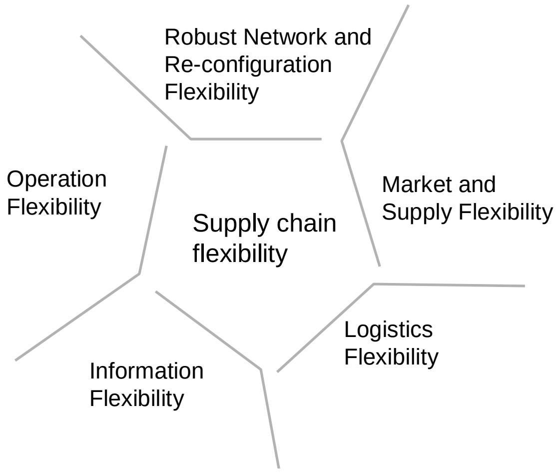

Figure 3-1 A Framework for Assessing Supply Chain Flexibility

And the five components of supply chain flexibility are identified below in Table 3-1, which are respectively the flexibility from operation, logistics, information, robust and reconfiguration, and market and supply aspects.

Table 3-1 Supply Chain Flexibility Taxonomy Definitions

Flexibility Type	**Definition**
Operation flexibility	The ability of operation, including the capability to change products, equipment, people and processes within the operations function
Logistics flexibility	The ability of the integrated logistic system to distribute and deliver the product economically
Information flexibility	The ability to align information system architectures, and systems with the changing information needs of the organization as it responds to changing customer demand
Robust network and re-configuration flexibility	The ability to align entities and the ease of changing supply chain partners with minimum damage alteration
Market and supply flexibility	The ability to meet the changing needs of customers or downstream firms requires changing the supply of product

This framework focuses on the essential characteristics of supply chain and the multi-dimensional flexibility, including the intra-company abilities and external relationships to provide a comprehensive assessment of supply chain flexibility.

3.3.2 Detailed Explanation of the SC Flexibility Elements

Based on the definition of Li and Qi [LQ 07], further in this section, the supply chain flexibility elements will be explained in detail:

1. Operation Flexibility

Operation flexibility focuses on intra-company abilities of the strategic business unit within a company, including the flexibility of manufacture and resources usage. Manufacturing flexibility represents organizational abilities to produce a variety of products by the use of advanced technology and automatic capability, concretely consisting of product flexibility and technology flexibility. Resource flexibility refers to the ability to dynamically reallocate units of resource in response to shifting bottlenecks, concretely consisting of labour flexibility, financial flexibility and machine flexibility. It is comprehensive consideration to use three different aspects to measure resource flexibility.

2. Logistics Flexibility

Logistics flexibility refers to the ability to cost effectively stock and deliver product in response to changes in customer demand, including the ability to adjust to global requirements, serve distinct customer shipping requirements, and vary warehouse space. In general, it can be summarized as inventory flexibility and delivery flexibility. Inventory flexibility focuses on the ability to vary warehouse space and stock strategy, which can be assessed by range of optional stock strategy and turnover rate of inventory. Delivery flexibility implies the ability of transportation and distribution across the chain. It is mainly evaluated by range of optional distribution channels and ability of adjusting specific distribution.

3. Information Flexibility

Information flexibility focuses on the ability to synchronize information systems with supply chain partners, share information across internal business processes and pass information along the chain. Effective information communicating mechanism can improve transparency, avoid lost sales, speed up payment cycles, create trust, avoid over-production and reduce inventories. The information systems and technologies must be reconfigurable, reusable and easily extendible, which allows organizations to be more effectively coordinated at the SC-level. There are three items that affect information sharing degree, which are: information transmission speed, information transmission quality and information sharing depth.

4. Robust Network and Re-configuration Flexibility

Robust network and re-configuration flexibility focuses on the robustness of existing relationships in response to changes in the business environment and the ability to re-configure the supply chain, concretely consisting of relationship flexibility and cultural flexibility. Relationship flexibility refers to the ease of changing supply chain partners in response to changes in the business environment. Effective cultural flexibility can syncretise company’s culture at each node of the supply chain, which can improve cooperation and communication across the chain.

5. Market and Supply Flexibility

Market and supply flexibility focuses on the ability of market forecast and the ability to change the supply of product, including mix, volume, product variations, and new products in order to meet the changing needs of customers or downstream firm, concretely consisting of market flexibility and supply flexibility. Market flexibility is the responsiveness to changing market conditions and customer needs and wants. This flexibility can be assessed by the ability of response and introducing new product. Supply flexibility refers to the ability of changing supply plan in response to the changes in customers and downstream firm, which can be assessed by consignment flexibility, order fulfilment rate and on-time delivery rate.

The above mentioned elements will be used as evaluation indices for the latter supply chain flexibility evaluation.

3.4 Automotive Supply Chain Reliability – Risk Management

In order to obtain high efficiency and effectiveness in supply chain management, supply chain must have a high reliability as guarantee. Reliability has now become an important performance measure for evaluation supply chain safety, especially when considering changes in supply chain operation conditions [LWL 08]. Based on the theory of systems reliable engineering, the concept of the supply chain reliability and reliability of the supply chain members will be discussed based on the risks analysis and risk management.

3.4.1 Supply Chain Reliability

With the development of information technology and economic globalization, the enterprises face with a more complex and ever-changing market environment and increasingly fierce competition. The focus of the competition among single enterprise products, functions and distribution channels have been extended to supply chain competition. The supply chain is the integration of logistics, information flow circuit and capital flow. In such circumstances, in order to make the supply chain management of high efficiency and effectiveness, the supply chain must have high reliability as a guarantee, thus enhancing the overall competitiveness of supply chain.

In the reliability engineering practice, people have wide variety of methods to understand it. Such as the American National Standards Commission, the United States Advisory gives the definition to the reliability as follows: Reliability refers to products within the required timeframe and the conditions, to complete the trouble-free function of probability. China National Bureau of Standards-related files give also the definition: Reliability refers to products within the time prescribed in the regulations and conditions, the ability to complete the function [CL 08].

Based on system reliability engineering theory, it is concluded that the supply chain reliability is the measurement to the work ability without fault in supply chain system. Specific performance in the outside interference, the supply chain at a stipulated time and conditions, the demand for the completion of order’s functional capacity, the completion of this function, and the probability of reliability are all important aspects to the measurements. Similarly we have members of the supply chain to define the reliability of enterprise: In the supply chain management of the environment, members of the supply chain enterprises in a certain period of time to the normal operation of the capacity.

In the SC reliability study, the main concerns are overall measurement and evaluation of the supply chain reliability [Tan 06]. However, Supply chain is a complex network structure with various enterprises as nodes which compose network. Since the relationship between each node enterprise is cooperation, each node has some uncertainties and risks which will affect the reliability of whole supply chain. So reliability of the supply chain member enterprises is the microeconomic foundation of overall reliability of the supply chain. The impact of its change on the overall reliability of the supply chain is relatively large.

In the following sections, based on the qualitative and quantitative risk analysis, overall risks and structural risks, how to minimize the risks and increase the reliability will be discussed.

3.4.2 Risk Analysis in Automotive Industry

A number of trends have made the automotive supply chain more vulnerable. Each SC risk - to forecasts, information systems, intellectual property, procurement, inventory and capacity - has its own drivers and effective mitigation strategies, and companies can then select the best mitigation strategy: Holding "reserves", pooling inventory, using redundant suppliers, balancing capacity and inventory, implementing robust backup and recovery systems, adjusting pricing and incentives, bringing or keeping production in-house, and using continuous replenishment programs, collaborative planning, forecasting and replenishment and other supply chain initiatives. Despite increasing awareness among practitioners, the concepts of supply chain vulnerability and its managerial counterpart supply chain risk management still need to be improved.

This section describes the possible risks in the entire automotive industry, from both the general point of view and the automotive companies’ point of view. According to the CSM Auto research, Table 3-2 demonstrates the low, medium and high degree of risks both in short term and long term.

Table 3-2 Risks of Automotive Industry from Long Term and Short Term Point of View

	Low	Medium	High
Short - Term	• Low risk of SOP slip or significant advance • On-time or near expected launch • Below-average monthly production variation • Annual volumes meet or slightly exceed OEM CPV expectation in first 24 months • Strong performance of prior vehicle and in established segment	• Risk of a 3 month slip within 18 months of SOP • Launch curve could be slowed by production, supplier or development issues • Monthly production variation is slightly above or below market average • Annual volumes meet or approach expectation but degrade 5-15% over vehicle life cycle • Average performance of prior vehicle and is in very competitive segment	• Risk of a 3 month or more slip within 18 months of SOP • Launch may slip and expected curve may not be supported • Above average monthly production variation • Short-term volume degradation is expected due to inventory • Weak performance (high inventory) of prior vehicle and in a new or niche segment
Long - Term	• No or low volume degradation over the vehicle life cycle • Cadence is well defined and the life cycle is ‘lively’ • Vehicle is a segment leader in a stable segment • Low or little affect of new segment entrants on vehicle volume • Vehicle volume is diversified over many markets	• Volume degrades by 10-20% over the vehicle life cycle • Cadence may slip from the expected period, usually extended to cover fixed costs due to low vehicle volumes • Vehicle is strong but not a segment leader and is somewhat negatively affected by new competitors or revisions in a leading vehicle • Exports are possible but are a small percentage of total	• Volume degrades by more than 20% over a 5-year cycle • Cadence is almost sure to be breached due to funding priorities • Body style is new to the market, unproven and thus risky • Vehicle is seen as niche in volume and execution and does not have an established track record • Little chance of vehicle export

(Source: Based on CSM Auto, 2008)

But to the manufactures, both OEMs and upstream suppliers, there are more possible risks within the supply chain scope. In most companies, a method named FMEA (Failure Mode Effective Analysis) is used in the TQM (Total Quality Management) and the entire supply chain management. Here the potential failure modes are summarized as following in Table 3-3 for the automotive manufactures.

Table 3-3 Potential Failure Modes in Automotive Companies

Potential failure event	**Supply-base condition influencing the likelihood of the failure event**	**Detailed description**
Delivery Failure: A supplier fails to make a delivery as promised	Capacity	Supplier is near or at full capacity
	Material availability	Supplier's sources for raw material unreliable
	Cycle time	Supplier has unreliable cycle time
	Natural disaster	Supplier is located in an area prone to natural/ political disruptions
	Logistics	The logistics infrastructure from supplier is unreliable
Cost Failure: The price of the supplied product becomes above expectations	Cost management	Supplier has poor cost management skills
	Financial	Supplier is in poor financial health
	Market strength	Supplier has power in the marketplace to dictate pricing or is powerless to manage prices
	Currency	Supplier's common currency is volatile
Quality Failure: The supplier provides unacceptable product that is now the responsibility of the firm	Quality system	Supplier's quality control methods are substandard
	Legal standards	Supplier is unaware/ unconcerned with legal/ environmental standards
Flexibility Failure: The supplier is unable/ refuses to make design or volume changes	R&D	Supplier has poor product develop methods
	Flexibility	Supplier has processes which don't allow significant changes in volume
Confidence Failure: A supplier drops in standing as a reliable, strategic supplier	Information	Supplier's information systems are outdated or unreliable
	Management	Supplier lacks clear management vision or experience
	Market characteristics	The market in which the supplier operates is volatile
	Product type	The supplier may not be able to handle the complexity or sensitivity of this product
	Relationship	The relations with this supplier are strained or difficult to manage (communication issues)

Since there are risks, correspondingly there should be the countermeasures for risk management, in the following table, the risks are managed in five aspects: supply chain design, sourcing strategy, supply and sales contract portfolio design, strategic acquisitions and outsourcing strategic partnership and alliances.

Table 3-4 Approaches for Strategic Risk Management

	Leverage	**Diversification**	**Hedging**	**Restructuring**
Supply chain design	• Modify using changes in production technology • Modify by outsourcing production	• Geographical diversification to reduce hazard risk • Political unit diversification to reduce political risk and tax risk • Geographical diversification to reduce labour price risk	• Natural hedging of foreign exchange risk • Matching inbound and outbound capacities • Matching supply chain capacity to marketing capability • Matching supply chain flexibility to customer demand volatility	• Supply chain and resigning and restructuring • Alternative supply chain interactions • Supply chain simplification • Create growth and flexibility options
Strategic sourcing strategy	• Increase by selecting vendors requiring capacity commitments • Reduce by consolidating spending to improve flexibility terms	• Vendor diversification to reduce supply and price risk • Vendor diversification to reduce hazard risk	• Hedge demand volatility with supply-demand matching • Natural hedging of foreign exchange risk	• Reduce number of suppliers • Increase information sharing with core suppliers • Improve coordination and synchronization • Increase flexibility with spot market buys • Create growth and flexibility options
Supply and sales contract portfolio design	• Modify by changing contract terms • Modify by making changes in portfolio composition • Modify by considering relationship with strategic sourcing	• Manage portfolio of flexibility options • Manage portfolio of embedded options • Diversify to improve portfolio risk-return trade-off	• Hedge demand volatility with supply flexibility terms • Hedge price and foreign exchange risk with embedded options • Hedge demand volatility with product choices • Parts commonality to hedge supply risk	• Improve information sharing with contact incentives • Create learning, growth and flexibility options
Strategic acquisitions	• Modify by acquiring new production facilities • Modify by acquiring new production technology	• Customer and market segment diversification to reduce demand risk • Geographical diversification to reduce demand risk • Technological diversification to reduce product risk	• Hedge demand volatility with complementary product lines • Hedge supply risk with complementary suppliers	• Create learning, growth and flexibility options
Outsourcing strategic partnership and	• Modify by investing in new joint production facilities • Modify by obtaining access to new production technology	• Customer and market segment diversification to reduce demand risk • Geographical diversification to reduce demand risk • Technological diversification to reduce product risk	• Hedge technology risk by placing multiple bets • Hedge demand volatility with new products • Hedge demand volatility by targeting new geographies and market segments	• Create learning, growth and flexibility options

(Source: Based on Lee [Lee 08], Juttner [Jut 04] and Fu et al. [FZHL 05])

3.4.3 Structural Risk Analysis and Evaluation

We can not enumerate all the risks which supply chain may encounter. So the systematic method to control supply chain risk must be used. Understanding risk assessment processes within supply chain networks and the risk implications of different network structures, and developing more practical approaches to guide the risk assessment process in supply chain networks, are both critical aspects in supply chain risk management.

So in this section the effect of supply chain structure to supply chain risk transfer and risk control is described. According to the characteristics of supply chain structure, the risk transfer processes can be sorted into series process, parallel process, distribution process, assembly process, and switch process. The formulas of risk value developed by Zhang et al. [ZWHL 05] are used later on for risk/ reliability evaluation of my supply models.

The systematic framework of supply chain risk management include following steps: risk identification, estimation, assessment, management planning, controlling and monitoring. If all the single risk probabilities are known by risk estimation, it is possible to assess the whole risk value for the total supply chain. The whole supply chain risk is partially determined by supply structure.

3.4.3.1 Supply Chain Risk and Supply Structure Analysis

Supply chain risk is the possibility of deviation of supply chain from management objectives. According to supply chain system constitution, supply chain risk can be classified as the risk by supply chain entities (such as supplier, manufacturer, distributor, retailer, customer, etc), the risk by supply chain structure, and the risk by external environment. Risk sources by supply chain entity lie within the boundaries of the supply chain parties and range from labour (e.g. strikes) or production uncertainties (e.g. machine failure) to IT-system uncertainties. External environmental risk sources comprise any uncertainties arising from the supply chain environment interaction. These may be the result of accidents (e.g. fire), socio-political actions (e.g. fuel protests or terrorist attacks) or acts of nature (e.g. extreme weather or earthquakes). Structure-related risk sources arise from interactions between organizations within the supply chain. Whatever damage is caused by suboptimal interaction between the organizations along the chain is attributable to structure related risk sources.

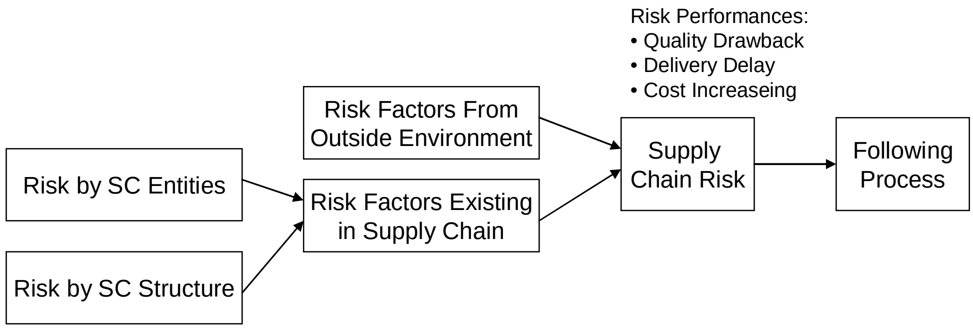

Figure 3-2 Forming Processes of Supply Chain Risks

Forming process of supply chain risk is shown as Figure 3-2. The supply chain is affected by the unfavourable factors from both the outside environment and the entities in the chain to form supply chain risk. Supply risks that occur to upstream partner operations will almost always ripple through each firm's supply chain and cause it to face risk issues as well, that is the effects of risk transfer downstream following the supply chain. The network structure of a supply chain influences the supply chain effects of risk events, and it can either absorb or amplify the impact of risks from environment or supply chain entities.

Next sub section the effects of supply chain structure to supply chain risk transfer processes and the whole risk value of the total supply chain will be explored.

3.4.3.2 Supply Chain Risk Transfer Process

According to the characteristics of supply chain structure and the related logistics processes, the risk transfer processes can be sorted into series process, parallel process, distribution process, assembly process, and switch process.

Given P_1, P_2, , P_n. are the risk probabilities of n segments of a supply chain, and assume every segment risk is independent to each other. P is the total risk probability of risk transfer process that should be calculated.

1. Series Process

For all supply chains, from source, to manufacture and delivery, the risk transfer process is a series process. A transportation system with many stages (such as highway, railway, air-freight, and sea-freight) is a series process too. The locations of risk events on supply chain are shown as Figure 3-3. According to the characteristic of series system, the total risk probability P can be given by following equation:

$$P = 1 - \prod_{i=1}^{n} (1 - P_i) \tag{3.3}$$

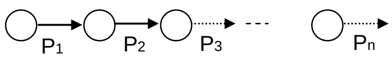

Figure 3-3 Series Process

For a series process, it means more segments, higher risk probability and lower reliability. The risk emerges in any one segment will be the holistic risk. In order to improve the reliability of the system and mitigate risks, unnecessary series segments should be removed.

2. Parallel Process

An enterprise has n suppliers for one type of raw material. If one of the n suppliers can not supply normally, other suppliers can meet the demand, and any one of the suppliers has the capacity to supply all the sourcing products, the supply risk transfer process in supply chain is a typical parallel process (shown as Figure 3-4). Only when n suppliers all cannot supply products normally, supply risk may happen. The total risk of parallel process is given as follows:

$$P = \prod_{i=1}^{n} P_i \tag{3.4}$$

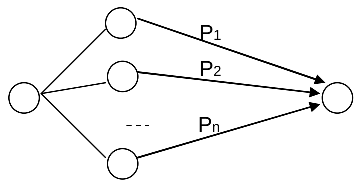

Figure 3-4 Parallel Process

Parallel process has higher reliability. So multi-suppliers strategy is the ordinary way to improve supply reliability and mitigate risk. But too many parallel segments will make the supply chain structure complicated. It means more costs and more management difficulty for complicated supply chain.

If any one of the suppliers doesn’t have the capacity to supply all the sourcing products, at least m suppliers are needed to supply all the products sourced. If more than $n-m$ suppliers lose their supply capability totally, the supply risk emerges, and it will influence the normal supply. In this case the risk transfer process in supply chain is called vote process.

3. Distribution Process

A manufacturer provides products to *n* warehouses. If the manufacturer is interrupted by accidents and is unable to provide products according to the planned quantity, it can not meet all the demands of every warehouse, so it is possible for n warehouses to be out of stock owing to the supply shortage. The percentage of delivered products to original planned products for every warehouse are d_1, d_2, -, d_n. The shortage percentage for warehouse i is as follows:

$$A_i = 1 - d_i \tag{3.5}$$

There are two special cases. $d_i = 0$, it means stopping the supply to warehouse i; $d_i = 1$, it means that the demand of warehouse i is fully met although there is capacity shortage in total. Important customers are always provided with higher priority, so d, may be different for different downstream partners. If the ratio of qualified products from the supplier is q_i, the ratio of qualified products in every warehouse is q_i, the quality risk is $1-q_j$, and the risk transfer process is also distribution process (for example, see Figure 3-5). There are different calculating methods for different kinds of risks and different performance metrics.

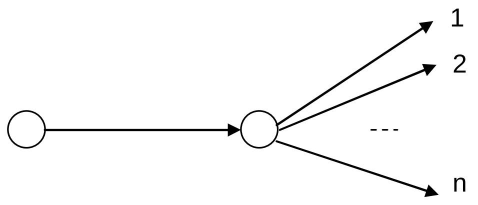

Figure 3-5 Distribution Process

4. Assembly Process

An enterprise has many suppliers providing one kind of material, its total supply risk is the assembly of all supply risks from suppliers, and in this case the risk transfer process is an assembly process shown in Figure 3-6. The total risk of assembly process is related to the supply risk of every supplier and the quantity of the material supplied.

Assume the percentages of material quantity procured from every supplier to the total sourcing quantity are s_1, s_2, ..., s_n, and

$$\sum s_i = 1 \tag{3.6}$$

The total supply risk is as follows:

$$P = \sum_{i=1}^{n} P_i s_i \tag{3.7}$$

According to this, the reliable suppliers should get more orders.

When every supplier's capacity has enough flexibility, any supplier can provide the buyer all the products, if some suppliers are affected by unfavourable accidents therefore they cannot provide material normally, other suppliers would complete all supply task. In this case, the supply risk transfer process becomes to parallel process.

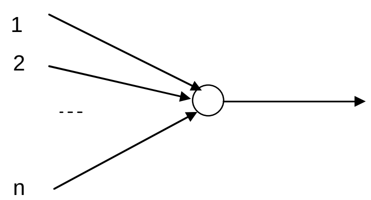

Figure 3-6 Assembly Process

5. Switch process

Contingency plan and reserved resources are the common tactics to control supply chain risk. Once any segment of the supply chain is in bad condition and may not achieve the planned objectives, managers can execute the contingency plan and put the reserved resources into use immediately. When contingency channels exist in supply chain, supply chain risk transfer process is called switch process shown in the following figure.

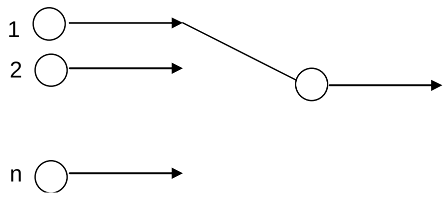

Figure 3-7 Switch Process

There are n usable channels as shown in Figure 3-7. Channel 1 is the necessary channel, channel 2 to channel n are reserved channels. Given the reliabilities of every channel are q_1, q_2, …, q_n and failure risks for every channel are $p_1, p_2, \ldots, p_n$, and

$$p_i = 1 - q_i \tag{3.8}$$

The total reliability when only channel 1 is utilized is as follows:

$$R_1 = q_1 \tag{3.9}$$

If channel 1 is failed and channel 2 is utilized, the total system reliability is as follows:

$$R_2 = q_1 + (1 - q_1)q_2 = q_1 + p_1 q_2 \tag{3.10}$$

The rest may be deduced by analogue, the total system reliability that all channel n are used is given by the following:

$$R_n = q_1 + \sum_{i=2}^{n} (q_i \prod_{j=1}^{i-1} P_j) \tag{3.11}$$

Total risk probability by system failure is:

$$P = 1 - R_n \tag{3.12}$$

What we can find from the analysis is that existing reserved channels can reduce the supply chain risk and increase the reliability effectively. But reserved channels may lead to increasing costs. It is a trade off to balance supply chain risk and costs. In practice *n* is no more than 4 [ZH 06].

All in all, the holistic supply chain risk transfer process is the mixture of the processes discussed above, and we will see the application in next chapter the evaluation model.

4. Supply Chain Evaluation with Conventional Model

Supply chain management presents significant opportunities for improving profit margins and reducing cost. It encompasses functional and geographical integration as well as integration of tactical and operational decisions. The integration aspects involve purchasing, manufacturing, material flow and sales distribution within the company and across the supply chain. The design of a supply chain for a typical product with various upstream suppliers and downstream customers is extremely important for the automotive companies. The cost and strategic considerations play an important role in selecting among various options. Suppliers differ in their production cost, inventory holding capacity and cost, first-time quality levels, overall reliability, and the ability to deliver on time. In addition, multiple options exist for shipping and transportation with different associated cost.

An important outcome of the increased quest for competitiveness is globalization with the international distribution of production facilities as well as localization with sourcing of material and labour locally. However, these decisions must be made with full consideration of the total supply chain structure in view of the increasing need for efficient supply and cost reduction strategies.

A framework to design a supply chain for products with multiple customers, multiple levels with multiple suppliers at each level, and multiple transportation options, while considering the suppliers' quality and on time delivery risk to meet the customer demands as well as minimize the total supply chain cost is developed in this chapter, based on the case of a Tier 1 supplier which produces door modules. The selection of suppliers, determination of production quantities, inventory locations and size, selection of transportation modes and transported quantities are investigated and evaluated. The example of automotive door module supply chain design is used to illustrate the effects of various factors. The 3 supply chain scenarios applied in the evolution process during the product and production localization will be evaluated with a conventional model from all aspects like cost, transportation, stability, flexibility and reliability etc. Another integrated evaluation model using fuzzy control method will be discussed in next chapter with the case of entire vehicle door supply chain design.

4.1 Case Description

A "vehicle door" is a partition, typically hinged, but also frequently attached by other mechanisms such as tracks, in front of an opening which is used for entering and exiting a vehicle. A vehicle door can be opened to provide access to the opening, or closed to secure it. Like shown in Figure 4-1, a door module normally refers to a functional combination, which consists of a carrier plate (steel carrier or plastic carrier), stamping parts (arms and rails), electronic control unit (ECU), motor, wire harness, and loudspeaker etc.

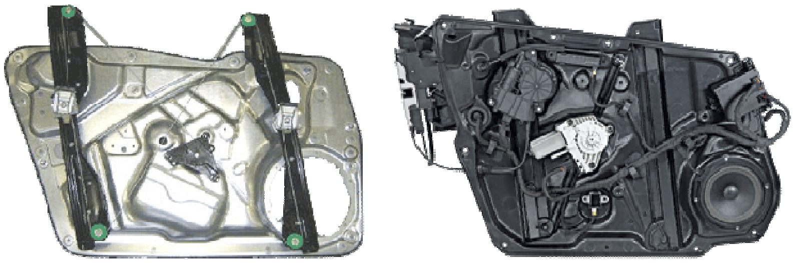

Figure 4-1 Door Module with Steel Carrier and Plastic Carrier

Abstracted from the above description and making it clearer for the investigation afterwards, I graphically illustrate the door module composition in Figure 4-2.

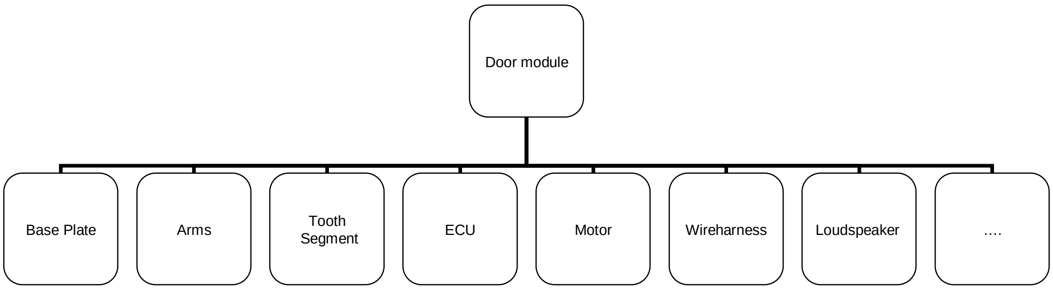

Figure 4-2 Simplified Door Module Composition Model

In the reference case for our investigation, the door module is originally assembled in Germany, with the different parts and components coming from all around the world. Base plates come from Germany and Brazil, ECU and Motor come from south Germany, stamping parts are produced locally, and small parts like nuts, grease and gummy rings are bought in from Poland, Austria and Korea respectively, while the wire harnesses are imported from Taiwan China and loudspeaker from mainland China. The finished products with different varieties and finishing degrees are then delivered to the automotive OEMs directly or to their pre- assemblers located in their supplier parks. So as illustrated in the following Figure 4-3, the global sourcing and global supply actually knit a big and complicated supply network.

Figure 4-3 Simplified Original Supply Network Illustration

And theoretically a typical multi-stage supply chain can be illustrated as following in the Figure 4-4, based on this principle and the case previously described, I will be discussing different scenarios combining the theoretical model and real door module case.

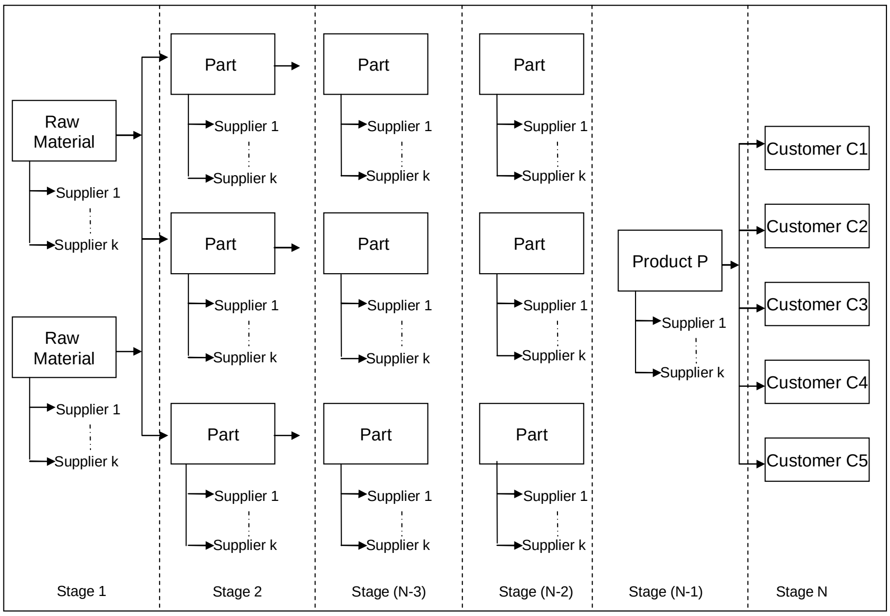

Figure 4-4 Multi-stage Supply Chain Illustration

4.2 Door Module Supply Chain Design Scenarios

The case we are dealing with is a localization program. The door modules are originally produced in Germany and supplied to different customers with different varieties. But basically, the parts assembled in Tier 1 come from a certain fixed supplier system. The final products with different finishing degree are supplied to different OEMs according to their individual requirements. Since the same platforms are introduced in China, the door modules are then also required to be supplied to China. Whether to produce them in Germany and supply them internationally to china, or to assemble the modules locally in China but with the existing international suppliers, or even produce the door modules completely locally in China involving local new suppliers, is a decision to be made by the supply chain designers. 3 scenarios based on the above thinking are developed and applied in the next sections, and these scenarios will be analyzed and evaluated especially from the SC point of view to get a summary: which one is the best solution.

4.2.1 Door Module SC Scenario I: Global Sourcing, Global Supply

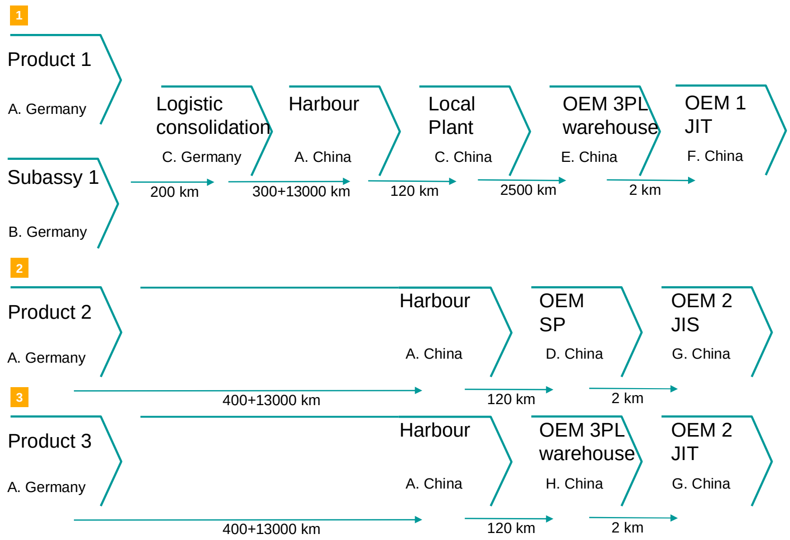

Figure 4-5 Door Module Supply Chain Scenario I

In this case the door modules are simply supplied from Germany to the China customers as illustrated in Figure 4-5. And the situation is considered with 3 product varieties.

Product 1 with a sub assembly 1 is transported to a logistic consolidation about 200 km far away from the original plant in Germany. All together the product 1 and assembly 1 are shipped to China, and after custom clearance to the local Chinese plant C. Product 1 is then further assembled in plant C, and afterwards delivered to customer's 3PL warehouse, waiting to be supplied according to the OEM 1's production plan just-in-time.

Product 2 is directly shipped out from the German plant, after custom clearance in the Chinese harbour, the products are firstly transported to customer supplier park for a further treatment, and then just-in-sequence supplied to the customer 2.

For product 3 is relative simple, the products are shipped out directly to the customer warehouse after the normal transport and custom procedure, and the parts are supplied just-in-time to customer 2.

4.2.2 Door Module SC Scenario II: Global Sourcing, Local Supply

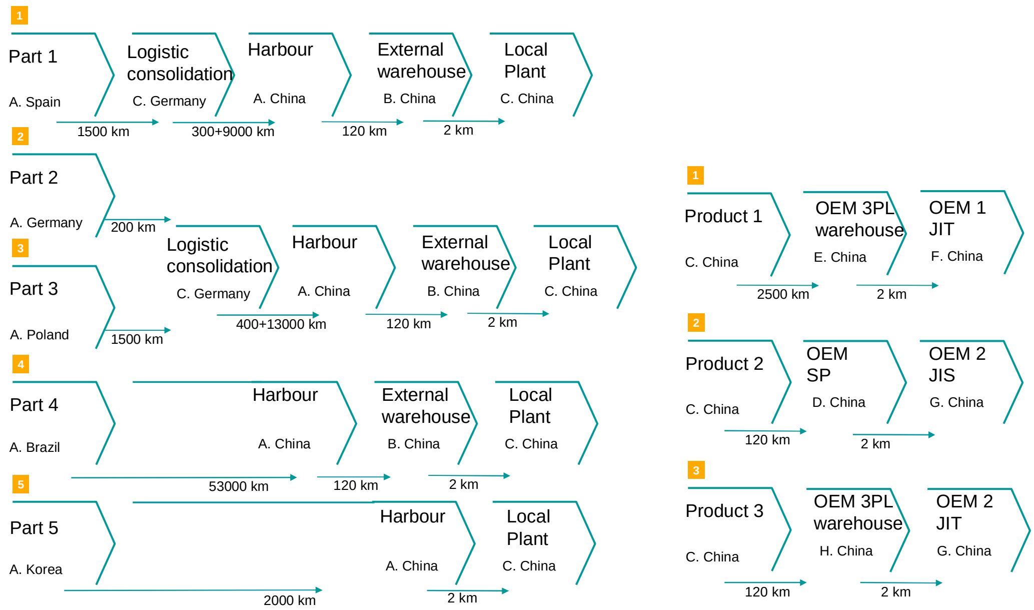

Figure 4-6 Door Module Supply Chain Scenario II

As illustrated in Figure 4-6, Scenario 2 is like a transition solution to the complete localization, the parts are sourced still from the existing supplier system, so we have the parts from Spain, Germany, Poland, Brazil and Korea etc. Those parts are either shipped directly to China or shipped through a German logistic consolidation and then to China. The big parts have to go to the external warehouse for entrance inspection and stay as inventory, and the small parts go directly into the local Chinese plant.

Using those parts from different international suppliers, 3 kinds of products are then assembled in the local plant C. And those products are afterwards supplied to customers either just in time or just in sequence according to the customers' requirements.

4.2.3 Door Module SC Scenario III: Local Sourcing, Local Supply

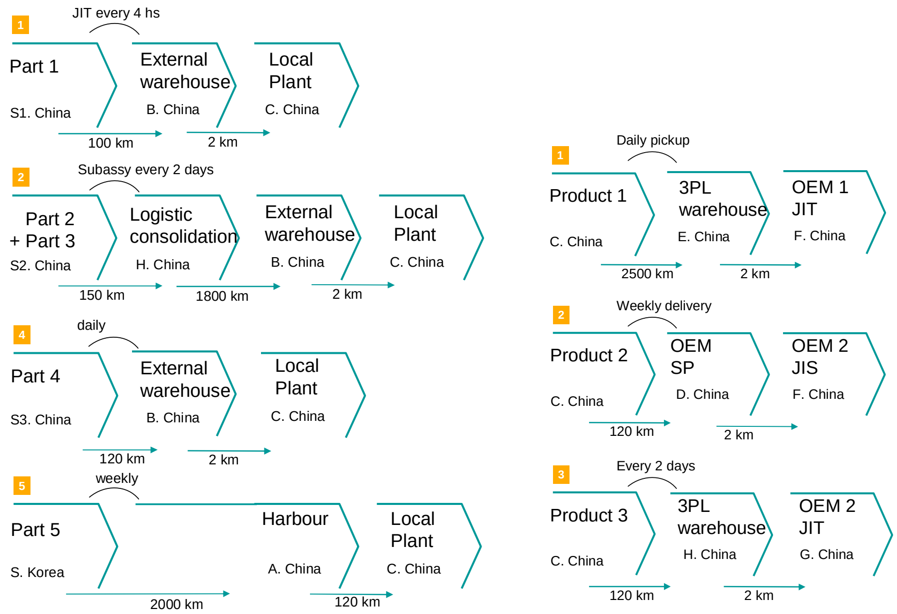

Figure 4-7 Door Module Supply Chain Scenario III

Scenario III is a deeper localized scenario. The main parts are sourced locally in China, which means some local suppliers are newly developed, new tools are made and new techniques are applied. Some small parts are still purchased from the existing supplier, since it makes no sense to change considering the quantity and quality. Again, the products are supplied to customer JIT or JIS. Differentiating from scenario II, the product 1 in this case will be picked up by the customer 1 through a “milk-run”.

In the next sub chapter, the performances of the 3 supply chain scenarios are about to be respectively evaluated, and the corresponding comparisons will be made.

4.3 Supply Chain Evaluation Using Conventional Model

It is very difficult to develop a generalized mathematical model that incorporates all the salient features such as demand pattern, lead time (processing time, waiting time, conveying time), information (Kanban) delivery time/ cost, setup time/ cost, production capacity, and batch size. In the following sections, the different supply chain scenarios introduced above will be evaluated from cost, routing, stability, flexibility and reliability/risk aspects. With the variable approaches, a conventional evaluation model is established.

4.3.1 Cost analysis

From cost point of view, pursuing a minimum cost is always the target of supply chain design. Here based on the ElMaraghy and Majety [EM 08] model and under the industry background, a special cost model concerning the actual situation will be developed. The objective is to minimize the cost of the total supply chain, which is the sum of material cost, production cost, inventory carrying cost, transportation cost, packaging cost and corresponding handling cost.

C_T	Total cost of the entire supply chain
C_m	Material cost of the purchased parts from upstream suppliers
C_p	Production cost of assembling the parts
C_t	Transportation cost
C_{pa}	Packaging cost
C_{inv}	Inventory cost
C_{hl}	Handling cost
i	Part index, $i = 1...I$
j	Product index, $j = 1...J$
l	inventory l, $l = 1,2,3$
k	Transport stage, $k = 1...K$
m	Packaging stage, $m = 1...M$
n	Handling stage, $n = 1...N$

$$\begin{aligned}\text{Total cost} &= \underbrace{\text{material cost} + \text{production cost}}_{\text{A cost}} + \\ &\quad \underbrace{\text{transport cost} + \text{packaging cost} + \text{inventory cost} + \text{handlingcost}}_{\text{B cost}} \\ &= \text{production cost} + \text{holdingcost of raw material} * \text{average inventory} \\ &\quad + \text{inland transport cost} + \text{oversea transport cost} + \text{packing cost} + \text{repack cost} \\ &\quad + \text{subassy inventory cost} + \text{product inventory cost at tier 1} \\ &\quad + \text{product inventory cost on way} + \text{product inventory cost at customer} + \text{handling cost}\end{aligned} \tag{4.1}$$

ElMaraghy and Majety [EM 08] also quantified the risks into a certain cost, but here I would rather consider the on-time delivery guarantee with a certain amount of inventory level than calculate the risk cost separately. The risk aspects will be discussed later on in the sections afterwards.

$$\begin{aligned}C_T &= C_m + C_p + C_t + C_{pa} + C_{inv} + C_{hl} \\ &= C_m + C_p + \sum_{k=1}^{K} C_{tk} + \sum_{m=1}^{M} C_{pam} + \sum_{l=1}^{L} C_{invl} + \sum_{n=1}^{N} C_{hln}\end{aligned} \tag{4.2}$$

With constraints:

$$\text{Logistic performance} \geq \text{mimimum requirements} \tag{4.3}$$

Below in the table I collected the corresponding data of the 3 supply chain scenarios, the single cost items are all amortized into part/product unit. The data are collected in the daily work, however, for confidential reason, the applied data are already processed.

Table 4-1 Cost Breakdown and Profit Analysis

	Item	Unit cost	Trans. cost	Pack. cost	Inv. cost	Handl. cost	Item	Trans. cost	Pack. cost	Handl. cost	total cost	unit sales price	Profit-bility
Scenario I	Prod 1	25,5	2,6	0,7	0,2	0,7		1,2	0,6	0,6	32,1	34,6	7,00%
	Assy 1	6,24	1,5	0,5	0,2	0,6							
	Prod 2	35,8	2,8	0,65	0,3	0,4		1,3	0	0,3	41,5	44,1	5,92%
	Prod 3	48,5	2,9	0,65	0,3	0,4		1,3	0	0,35	54,4	57.80	5,88%
Scenario II	Part 1	12,1	2,3	0,4	0,12	0,1	Prod 1	1,2	0,4	0,3	30,2	33,51	9,80%
	Part 2	6,52	1,9	0,36	0,1	0,08							
	Part 3	3,35	0,8	0,2	0,08	0,08	Prod 2	1,3	0,45	0,3	39,8	42,80	7,00%
	Part 4	1,27	0,6	0,15	0,08	0,07							
	Part 5	0,65	0,2	0,15	0,05	0,02	Prod 3	1,3	0,45	0,35	52,4	56,07	6,54%
Scenario III	Part 1	13,2	0,24	0,12	0,07	0,15	Prod 1	0,8	0,4	0,15	29,1	32,84	11,40%
	Part 2+3	10,5	0,2	0,1	0,02	0,15							
	Part 4	1,47	0,08	0,05	0,02	0,1	Prod 2	1,1	0,45	0,2	37,2	41,94	11,30%
	Part 5	0,65	0,2	0,08	0,02	0,1							
							Prod 3	1	0,45	0,2	48,2	54,94	12,28%

(Unit: Euro)

Based on the above analysis, the profitabilities of the 3 kinds of products based on the 3 different scenarios are compared in Figure 4-8.

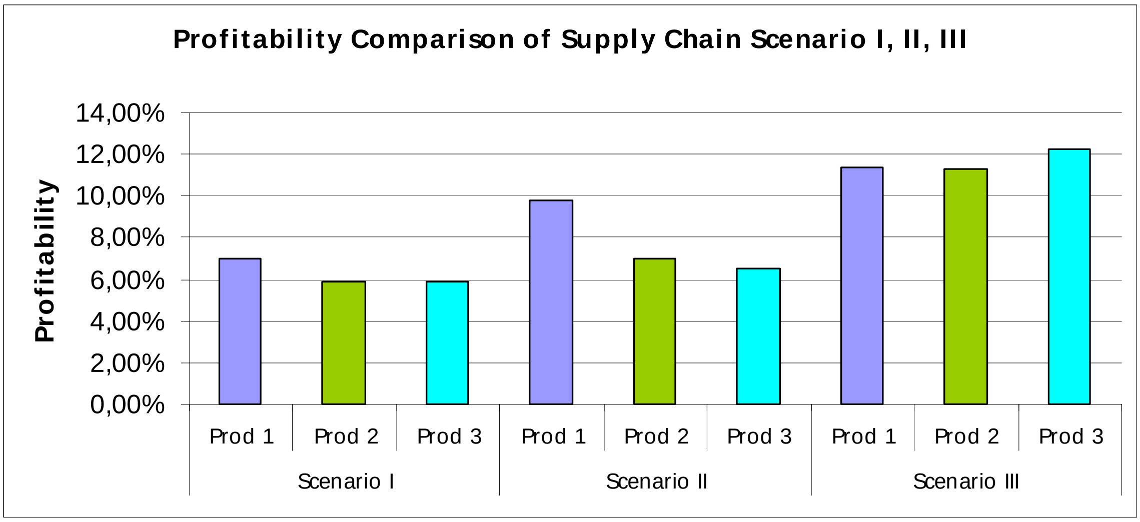

Figure 4-8 Profitability comparison of SC scenario I, II, III

Quite obviously, we can see the profitability of scenario II is higher than that of scenario I, and the profitability of scenarios III is the highest among all.

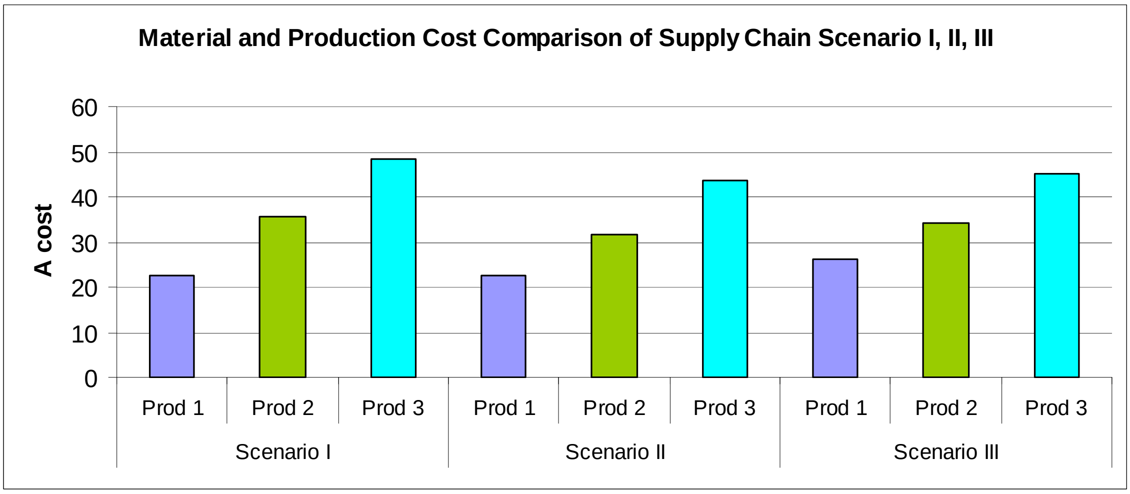

Figure 4-9 A cost comparison of SC scenario I, II, III

Here the A cost, namely the material and production cost are compared among the 3 scenarios. For product 1, the A cost of scenario I and II are similar since the same material from same suppliers are used and the products both have to be assembled to certain degree in the local china plant; the higher cost in scenario III is due to the assembly complexity since in this scenario the assembly work is based on pieces instead of sub assemblies.

Scenario II has among all the lowest cost, although the difference is not distinct. Compared to scenario I, it has the relative cheaper labour cost and some manual operations, and compared to scenario III, the effect of supplier development cost, tooling cost, machine invest and so on which are amortized to the piece cost in the localized scenario, are not so huge. Taking also the different assembly technique into consideration, we cannot simply say which scenario is really better than the others.

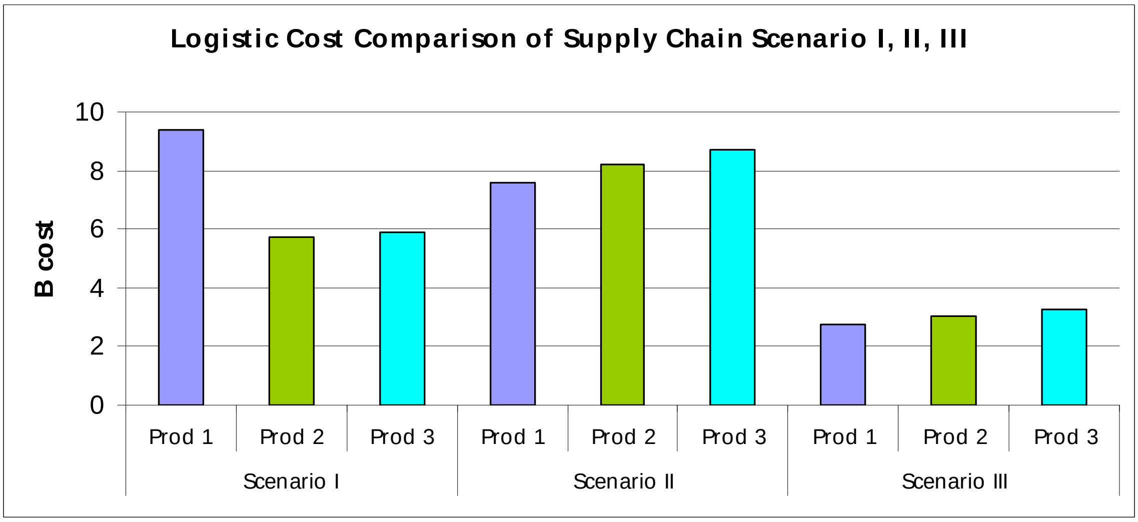

Figure 4-10 B cost comparison of SC scenario I, II, III

The comparisons of B cost, namely the logistic cost is quite clear. The local scenario III enjoys greatly the logistic advantage because of the short transport distance. Product 1 for scenario I has a higher logistic cost for its relative complicated delivery mode since it has to be delivered together with assembly 1. However, scenario II has the relative high logistic cost generally, because of the long transport distance for each individual part and the high logistic handling requirement.

4.3.2 Transportation Routing Analysis

The transportation includes transporting the parts and components from upstream suppliers to Tier 1, as well as transporting the products from Tier 1 assembly plant to the final customers.

4.3.2.1 Transportation Mode Analysis

Both the purchasing and distribution processes of the 3 scenarios are well illustrated in Figure. 4-11, 4-12 and 4-13. In scenario I, except the product 1 and sub assembly 1 are transferred through a consolidation centre, the other 2 products are directly delivered to the customer over 10 tkm away. And in scenario II, part 1, 2, and 3 from Spain, Germany and Poland are all firstly transferred to a designated consolidation centre in Germany which is close to the manufacturing plant, and then shipped out to China plant. Part 4 and part 5 from Brazil and Korea are shipped directly to China on their own. The choice between direct delivery and consolidation is one of the key factors deciding the logistic performances, so here these two transportation solutions based on our reference cases will be investigated.

Figure 4-11 Transportation Routing Scenario I

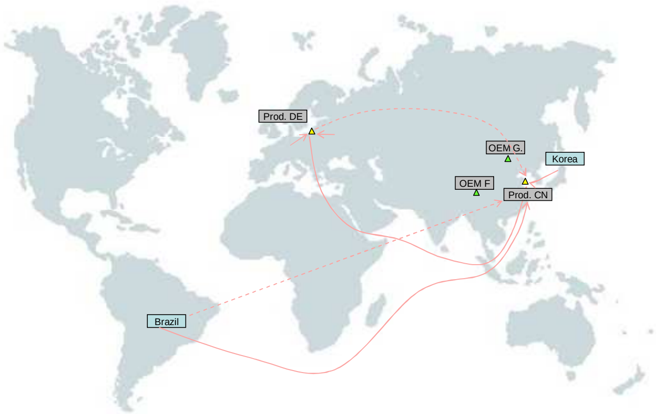

Figure 4-12 Transportation Routing Scenario II

The first option “direct delivery” refers to the direct transport from the supplier plant to the downstream partner, as in our case from Tier 2 suppliers to Tier 1, and from Tier 1 to OEM customers. There is no intermediate transhipment point and the routes are easy to coordinate. However, direct transport tends to cause higher logistics costs and disposition management complexity degree. Either the parts are stored temporarily until an economic lot can be shipped or transports leave the supplier plant with low capacity utilization. Since the first option increases lead time to the downstream partner, the second option seems more viable in the competitive supply chain environment. The consequences of the direct delivery are higher transport costs, which are a drawback of this solution. As already found out in last section, the B cost of the direct deliveries is extremely high considering the transportation and unused capacities.

The use of “consolidation centre” reduces planning complexity, as routes are split up into consolidated transport from the Tier 2 suppliers’ plants to the transhipment point and from there to the Tier 1 assembly plant, and on the other hand, from Tier 1 to transhipment point and from transhipment point to OEMs. And what’s more, the assembly work in Germany in Scenario I can be somehow also considered as a consolidation process. This consolidation work is especially beneficial when long distances between supply chain partners, which is exactly our cases in Scenario I and scenario II, have to be covered in specific regions. Routes with high capacity utilization bear economies of scale and could even be run by alternative means of transport (e.g. trains for transport in Europe), which would further decrease transport costs. However, compared with direct delivery from the supplier plant, the lead time to the customer increases due to the additional handling effort and detours.

However, no matter how beneficial the direct delivery and consolidation centre are, the long transport distance in the first 2 scenarios are all the time a huge flaw within the entire SC perspective. Once there is any delay, no matter caused by manual reason or unavoidable natural disasters, nothing can be done to remedy, and this might result in tremendous loss including even line stop in the downstream partners. The large on-way inventory takes up a big part of the invest, and the expensive emergency solutions like air freight etc add up the cost as well. Therefore from the transportation point of view, shortening the transport distance is a fundamental rule of the supply chain design.

Figure 4-13 Transportation Routing Scenario III

The local sourcing and local delivery scenario greatly shortens the transportation distance, and therefore it assures a much shorter lead time and lower delivery complexity degree. Meantime, the weekly or daily delivery particularly reduces the inventory as well. In this case, a special method is applied, which is the “customer-pick-up”, where the customer picks up his products from the local Tier 1 suppliers in a “delivery run”, instead of having them delivered to their home address. In order to apply this concept on a larger scale, the distances between the different Tier 1 suppliers and the geographic layout of the suppliers would have to be kept at a reasonable level, and the pick-up round routine should also be carefully considered. In our case, the customer drive out from the OEM plant with trucks full of returnable empty racks, and the empty racks are changed to full racks with products by every passing suppliers on the run-way. On one hand is the truck capacity fully used, and on the other hand the transport cost and time are considerably cut down. Only efforts required to organize the pick-up have to be kept in mind, for example the capital investments in the packaging racks because of the long run. In addition to the reduced transport cost, the managing complexity by Tier 1 is also tremendously reduced.

4.3.2.2 Sustainability Analysis - Carbon Footprint

The emphasis on global climate change is increasingly putting pressure on automotive companies, the emission level targets are not only restricted in the OEMs, but are also challenging the entire automotive supply chain. The emphasis is made especially to the transportation aspect, since road transport is the second biggest source of greenhouse gas emissions right after power generation. According to VDI report, the road transport contributes about one-fifth of the total emissions of carbon dioxide (CO_2), which is the main greenhouse gas. In regard to the "green" challenge, the focus on designing an optimal transportation routing from the logistic point of view, is contributing more and more to the competitiveness of an automotive supply chain. Reducing carbon footprint of the entire operations is becoming rather a must trend. As defined by "UK Carbon Trust 2008", a "carbon footprint" is "the total set of GHG (greenhouse gas) emissions caused directly and indirectly by an individual, organization, event or product", the size of carbon footprint can be calculated and the offset strategy can be also suggested. Here in this sub section, I am about to calculate transportation time and the distance and roughly the pollutant emission as well.

Basically I calculate the transportation time between Tier 1 and the OEMs, and the pollutant emission based on monthly base. So in order to meet the monthly requirement, the pollutant emission of the transportation (purchasing procedure and distribution procedure) are illustrated as the blue columns, and the transportation time (mainly distribution time) are illustrated as the yellow columns.

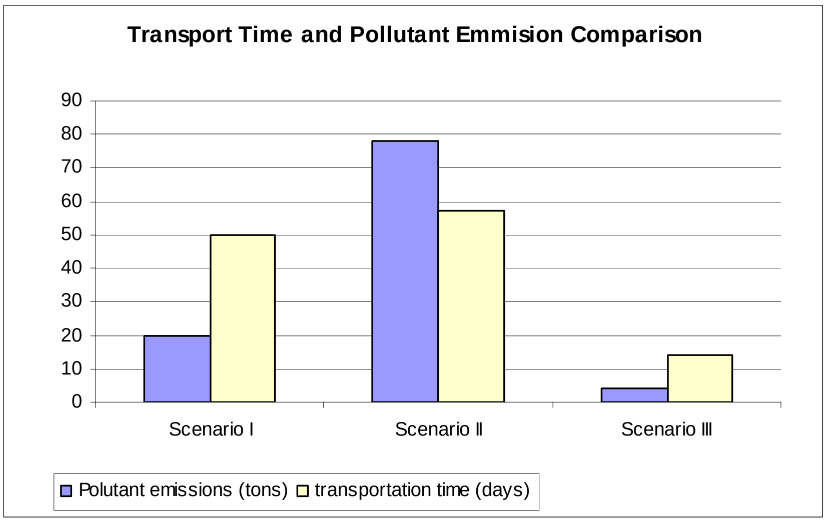

Figure 4-14 Transportation Time and Pollutant Emission Comparison

As can be seen from Figure 4-14 the transport times and pollutant emissions both show the lowest values in scenario III, since the local source and local deliver obviously reduced the long overseas transportation distances. Scenario II has the highest transport time and pollutant emissions because of the direct single source from original European and Brazil suppliers. However, this figure has to be read carefully, as to the final product shipped out from Scenario I, we should also consider the transport and emission factors before the products are assembled in German plant, which is to say, there are also transport time and pollutant emissions before the product shipment. Since this is already calculated into cost factors before in the cost analysis, and will not greatly effecting the results in supply chain scenario comparison, this pre-shipment factor will be neglected in this case study.

In general, from environment friendliness and sustainability points of view, the local sourcing local assembly scenario is among all the most beneficial, and the single international sourcing scenario is most unfavourable.

4.3.3 Stability Analysis

By stability the bullwhip effect will be discussed in this section. Bullwhip effect has always been considered as one of the critical problems in a supply chain that negatively influences costs, inventory, reliability and other important business processes especially in upstream companies. The stability problem has become more critical due to the increase complexity of global supply chains. Before in the previous chapter, the quantification model of measuring a multi-level multi-product supply chain has been theoretically talked about. Here in this chapter, how the bullwhip effect work to the 3 supply chain scenarios of our reference case and the optimal way to reduce the bullwhip effect by adjusting the supply chain structure and parameters will be discussed.

The daily volume data was collected from OEMs and from Tier 1, based on a time frame of 3 month for each scenario. The ordered quantities for Tier 2 suppliers were collected as well. For research purpose, the corresponding data of 1 month are processed.

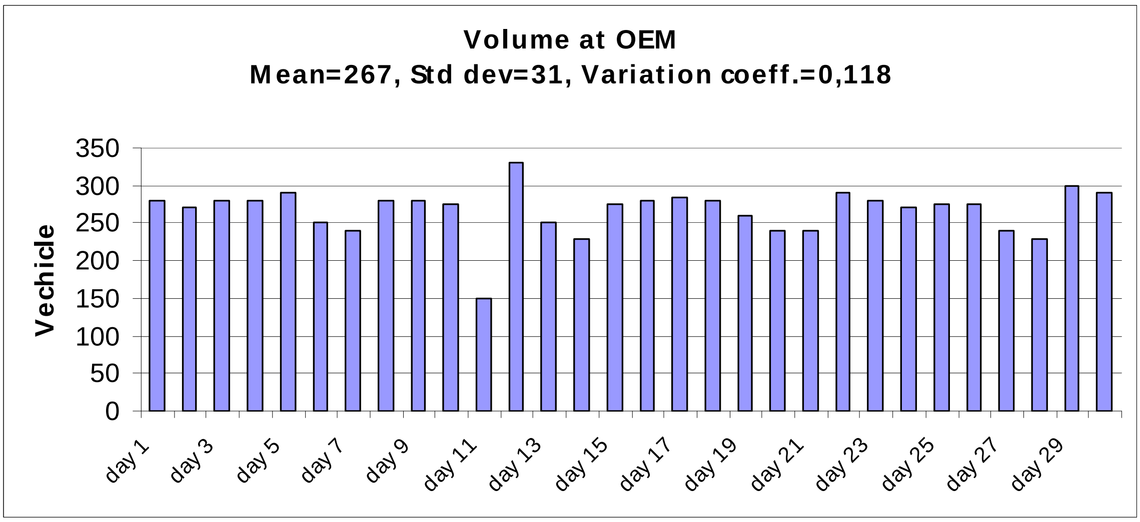

Figure 4-15 Vehicle production at OEMs

Summarizing all the 3 kinds of products together, Figure 4-15, shows the vehicle production situation at OEMs, this volume is the actual volume produced every day at OEM plants. As per calculation, the average volume is 267 vehicles per day, and the standard deviation is 31 vehicles, with the variation coefficient of 0,118.

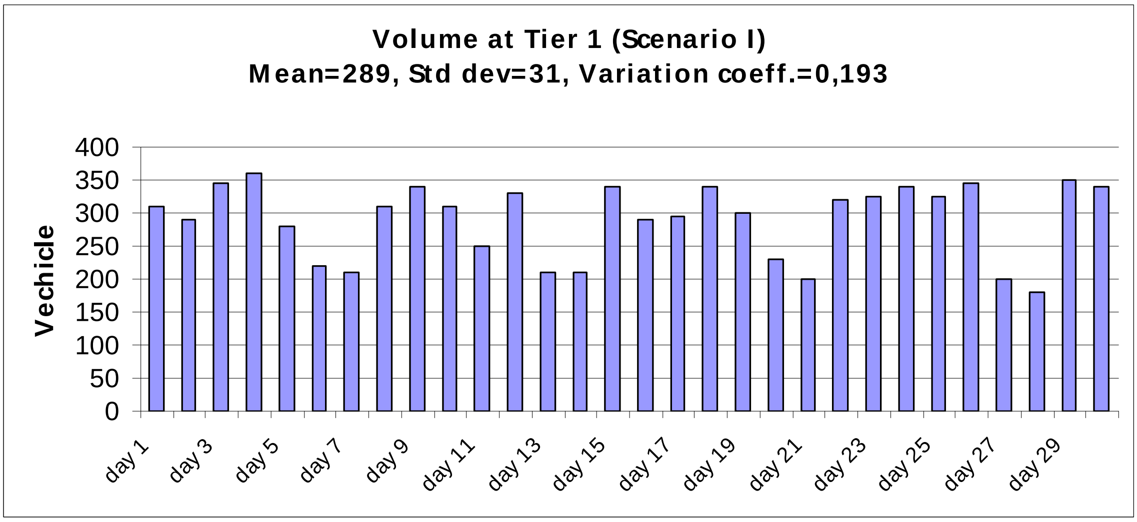

Figure 4-16 Vehicle production at Tier 1, scenario I

Figure 4-16 shows the production volume at Tier 1. The customer forecast is updated with daily, weekly, monthly and yearly volume as rolling plan, this information accords technically to the OEM volume quite well, however, for safety reason, the OEM logistic departments always add a safety volume on it. Since the safety stock at OEM should be kept on a certain level, when the stock is over the limiting line, the volume plan will be adjusted manually. Therefore, the forecast at Tier 1 is already processed and marked up.

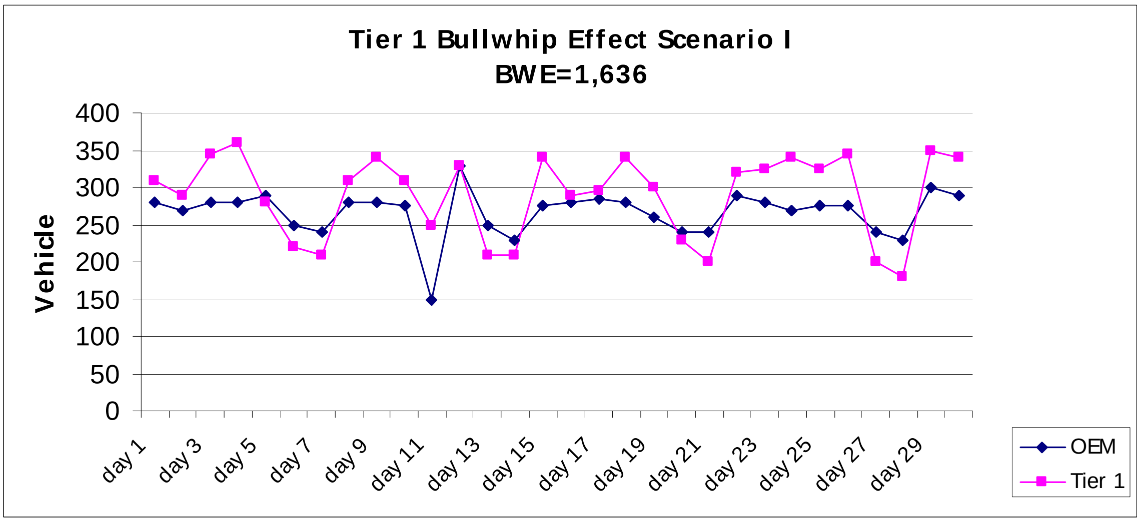

Figure 4-17 Bullwhip Effect Tier 1, Scenario I

According to the theory introduced in the previous chapter, the bullwhip effect between Tier 1 and OEM can be calculated. Above the Figure 4-17 shows the bullwhip effect of scenario I at Tier 1 (calculated according to formula (3.2)).

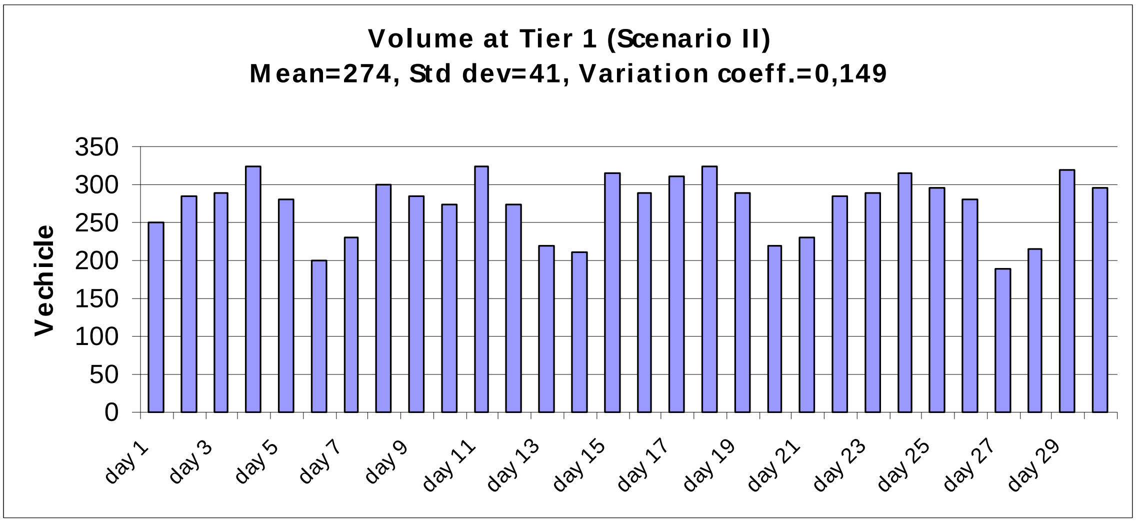

Figure 4-18 Vehicle production at Tier 1, scenario II

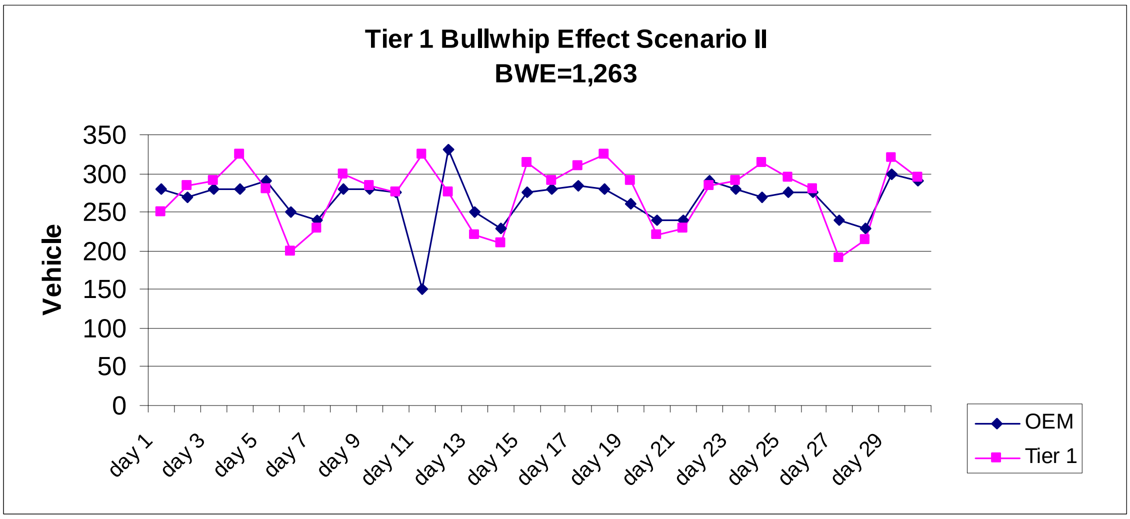

Figure 4-19 Bullwhip Effect Tier 1, Scenario II

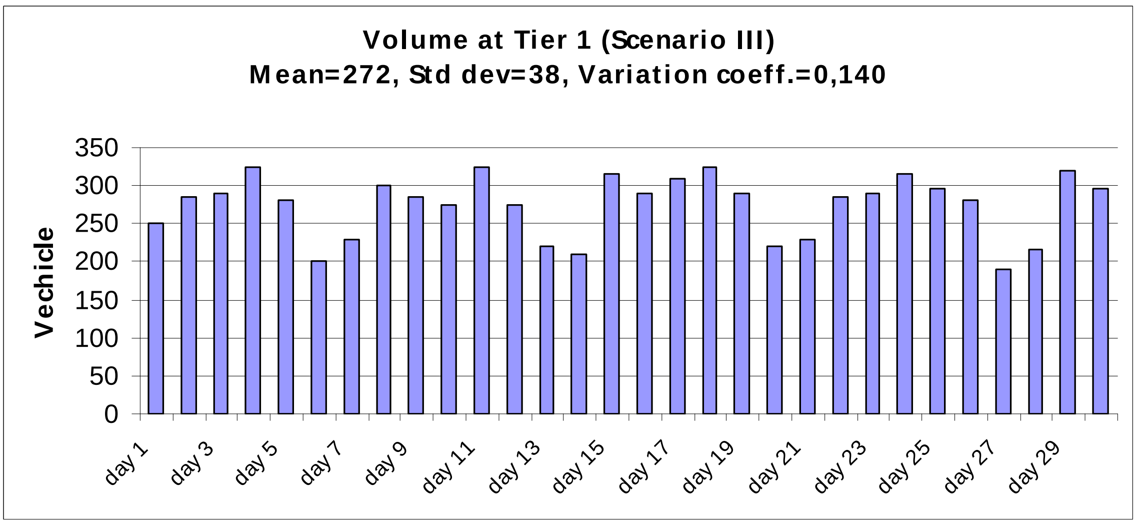

Figure 4-20 Vehicle production at Tier 1, scenario III

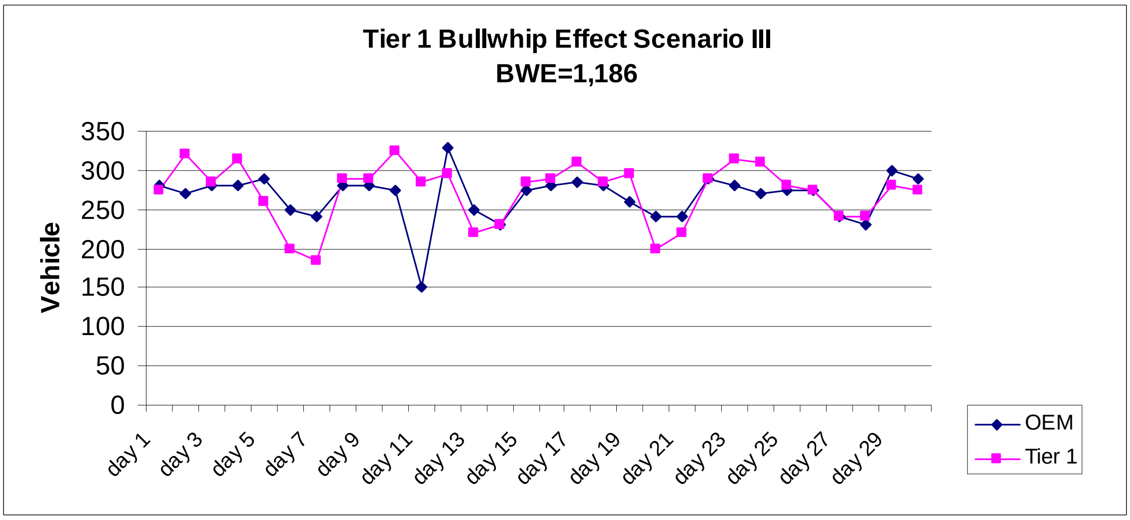

Figure 4-21 Bullwhip Effect Tier 1, Scenario III

In the same way, bullwhip effects of scenario II and scenario III are calculated and illustrated in the above figures.

Following in the figures the bullwhip effect at Tier 2 suppliers are also calculated, whose forecasts are based on the data further processed at Tier 1.

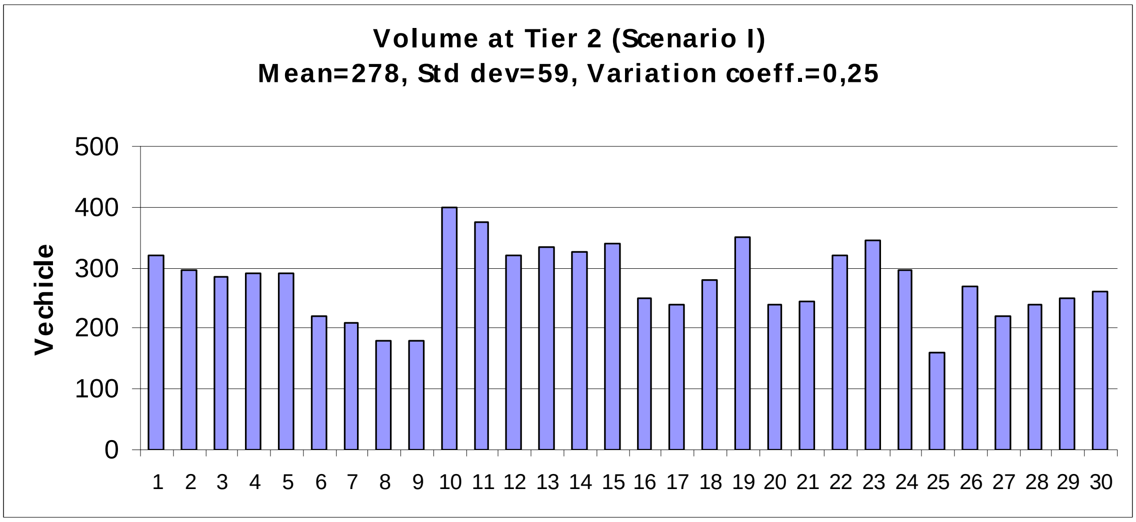

Figure 4-22 Vehicle production at Tier 2, scenario I

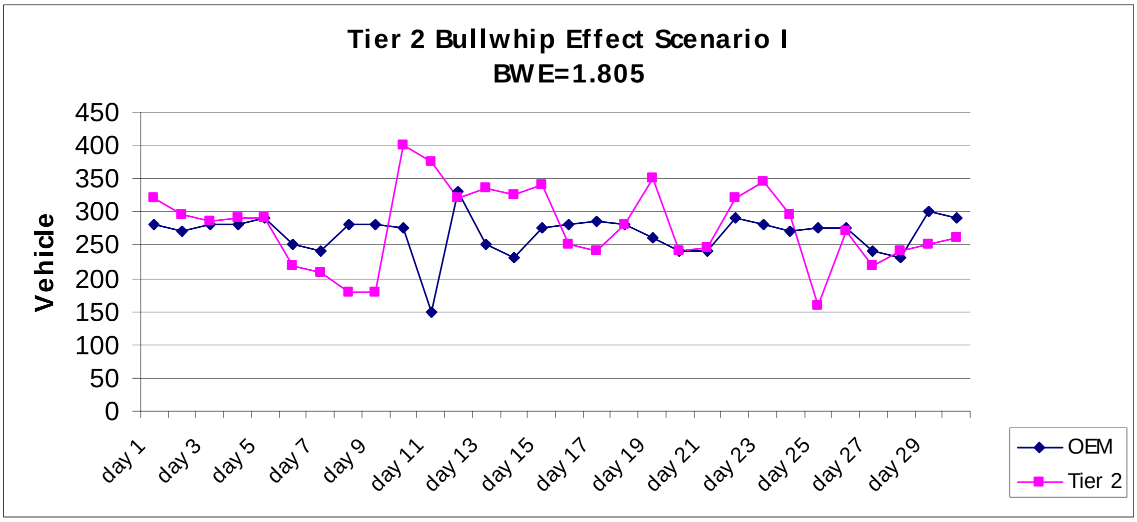

Figure 4-23 Bullwhip Effect Tier 2, Scenario I

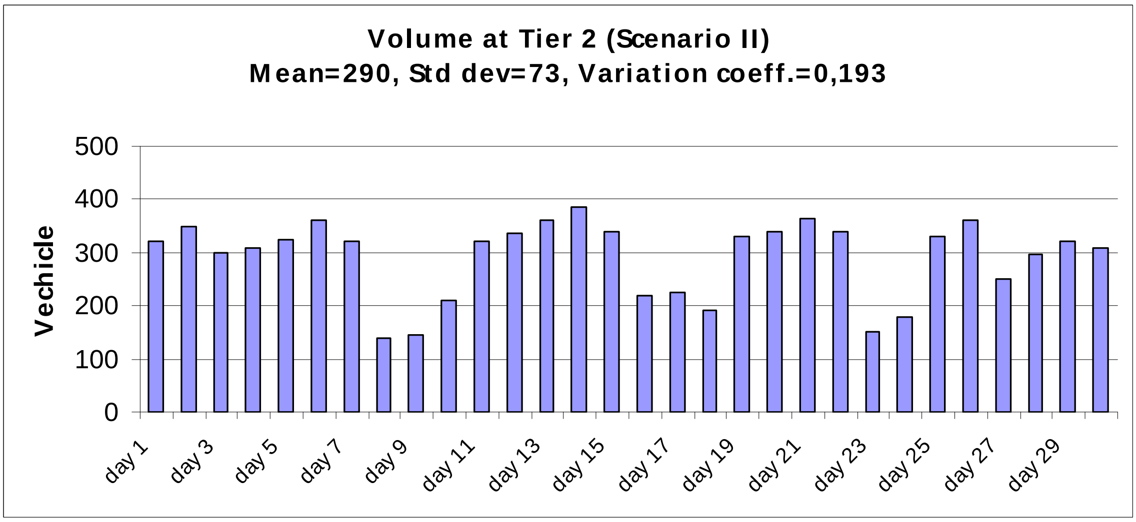

Figure 4-24 Vehicle production at Tier 2, scenario II

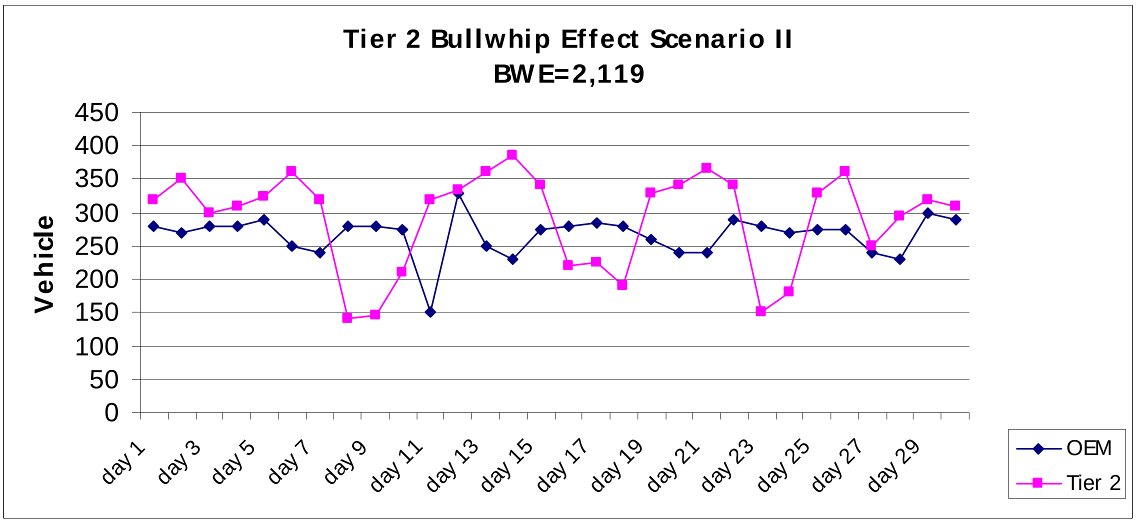

Figure 4-25 Bullwhip Effect Tier 2, Scenario II

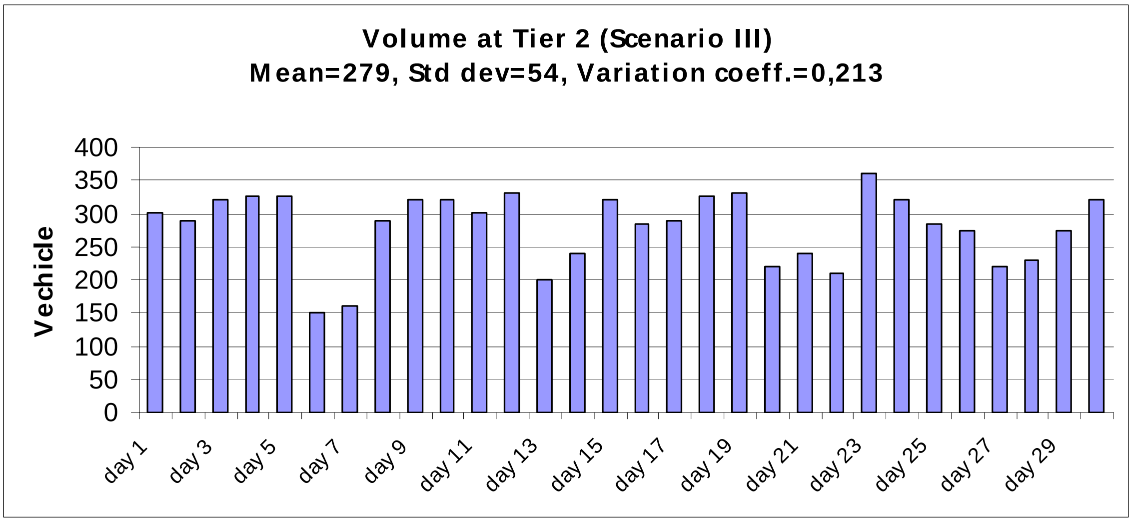

Figure 4-26 Vehicle production at Tier 2, scenario III

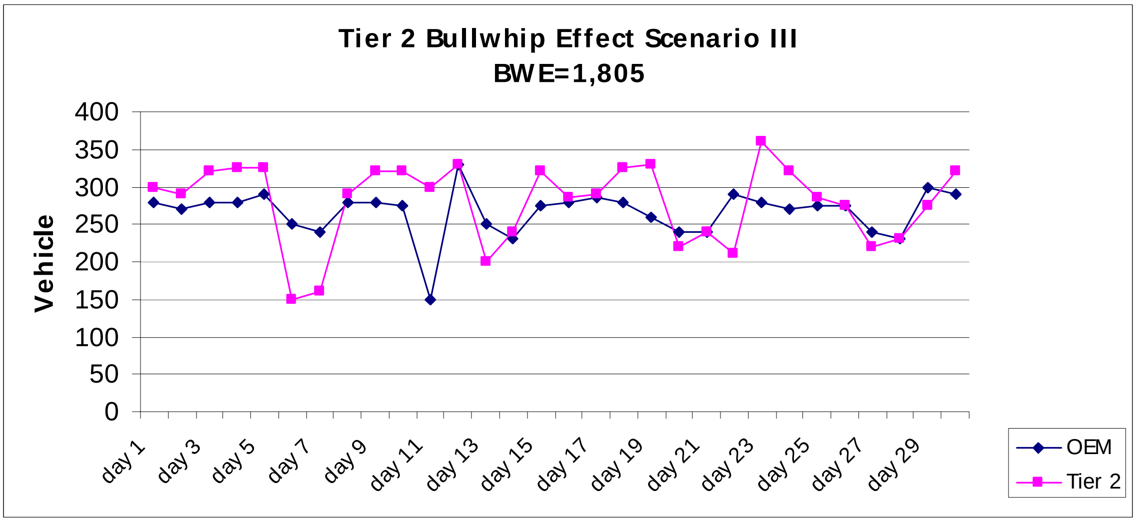

Figure 4-27 Bullwhip Effect Tier 2, Scenario III

So from the above analysis, basically the forecast volumes are transferred with an increase from down stream companies to the upstream companies, though the IT system already made the "synchronous" plan theoretically possible.

Summarized in Figure 4-28, we may see the bullwhip effects at Tier 2 suppliers are generally higher than those at the Tier 1, and quite obviously, this is because of the data processing stage after stage. At Tier 1, the first scenario, by which the Chinese OEMs are supplied with German products, has the biggest bullwhip effect, since the strategy of assembling in Germany requires more safety stock to meet the stability requirements. And at Tier 2, scenario II has the biggest bullwhip effect, due to the complicated and unstable supply network. In general, the local sourcing and local assembly strategy is relative with the best stability among the 3 scenarios.

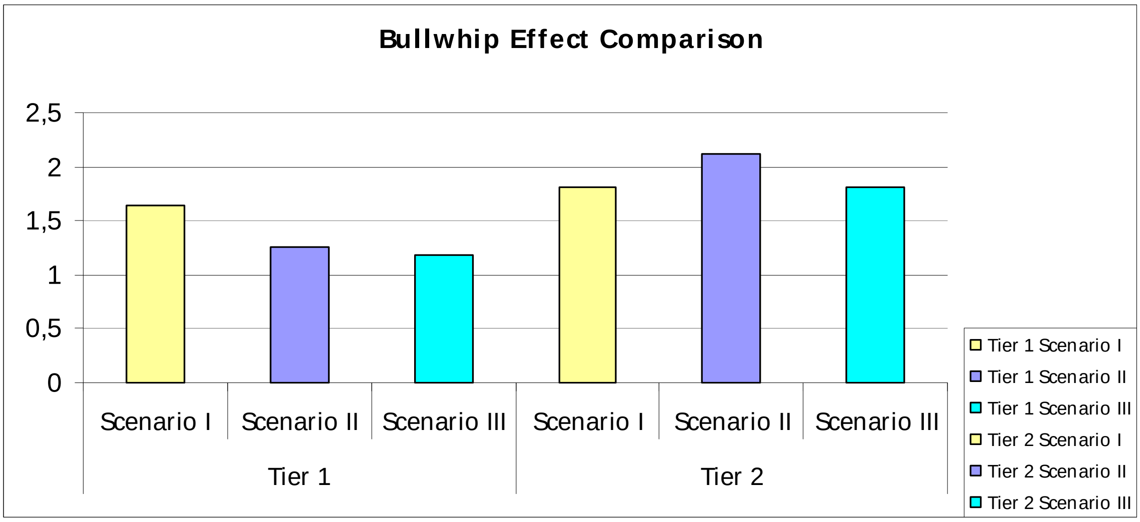

Figure 4-28 Bullwhip Effect Comparison

Here based on the above analysis, it makes sense to talk more about how to eliminate the bullwhip effect in the supply chain design. The most effective way out is the information sharing, which means the share of inventory information, sales and demand information, and forecast information. The bullwhip effects are actually caused by the multi-level forecast, since the downstream order quantity is the key information source for the upstream companies to make decisions, and this information is unfortunately always exaggerated for all kinds of reasons. Currently in the automotive production, the advanced IT system has already made it possible to share each other's order information, but there is still big space to increase the sharing degree. And to improve the situation, the VMI, vendor managed inventory is another good way to realize the sharing of inventory information. Like in our case, the 2 days stock in customer's SP is actually the application of VMI strategy.

4.3.4 Flexibility Analysis

Based on the theories introduced in last chapter, the 3 scenarios of supply chains will be assessed from 5 aspects, namely the operation flexibility, logistics flexibility, information flexibility, network and reconfiguration flexibility and market and supply flexibility. Here an evaluation with a result marked by 1-10 is made, where 10 is the highest value and 1 is the lowest value. The higher the mark is, the higher flexibility the supply chain has. The data used here are from real case experiences and the marks are made by logistic experts in the company.

Table 4-2 Flexibility Comparison

	Operation	Logistics	Information	Network & reconfiguration	Market& supply	Total
Scenario I	6	4	6	5	4	**25**
Scenario II	4	4	4	6	5	**23**
Scenario III	8	8	8	9	9	**42**

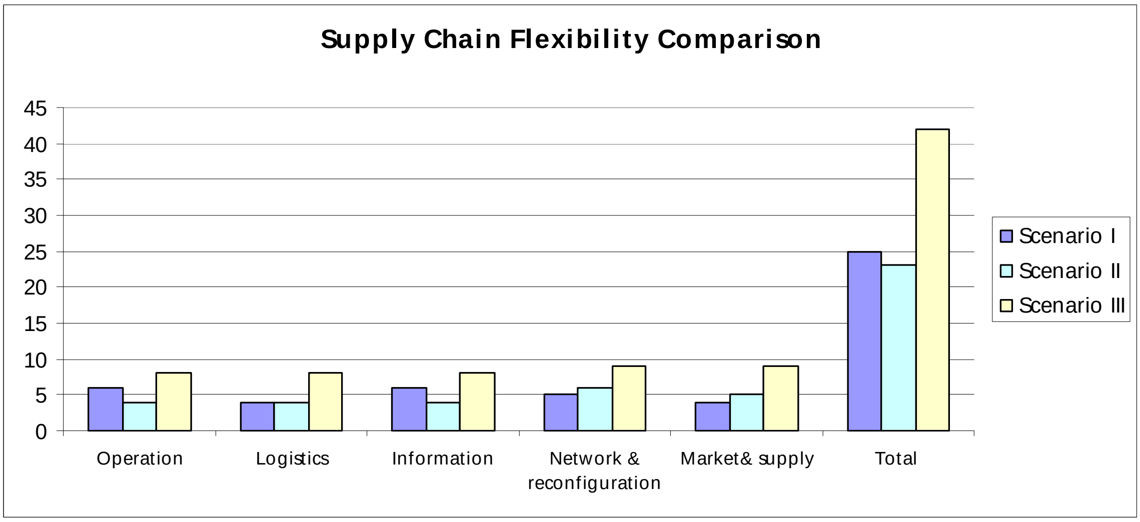

Figure 4-29 Supply Chain Flexibility Comparison

Obviously, scenario III enjoys the biggest flexibility, and the flexibility mark leads distinctly ahead. Scenario I is a little bit more flexible than scenario II, however, both are not flexible enough.

4.3.5 Reliability- Risk Analysis

The supply chain risks are qualitatively analyzed before in chapter 3, and a Risk quantification model was established by ElMaraghy and Majety [EM 08]. In the model, the risks are converted to cost, which is easier to be measured.

$$\text{Minimize } Z = \sum_{t=1}^{T} \sum_{i=1}^{nst-1} \sum_{l=1}^{L_i} \sum_{j=1}^{S_{li}} [LD_{i,l,j,t} * X_{i,l,j,t} * PenRt * Exp(Risk_{iljt})] \qquad (4.4)$$

with :

$LD_{i,l,j,t}$	Late delivery of parts (as percentage) by supplier I, level l, supplier j, in period t
$Risk_{i,l,j,t}$	Supplier i risk, level l, supplier j in period t (Low: 1, Medium: 2, High: 3) for supplying parts late to their customer
PenRt	Base penalty rate, defined as the dollar penalty for every part that is delivered late
$X_{i,l,j,t}$	Number of unit produced at stage I, level l, supplier j, period t

Since the cost issue is already analyzed, here in this work, regarding the risk aspect, it will be more concentrated on the supply chain structural risks. Following the structural risks of the 3 different supply chain strategies will be analyzed.

Scenario I: In this international sourcing and international supply SC, from the Tier 1 German plant to the OEMs in China, the delivery and risk transfer process is a series process. A multi-mode transportation system including highway truck transport inside Germany, sea freight from Germany to China, and water and highway transport in China has the typical characteristics of a series process. According to the formula introduced in the previous chapter, total risk events on supply chain are accordingly calculated as:

$$P_I = 1 - \prod_{i=1}^{3}(1 - P_i)\,,$$

where P_1 is the risk probability inland Germany, P_2 is the risk probability on the way from Germany to China, and P_3 is the risk probability inland China. According to the delivery situation investigated for 3 month, the following probabilities are taken:

$$P_1 = 0,06\,,\ P_2 = 0,2\,, P_3 = 0,08$$

And the total risk probability is therefore: $P_I = 0,308$

For scenario I, since there are not a lot of segments in the supply chain, the risk probability is relatively low and the reliability is relatively high from the structure point of view. However, considering the very long transportation distance, great possibility of unavoidable risks might happen on the way. So this is not the perfect way.

Scenario II: In this international sourcing and local supply SC scenario, Tier 1 has many suppliers providing different single parts from all around the world, the total risk is quite high because a failure at any of the suppliers might cause great loss, since in the final assembly, not one piece is supposed to be missing. And there are no substitutes once a supplier failed to deliver overseas. Given the long transportation distance and the uncertainties that may occur, this supply chain scenario is extremely risky. The total risk may be calculated as:

$$P = \sum_{i=1}^{5} P_i\,,$$

where in our case 5 suppliers are considered. Again according the data collected and analyzed, the risk probabilities from different suppliers are taken as:

$$P_1 = 0,18\,, P_2 = 0,16\ P_3 = 0,16\ P_4 = 0,18\ P_5 = 0,08\,,$$

And the total risk probability is therefore $P_{II} = 0,76$

Obviously, this is a very high risk probability from structural point of view, so in regards to risk aspect, Scenario II is definitely not a good choice.

Scenario III: Structurally this local sourcing and local delivery supply chain is quite like the one in scenario I, the only difference is that the single risk probability is lower of every single SC segment because of the much shorter transportation distance and the possible alternatives. Since for the normal supply, in case of the failure by Chinese local suppliers or local Tier 1 manufacture, the original European suppliers and Tier 1 plant could serve as emergency solution as substitute. So actually for each part, it has a parallel risk process, and for the entire SC, it's another adding process like Scenario II.

Therefore the total risk probability could be calculated as:

$$P_{III} = \sum_{i=1}^{4}\prod_{j=1}^{2} P_{ij}\,,$$

where we take

$P_{11} = 0,03$, $P_{12} = 0,18$, $P_{21} = 0,02$, $P_{22} = 0,22$, $P_{31} = 0,04$, $P_{32} = 0,2$, $P_4 = 0,1$

And the total risk probability of scenario 3 is then $P_{III} = 0,097$

After all, based on the above structure analysis, Scenario II has the highest risk probability, and scenario III is the most reliable one.

4.3.6 Summary

In this chapter a conventional model was offered to evaluate a supply chain design case of a Tier 1 door module producer's different scenarios, and here in the chapter summary, the evaluation results are about to be analyzed in general, and other scenarios with different supply backgrounds are to be discussed further.

4.3.6.1 Summarized Evaluation Result

The SC strategies are analyzed from different aspects. Based on the above analysis, the performance evaluation results can be roughly summarized from the investigated aspects:

Table 4-3 Summarized Evaluation Result

Aspects		Evaluation Results
Cost	Profitability	III > II > I
	A-cost	I ≈ II ≈ III
	B-cost	III < II < I
Transport	Simplicity	III > I > II
	Pollutant Emission	III < I < II
Stability	Bullwhip Effect	III < II < I Tier 2 > Tier 1
Risk probability	Structural	III < I < II
Flexibility		III > I > II

From the rough summary in the above table, it is noticed that from cost point of view, although the material and production costs are almost the same, the greatly reduced logistic cost with local sourcing and local production increased the total profitability of the entire supply chain. And analyzing the transport routes, the design scenario III is the simplest and "greenest" one, while scenario II has the biggest complexity and biggest pollutant emission. Concerning the supply chain stability, we may see the bullwhip effects are fiercer at Tier 2 than at Tier 1, and the scenario I supply chain suffers most from the bullwhip effects and scenario III has the least effects. Then coming to the risk and flexibility analysis, scenario III is the most reliable and flexible solution, while scenario II is the relative risky and inflexible one.

So in general, Scenario III is of the most preference when taking the overall evaluation results into consideration, however, different departments have different benefit requirements, and with this conventional model it is possible to assess the supply chain performance from different points of view, but since it is not really a generalized model, we are still not able to get a very precise conclusion especially when dealing with more complicated supply chain design cases.

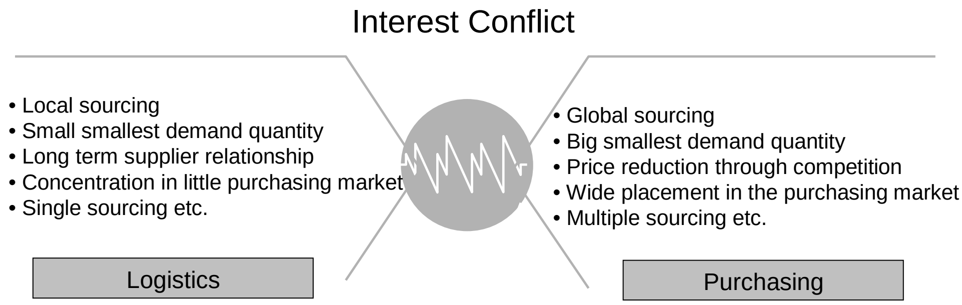

Figure 4-30 Interest Conflict between Different Departments

For example as shown in the Figure 4-30, the logistic department cares more about the traffic and order convenience and the purchasing department cares more about cost reduction. Meantime, how to assure a reliable supply might be the main target of sales team. So although this conventional model is clear, quantitative, reflective, it cannot reflect the general interest of the entire supply chain participants. Therefore in the next chapter, an integrate evaluation model using index system will be introduced, by which the supply chain performance can be more comprehensively evaluated.

However, the evaluation discussed above is only based on this very case, it can not be simply stated that localization scenario is better than the others, rather different circumstances may cause different profit orientations and thus totally different statements and conclusions, some other conditions are then taken into consideration in next sub section.

4.3.6.2 Further Discussion under Different Supply Circumstances

As mentioned before in chapter 1, the reason for choosing door system supply as the research case, is its representativeness for the characteristics of automotive supply chain. A door system is complicated, and it contains parts and sub-systems with different materials from different suppliers tier by tier. And this complexity and tier supply structure is stated to be the main characteristics of an automotive supply chain [Sch 08]. Therefore the evaluation results for such a system are to a large content reflecting the entire automotive supply chain performance. However, certain restrictions can still not be neglected, and for other different supply circumstances, situation might be far away from the case studied in this work and even with quite the opposite results.

Here in chapter 4 the vehicle door system supply from Germany to China has been talked about, which is quite a representative of supply chain with goods of relative high value from relative high cost region to low cost region. From the case in this chapter we got the conclusion that localization is a solution, however, what happens to the case of supplying goods from low cost region to high cost region, like from China or India to Europe? And what influences to the door design and supply might be caused with the newly developed low cost vehicle? What should be changed to cope with the E-mobility trend? Will it still be the same evaluation results if the supply volume changes? … Those are questions to be considered as well.

Again the project case from the same door module supplier is used as example: when we were designing the supply chain of a complex global project, we got some quite interesting outcomes. The project is organized in a very international way: R&D in Germany, project management in China mainland, customer purchasing in Taiwan China, OEM engineering in Australia, door production in China and OEM production in different Asia, Africa and North/ South American countries.

Obviously this is not the simple supply chains we evaluated before with the easily collected data and uncomplicated math tools. And this is rather a case that needs a much more general consideration of all related aspects. Under this circumstance we cannot simply say either localization is more beneficial or globalization is more advantageous. And after a long time work, we got in the end a solution with some parts global supplied and some parts local supplied; Asian countries supplied from different China plants, American countries supplied from Mexico and Africa supplied from Germany; in addition, for each customer location, a new JIT plant or warehouse was built up in the OEM supplier parks. So in this case, the conventional evaluation methods offered before seem to be quite limited.

Regarding the localization or globalization strategy of many companies, beyond the aspects discussed before in the evaluation model, there are more reasons to be considered. Reasons for moving the production facilities abroad differ for OEMs and suppliers. Successful OEMs follow their demand abroad to learn about the markets directly and to be able to respond more quickly. And their first tier suppliers just simply follow them [GSD 08]. OEMs may want to leverage local advantages in the form of lower labour costs, and many n-tier companies move because they manufacture simple, labour intensive and logistic inconvenient parts, not only because of their customers. Besides the flexibility, reliability, logistic and in the end cost reasons, another motive for some movement is the avoidance of high duty related expenses. And engagement in other important markets reduces the currency risks because components are purchased with the same currency for which the finished product is sold.

And regarding the degree of localization, another aspect has to be thought about. There are parts of “completely knocked down” (CKD) or “semi knocked down” (SKD), which refer to those products that require final assembly and/or finishing. Plants that produce SKD or CKD may also be used to develop the market of a country if the expected quality output level there does not currently meet the requirements for a complete production location. Many countries are now requiring a “local content ratio”, which is a specification of the percentage of local parts in a completely assembled car. To meet this requirement, OEMs have to transfer the responsibility to their first tier suppliers as for example in the door supply case to Ford China, the system localization was actually officially required by OEM, which is indirectly required by the local government.

Other aspects should be also taken into consideration before pursuing a relocation strategy. A volume manufacturer generally does not suffer negative consequences if it produces its cars in a cheap labour country as long as certain quality standards are met. A premium supplier may probably follow its customers to an important foreign market with new production locations. However, the high quality and tradition of the home market are essential brand images of a premium brand. The production of premium cars in new boom regions, could damage the image of the vehicles, even if the customer base for premium cars is rapidly growing in such regions. Suppliers should always weigh the benefit of cheap labour against the cost resulting from higher logistic and transport expenses and brand implications before they decide on a new location.

Back to the door case, in regards to the new vehicle development trend, the door system must also be changed accordingly, both product design and the supply mode, especially with the higher requirements to supply chain design caused by the increasing variants and vehicle individualization. Instead of waiting for a long time, people are rather expecting a tailored vehicle with their personal interested features more efficiently. The BTO strategy requires a more complex yet more precise supply from the suppliers and the OEMs, which might be the biggest challenge ever happened to the automotive companies; the new low cost vehicle requires deeper cost reduction from suppliers, where the product structure and supply chain improvement is the only way out when the material prices and facility invest are already kept in a limit margin; and as to the E-vehicles which are already catching the entire society's eye, totally different configuration from the traditional vehicle and the more individualized body design with small batch production, requires extreme accurate and updated supply chain. How to cope with those trends, and how to design and evaluate so as to get the most matching supply chain solution, is a new topic for us. Therefore later in the work, besides the new integrated evaluation model, the new automotive supply chain scenarios will also be suggested, structurally and with implementary details.

5. Automotive Supply Chain Evaluation with Integrated Model

In the previous chapter how to evaluate the supply chain has been discussed from different aspects individually, summarizing the evaluation results we get a relative comprehensive assessment which was named as conventional evaluation model. However, considering the conflicting interests of different departments and the complexity in analyzing the characteristics in such high details, when coming to a really big and complicated supply chain, the conventional model is somehow not that applicable for its detailed data requirement and scope restriction. The conventional evaluation is limited and lacking of a general view to assess the performance of more complicated supply chains. Therefore in this chapter, another method – the integrated evaluation model, is going to be presented to evaluate some complicated supply chains. Applying a properly structured index system, the model is designed based on real case, and the evaluation results are then well analyzed to direct the further optimization.

5.1 Case Description

Previously in Chapter 4, a vehicle door is defined from functional point of view, structurally, as illustrated in the following figure, a door system is composed by door frame, window regulator, electronics and motor, latch system, glass, interior components and so on.

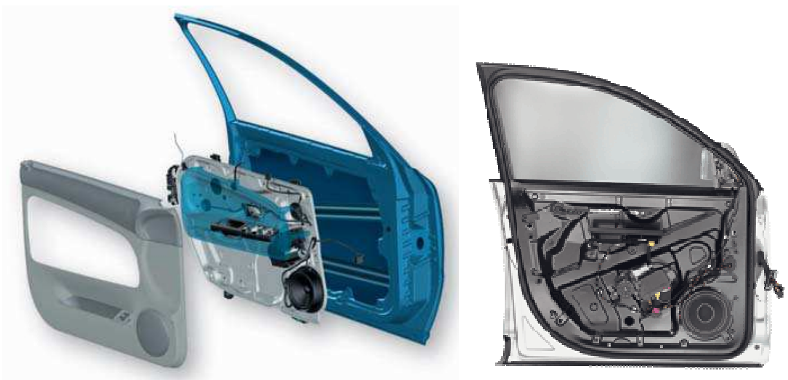

Figure 5-1 Door System with Frame

When we design the entire automotive door system supply chain, products of different integration degree, namely complex degree could be supplied to OEM customers. The products listed in the following structure could be either supplied individually or with different degrees of combinations. Next in the following subchapters, the different scenarios of automotive door system supply will be introduced. Optimized supply mode is investigated based on the performance evaluation results.

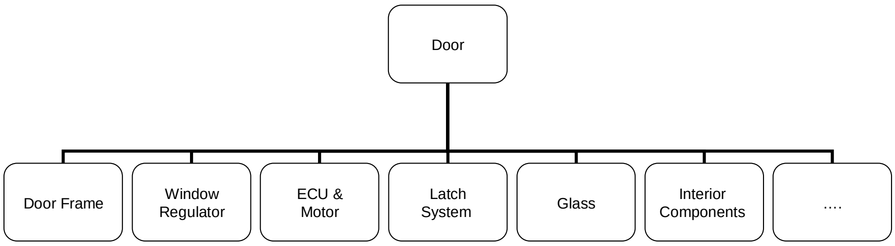

Figure 5-2 Simplified Door System Composition Model

5.1.1 ASC Scenario I: Single Component/ Assembly Supply

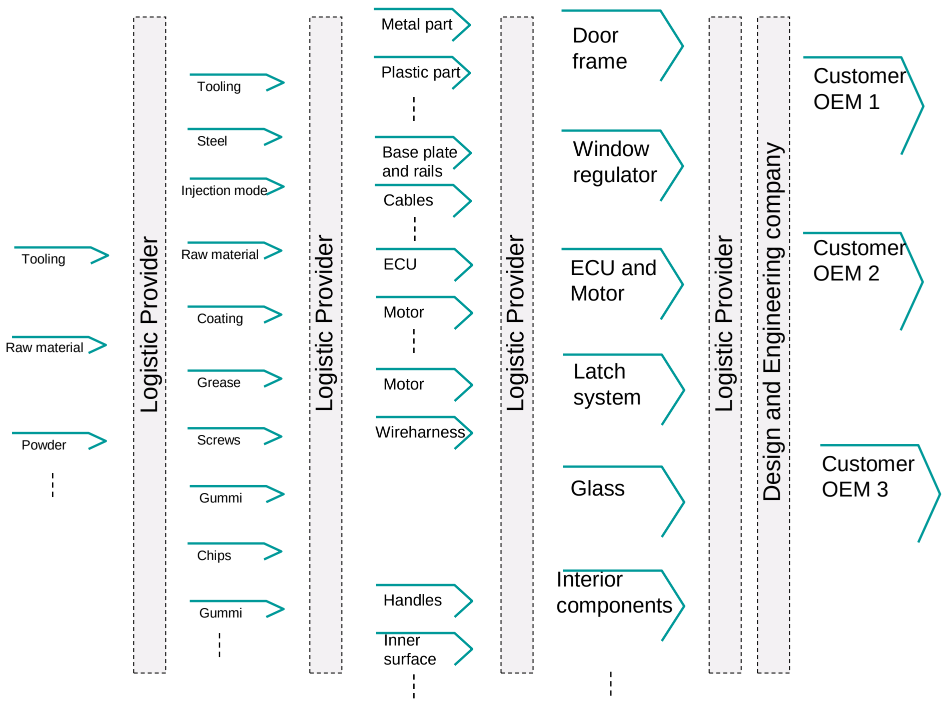

Figure 5-3 ASC Scenario I: Single Component/ Assembly Supply

In this supply chain scenario, the different components required by a door system are supplied individually to OEMs, the OEMs are responsible for the supplier management and the door system assembly in their own plants. Between Tier 1 and OEM there are logistic providers and Design and Engineering companies taking care of the logistic related issues and helping in the product and process design. These companies serve as a special tier.

Coming detailed to the door system itself, the suppliers for door frame, window regulator, ECU and motor, latch system, glass and interior components are serving as Tier 1 suppliers, the suppliers for metal and plastic parts, cables, wire harnesses, handles etc are serving as Tier 2 suppliers, furthermore the steel blank, coating, screw suppliers are considered to be the Tier 3, and the raw material suppliers are considered as Tier 4. Basically, this is the traditional way of supply tier organization.

5.1.2 ASC Scenario II: Module Supply

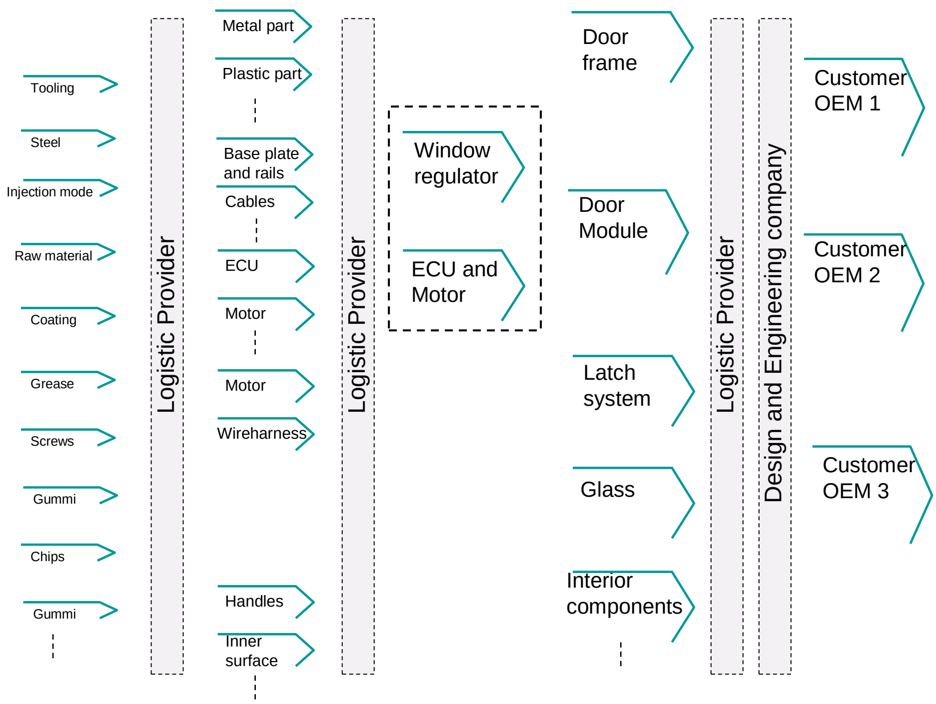

Figure 5-4 ASC Scenario II: Module Supply

In this supply chain scenario, the supply tiers are basically organized the same as in scenario I, the only difference is the Window Regulator (WR) and ECU and motor are supplied as door module instead of individual components, the door module supplier takes care of the management of WR, ECU and motor suppliers, and is a relative big system supplier.

5.1.3 ASC Scenario III: Semi-system Supply

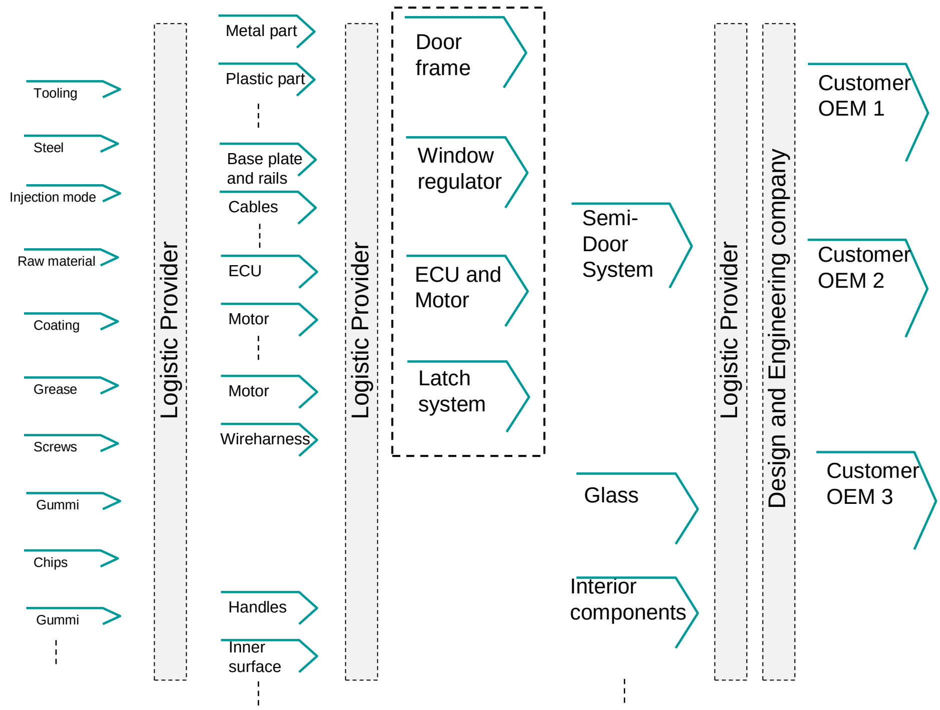

Figure 5-5 ASC Scenario III: Semi-system Supply

In this scenario the integration of Tier 1 comes to a larger extent. The door module is supplied together with door frame and latch system as Semi-door system. Rather than dealing with the component suppliers individually, the OEMs only have to manage the semi-door system supplier, and this big supplier will be managing the upstream component suppliers who used to be the OEM direct contacts before.

5.1.4 ASC Scenario IV: Complete System Supply

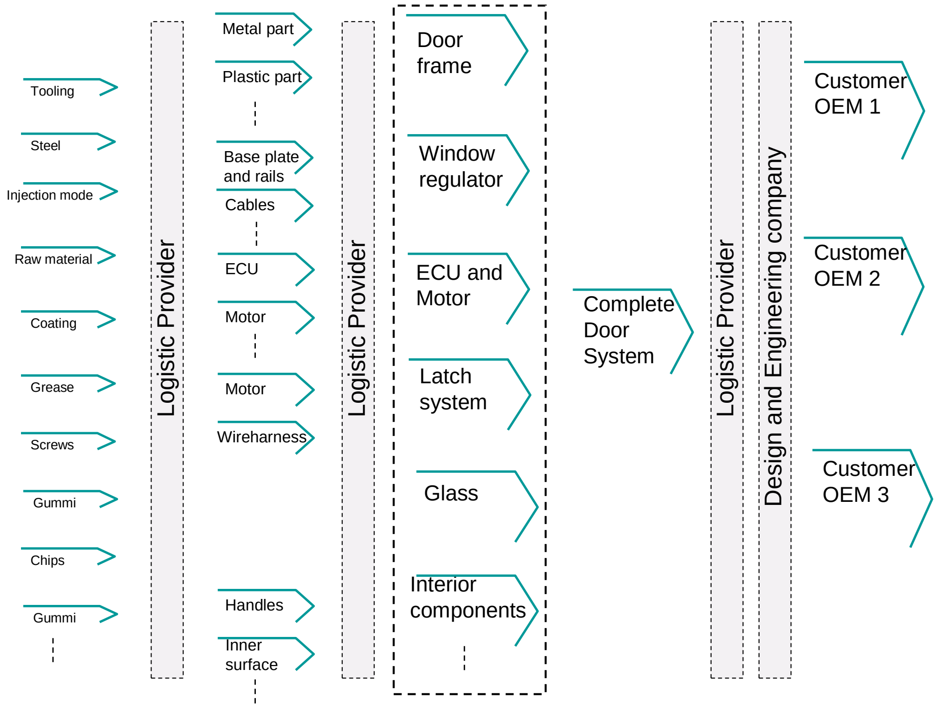

Figure 5-6 ASC Scenario IV: Complete System Supply

The last scenario to be investigated comes to a big integration – a complete door system supplier is supposed to supply the entire doors to OEMs. And this supplier is supposed to be in charge of all relevant managerial, engineering, logistic and commercial problems overall. The customers have now only 1 supplier instead of before the many suppliers for the vehicle door system. And simplified in Figure 5-7, only the complete door system supplier is considered to be Tier 1. And the previous Tier 1 component suppliers are now switched to Tier 2.

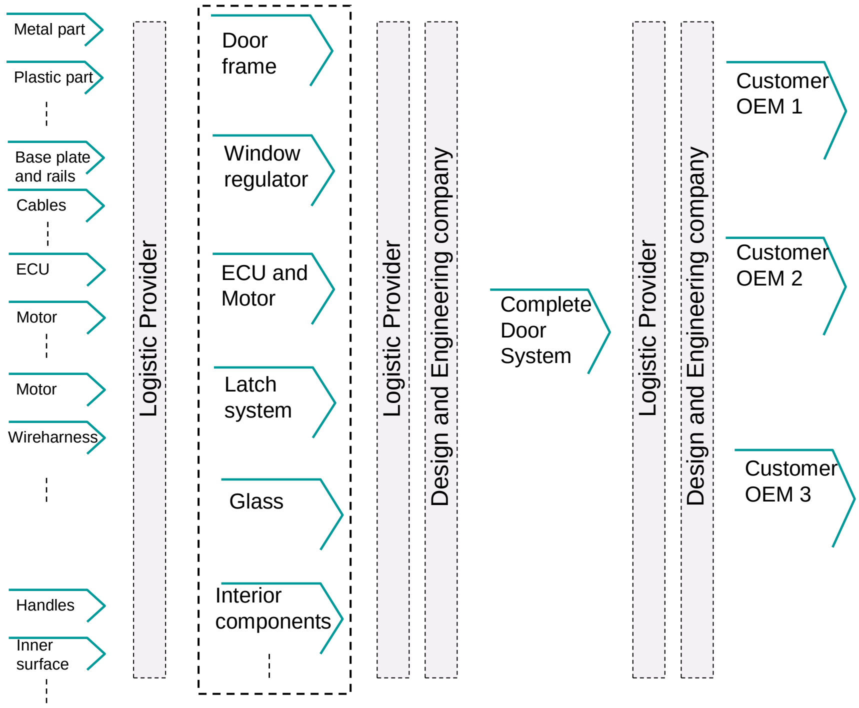

Figure 5-7 ASC Scenario IV: Complete System Supply – Simplified

5.2 Model and Index Definition

Based on the scenarios with different supply tier structures, it makes sense to know how the different tier organizations influence the SC performance. As is known, the behaviour of every participating company in the automotive supply chain can influence the upstream and downstream partners. The optimization of any single node company might conflict with each other’s strategy and cause a qualitative change of the entire supply chain. Meantime, since it is currently not possible to describe the profit allocation, the partial decision optimization might jeopardize the entire supply chain performance if the overall benefit of supply chain is not considered. Therefore, the most important evaluation standard to assess the operation results of a supply chain is the integral performance. The integral evaluation of automotive supply chain is drawing more and more emphasis and is now playing a more important role in the company management activities.

So here in this sub chapter, an integrated model will be established for a proper assessment of the entire supply chain performance in general.

5.2.1 Concept of Integrated Automotive Supply Chain Performance Evaluation

To some extend, the operation of the automotive supply chain is the process of creating or increasing the automotive supply chain value by effectively coordinating the SC participators’ activities. And the so-called “automotive supply chain performance” refers to the overall value created by SC participators. This value is created under the support of SC internal and external resources such as infrastructure, human resource and R&D,

etc. The activities of technical development, logistic management, manufacturing, sales and marketing, customer service and information techniques all together contribute to the creation process.

5.2.1.1 Evaluation System Structure

The total value mentioned is consisting of 2 parts: automotive customer value and automotive supply chain value, the former refers to the customer value gained by purchasing of an automotive product or receiving relative services; and the latter refers to the value created or added by the activities of automotive supply chain participators, which is made up by the value of individual activities and the value of collaborative activities and the capability of automotive supply chain to meet the customer requirements.

The basic target of Automotive Supply Chain (ASC) system is to supply the right item in the right quantity at the right time at the right place for the right price in the right condition (6Rs). Since the target of the performance evaluation index should be same or with positive correlation, the ASC operation target is meantime also the evaluation base of ASC performances.

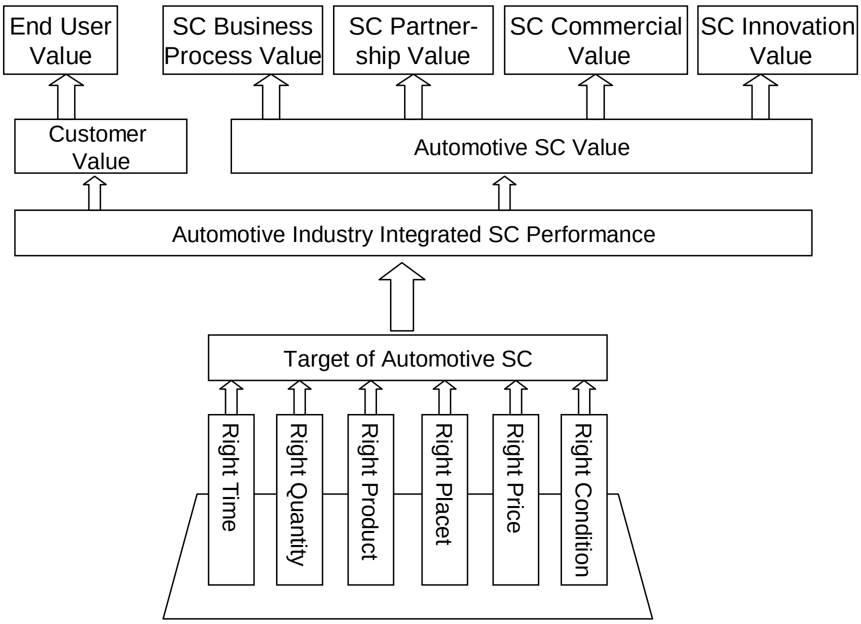

Figure 5-8 General Structure of the ASC Integrated Performance Evaluation

As shown in the above figure, customer value and SC value are defined for the ASC performance. These two values define the ASC performance level from both external and internal points of view, and are the decisive aspects of an integrated evaluation. Figure 5-8, clearly explained the evaluation structure.

5.2.1.2 Driving Force of Automotive SC Performance

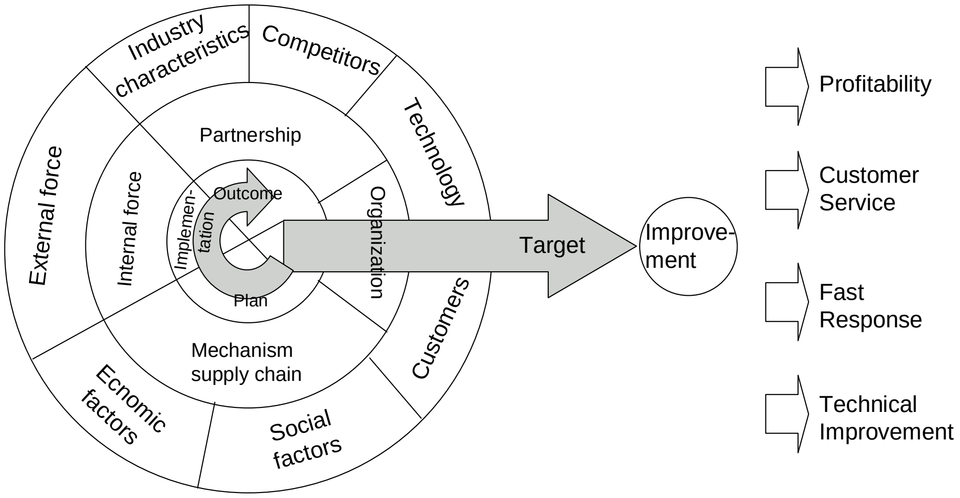

Figure 5-9 ASC Driving Force Analysis

The operation of automotive supply chain is within an always changing environment. The internal improvement is to counteract the external negative influence as offset, and increase the overall adaptability of supply chain and increase competitiveness. Figure 5-9 illustrated a feasible structure analysis, which includes the effecting external driving forces and internal driving forces. This structure reflects that the change of internal/external environment and the supply chain itself, is to support the competitive advantage through reducing cost, increasing service level, speeding up the market response, and improving technology etc. The outer two rings show the external and internal forces that influence the automotive supply chain performance, and the outcome is the result of comprehensive function of the forces.

5.2.2 Evaluation Index System

To establish an integral supply chain evaluation system, the final evaluation standard is the customer satisfaction degree and the added value. So the evaluation must be based on the main strategic supply chain target, and the evaluation system should also be able to reflect the overall supply chain operation situation and the relationship between upstream and downstream partners, especially the influence of a company at the supply chain node to it’s neighbour companies and the overall supply chain performance.

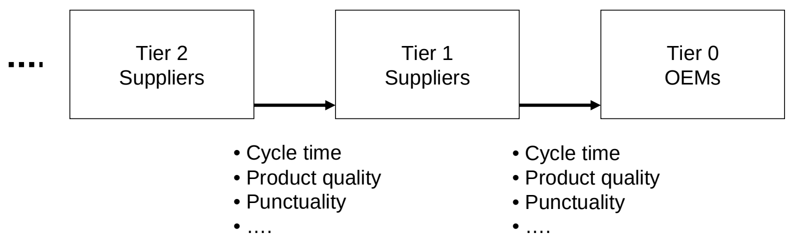

Figure 5-10 Illustration of ASC Integrated Performance Evaluation Process

An effective quantified evaluation system based on key indices, can support the companies to check their management performance, analyze the problems and improve the supply chain performance with correct measurement. The model which is going to be used should be dynamic and comprehensive, it should be able to assess the delivery time, quality, punctuality, etc, rather than only the cost and productivity, as shown in Figure 5-10, and it should also be reflecting the key criteria, be dynamic, be combinable, and be of most importance applicable.

In the next sub sections, the index system applied for the later evaluations will be introduced.

5.2.2.1 Establishing an Integrated ASC Performance Evaluation Index System

Based on the door system supply case, an integrated evaluation model with a relative comprehensive index system was developed. As shown in Figure 5-11, an evaluation index system for automotive supply chain performance is constructed, and will be detailed introduced in the following sub section.

This index system is composed of two first hierarchy indices: customer value and automotive supply chain value. The customer value is reflected by flexibility, reliability, price and quality indices, and the supply chain value is reflected by SC business process value, SC partnership value, SC commercial value and SC innovation value. In addition, the second hierarchy indices are further detailed into more evaluation indices, as show in the following figure.

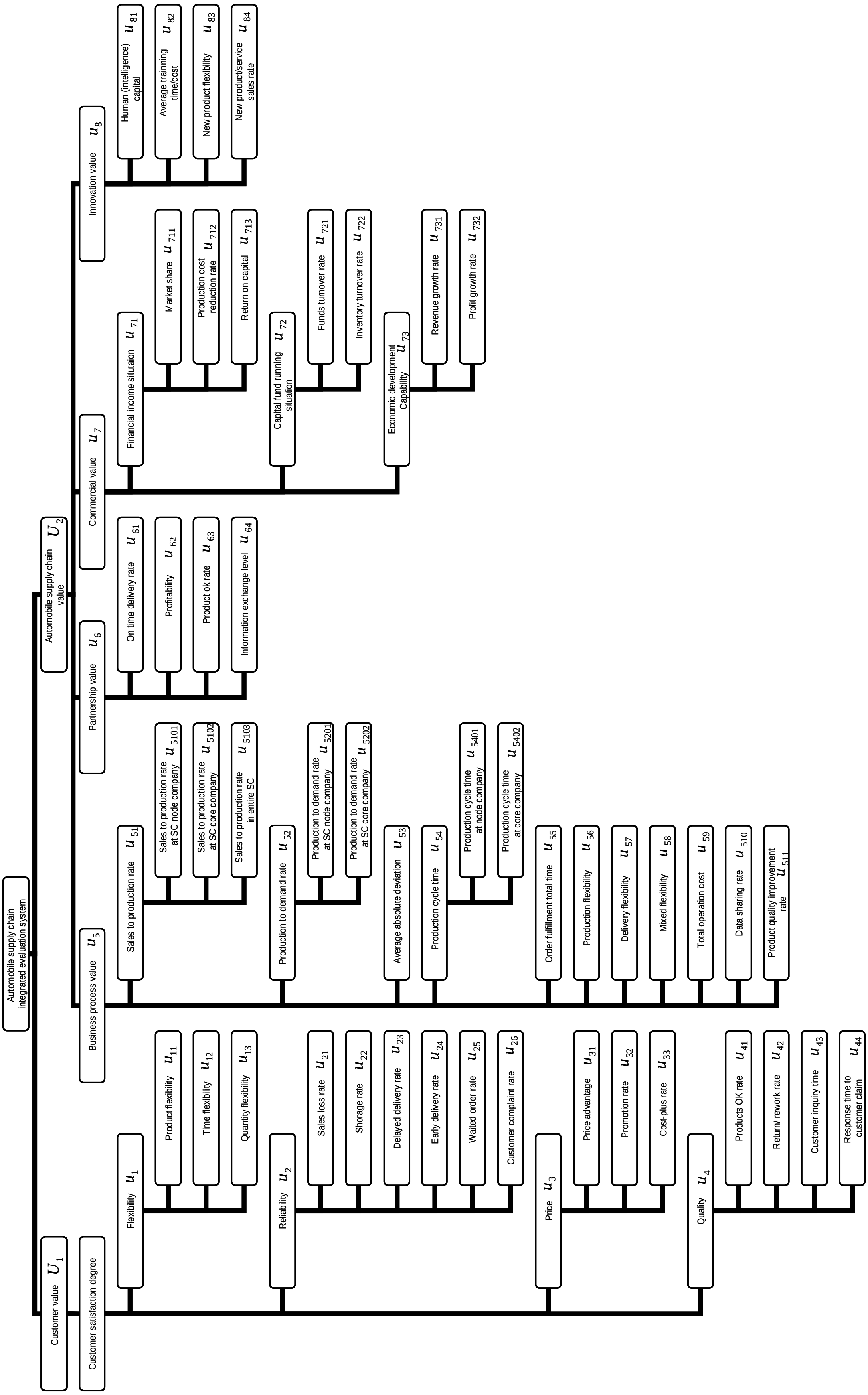

Figure 5-11 Integrated ASC PE Index System

5.2.2.2 Index Definition

According to the automotive SC evaluation concept, an evaluation index system is detailed designed as follows:

I. Customer Value (U_1)

The customer value is the external expression of the automotive supply chain performance. The customer value is the value gained by customer purchasing the products and services, and it is a very important component of the supply chain integral performance. Since customer satisfaction is the concentrated expression of customer value, therefore the customer satisfaction is considered to be the single evaluation index for customer value.

The customer satisfaction index is an index which reflects the cooperative relationship between supply chain partners, namely the comprehensive satisfaction degree of the downstream company to its upstream companies in a certain time period. The lower the satisfaction index value is, the worse the upstream companies' performances are, and the low value reflects the low productivity and management level of upstream companies, whose performance influences the normal operation of downstream customers, and will further influence the entire supply chain performance.

The customer satisfaction degree can be represented by the four second hierarchy indices: flexibility, reliability, price, and quality.

1. Flexibility u_1

1) Product flexibility

$$u_{11} = \frac{\text{new product}}{\text{total product}} * 100\% \tag{5.1}$$

with $0 \le u_{11} \le 100\%$

The product flexibility reflects the ASC's capability of producing new parts catering to the new vehicles in a certain period. By new vehicles we mean the complete new cars, substitutive new cars, and modified new cars, etc. The bigger the value is, the more product flexibility it has.

2) Time flexibility

$$u_{12} = (1 - \frac{\text{actual reaction time}}{\text{planned reaction time}}) * 100\% \tag{5.2}$$

with $0 \le u_{12} \le 100\%$

Time flexibility reflects the ASC's response time to customer needs. It includes mainly 2 aspects: response time of pre-sale and after-sale service, capability of changing delivery time in sale. The response time can be measured as the average response time of the supply chain to end customer, and the delivery flexibility can be measured by the difference between average delivery time and the minimum delivery time. The bigger the value is, the more time flexibility it has.

3) Quantity flexibility

$$u_{13} = \frac{\text{demand met by SC}}{\text{total demand}} * 100\% \tag{5.3}$$

with $0 \le u_{13} \le 100\%$

Quantity flexibility is caused by the uncertainty of demands from end customers. It reflects the supply chain's adaptive capacity to the customer demand change. It can be calculated as the ratio of the demand met by SC and the total demand. The bigger the value is, the more quantity flexibility it has.

2. Reliability u_2

1) Sales loss rate

$$u_{21} = \frac{\text{lost revenue (forecasted)}}{\text{total revenue}} * 100\% \tag{5.4}$$

with $0 \le u_{21} \le 100\%$

It reflects the situation when ASC cannot meet the defined demands. The smaller the value is, the less sales loss is, and the more reliable the supply chain is.

2) Product shortage rate

$$u_{22} = \frac{\text{shortage time (days)}}{\text{time in sale (days)}} * 100\% \tag{5.5}$$

with $0 \le u_{22} \le 100\%$

It reflects the ASC's ability of meeting the customer demands with current inventory level. The smaller the value is, the less product shortage there is, and the more reliable the supply is.

3) Delayed delivery rate

$$u_{23} = \frac{\text{number of orders delayed}}{\text{total number of orders}} * 100\% \tag{5.6}$$

with $0 \le u_{23} \le 100\%$

It reflects the ability of meeting the delivery time requirements of customers. The smaller the value is, the less delivery is delayed, and the more reliability it has.

4) Early delivery rate

$$u_{24} = \frac{\text{number of early delivered orders}}{\text{total number of orders}} * 100\% \tag{5.7}$$

with $0 \le u_{24} \le 100\%$

Together with the delayed delivery ratio, it reflects the delivery punctuality of automobile supply chain in meeting the customer requirements. The bigger the value is, the more reliable the supply chain is.

5) Waited order rate

$$u_{25} = \frac{\text{number of waited orders}}{\text{total number of orders}} * 100\% \tag{5.8}$$

with $0 \le u_{25} \le 100\%$

It reflects comprehensively the shortage and early delivery situation. The smaller the value is, the fewer orders wait, and the more reliable the supply chain is.

6) Customer complaint rate

$$u_{26} = \frac{\text{number of customer complaints}}{\text{total number of trades}} * 100\% \tag{5.9}$$

with $0 \le u_{26} \le 100\%$

It reflects the unqualified service or products ratio that offered by ASC. The smaller the value is, the less the customers complain, and the better the supply chain performs.

3. Price u_3

1) Price advantage

$$u_{31} = \left(\frac{\text{target SC revenue}}{\text{target sales quantity}} \right) \div \left(\frac{\text{reference SC revenue}}{\text{reference SC's sales quantity}} \right) * 100\% \tag{5.10}$$

with $u_{31} \ge 0$

It reflects the price comparison of the target ASC and other reference ASCs. Since it relates to many supply chains, the price should be weighted with different single products. The bigger the value is, the more price advantage it has.

2) Promotion rate

$$u_{32} = \frac{\text{number of promotions}}{\text{correnspondingpromotion time period}} \tag{5.11}$$

with $u_{32} \geq 0$

Promotion is a very important pricing strategy, and considering the diversity of promotions, the above formula simplifies the promotion ratio. Here in the later evaluation, the promotion ratio per year is taken.

3) Cost-plus rate

$$u_{33} = \frac{\text{sales price} - \text{buying price}}{\text{buying price}} * 100\% \tag{5.12}$$

with $u_{33} \geq 0$

It is the rate of price difference (selling and buying) and buying price. The bigger the value is, the more benefits there are.

4. Quality u_4

1) Products ok rate:

$$u_{41} = \frac{\text{number of ok products}}{\text{number of total products}} * 100\% \tag{5.13}$$

with $0 \leq u_{41} \leq 100\%$

It is the rate of qualified product number to the total product number. The bigger the value is, the better the quality is.

2) Return/rework rate:

$$u_{42} = \frac{\text{number of return/rework}}{\text{total sales number}} * 100\% \tag{5.14}$$

with $0 \leq u_{42} \leq 100\%$

The products with quality problems will be returned or reworked, the satisfaction degree could be calculated by analyzing the return or rework information. The smaller the value is, the better the quality is.

3) Customer inquiry time

$$u_{43} = \frac{\text{total inquiry time}}{\text{number of inquiries}} \tag{5.15}$$

with $u_{43} \geq 0$

It reflects partly of the customer service level. The information customer asked is supposed to be offered within the shortest time, therefore the shorter time it takes for the customer to get the required information, the higher the service level is. The unit here is minute.

4) Response time to customer complaints

$$u_{44} = \frac{\text{number of over targeted time problem solving}}{\text{total number of complaints}} * 100\% \tag{5.16}$$

with $0 \leq u_{44} \leq 100\%$

The response time is the time from customer complains until the complained problem is solved. The shorter this time is, the higher the customer satisfaction degree is. When quantifying this term, a target value could be set up firstly, after comparing the actual values with the set value, the actual values which are over or under targeted value are numbered and analyzed. The smaller the value is, the better the supply chain reacts to customer complaints.

II. Automotive Supply Chain Value (U_2)

5. Business process value u_5

The automotive supply chain has greatly accelerated the feedback and response to market information, under the support of Internet, Intranet and EDI techniques. In order to meet the 6R delivery target, a well organized business process should be assured, which includes the following indices:

1) Sales to production rate u_{51}

It represents the rate of sold out product quantity to the produced quantity in a certain time period. The time unit is normally “month” or “year”. And as the improvement of ASC management, the unit could be even smaller, even the “day”. Since it reflects efficiently the utilization of supply chain resources, normally the closer it is to 1, the better the SC resources are utilized, the smaller the inventory is and the better the product quality is.

And this is represented by 3 indices in detail:

a. Sales to production rate at SC node company

$$u_{5101} = \frac{\text{number of products sold at node company}}{\text{number of products produced at node company}} * 100\% \tag{5.17}$$

with $0 \leq u_{5101} \leq 100\%$

It reflects the sales-production situation at Node company in a certain time period. And the here the Node company means the up-stream supplier in the supply chain. The bigger the value is, the better the product sells.

b. Sales to production rate at SC Core Company

$$u_{5102} = \frac{\text{number of products sold at core company}}{\text{number of products produced at core company}} * 100\% \tag{5.18}$$

with $u_{5102} \geq 0$

It reflects the sales-production situation at Core Company in a certain time period. And here the Core company means the target company in research. The value could be even bigger than 100%, which means the products are from financial point of view “sold” to customers, but the customers have to wait until the product produced.

c. Sales to production rate in the entire automobile supply chain

$$u_{5103} = \frac{\text{total number of products sold}}{\text{total number of products produced}} * 100\% \tag{5.19}$$

With $u_{5103} \geq 0$

It reflects the sales-production situation of the entire ASC in a certain time period.

2) Production to demand rate u_{52}

It represents the rate of produced products to the demanded products from downstream. It reflects the demand-offer relationship between different nodes in the supply chain. And according to the “Barrel Principle”, I choose the lowest rate at the node company for the evaluation of the entire supply chain.

a. Production to demand rate at SC node company

$$u_{521} = \frac{\text{number of products produced at node company}}{\text{number of products demanded from down stream}} * 100\% \tag{5.20}$$

with $u_{521} \geq 0$

It reflects the demand-offer relationship between the upstream and downstream companies. The closer it is to 1, the better the node companies cooperate with each other and the higher the on time deliver level it has.

b. Production to demand rate at SC core company

$$u_{522} = \frac{\text{number of products produced at core company}}{\text{number of products demanded from customer}} * 100\% \quad (5.21)$$

with $u_{522} \geq 0$

It reflects the entire supply chain’s market response ability. If this index is bigger or equal to 1, the supply chain is considered to be strongly productive and fast reacting and competitive to market demand. If this index is smaller than 1, the production capacity is considered to be weak and not able to meet the customer demand.

3) Average absolute deviation u_{53}

$$u_{53} = \frac{\sum_{1}^{n} |p_i - s_i|}{\sum_{1}^{n} P_i} * 100\% \quad (5.22)$$

It reflects the inventory level of the entire automobile supply chain in a certain time period. The bigger the value is, the higher the inventory level is and the higher the inventory cost is.

In the above formula, n is the number of node companies, p_i is the produced quantity of i^{th} Node company in a certain time period, and s_i is the sales quantity of i^{th} Node company.

4) Production cycle time u_{54}

It reflects the tact time and production interval of a certain product in a mixed production line in the node/ core company. As illustrated in the following figure, the cycle time is normally referred to as the production interval time for the same product.

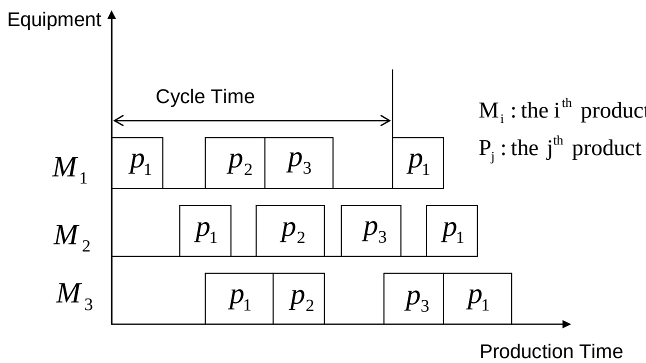

Figure 5-12 Production Cycle Time

As this cycle time index reflects the response degree of a node company to its downstream company, in the actual evaluation, the node with longest cycle time is chosen to evaluate the product cycle time in the entire supply chain. The following two indices are taken into account in detail:

a. Production cycle time at node company u_{541}

$$\begin{aligned} u_{541} &= \text{time product p batch (i) is produced} - \\ &\text{time product p batch (i} - 1\text{) is produced (at node company)} \end{aligned} \tag{5.23}$$

The shorter the cycle time is, the better respond the node company is to its downstream companies.

b. Production cycle time at core company u_{542}

$$\begin{aligned} u_{542} &= \text{time product p batch (i) is produced} - \\ &\text{time product p batch (i} - 1\text{) is produced (at core company)} \end{aligned} \tag{5.24}$$

To reduce the cycle time of the core company, several measures should be taken: 1. cope the node company's cycle time with Core Company and cope the core company's cycle time with customer demand; 2. use the optimized production plan or efficient production facility or overwork to shorten the node/core company's cycle time. Among which the production plan optimization is the best choice since it doesn't require additional investment.

5) Order fulfilment total time u_{55}

$$u_{55} = \text{time of order end} - \text{time of order start} \tag{5.25}$$

This index reflects the total response time to customer orders of the entire supply chain. The shorter it is, the more sensitive the supply chain is to the customer requirement, and the more favourable it is to reduce the customer cost and increase the customer value.

6) Production flexibility u_{56}

Flexibility is a very important index of measuring the adaptive capability of a supply chain to the changing environment. It reflects how capable the automobile supply chain is when the customer demands change.

Assuming the customer demand d obeys normal distribution, namely $d \sim N(\mu, \sigma^2)$, Q_{min} and Q_{max} are defined as the minimum and maximum production that brings profits in a certain time period; we assume d_t is the customer demand at time period t, N is the considered time period, and then the average demand d' and the demand variance S_d^2 are calculated as following:

$$d' = \sum_{i=1}^{N} d_i / N_i \tag{5.26}$$

$$S_d^2 = \sum_{i=1}^{N}(d_t - d')^2/N - 1 \tag{5.27}$$

So the production flexibility is represented by the probability of customer demand within the production scope as:

$$u_{56} = P(Q_{min} \le d \le Q_{max}) \tag{5.28}$$

$$u_{56} = \frac{\phi[Q_{max} - d'] - \phi[Q_{min} - d']}{S_d} \tag{5.29}$$

7) Delivery flexibility u_{57}

$$u_{57} = \sum_{m=1}^{n}(L_m - E_m)/\sum_{m=1}^{n}(L_m - t^*) \tag{5.30}$$

The unplanned volume caused by the market demand variation will increase the time for supply chain internal reorganization, plan, and production. The delivery flexibility reflects the node company's capability of adjusting the delivery time, and to adapt the sudden important orders and special orders. We assume t^* is the time when the node company gets the order, L_m represents the latest time when work m ($m = 1,2,...,n$) has to be finished, E_m represents the earliest finishing time of work m, so the delivery flexibility can be represented by the ratio of unoccupied time within the delivery time and the total delivery time.

8) Mixed flexibility u_{58}

$$u_{58} = \frac{\sum_j \sum_i T_{ij}}{N(t)} \tag{5.31}$$

This index is used to evaluate the products variation scope and response time in certain time period. The mixed flexibility includes products mixing flexibility scope (e.g. different product volume in certain time) and mixing flexibility response (e.g. the time to produce new products).

In the mixing flexibility scope calculation, N(t) represents the volume of different product type produced in time period t, and $t > 0$.

The mixing flexibility response time can be calculated as T_{ij}, which represents the time to change from product i to product j.

9) Total cost/revenue u_{59}

$$u_{59} = \text{purchasing cost} + \text{inventory cost} + \text{information cost} + \text{transportation cost} + \text{quality cost} + \ldots \tag{5.32}$$

It includes the purchasing cost, inventory cost, information cost, transportation cost and quality cost, etc along the entire supply chain. And by this index, the effectiveness and cost intensification of supply chain are reflected.

10) Data sharing rate u_{510}

$$u_{510} = \frac{\text{actual volume of shared data in ASC}}{\text{volume of data to be shared in ASC}} * 100\% \tag{5.33}$$

It represents the percentage of the shared data to the total data that are supposed to be shared of the entire automotive supply chain. Information sharing is a very important character that the ASC works cooperatively and is the key point of maintaining a successful partnership in ASC. The content of important information share represents the supply chain management degree of the related companies in the chain. The shared information includes: demand forecast, sales data, production plan, strategic direction, and customer target, etc, to realize the integration of the companies in automotive supply chain.

11) Product quality improvement rate u_{511}

$$u_{511} = \text{ok rate of product p in batch (i)} - \text{ok rate of product p in batch (i} - 1) \tag{5.34}$$

6. Partnership value u_6

Whether an ASC could succeed or not lies greatly on the cooperation of the node companies. The satisfaction degree is a very important factor to maintain the supply chain stable and developing, and to improve the entire chain performance. The relationship between the adjacent node companies means the satisfaction degree to its adjacent upstream or downstream company, which includes the following indices:

1) On time delivery rate u_{61}

$$u_{61} = \frac{\text{number of times of on time delivery}}{\text{total delivery number of times}} * 100\% \tag{5.35}$$

It refers to the percentage of on time delivery to the total delivery times from upstream company to a certain node company. The on time delivery situation reflects the cooperation capability among companies.

2) Profitability u_{62}

$$u_{62} = \frac{\text{profit product unit}}{\text{total cost product unit}} * 100\% \tag{5.36}$$

It refers to the percentage of pure profit of product/service unit to the total cost of product/service unit at the supply chain node companies. It reflects the profiting capability and managing level of upstream companies. The higher the index value is, the stronger the upstream company's profiting ability is and the higher managing level it has.

3) Product ok rate u_{63}

$$u_{63} = \frac{\text{quantity ok products}}{\text{total quantity offered}} * 100\% \tag{5.37}$$

It refers to the percentage of qualified product/service to the total product/service offered by the node companies, and it reflects the quality level of a supplier. The lower the value is, the worse the supplier's quality level is, and the on time delivery rate could be effected by the rework etc, and the total cost will also be increased and correspondingly decrease the profitability rate.

4) Information exchange level u_{64}

$$u_{64} = \frac{\text{exchanged infomation}}{\text{total information to be exchanged}} * 100\% \tag{5.38}$$

It is used to evaluate the degree of information communication between upstream and downstream companies.

6. Commercial value u_7

1) Financial income situation u_{71}

a. Market share

$$u_{711} = \frac{\text{product offered by supply chain i}}{\text{product offered by same type companies}} * 100\% \tag{5.39}$$

b. Product cost reduction rate u_{712}

$$u_{712} = \frac{\text{product cost in previous period} - \text{product cost in current period}}{\text{product cost in previous period}} * 100\% \tag{5.40}$$

c. Return on capital u_{713}

$$u_{713} = \frac{\text{profit of supply chain members}}{\text{asset occupancy}} * 100\% \tag{5.41}$$

It refers to the average occupancy percentage of profit to the automotive supply chain asset. And it reflects the scope of value adding performance after using the assets.

2) Capital fund running situation u_{72}

a. Funds turnover rate u_{721}

$$u_{721} = \frac{\text{turnover of funds}}{\text{occupation of capital}} * 100\% \quad (5.42)$$

It refers to the percentage of funds turnover to the occupation of capital in a certain time period, and it is a key index which links the entire process of ASC, and is used to evaluate the capital turnover situation in raw material, labour, semi-finished products and finished products in the supply chain. The automobile supply chain works by applying advanced IT and products, and collaborating cooperative partnership to achieve a faster capital turnover.

b. Inventory turnover rate u_{722}

$$u_{722} = \frac{\text{inventory turnover}}{\text{total inventory}} * 100\% \quad (5.43)$$

It reflects the inventory situation in the automotive supply chain. The bigger the value is, the shorter time the products are stored, and the stronger the supply chain operation capacity is.

3) Economic development capability u_{73}

a. Revenue growth rate u_{731}

$$u_{731} = \frac{\text{turnover of current period} - \text{turnover of previous period}}{\text{turnover of current period}} * 100\% \quad (5.44)$$

It reflects the sales increase in a certain period compared with that of the previous period. The bigger the index value is, the more efficient the supply chain works.

b. Profit growth rate u_{732}

$$u_{732} = \frac{\text{profit current period} - \text{profit previous period}}{\text{profit previous period}} * 100\% \quad (5.45)$$

It refers the profit increase in a certain period compared with that of the previous period. It reflects the value adding performance.

7. Innovation value u_8

1) Human (intelligence) capital u_{81}

$$u_{81} = \frac{\text{intangible assets} + \text{human capital}}{\text{total capital}} * 100\% \tag{5.46}$$

It refers to the ratio that intangible assets and human capital together occupies in the automobile supply chain. It reflects to some extent the long-term development capacity of a company.

2) Average training time/cost u_{82}

$$u_{82} = \frac{\sum \text{training time} * \text{number of trained staff}}{\text{total number of staff}} \tag{5.47}$$

or

$$u_{82} = \frac{\text{total training cost}}{\text{total number of staff}} \tag{5.48}$$

It refers to the ratio of the total training time and training cost to the total number of employees in a certain time period. It reflects a company's sense of knowledge oriented organization, and the company's performance of key reform. It is very important to an automotive company for its sustainable developing ability.

3) New product flexibility u_{83}

$$u_{83} = \frac{C}{C_t} * 100\% \tag{5.49}$$

It refers to the difficulty for a new product to be accepted by automotive supply chain, and it is summarized in time aspect and cost aspect.

The new product flexibility based on time can be represented as T_c, which is the time to introduce a new product. The new product flexibility based on cost can be represented as C_t, which is the cost to introduce a new product, with $T \geq 0$, $C \geq 0$. The u_{83} is represented as above the formula (5.49), where the C is product unit cost. The bigger the ratio is, the more flexible a new product is introduced.

4) Sales rate new product (service) u_{84}

$$u_{84} = \frac{\text{new product (service) turnover}}{\text{total turnover}} * 100\% \tag{5.50}$$

It refers to the percentage of new product (service) turnover to the total turnover in an ASC in a certain time period. It reflects the R&D capability and comprehensive sales ability of new product (service) in supply chain. The bigger the value is, the stronger the R&D and sales ability the supply chain has.

In general, the evaluation index system is constructed with all the elements introduced above. In order to precisely and comprehensively evaluate the automotive supply chain, and increase the ASC efficiency, some more emphasis should be put on to the following questions:

a) To have the information shared among supply chain participators as much as possible, and therefore make sure the data accuracy and being updated. The evaluation result should be kept accurate and objective based on the quantitative data analysis;

b) To update and improve the evaluation system according to the changing reality;

c) To combine the internal evaluation system with the integrated system effectively;

d) To understand the evaluation results correctly and convert the result into business intelligence which should contribute to the companies' decision making as reference.

5.3 Automotive Supply Chain Performance Evaluation Algorithm

The method used for ASC performance evaluation is defined as Multilevel Dynamic Fuzzy Integrated Evaluation (MDFIE). This method is the comprehensive utilization of AHP (Analytic Hierarchy Process) and FEP (Fuzzy Evaluation Process). In order to more correctly evaluate the supply chain performances, both qualitative and quantitative factors have to be considered and a trade-off between the tangible and intangible factors has to be made. As defined in the previous sub-chapter, it is obvious that the system to be dealt with is of multiple criteria and multilevel hierarchies. Based on the research from many scholars, the MDFIE is then defined to evaluate the objective automotive supply chain scenarios in this work.

5.3.1 Previous Research on AHP and FEP

The application of either AHP or FEP supporting decision making has been studied since decades, based on mathematics and psychology, the AHP was developed by Saaty in the 1970s and has been extensively studied and refined since then. Saaty introduced AHP as "a multicriteria decision making approach in which factors are arranged in a hierarchic structure"[Saa 90]. Ghodsypour and O'Brien used AHP for supplier selection [GO 98]. And Mon et. al proposed a new and general decision making method for evaluating weapon systems using fuzzy AHP based on entropy weight, against the traditional use in crips (Non-fuzzy) decision applications [MCL 94].

An AHP hierarchy is a structured means of modeling the problem at hand. It consists of an overall goal, a group of options or alternatives for reaching the goal, and a group of factors or criteria that relate the alternatives to the goal. The criteria can be further broken down into subcriteria, sub-subcriteria, and so on, in as many levels as the problem requires.

The first step in the Analytic Hierarchy Process is to model the problem as a hierarchy. In doing this, the aspects of the problem are explored at levels from general to detailed, and then expressed in the multileveled way that the AHP requires. The design of any AHP hierarchy does not depend only on the nature of the problem, but also on the knowledge, judgments, values, opinions, needs, wants, etc. of the participants in the process. In my thesis work, the automotive supply chain values are interesting and the hierarchical index system is then designed based on this interest.

And as for FEP, Mikhailov and Tsvetinov [MT 04] proposed a fuzzy prioritisation method using fuzzy pairwise comparison judgements rather than exact numerical values of the comparison ratios, which then transforms the initial fuzzy prioritisation problem into a non-linear program. Jin et. al [JWD 04] proposed a so called FCE-AHP method (analytic hierarchy process - fuzzy comprehensive evaluation), which is used to check and correct the inconsistency of judgment matrix by means of accelerated genetic algorithm, and offered the way of calculating element weights according to the fuzzy relative membership degree matrix of single evaluation index. Li [Li 01] constructed a decision matrix and proposed a practical “proportional scaling method” for evaluating mailing system. In general, the key process of FEP, is the identification of fuzzy membership degree. Since the application of FEP is stable and universal, it can be used for evaluating options and alternatives in different industries, as long as proper indices and factors are chosen [JDW 04].

Another principle used in this work is the maximum membership principle. Membership functions were firstly introduced by Zadeh [Zad 65], and according to his definition, the membership function of a fuzzy set is a generalization of the indicator function in classical sets. In fuzzy logic, it represents the degree of truth as an extension of valuation, and different from probabilities, fuzzy truth represents membership in vaguely defined sets, instead of likelihood of some event or condition. Civanlar and Trussell [CT 86] presented a guideline to construct the membership functions for fuzzy sets whose elements have a defining feature with a known probability density function in the universe of discourse, and Cheng [Che 97] evaluated missile systems by fuzzy AHP based on the grade value of membership function. From the study of previous researches, it can be seen that the membership function has been applied in many different industries and fields, and the final evaluation judgements of my work, is then also made according to the maximum membership principle.

Most of the previous researches make the so called comprehensive evaluation of multi level systems by simply combining the AHP method and FEP method together. It works well when the system is not big, and the dynamic characteristics don’t count much to the evaluation results. And it is also noticed, these evaluation methods have been applied in many different fields and industries, but not quite used in supply chain evaluation. On one hand, supply chain is rather a complicated system, especially in our reference case the automotive supply chain, it requires not only deep understanding of supply chain management itself, but also profound knowledge of the automotive industry; On the other hand, the dynamic characteristics count much to the automotive supply chain performance, this again requires a comprehensive index system which should reflect at least all the important features. Therefore, building up a proper index system is one of the key factors for successful performance evaluation, and applying a proper algorithm is another key factor. The index system has been built up in the previous sub chapter, and in the following section, the MDFIE (Multilevel Dynamic Fuzzy Integrated Evaluation) will be introduced – an algorithm defined especially for this thesis work.

5.3.2 Algorithm of MDFIE

As mentioned before, the method used in this work is developed on the basis of AHP and FEP. To explain the algorithm clearly, the procedure of applying the evaluation model will be firstly introduced, and then how to realize the evaluation functionally will also be explained.

5.3.2.1 MDFIE Model Application Procedure

In this evaluation, it's important to avoid taking the indices as constants, and also avoid taking the data from certain point of time to represent the performance of a long time period. If this representativeness cannot be avoided, then the parameters with most proper scales are to be chosen. In order to assess the ASC performance more properly and more actually, the evaluation should take the supply chain dynamics into consideration, and in addition, the evaluation results are supposed to be adjustable according to the indices at different time points. Besides, a time parameter K is also introduced, which in this door supply chain case should rather be called the scenario parameter. Although the integrated performance of the 4 scenarios won't be analyzed in the later calculation, considering the possible application for other cases, it is still quite an important parameter from my point of view. So based on the index system and the other necessary parameters, the performance of different scenarios at different time periods can be investigated and evaluated with the model shown as in Figure 5-13, namely the Multilevel Dynamic Fuzzy Integrated Evaluation model.

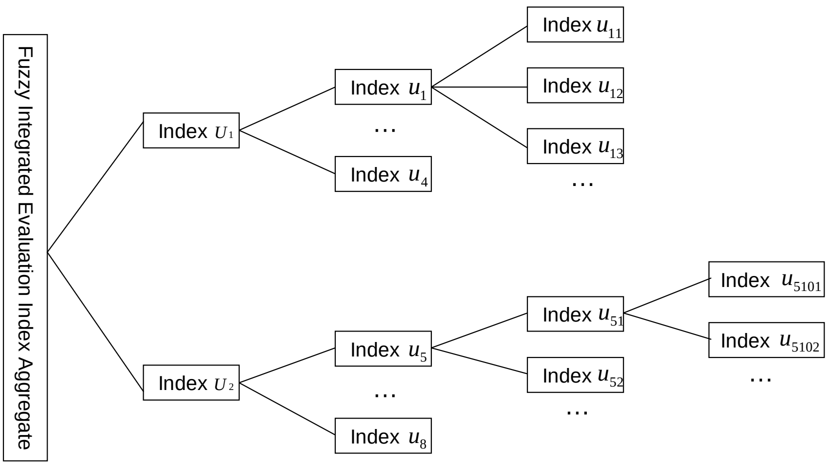

Figure 5-13 MDFIE Model

The procedure of applying the MDFIE is then introduced as following:

1. Establish the index aggregate U and the evaluation aggregate V

According to Figure 5-13, an evaluation system of 4 hierarchies is applied, which is the index aggregate U in the later discussions. And the evaluation results are rated with 5 levels: "Very good", "good", "ok", "bad", and "very bad", which make up the evaluation aggregate V.

2. Calculate evaluation matrix R

The evaluation indices are categorized into quantitative indices and qualitative indices, and the evaluation matrix R is defined correspondingly by 2 different methods.

1) Evaluation of quantitative indices

The evaluation matrix $R = [r_{ijk}]$ of time period K, namely scenario K, can be decided by membership function $r_{ijk} = \mu(X)$.

2) Evaluation of qualitative indices

It is difficult to quantify the qualitative indices, therefore the fuzzy statistic method is used. The evaluation experts or specialized evaluation team are required to assess the indices according to predefined evaluation categories, and the frequency N_{ij}, which is the frequency that the evaluation results fall into the category V_j, is collected and from which $\mu(U_i)$ can be calculated as $\mu(U_i) = N_{ij}/n$, where: n is the number of experts who evaluate; $\mu(U_i)$ is the membership function that reflects the membership of V_i to the category V_j, which is called the single evaluation of index U_i.

3) Calculate evaluation matrix R

The evaluation matrix R can be summarized based on the above calculation of the quantitative and qualitative indices.

3. Define the weightings of indices W

Though the indices shown in Figure 5-11 can reflect the ASC from a certain aspect, the importance of every index to the entire ASC performance differs from one another. Thus the coefficients to reflect the different importance of every index should be allocated, namely the “weightings”. The weightings can be defined by many different methods, e.g. by experiences, direct evaluates, or AHP, ect. And in this work, the weightings are defined by experience, namely according to the working experiences in automotive companies and interviews with automotive supply chain engineers.

4. Integrated Evaluation

The calculation is done according to Figure 5-13 from right to left, from the 4th hierarchy to 3rd hierarchy and step by step finally the evaluation result B_k is calculated as

$$B_k = W \cdot R = (b_{1k}, b_{2k}, b_{3k}, b_{4k}, b_{5k}) \tag{5.51}$$

$$B = \sum_{k=1}^{4} \lambda_k \cdot B_k = (b_1, b_2, b_3, b_4, b_5) \tag{5.52}$$

Where the λ_k is the weighting of different time period, and $\sum \lambda_k = 1$; b_1, b_2, b_3, b_4, b_5 are the integrated evaluation value of different hierarchies.

However, for our model, the overall performance of the 4 scenarios in general is not really making sense for the comparison, so final B is not going to be calculated. But for other cases when the integrated evaluation generally reflects for example the performance of different time periods, this result could be very meaningful, and to a certain extent, this can even be treated as another hierarchy.

The detailed calculation process is explained in Figure 5-14 in next section.

5.3.2.2 Functional Realization of MDFIE

It is relative complicated to apply the MDFIE for evaluation of supply chain performance, and it is also a reverse calculation process. As mentioned before, to reduce the calculation complexity, the index weightings are defined by experiences, and the algorithm is illustrated in the following chart.

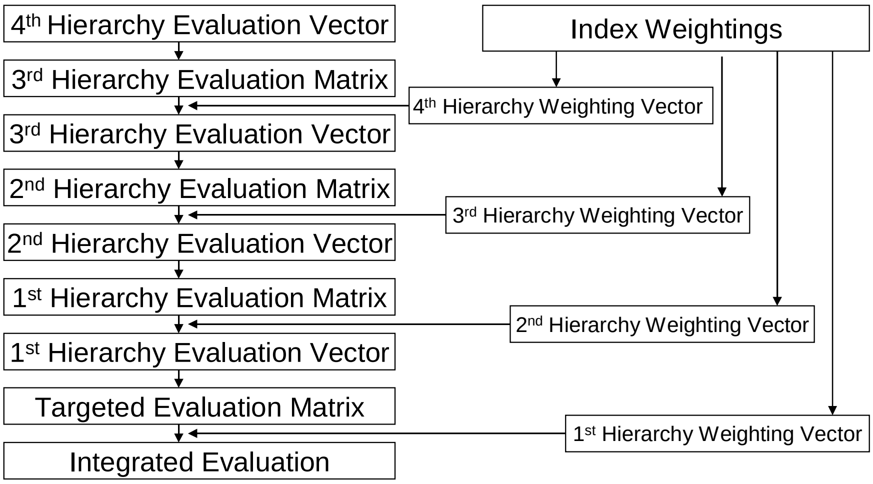

Figure 5-14 Algorithm of MDFIE Process

The 4th hierarchy evaluation vectors make up an evaluation matrix of 3rd hierarchy, this matrix is then fuzzy multiplied with 4th hierarchy weighting vector, and the result from this fuzzy composition is the 3rd hierarchy evaluation vector. The 2nd hierarchy matrix and vector, 1st hierarchy matrix and vector, in the end the final evaluation can be all calculated in the same way.

The basis curl for the fuzzy multiplication is illustrated as:

$$\mathrm{p}_{\mathrm{j}} = \mathrm{w}_{\mathrm{i}} \circ \mathrm{R}_{\mathrm{j}} = (w_1 \wedge r_{1j}) \vee (w_2 \wedge r_{2j}) \vee \ldots \vee (w_n \wedge r_{nj}) = \vee[w_i \wedge r_{ij}]$$

5.4 Automotive Supply Chain Performance Evaluation Realization

In this sub chapter, the corresponding data regarding the vehicle door system supply chains are collected and processed in section 5.4.1. By applying the MDFIE method, the 4 different ASC scenarios are then integrally evaluated in section 5.4.2, and by analyzing the performance assessment results with membership degree function, the different scenarios are compared in general.

5.4.1 Data Collection

According the automotive supply chain performance evaluation index system, the data of the 4 scenarios introduced before are collected in this section, and the data are summarized and processed as in table 5-1 and 5-2:

Table 5-1 Customer Satisfaction Degree Statistics

Customer Satisfaction Degree					
		ASC I	ASC II	ASC III	ASC IV
Flexibility u_1	Product flexibility u_{11}	0,1%	0,15%	0,25%	0,3%
	Time flexibility u_{12}	0,1%	0,2%	0,4%	0,4%
	Quantity flexibility u_{13}	90%	92%	95%	96%
Reliability u_2	Sales lost rate u_{21}	0,9%	0,6%	0,2%	0,1%
	Product shortage rate u_{22}	0,8%	0,6%	0,2%	0,1%
	Delayed delivery rate u_{23}	1,1%	0,9%	0,4%	0,2%
	Early delivery rate u_{24}	1,2%	1,5%	2%	3%
	Waited order rate u_{25}	1,5%	1,2%	0,6%	0,3%
	Customer complaint rate u_{26}	0,5%	0,4%	0,2%	0,1%
Pricing u_3	Price advantage u_{31}	70%	80%	85%	90%
	Promotion rate u_{32} (per year)	0,5	0,5	1	1
	Cost-plus rate u_{33}	10%	15%	18%	20%
Quality u_4	Products ok rate u_{41}	95%	96%	98%	99%
	Return/rework rate u_{42}	0,8%	0,5%	0,2%	0,1%
	Customer inquiry time u_{43} (min)	50	45	30	20
	Response time to customer complaints u_{44}	3%	2,7%	1,2%	1%

Table 5-2 Automotive Supply Chain Value Statistics

Automobile Supply Chain Value						
			ASC I	ASC II	ASC III	ASC IV
Business process value u_5	Sales to production rate u_{51}	u_{5101}	96%	97%	98%	99%
		u_{5102}	98%	101%	105%	108%
		u_{5103}	97%	99%	101%	103%
	Production to demand rate u_{52}	u_{521}	100%	100%	100%	100%
		u_{522}	90%	92%	96%	98%
	Average absolute deviation u_{53}		8%	5%	3%	1,5%
	Production cycle time u_{54}	u_{541} (h)	30	26	22	17
		u_{542} (h)	42	38	31	25
	Order fulfilment total time u_{55}		45	40	30	26
	Production flexibility u_{56}		0,18%	0,2%	0,25%	0,4%
	Delivery flexibility u_{57}		0,2%	0,3%	0,5%	0,6%
	Mixed flexibility u_{58} (min)		18	15	10	8
	Total operation cost u_{59} (mil €)		6	8	12	12.5
	Data sharing rate u_{510}		60%	75%	88%	94%
	Product quality improvement rate u_{511}		1%	2%	3%	5%
Partnership value u_6	On time delivery rate u_{61}		85%	90%	95%	98%
	Profitability u_{62}		9%	11%	12,5%	15%
	Product ok rate u_{63}		90%	93%	98%	99%
	Info communication level u_{64}		60%	75%	95%	98%
Commercial value u_7	Financial income situation u_{71}	u_{711}	2%	3%	6%	9%
		u_{712}	8%	12%	18%	20%
		u_{713}	10%	16%	25%	30%
	Capital fund running situation u_{72}	u_{721}	70%	75%	80%	90%
		u_{722}	70%	78%	82%	88%
	Economic development capability u_{73}	u_{731} (per year)	10%	15%	25%	30%
		u_{732} (per year)	10%	20%	25%	30%
Innovation value u_8	Human capital u_{81}		10%	20%	35%	45%
	Average training time u_{82} (h/year)		100	120	150	180
	New product flexibility u_{83}		0,1%	0,12%	0,2%	0,3%
	Sales rate new product/service u_{84}		98%	99%	99%	99%

The data of different supply chain scenarios which have been described before are collected and processed based on the ASC integrated performance evaluation index system. Most of those data come from the ERP data base, including the production management database, sales database, and customer relationship management data base, etc.

5.4.2 Application of MDFIE on the Case of Vehicle Door Supply Chains

Then the MDFIE process is applied to evaluate the supply chains according to the evaluation index system, and the automotive supply performance evaluation is here considered as a 4 hierarchy integrated evaluation problem. Here the evaluation for supply chain scenario I is firstly made:

1. Establish the evaluation aggregate V and index aggregate U

The evaluations are divided into 5 levels: very good, good, ok, bad, very bad

$$V = \{V_1\ (\text{very good}),\ V_2\ (\text{good}),\ V_3\ (\text{ok}),\ V_4\ (\text{bad}),\ V_5\ (\text{very bad})\} \tag{5.53}$$

The 4 hierarchy index system is constructed as follows:

1) Hierarchy 1

$$U = \{U_1, U_2\} \tag{5.54}$$

2) Hierarchy 2

a. $$U_1 = \{u_1, u_2, u_3, u_4\} \tag{5.55}$$
b. $$U_2 = \{u_5, u_6, u_7, u_8\} \tag{5.56}$$

3) Hierarchy 3

a. $$u_1 = \{u_{11}, u_{12}, u_{13}\} \tag{5.57}$$
b. $$u_2 = \{u_{21}, u_{22}, u_{23}, u_{24}, u_{25}, u_{26}\} \tag{5.58}$$
c. $$u_3 = \{u_{31}, u_{32}, u_{33}\} \tag{5.59}$$
d. $$u_4 = \{u_{41}, u_{42}, u_{43}, u_{44}\} \tag{5.60}$$
e. $$u_5 = \{u_{51}, u_{52}, u_{53}, u_{54}, u_{55}, u_{56}, u_{57}, u_{58}, u_{59}, u_{510}, u_{511}\} \tag{5.61}$$
f. $$u_6 = \{u_{61}, u_{62}, u_{63}, u_{64}\} \tag{5.62}$$
g. $$u_7 = \{u_{71}, u_{72}, u_{73}\} \tag{5.63}$$
h. $$u_8 = \{u_{81}, u_{82}, u_{83}, u_{84}\} \tag{5.64}$$

4) Hierarchy 4

a. $$u_{51} = \{u_{5101}, u_{5102}, u_{5103}\} \tag{5.65}$$
b. $$u_{52} = \{u_{521}, u_{522}\} \tag{5.66}$$
c. $$u_{54} = \{u_{541}, u_{542}\} \tag{5.67}$$

d. $u_{71} = \{u_{711}, u_{712}, u_{713}\}$ (5.68)

e. $u_{72} = \{u_{721}, u_{722}\}$ (5.69)

f. $u_{73} = \{u_{731}, u_{732}\}$ (5.70)

2. Calculate the evaluation matrix R

An evaluation group is organized with specialists, suppliers, customers, quality engineers and financial inspectors, etc. Based on the original data, an evaluation is firstly made to the 4th Hierarchy. Evaluation vector p_j is calculated by using membership function, and thus result in the evaluation matrix R_j.

The score is marked as following according to the statistics of the first supply chain:

Evaluation vector of u_{5101}: $p_{5101} = (0{,}1 \quad 0{,}5 \quad 0{,}3 \quad 0{,}1 \quad 0)$ (5.71)

Evaluation vector of u_{5102}: $p_{5102} = (0{,}1 \quad 0{,}2 \quad 0{,}5 \quad 0{,}2 \quad 0)$ (5.72)

Evaluation vector of u_{5103}: $p_{5103} = (0{,}1 \quad 0{,}2 \quad 0{,}5 \quad 0{,}1 \quad 0{,}1)$ (5.73)

By combining p_{5101}, p_{5102}, and p_{5103}, the evaluation matrix is then got:

$$R_{51} = \begin{bmatrix} 0{,}1 & 0{,}5 & 0{,}3 & 0{,}1 & 0 \\ 0{,}1 & 0{,}2 & 0{,}5 & 0{,}2 & 0 \\ 0{,}1 & 0{,}2 & 0{,}5 & 0{,}1 & 0{,}1 \end{bmatrix} \tag{5.74}$$

In the same way, following evaluation matrices could be got:

$$R_{52} = \begin{bmatrix} 0{,}2 & 0{,}5 & 0{,}3 & 0 & 0 \\ 0{,}1 & 0{,}4 & 0{,}4 & 0{,}1 & 0 \end{bmatrix} \tag{5.75}$$

$$R_{54} = \begin{bmatrix} 0{,}3 & 0{,}4 & 0{,}2 & 0{,}1 & 0 \\ 0{,}4 & 0{,}4 & 0{,}1 & 0{,}1 & 0 \end{bmatrix} \tag{5.76}$$

$$R_{71} = \begin{bmatrix} 0{,}2 & 0{,}4 & 0{,}3 & 0{,}1 & 0 \\ 0{,}3 & 0{,}5 & 0{,}2 & 0 & 0 \\ 0{,}2 & 0{,}3 & 0{,}4 & 0{,}1 & 0 \end{bmatrix} \tag{5.77}$$

$$R_{72} = \begin{bmatrix} 0{,}1 & 0{,}5 & 0{,}3 & 0{,}1 & 0 \\ 0{,}2 & 0{,}5 & 0{,}3 & 0 & 0 \end{bmatrix} \tag{5.78}$$

$$R_{73} = \begin{bmatrix} 0{,}1 & 0{,}3 & 0{,}5 & 0{,}1 & 0 \\ 0{,}1 & 0{,}2 & 0{,}4 & 0{,}2 & 0{,}1 \end{bmatrix} \tag{5.79}$$

Again in the same way, based on the scores of 3rd Hierarchy, the evaluation vectors of u_{53}, u_{55}, u_{56}, u_{57}, u_{58}, u_{59}, u_{510} and u_{511} are calculated as follows:

$$p_{53} = (0{,}3 \quad 0{,}4 \quad 0{,}3 \quad 0 \quad 0) \tag{5.80}$$
$$p_{55} = (0{,}3 \quad 0{,}4 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.81}$$
$$p_{56} = (0{,}2 \quad 0{,}3 \quad 0{,}5 \quad 0 \quad 0) \tag{5.82}$$
$$p_{57} = (0{,}3 \quad 0{,}4 \quad 0{,}3 \quad 0 \quad 0) \tag{5.83}$$
$$p_{58} = (0{,}2 \quad 0{,}3 \quad 0{,}3 \quad 0{,}1 \quad 0{,}1) \tag{5.84}$$
$$p_{59} = (0{,}3 \quad 0{,}4 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.85}$$
$$p_{510} = (0{,}5 \quad 0{,}3 \quad 0{,}2 \quad 0 \quad 0) \tag{5.86}$$
$$p_{511} = (0{,}4 \quad 0{,}3 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.87}$$

The rest of the 3rd Hierarchy indices are calculated as:

$$p_{11} = (0{,}3 \quad 0{,}5 \quad 0{,}2 \quad 0 \quad 0) \tag{5.88}$$
$$p_{12} = (0{,}2 \quad 0{,}3 \quad 0{,}3 \quad 0{,}1 \quad 0{,}1) \tag{5.89}$$
$$p_{13} = (0{,}4 \quad 0{,}3 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.90}$$
$$p_{21} = (0{,}3 \quad 0{,}4 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.91}$$
$$p_{22} = (0{,}2 \quad 0{,}3 \quad 0{,}3 \quad 0{,}2 \quad 0) \tag{5.92}$$
$$p_{23} = (0{,}3 \quad 0{,}4 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.93}$$
$$p_{24} = (0{,}5 \quad 0{,}3 \quad 0{,}2 \quad 0 \quad 0) \tag{5.94}$$
$$p_{25} = (0{,}4 \quad 0{,}3 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.95}$$
$$p_{26} = (0{,}4 \quad 0{,}4 \quad 0{,}2 \quad 0 \quad 0) \tag{5.96}$$
$$p_{31} = (0{,}3 \quad 0{,}4 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.97}$$
$$p_{32} = (0{,}3 \quad 0{,}5 \quad 0{,}2 \quad 0 \quad 0) \tag{5.98}$$
$$p_{33} = (0{,}3 \quad 0{,}4 \quad 0{,}3 \quad 0 \quad 0) \tag{5.99}$$
$$p_{41} = (0{,}2 \quad 0{,}4 \quad 0{,}3 \quad 0{,}1 \quad 0) \tag{5.100}$$
$$p_{42} = (0{,}3 \quad 0{,}4 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.101}$$
$$p_{43} = (0{,}5 \quad 0{,}3 \quad 0{,}2 \quad 0 \quad 0) \tag{5.102}$$
$$p_{44} = (0{,}3 \quad 0{,}3 \quad 0{,}3 \quad 0{,}1 \quad 0) \tag{5.103}$$
$$p_{61} = (0{,}3 \quad 0{,}4 \quad 0{,}3 \quad 0 \quad 0) \tag{5.104}$$
$$p_{62} = (0{,}3 \quad 0{,}4 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.105}$$
$$p_{63} = (0{,}2 \quad 0{,}4 \quad 0{,}4 \quad 0 \quad 0) \tag{5.106}$$
$$p_{64} = (0{,}3 \quad 0{,}4 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.107}$$
$$p_{81} = (0{,}2 \quad 0{,}4 \quad 0{,}3 \quad 0{,}1 \quad 0) \tag{5.108}$$
$$p_{82} = (0{,}3 \quad 0{,}5 \quad 0{,}2 \quad 0 \quad 0) \tag{5.109}$$
$$p_{83} = (0{,}5 \quad 0{,}3 \quad 0{,}2 \quad 0 \quad 0) \tag{5.110}$$
$$p_{84} = (0{,}4 \quad 0{,}3 \quad 0{,}2 \quad 0{,}1 \quad 0) \tag{5.111}$$

3. Define the weightings of 3rd hierarchy indices according to experiences

$$w_{51} = (0{,}25 \quad 0{,}5 \quad 0{,}25) \tag{5.112}$$
$$w_{52} = (0{,}5 \quad 0{,}5) \tag{5.113}$$
$$w_{54} = (0{,}5 \quad 0{,}5) \tag{5.114}$$

$$w_{71} = (0{,}4 \quad 0{,}3 \quad 0{,}3) \tag{5.115}$$

$$w_{72} = (0{,}6 \quad 0{,}4) \tag{5.116}$$

$$w_{73} = (0{,}5 \quad 0{,}5) \tag{5.117}$$

4. Fuzzy calculation of 2nd hierarchy evaluation matrices

According to the formula $B_k = W \circ R = (b_{1k}, b_{2k}, b_{3k}, b_{4k}, b_{5k})$, calculate the evaluation results of the 3rd hierarchy by fuzzy conversion:

$$p'_{51} = w_{51} \circ R_{51} = (0{,}25 \quad 0{,}5 \quad 0{,}25) \circ \begin{bmatrix} 0{,}1 & 0{,}5 & 0{,}3 & 0{,}1 & 0 \\ 0{,}1 & 0{,}2 & 0{,}5 & 0{,}2 & 0 \\ 0{,}1 & 0{,}2 & 0{,}5 & 0{,}1 & 0{,}1 \end{bmatrix} \tag{5.118}$$
$$= (0{,}1 \quad 0{,}25 \quad 0{,}5 \quad 0{,}2 \quad 0{,}1)$$

$$p'_{52} = w_{52} \circ R_{52} = (0{,}5 \quad 0{,}5) \circ \begin{bmatrix} 0{,}2 & 0{,}5 & 0{,}3 & 0 & 0 \\ 0{,}1 & 0{,}4 & 0{,}4 & 0{,}1 & 0 \end{bmatrix} \tag{5.119}$$
$$= (0{,}2 \quad 0{,}5 \quad 0{,}4 \quad 0{,}1 \quad 0)$$

$$p'_{54} = w_{54} \circ R_{54} = (0{,}5 \quad 0{,}5) \circ \begin{bmatrix} 0{,}3 & 0{,}4 & 0{,}2 & 0{,}1 & 0 \\ 0{,}4 & 0{,}4 & 0{,}1 & 0{,}1 & 0 \end{bmatrix} \tag{5.120}$$
$$= (0{,}4 \quad 0{,}4 \quad 0{,}2 \quad 0{,}1 \quad 0)$$

$$p'_{71} = w_{71} \circ R_{71} = (0{,}4 \quad 0{,}3 \quad 0{,}3) \circ \begin{bmatrix} 0{,}2 & 0{,}4 & 0{,}3 & 0{,}1 & 0 \\ 0{,}3 & 0{,}5 & 0{,}2 & 0 & 0 \\ 0{,}2 & 0{,}3 & 0{,}4 & 0{,}1 & 0 \end{bmatrix} \tag{5.121}$$
$$= (0{,}3 \quad 0{,}4 \quad 0{,}4 \quad 0{,}1 \quad 0)$$

$$p'_{72} = w_{72} \circ R_{72} = (0{,}6 \quad 0{,}4) \circ \begin{bmatrix} 0{,}1 & 0{,}5 & 0{,}3 & 0{,}1 & 0 \\ 0{,}2 & 0{,}5 & 0{,}3 & 0 & 0 \end{bmatrix} \tag{5.122}$$
$$= (0{,}2 \quad 0{,}5 \quad 0{,}3 \quad 0{,}1 \quad 0)$$

$$p'_{73} = w_{73} \circ R_{73} = (0{,}5 \quad 0{,}5) \circ \begin{bmatrix} 0{,}1 & 0{,}3 & 0{,}5 & 0{,}1 & 0 \\ 0{,}1 & 0{,}2 & 0{,}4 & 0{,}2 & 0{,}1 \end{bmatrix} \tag{5.123}$$
$$= (0{,}1 \quad 0{,}3 \quad 0{,}5 \quad 0{,}2 \quad 0{,}1)$$

Those vectors are then normalized as:

$$p_{51} = \frac{1}{1.15}(0{,}1 \quad 0{,}25 \quad 0{,}5 \quad 0{,}2 \quad 0{,}1) = (0{,}087 \quad 0{,}217 \quad 0{,}435 \quad 0{,}174 \quad 0{,}087) \tag{5.124}$$

$$p_{52} = \frac{1}{1.2}(0,2 \quad 0,5 \quad 0,4 \quad 0,1 \quad 0) = (0,167 \quad 0,417 \quad 0,333 \quad 0,083 \quad 0) \tag{5.125}$$

$$p_{54} = \frac{1}{1.1}(0,4 \quad 0,4 \quad 0,2 \quad 0,1 \quad 0) = (0,364 \quad 0,364 \quad 0,181 \quad 0,091 \quad 0) \tag{5.126}$$

$$p_{71} = \frac{1}{1.2}(0,3 \quad 0,4 \quad 0,4 \quad 0,1 \quad 0) = (0,25 \quad 0,333 \quad 0,333 \quad 0,084 \quad 0) \tag{5.127}$$

$$p_{72} = \frac{1}{1.1}(0,2 \quad 0,5 \quad 0,3 \quad 0,1 \quad 0) = (0,182 \quad 0,454 \quad 0,273 \quad 0,091 \quad 0) \tag{5.128}$$

$$p_{73} = \frac{1}{1.2}(0,1 \quad 0,3 \quad 0,5 \quad 0,2 \quad 0,1) = (0,083 \quad 0,25 \quad 0,417 \quad 0,167 \quad 0,083) \tag{5.129}$$

To form the evaluation matrix R_5, the evaluation vectors p_{51}, p_{52}, p_{53}, p_{54}, p_{55}, p_{56}, p_{57}, p_{58}, p_{59}, p_{510} and p_{511} are combined together as the evaluation matrix.

By which we get

$$R_5 = \begin{bmatrix} p_{51} \\ p_{52} \\ p_{53} \\ p_{54} \\ p_{55} \\ p_{56} \\ p_{57} \\ p_{58} \\ p_{59} \\ p_{510} \\ p_{511} \end{bmatrix} = \begin{bmatrix} 0,087 & 0,217 & 0,435 & 0,174 & 0,087 \\ 0,167 & 0,417 & 0,333 & 0,083 & 0 \\ 0,3 & 0,4 & 0,3 & 0 & 0 \\ 0,364 & 0,364 & 0,181 & 0,091 & 0 \\ 0,3 & 0,4 & 0,2 & 0,1 & 0 \\ 0,2 & 0,3 & 0,5 & 0 & 0 \\ 0,3 & 0,4 & 0,3 & 0 & 0 \\ 0,2 & 0,3 & 0,3 & 0,1 & 0,1 \\ 0,3 & 0,4 & 0,2 & 0,1 & 0 \\ 0,5 & 0,3 & 0,2 & 0 & 0 \\ 0,4 & 0,3 & 0,2 & 0,1 & 0 \end{bmatrix} \tag{5.130}$$

$$R_7 = \begin{bmatrix} p_{71} \\ p_{72} \\ p_{73} \end{bmatrix} = \begin{bmatrix} 0,25 & 0,333 & 0,333 & 0,084 & 0 \\ 0,182 & 0,454 & 0,273 & 0,091 & 0 \\ 0,083 & 0,25 & 0,417 & 0,167 & 0,083 \end{bmatrix} \tag{5.131}$$

And analogously, the rest of the 2nd hierarchy evaluation matrices are calculated as follows:

$$R_1 = \begin{bmatrix} p_{11} \\ p_{12} \\ p_{13} \end{bmatrix} = \begin{bmatrix} 0,3 & 0,5 & 0,2 & 0 & 0 \\ 0,2 & 0,3 & 0,3 & 0,1 & 0,1 \\ 0,4 & 0,3 & 0,2 & 0,1 & 0 \end{bmatrix} \tag{5.132}$$

$$R_2 = \begin{bmatrix} p_{21} \\ p_{22} \\ p_{23} \\ p_{24} \\ p_{25} \\ p_{26} \end{bmatrix} = \begin{bmatrix} 0,3 & 0,4 & 0,2 & 0,1 & 0 \\ 0,2 & 0,3 & 0,3 & 0,2 & 0 \\ 0,3 & 0,4 & 0,2 & 0,1 & 0 \\ 0,5 & 0,3 & 0,2 & 0 & 0 \\ 0,4 & 0,3 & 0,2 & 0,1 & 0 \\ 0,4 & 0,4 & 0,2 & 0 & 0 \end{bmatrix} \tag{5.133}$$

$$R_3 = \begin{bmatrix} p_{31} \\ p_{32} \\ p_{33} \end{bmatrix} = \begin{bmatrix} 0,3 & 0,4 & 0,2 & 0,1 & 0 \\ 0,3 & 0,5 & 0,2 & 0 & 0 \\ 0,3 & 0,4 & 0,3 & 0 & 0 \end{bmatrix} \tag{5.134}$$

$$R_4 = \begin{bmatrix} p_{41} \\ p_{42} \\ p_{43} \\ p_{44} \end{bmatrix} = \begin{bmatrix} 0,2 & 0,4 & 0,3 & 0,1 & 0 \\ 0,3 & 0,4 & 0,2 & 0,1 & 0 \\ 0,5 & 0,3 & 0,2 & 0 & 0 \\ 0,3 & 0,3 & 0,3 & 0,1 & 0 \end{bmatrix} \tag{5.135}$$

$$R_6 = \begin{bmatrix} p_{61} \\ p_{62} \\ p_{63} \\ p_{64} \end{bmatrix} = \begin{bmatrix} 0,3 & 0,4 & 0,3 & 0 & 0 \\ 0,3 & 0,4 & 0,2 & 0,1 & 0 \\ 0,2 & 0,4 & 0,4 & 0 & 0 \\ 0,3 & 0,4 & 0,2 & 0,1 & 0 \end{bmatrix} \tag{5.136}$$

$$R_8 = \begin{bmatrix} p_{81} \\ p_{82} \\ p_{83} \\ p_{84} \end{bmatrix} = \begin{bmatrix} 0,2 & 0,4 & 0,3 & 0,1 & 0 \\ 0,3 & 0,5 & 0,2 & 0 & 0 \\ 0,5 & 0,3 & 0,2 & 0,1 & 0 \\ 0,4 & 0,3 & 0,2 & 0 & 0 \end{bmatrix} \tag{5.137}$$

5. Define the weightings of 3rd hierarchy indices according to experiences

$$w_1 = (0,4 \quad 0,3 \quad 0,3) \tag{5.138}$$
$$w_2 = (0,1 \quad 0,2 \quad 0,2 \quad 0,2 \quad 0,1 \quad 0,2) \tag{5.139}$$
$$w_3 = (0,4 \quad 0,2 \quad 0,4) \tag{5.140}$$
$$w_4 = (0,4 \quad 0,2 \quad 0,2 \quad 0,2) \tag{5.141}$$
$$w_5 = (0,15 \quad 0,1 \quad 0,15 \quad 0,1 \quad 0,1 \quad 0,15 \quad 0,1 \quad 0,15) \tag{5.142}$$
$$w_6 = (0,3 \quad 0,3 \quad 0,3 \quad 0,1) \tag{5.143}$$
$$w_7 = (0,4 \quad 0,3 \quad 0,3) \tag{5.144}$$
$$w_8 = (0,2 \quad 0,2 \quad 0,3 \quad 0,3) \tag{5.145}$$

6. Fuzzy calculation of 2nd hierarchy evaluation matrices

$$p_1' = w_1 \circ R_1 = \left(0{,}4 \quad 0{,}3 \quad 0{,}3\right) \circ \begin{bmatrix} 0{,}3 & 0{,}5 & 0{,}2 & 0 & 0 \\ 0{,}2 & 0{,}3 & 0{,}3 & 0{,}1 & 0{,}1 \\ 0{,}4 & 0{,}3 & 0{,}2 & 0{,}1 & 0 \end{bmatrix} \tag{5.146}$$

$$= (0{,}3 \quad 0{,}4 \quad 0{,}3 \quad 0{,}1 \quad 0{,}1)$$

$$p_2' = w_2 \circ R_2 = \left(0{,}1 \quad 0{,}2 \quad 0{,}2 \quad 0{,}2 \quad 0{,}1 \quad 0{,}2\right) \circ \begin{bmatrix} 0{,}3 & 0{,}4 & 0{,}2 & 0{,}1 & 0 \\ 0{,}2 & 0{,}3 & 0{,}3 & 0{,}2 & 0 \\ 0{,}3 & 0{,}4 & 0{,}2 & 0{,}1 & 0 \\ 0{,}5 & 0{,}3 & 0{,}2 & 0 & 0 \\ 0{,}4 & 0{,}3 & 0{,}2 & 0{,}1 & 0 \\ 0{,}4 & 0{,}4 & 0{,}2 & 0 & 0 \end{bmatrix}$$

$$= (0{,}2 \quad 0{,}2 \quad 0{,}2 \quad 0{,}2 \quad 0) \tag{5.147}$$

$$p_3' = w_3 \circ R_3 = \left(0, \;, \quad 0, \;, \quad 0, \;, \right) \circ \begin{bmatrix} 0{,}3 & 0{,}4 & 0{,}2 & 0{,}1 & 0 \\ 0{,}3 & 0{,}5 & 0{,}2 & 0 & 0 \\ 0{,}3 & 0{,}4 & 0{,}3 & 0 & 0 \end{bmatrix} \tag{5.148}$$

$$= (0, \;, \quad 0, \;, \quad 0, \;, \quad 0, \;, \quad 0)$$

$$p_4' = w_4 \circ R_4 = \left(0{,}4 \quad 0{,}2 \quad 0{,}2 \quad 0{,}2\right) \circ \begin{bmatrix} 0{,}2 & 0{,}4 & 0{,}3 & 0{,}1 & 0 \\ 0{,}3 & 0{,}4 & 0{,}2 & 0{,}1 & 0 \\ 0{,}5 & 0{,}3 & 0{,}2 & 0 & 0 \\ 0{,}3 & 0{,}3 & 0{,}3 & 0{,}1 & 0 \end{bmatrix} \tag{5.149}$$

$$= (0{,}2 \quad 0{,}4 \quad 0{,}3 \quad 0{,}1 \quad 0)$$

$$p_5' = w_5 \circ R_5 = \left(0, \;, 1 \quad 0, \;, \quad 0, \;, 1 \quad 0, \;, \quad 0, \;, \quad 0, \;, 1 \quad 0, \;, \quad 0, \;, 1\right)$$

$$\circ \begin{bmatrix} 0{,}087 & 0{,}217 & 0{,}435 & 0{,}174 & 0{,}087 \\ 0{,}167 & 0{,}417 & 0{,}333 & 0{,}083 & 0 \\ 0{,}3 & 0{,}4 & 0{,}3 & 0 & 0 \\ 0{,}364 & 0{,}364 & 0{,}181 & 0{,}091 & 0 \\ 0{,}3 & 0{,}4 & 0{,}2 & 0{,}1 & 0 \\ 0{,}2 & 0{,}3 & 0{,}5 & 0 & 0 \\ 0{,}3 & 0{,}4 & 0{,}3 & 0 & 0 \\ 0{,}2 & 0{,}3 & 0{,}3 & 0{,}1 & 0{,}1 \\ 0{,}3 & 0{,}4 & 0{,}2 & 0{,}1 & 0 \\ 0{,}5 & 0{,}3 & 0{,}2 & 0 & 0 \\ 0{,}4 & 0{,}3 & 0{,}2 & 0{,}1 & 0 \end{bmatrix} \tag{5.150}$$

$$= (0{,}15 \quad 0{,}15 \quad 0{,}15 \quad 0{,}15 \quad 0{,}1)$$

$$p_6' = w_6 \circ R_6 = (0{,}3 \quad 0{,}3 \quad 0{,}3 \quad 0{,}1) \circ \begin{bmatrix} 0{,}3 & 0{,}4 & 0{,}3 & 0 & 0 \\ 0{,}3 & 0{,}4 & 0{,}2 & 0{,}1 & 0 \\ 0{,}2 & 0{,}4 & 0{,}4 & 0 & 0 \\ 0{,}3 & 0{,}4 & 0{,}2 & 0{,}1 & 0 \end{bmatrix} \tag{5.151}$$

$$= (0{,}3 \quad 0{,}3 \quad 0{,}3 \quad 0{,}1 \quad 0)$$

$$p_7' = w_7 \circ R_7 = (0{,}4 \quad 0{,}3 \quad 0{,}3) \circ \begin{bmatrix} 0{,}25 & 0{,}333 & 0{,}333 & 0{,}084 & 0 \\ 0{,}182 & 0{,}454 & 0{,}273 & 0{,}091 & 0 \\ 0{,}083 & 0{,}25 & 0{,}417 & 0{,}167 & 0{,}083 \end{bmatrix} \tag{5.152}$$

$$= (0{,}25 \quad 0{,}454 \quad 0{,}333 \quad 0{,}167 \quad 0{,}083)$$

$$p_8' = w_8 \circ R_8 = (0{,}2 \quad 0{,}2 \quad 0{,}3 \quad 0{,}3) \circ \begin{bmatrix} 0{,}2 & 0{,}4 & 0{,}3 & 0{,}1 & 0 \\ 0{,}3 & 0{,}5 & 0{,}2 & 0 & 0 \\ 0{,}5 & 0{,}3 & 0{,}2 & 0{,}1 & 0 \\ 0{,}4 & 0{,}3 & 0{,}2 & 0 & 0 \end{bmatrix} \tag{5.153}$$

$$= (0{,}3 \quad 0{,}3 \quad 0{,}2 \quad 0{,}1 \quad 0)$$

To normalize those vectors I get:

$$p_1 = \frac{1}{1{,}2}(0{,}3 \quad 0{,}4 \quad 0{,}3 \quad 0{,}1 \quad 0{,}1) = (0{,}25 \quad 0{,}334 \quad 0{,}25 \quad 0{,}083 \quad 0{,}083) \tag{5.154}$$

$$p_2 = \frac{1}{0{,}8}(0{,}2 \quad 0{,}2 \quad 0{,}2 \quad 0{,}2 \quad 0) = (0{,}25 \quad 0{,}25 \quad 0{,}25 \quad 0{,}25 \quad 0) \tag{5.155}$$

$$p_3 = \frac{1}{1{,}1}(0{,}3 \quad 0{,}4 \quad 0{,}3 \quad 0{,}1 \quad 0) = (0{,}273 \quad 0{,}363 \quad 0{,}273 \quad 0{,}091 \quad 0) \tag{5.156}$$

$$p_4 = (0{,}2 \quad 0{,}4 \quad 0{,}3 \quad 0{,}1 \quad 0) \tag{5.157}$$

$$p_5 = \frac{1}{0{,}7}(0{,}15 \quad 0{,}15 \quad 0{,}15 \quad 0{,}15 \quad 0{,}1) = (0{,}214 \quad 0{,}214 \quad 0{,}214 \quad 0{,}214 \quad 0{,}143) \tag{5.158}$$

$$p_6 = (0{,}3 \quad 0{,}3 \quad 0{,}3 \quad 0{,}1 \quad 0) \tag{5.159}$$

$$p_7 = \frac{1}{1{,}287}(0{,}25 \quad 0{,}454 \quad 0{,}333 \quad 0{,}167 \quad 0{,}083) \tag{5.160}$$

$$= (0{,}194 \quad 0{,}353 \quad 0{,}259 \quad 0{,}130 \quad 0{,}064)$$

$$p_8 = \frac{1}{0{,}9}(0{,}3 \quad 0{,}3 \quad 0{,}2 \quad 0{,}1 \quad 0) = (0{,}333 \quad 0{,}333 \quad 0{,}222 \quad 0{,}111 \quad 0) \tag{5.161}$$

Based on the above calculation, I get the 2nd hierarchy evaluation matrices:

$$R_1 = \begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \end{bmatrix} = \begin{bmatrix} 0{,}25 & 0{,}334 & 0{,}25 & 0{,}083 & 0{,}083 \\ 0{,}25 & 0{,}25 & 0{,}25 & 0{,}25 & 0 \\ 0{,}273 & 0{,}363 & 0{,}273 & 0{,}091 & 0 \\ 0{,}2 & 0{,}4 & 0{,}3 & 0{,}1 & 0 \end{bmatrix} \tag{5.162}$$

$$R_2 = \begin{bmatrix} p_5 \\ p_6 \\ p_7 \\ p_8 \end{bmatrix} = \begin{bmatrix} 0{,}214 & 0{,}214 & 0{,}214 & 0{,}214 & 0{,}143 \\ 0{,}3 & 0{,}3 & 0{,}3 & 0{,}1 & 0 \\ 0{,}194 & 0{,}353 & 0{,}259 & 0{,}13 & 0{,}064 \\ 0{,}333 & 0{,}333 & 0{,}222 & 0{,}111 & 0 \end{bmatrix} \tag{5.163}$$

7. Define the weightings of 2nd hierarchy indices according to experiences

$$W_1 = (0{,}2 \quad 0{,}2 \quad 0{,}3 \quad 0{,}3) \tag{5.164}$$
$$W_2 = (0{,}3 \quad 0{,}2 \quad 0{,}3 \quad 0{,}2) \tag{5.165}$$

8. Fuzzy calculation of 1st hierarchy evaluation matrices

$$P_1' = W_1 \circ R_1 = (0{,}2 \quad 0{,}2 \quad 0{,}3 \quad 0{,}3) \circ \begin{bmatrix} 0{,}25 & 0{,}334 & 0{,}25 & 0{,}083 & 0{,}083 \\ 0{,}25 & 0{,}25 & 0{,}25 & 0{,}25 & 0 \\ 0{,}273 & 0{,}363 & 0{,}273 & 0{,}091 & 0 \\ 0{,}4 & 0{,}2 & 0{,}3 & 0{,}1 & 0 \end{bmatrix}$$
$$= (0{,}3 \quad 0{,}3 \quad 0{,}3 \quad 0{,}2 \quad 0{,}083) \tag{5.166}$$

$$P_2' = W_2 \circ R_2 = (0{,}3 \quad 0{,}2 \quad 0{,}3 \quad 0{,}2) \circ \begin{bmatrix} 0{,}214 & 0{,}214 & 0{,}214 & 0{,}214 & 0{,}143 \\ 0{,}3 & 0{,}3 & 0{,}3 & 0{,}1 & 0 \\ 0{,}194 & 0{,}353 & 0{,}259 & 0{,}13 & 0{,}064 \\ 0{,}333 & 0{,}333 & 0{,}222 & 0{,}111 & 0 \end{bmatrix}$$
$$= (0{,}214 \quad 0{,}3 \quad 0{,}259 \quad 0{,}214 \quad 0{,}143) \tag{5.167}$$

To normalize these two vectors I get:

$$P_1 = \frac{1}{1{,}183}(0{,}3 \quad 0{,}3 \quad 0{,}3 \quad 0{,}2 \quad 0{,}083) = (0{,}254 \quad 0{,}254 \quad 0{,}254 \quad 0{,}169 \quad 0{,}07) \tag{5.168}$$

$$P_2 = \frac{1}{1{,}13}(0{,}214 \quad 0{,}3 \quad 0{,}259 \quad 0{,}214 \quad 0{,}143)$$
$$= (0{,}189 \quad 0{,}265 \quad 0{,}229 \quad 0{,}189 \quad 0{,}127) \tag{5.169}$$

Based on the above calculation, the 1st hierarchy evaluation matrix can be got:

$$R = \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} = \begin{bmatrix} 0{,}254 & 0{,}254 & 0{,}254 & 0{,}169 & 0{,}07 \\ 0{,}189 & 0{,}265 & 0{,}229 & 0{,}189 & 0{,}127 \end{bmatrix} \tag{5.170}$$

9. Define the weightings of 1st hierarchy indices according to experiences

$$W = \begin{pmatrix} 0{,}4 & 0{,}6 \end{pmatrix} \tag{5.171}$$

10. Fuzzy calculation of the evaluation result

$$\begin{aligned} B'_I = W \circ R = \begin{pmatrix} 0{,}4 & 0{,}6 \end{pmatrix} \circ \begin{bmatrix} 0{,}254 & 0{,}254 & 0{,}254 & 0{,}169 & 0{,}07 \\ 0{,}189 & 0{,}265 & 0{,}229 & 0{,}189 & 0{,}127 \end{bmatrix} \\ = (0{,}254 \quad 0{,}265 \quad 0{,}254 \quad 0{,}189 \quad 0{,}127) \end{aligned} \tag{5.172}$$

After normalization we get:

$$\begin{aligned} B_I = \frac{1}{1{,}089}(0{,}254 \quad 0{,}265 \quad 0{,}254 \quad 0{,}189 \quad 0{,}127) \\ = (0{,}233 \quad 0{,}243 \quad 0{,}233 \quad 0{,}174 \quad 0{,}117) \end{aligned} \tag{5.173}$$

Until now, the integrated evaluation result of scenario I has been calculated available, and with MDFIE method, the performance evaluation results of the other automotive door supply chain scenarios are also calculated as following:

$$B_{II} = (0{,}257 \quad 0{,}354 \quad 0{,}169 \quad 0{,}117 \quad 0{,}103) \tag{5.174}$$

$$B_{III} = (0{,}287 \quad 0{,}249 \quad 0{,}233 \quad 0{,}143 \quad 0{,}088) \tag{5.175}$$

$$B_{IV} = (0{,}386 \quad 0{,}247 \quad 0{,}201 \quad 0{,}119 \quad 0{,}047) \tag{5.176}$$

According to the maximum membership principle, it can be clearly seen that the performance of ASC I and ASC II are “good”, since the maximum membership degrees 0,243 of ASC I and 0,354 of ASC II are located in the “good” category. The performance of ASC III and ASC IV are “very good”, since the maximum membership degrees 0,249 of ASC III and 0,386 of ASC IV are located in the “very good” category. And if we look into more details, it can be noticed that the evaluation result of ASC II is better than ASC I, since it’s closer to good and very good, the membership degree values of these two categories are both bigger; and also the evaluation result of ASC IV is better than ASC III, since to the very good result, it’s also closer and the degree value is larger. All in all, the evaluation result can be summarized as:

$$\text{ASC IV} > \text{ASC III} > \text{ASC II} > \text{ASC I} \tag{5.177}$$

And this is to say, the deeper the integration degree is, the better performance the door module supply chain has. However, some more aspects especially the restrictions of this evaluation method should be taken into consideration as well:

a. Restrictions of the index system: As mentioned before, this index system is built up based on the understanding of interests for this certain project case, and for different purposes, people may have different index system. It could be either more complicated or more simplified, and it could also be just with some of the interesting indices which are required for the individual cases. So the restrictions of the index system can not be neglected in the final evaluation results.

b. Inaccuracy of the weighting definition: The weightings applied in this system are defined according to experiences, though they are suggested, discussed and finally determined by the responsible specialists, they are still not accurate enough. Because for different evaluation purpose, the indices may actually have different degree of importance, so in the reality evaluation cases under other circumstances, weightings should possibly be redefined according to the certain conditions.

   In addition, the weightings can be calculated with many other methods, such as AHP, minimum deviation, and regressive analysis, etc [JWD 04]. Those methods are theoretically more accurate for getting the weightings, however, since the weightings are then calculated again with fuzzy methods, it doesn't make much sense to have the weighting values more accurate in this case. Therefore the experienced value is used on one hand for reducing the calculation complexity, and on the other hand for serving the evaluation purpose more easily while the weightings can be flexibly adjusted.

c. Subjective evaluation results from the lowest hierarchy: Since some of the evaluations are made by experts scoring, though the notes are taken for every single indices of the 4^{th} hierarchy, except the quantitative values, the human restrictions can not be eliminated for the qualitative values anyway. Therefore the evaluations are somehow subjective, and with different criteria and different evaluation specialist teams, the result may different from each other. But here in this work, since the calculation has been done hierarchy by hierarchy and the membership degree of final evaluation vectors are quite obvious, especially that of scenario IV, the results locate dominantly in the category "very good" and then in the category "good", it is still very reflecting to the real supply chain performance.

In general, despite the above restrictions, the performance evaluation results are still quite reliable. Since the automotive supply chain system is such a complicated system, it is possible to evaluate some certain aspects with other methods, but for an integrated evaluation, this MDFIE method is more suitable and more preferable.

5.5 Discussion

Based on the index system built up according to the automotive door supply chain case, the ASC performances are evaluated hierarchy by hierarchy, and the final results are calculated as well in the above sub-chapters. In the end of this chapter, I would like to discuss more about the evaluation results, and the further steps we are supposed to do based on the results.

5.5.1 Further Indication of the Evaluation Results to ASC Design

The four different automotive door supply chains are investigated with MDFIE methods, from the evaluation results it is known that the performances are getting better as the integration degree gets deeper. In ASC scenario I, the OEMs have to deal with many suppliers who supply the single door components, both the management complexity and the supply risk are very high. The upstream layer of OEMs has many nodes and each node company's performance has to be considered which adds a big deal of work to the OEMs, and the entire supply chain performance is meantime still not very satisfying, as can be seen from the evaluation results, the performance is only assessed as "good".

Then in the ASC scenario II, some components are combined as door module, and the module supplier is now taking more responsibilities. From the evaluation result it can be noticed that the performance is better than ASC I. Then as the supplier integration gets to a larger degree, as to a relative extreme situation in ASC scenario IV, one supplier is supplying the entire door: the previous OEM work is now done by a big supplier who has not only the ability of production but also the R&D capability and comprehensive managing responsibility. This big supplier is right now managing the previous Tier 1 suppliers, and it's playing an important and special roll in the new supply chain design. The full involvement and large responsibility make it different from any of the previous Tier 1 suppliers, and this new ASC player here will be later defined as a special tier in Chapter 6. Some newly appeared special providers which are dealing with design, development, logistic and other service work, will also be defined afterwards in the next chapter.

5.5.2 Benefits of ASC Performance Evaluation and Optimization Methods

Whenever dealing with the automotive supply chain designs, the SC performances have to be evaluated and through which we get the basis of further activities. The evaluation system built up in this work offers an objective reference for the real case study in automotive industry. It has the following advantages in comparison with other evaluation methods:

1. Unified and objective system

Though previously the human reasons have been talked about as a restriction of the system, nevertheless, compared with other evaluation systems, this system and method is still enjoying the advantage of being relatively objective and impersonal. The characteristic of unification can reduce or even eliminate the unfairness and incomplete results to a large extent.

2. Help to figure out the weak points of automotive supply chains

Through the performance evaluation, it is more efficient to find out the weak nodes of the supply chain, and implement adjustments accordingly. The evaluation helps to keep the supply chain lean and with a minimum waste.

3. Basis of management policy

The evaluation results can be also used as a guideline to inspect the work efficiency, performance of individual workers and the management system. For example the results can be used as the basis of rewards and penalty system.

Base on evaluation results, there should be a way to make the improvement, and very generally, the optimization method is suggested as illustrated in the following Figure 5-15.

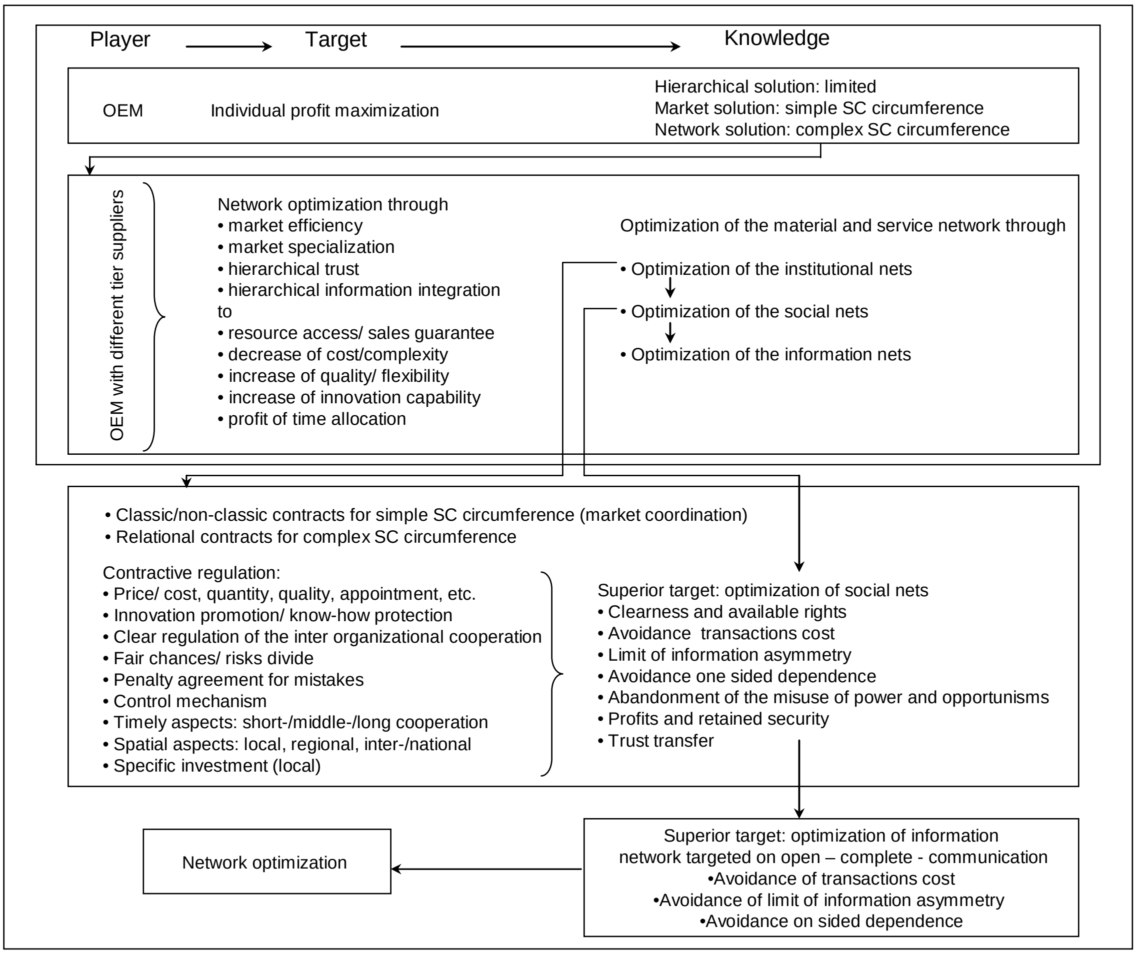

Figure 5-15 Multivariable Handling Concept to Optimization of an Automobile Supply Chain

Above the optimization process was actually a modification of the model developed by Schonert [Sch 08], and it illustrates a multivariable handling concept to optimize an automotive supply chain. In this optimization concept, a way of optimization of the different networks is suggested, including institutional, social and information networks through aspects like resources, production, organizations and marketing and so on. By investigating of the price, quality, quantity, techniques, risks, controlling, etc into details, and modifying the supply chain structure, a final target of supply network optimization based on the information sharing, risk avoidance can be realized.

The optimization is supposed to be carried out among all the ASC participators from different tiers. Here in this work only this general way of optimization is offered based on the evaluation study, the detailed optimizing solutions will not be discussed since for the different cases, solutions may vary much from each other. Some new automotive supply chain phenomena and proposals will be discussed further in Chapter 6.

6. Analysis and Conclusions of the two Evaluation Cases

In a highly competitive environment, an effective and efficient global supply chain is a must for automotive manufacturers and their suppliers. The industry landscape is exposed to a set of critical challenges and trends that are leading, if not accelerating, the need to fine-tune supply chain strategies and operations even further. The increasing requirements for thorough information exchange and effective communication across the supply network are critical for managing and optimizing the supply chain on a flexible basis, and meantime keeping costs under control. While most global car manufacturers and Tier 1 suppliers are in the process of addressing these requirements, smaller Tier 2 and Tier 3 auto suppliers have to make big efforts in catching up the developing pace.

Recent emphasis on global climate change is an increasing pressure on automotive manufacturers to make the right decisions in many areas, including R&D, manufacturing and the general supply chain scope. In fact, emission level targets, currently in question, threaten to alter the entire structure of the auto industry. In regard to the “green” challenge, the focus on the environment might reshape the supply chain scenario even more radically. Rising energy and regulation concerns, and the demands of continuous customers require automakers and their suppliers to reduce the carbon footprint of their overall operations - including supply networks.

These challenges hit an industry already plagues with high costs, low profit margins, and accelerating competitions. Only a handful of established layers are consistently delivering satisfactory profits, and most of the players are undergoing some form of restructuring. Meantime the general macroeconomic and financial circumstances are not necessarily favourable, either. The world economy has experienced a recession since end of year 2007, and automotive industry has been suffering the most from this recession and is still not fully recovered. The overcapacity problem is not yet solved and will be existing longer. The cost of energy and raw materials continues to increase due to rising global demand. Strong fluctuations in exchange and interest rates pose another challenge and are difficult and costly. The general circumstances are critical and challenging.

In this dynamic business environment, a superior supply chain is one critical element to help automotive companies differentiate themselves from the competitors. The situation is reinforcing the need to redefine supply chain strategies, layouts, operations, and IT level, and this redefinition can only be made based on a proper performance evaluation. Therefore in this chapter, supply chain evaluation methodology will be further investigated, based on the conventional and integrated models applied in this work. And two other aspects will also be discussed as key role players in automobile industry, especially the automobile supplier industry, which are the application of RFID and the higher supplier integration. The RFID technique represents the future way of increasing automotive productivity and improving quality of the information flow, and the formation of half tiers represents the evolution trend of the supply chain structure. In the end of the chapter, a new automotive supply structure will be proposed based on the previous investigations.

6.1 Summary Methodology Automotive Supply Chain Evaluation

Supply chain performance evaluation is a very important part of supply chain management, and it is essential for assessing the completion degree of supply chain target and supporting the decision making.

The indicators for evaluating the supply chain should be properly reflecting the operation situation and the relationship among the supply chain participators. The effect to the entire supply chain caused by every single company should be taken into consideration during the supply chain evaluation. In the following sections, the evaluation models applied in this research work will be investigated and the evaluation results will be analyzed.

6.1.1 General Evaluation Models and Methodologies

There have been many supply chain studies dealing with the methods for evaluating the performance of supply chains: Some evaluation systems are based on SCOR (Supply Chain Operations Reference) model, some are based on supply chain BSC (Balanced ScoreCard) evaluation system, and also some others are based on the so called SaT (Sink and Tuttle) system, etc. These are basically the current leading methods for supply chain performance evaluation.

The SCOR model is more focusing on the measurement and improvement of internal and external business processes, and it is also conducting the SEM (Strategic Enterprise Management), which is normally investigated based on the benchmarking. The BSC system is not only an evaluation system but also a manifestation of management thinking, and it is rather an integration of evaluation, management, and communication than an individual evaluation tool. Then about the SaT system, it is developed with the basic model of “supplier – input – manufacturing – output – customer – results”, and contains seven basic evaluation indexes, which are the efficiency, effectiveness, productivity, profiting capability, quality, innovation and working environment. The characteristic of the SaT system is the close combination of performance evaluation and the strategy making process, and this system is mainly used in logistic companies.

Besides, as the financial indicators used to be playing the key role in performance evaluation, methods such as ABC (Active-Based Costing), and EVA (Economic Value Analysis) have been also applied, from the aspects of profit, investment, and ROI (Return On Investment) etc.

On all account, the basic principles of supply chain performance evaluation are listed as:

- Clear emphasis: selective analysis for key indexes;
- Clear reflection of the supply chain process;
- Clear reflection of the entire supply chain’s performance, instead of only analysing the behaviour of one single supply chain participant;
- Updated dynamic analysis rather than post-mortem analysis;
- Reflection of supply chain participants’ relationship, coverage of all interesting objects, enlargement of evaluation scope.

As finer design for automotive supply chain is required from almost every point of view, the above listed targets are new challenges for the ASC evaluation and its subsequent optimization. Besides the before mentioned methodologies, the two evaluation models established in this research work will be analyzed from mainly characteristic point of view in the following section, and the evaluation results will be analyzed as well. Some suggestions will be offered based on the evaluation results and will be further discussed in the next sub chapters.

6.1.2 Characteristics and Results Analysis of Two Evaluation Models

As is discussed previously, indicators for financial and accounting operations used to be very important for improving the financial situation of the enterprises, but are still inadequate in the supply chain performance evaluation and improvement. In order to make up the gap for the traditional methods, two models based on the special needs of automotive supply chain management are investigated in this work, with other methods and evaluation aspects instead the ones listed above.

In the first model, a case of automotive door module supply was studied, based on the 3 scenarios happened during the localization process. This case was mainly investigated from the module supplier's point of view, so some main interesting indicators were chosen for the evaluation, namely as discussed before the cost, transport routing, stability, flexibility, and reliability. Additionally, to cater with the green requirement, the carbon footprint was also calculated when analyzing the transport routing. The reasons for choosing such indicators are based on the actual interest. As in the researched case, it is not really necessary to care about the entire supply chain from the very basic material or component suppliers to the final car users, but the interest of door module supplier is of highest priority. So all the calculations were actually done within the module supplier's scope.

Besides it's a localization process, the evolution trend of the three scenarios is also somehow a gradually integrated supply process, as the scenario III achieves the highest integration by complete local supply. Since before in Chapter 4, the evaluation results implied this scenario is superior to the other two scenarios from every single perspective, therefore under this certain circumstances where the actual case happened, the conclusion is that the localization and integration supply enjoys the biggest advantage.

However, the conventional model focuses on single dimension evaluation, though big efforts have been made to evaluate the supply chain performance comprehensively from different perspectives, the evaluation results can not be perfectly integrated. These evaluation results may reflect the supply chain regarding certain orientation or interest, the balanced configuration of supply chain design is still difficult to find, especially when the supply chain is big and complicated and involving large quantity of elements. The lack of consideration about overall supply chain performance and the relationship between the various members of the supply chain is one of the key limitations of this model. As the impacts and constraints, and the overall efficiency of the supply chain are with non-linear relations, how the coordination of supply chain elements affect the performance is an interesting question to be solved. In addition, since the supply chain is with multi-level structure and multi-level interests, it is necessary to establish the corresponding hierarchical model to evaluate, which not only evaluate the entire system by analyzing sub-system behaviour, but also conduct a comprehensive evaluation by balancing the relationships of all supply chain participators.

Then another integrated model was developed in this work, which makes it possible to solve the interest balance problem by introducing an integrated index system, which consists four hierarchies in this case and reflects every one's interest by setting up a proper weighting factor for them. This index system is adjustable according to different companies' own situations, and the weighting system could also be adjusted as the change of time, or supply chain focus, or any kind of possible changes especially when the point of departure for the evaluation is changed. Based on this thinking, the system model itself, is a flexible system, which can be adapted to any supply chain configuration by defining and setting up new evaluation parameters.

Therefore one of the key achievements of this work is the establishment of the integrated model, especially the index system. Since this system is adjustable, it can be adapted in the automotive companies by picking up the appropriate indexes or defining new indexes for the researched objects, not necessarily to be OEM or big suppliers. And the completion of this new system also make up the limitation of the previous researches, which focus mostly on the supplier selection and evaluation, rather, this new system takes the customer satisfaction, service level etc. also into consideration, which caters more to the current requirements of automotive supply chain management.

With a clear evaluation purpose, the evaluation results of the second case were quite logical. By using the integrated model, four supply chain scenarios about the automotive door system supply were investigated and evaluated with the established comprehensive index system, through the own developed MDFIE algorithm. As the four scenarios are with gradually deeper integration degree, the conclusion of the case under this certain circumstances is that deepest integration supply enjoys the biggest advantages.

The cases being evaluated by the two models are with certain similar characteristics, and enjoy certain common points such as the data resources: both of them are originally based on the automotive door system supply, though the integrated model is actually dealing with a much more complex supply chain and contains more participators and components.

The evaluation results could be used for decision making, still, it requires higher precision. One thing that can help in increasing the precision is the quality of data to be captured - a well maintained data base with timely update may contribute much to the evaluation work and sustainable improvement.

Based on the evaluation results of the two models, some suggestions are proposed in the next section for further improvement of the supply chain performance.

6.2 The Application of RFID Technique in Automotive Supply Chain

While most global OEMs and Tier 1 suppliers are in the process of addressing the previously mentioned requirements for the new competition, information technology plays an increasingly important role in the automotive industry. Effectively turning IT from an "operational delivery" function into a "strategic, differentiating" asset, is now a new challenge the decision makers are confronting. Among all the new techniques, RFID is catching up more eye lights of the executives.

As is known, the continually changing market environment needs the effective control of the production processes. Essential condition of the control is that the information is available in time and of good quality. The quickest way it can be assured is directly from the production processes where it arises. To hit the target it is essential to collect the pieces of data and integrate them with the control and planning systems. Thereafter the E-kanbans are used, MES system are implemented, and further more, a new and promising solution based on the RFID technology in production control system, is also started to be applied in some of the automotive manufacturing companies.

As is summarized from some existing researches and my own study, the RFID technology enjoys the following advantages:

- Not requiring line of sight access to be read;
- The tag can trigger security alarm systems if removed from its correct location;
- Scanner/reader and RFID tag are not so orientation sensitive;
- Automatic scanning and data logging is possible without operator intervention;
- Each tag can hold more than just one unique product code;
- Each item can be individually ‘labelled’;
- Tag data can be comprehensive, unique in parts/common in parts, and is compatible with data processing;
- With the right technology a plurality of tags can be concurrently read;
- It can be read only or read-write;
- There is a very high level of data integrity (character check sum encoding);
- Provides a high degree of security and product authentication – a tag is more difficult to counterfeit than a barcode;
- The supporting data infrastructure can allow data retrieval and product tracking anywhere provided the scanner/reader is close enough to the tag;
- Combined with its authentication is the ability to monitor shelf life - a societal advantage in the pharmaceutical and food industry;
- Since each tag can be unique they can act as a security feature if lost or stolen e.g. a stolen smart travel card can be cancelled;
- The technology is rugged and can be used in hostile environments (heat and pressure) to carry data to remote equipment;
- The technology lends itself to being updated, for example, as a car goes through its life its service record can be electronically logged with the car.

Especially in the automotive industry, the application of RFID helps the real time control and reducing of manpower, meantime increasing the operating accuracy. Besides the great power RFID already demonstrated in the production system, the traceability capability RFID offers considerably improves the communication among supply chain parties and thus correspondingly improves the efficiency. More important, it improves the service level tremendously, and make it more possible to meet the downstream partners’ and in the end the end customers’ requirements, and increases the customer satisfaction degree.

However, despite of the promising advantages RFID has, there are also some disadvantages. One of the factors that slow down the application of RFID is the high cost of installation. For large scale application this cost has to be reduced in the near future. And another big disadvantage is the insecurity of RFID technology at the current level. As the development goes further and technology is more improved, this problem is supposed to be solved soon in the near future.

6.3 Introduction of a New Tier - Tier 0,5

As discussed before in Chapter 3, the modularity requirements demonstrated the evolution trend of the suppliers, and it is also predicted that some of the mighty restructuring trends afoot in automotive supply chain based on the performance evaluation results, among which one important way is that the future emphasis of OEMs are being transferred more and more to the brand image management and automobile financial business instead of the traditional “Manufacturing”. This is to say, the OEMs are outsourcing more and more “non - core” processes to supply chain partners so that they become more market responsive themselves and become less exposed to demand fluctuations by reducing their investment in fixed assets. The extent and nature of outsourcing have been subjects to many experiments and new solutions. The growing demand for niche vehicles is set to encourage OEMs to use suppliers in further innovative ways. There is plenty of scope for shifting more engineering and production work upstream to the inbound supply chain.

A key aspect of outsourcing is the development of enhanced capabilities by suppliers. An obvious cost benefit is that supplier wage rates are often less than those at the OEMs. In addition, time (synchronous production and delivery to point-of-fit) and quality (zero defects) benefits are also expected, together with increasingly sophisticated engineering and operational capabilities. This can be seen as a staged development.

6.3.1 From Tier 1 to Tier 0,5

As the traditional definition of supplier tiers was talked about before, to make the differentiation clearer between the current Tier 1 and the Tier 0,5 that is about to be introduced, a detailed categorization with two kinds of Tier 1 suppliers is firstly presented:

Tier 1 basic: Suppliers with in-house design capability and project management capability who can assure timely delivery and reasonable quality reliability.

An example would be a system manufacturer who holds 4-5 days stock and who delivers “just in time” to set time windows.

Tier 1 synchro: Suppliers who provide all of the basic capabilities, but with virtually no safety stock and actually closer integration of logistics and IT expertise to OEM.

Parts are delivered ‘just in sequence’, with stock being limited to what is needed to transport parts from the supplier’s plant to the customer. Additional capabilities for the supplier are synchronic logistics and IT expertise that is closely integrated with the OEM, greater flexibility and more secure emergency procedures. They operate through ‘clone’ plants that are situated in supplier parks no more than 10 minutes’ travel time from the OEM’s production line.

Based on the above classification of Tier 1 suppliers, and all the investigations done before in this work, a new concept of Tier 0,5 is of great interest. Actually it would be rather defined as the Tier 0,5 Supplier, and meantime also the Tier 0,5 OEM, for its big involvement in the OEM work and the special supplier role it is still playing. Therefore in this work, the Tier 0,5 will be exactly defined as:

Tier 0,5: Full service providers, integrated in OEM activities, whose business covers a scope of automotive marketing study, engineering design, manufacturing and entire upstream and down stream supply chain management.

For emphasising its supplier role, this Tier 0,5 is also called the Mega System Supplier. Basically, this new player integrates component or system manufacturing through supply chain management to achieve the optimum design of a given module. They carry out pre-emptive market research and develop innovative designs together with OEM or through “shelf engineering”, where the innovative designs are developed in advance of need and placed “on the shelf” for potential rapid use in future. This new tier will also be taking care of the entire supply chain management by integrating the information, material and even finical flow which involves not only suppliers but also OEMs. Tier 0,5s are partners in major cost reduction projects at each model change, and in the process of engineering innovation, and also in all the continuous improvement activities in between.

There were actually some experts talking about a so-called “Tier 0,5” concept or similar concepts before, for example Harrison [Har 04] and executives from Magna Steyr in their interview, but no one really made a research in this field and no one has been able to give a clear definition. Besides, the concept they were talking about before is more like the Tier 1 Synchro defined in this work. So the Tier 0,5 definition which is put out here, is theoretically new to the automotive structure design, and more concrete structure proposals will made later.

6.3.2 Further Supplier Integration

Some global suppliers like Magna etc. were closely integrated with the product development teams (PDT) of OEM, and the R&D integration of suppliers means fast-tracking the process between digital mock-ups and production tooling. Among the entire supply chain, making it more competitive is the target of cost, quality and delivery timing control.

One aspect of Tier 0,5 integration is like in Ford Cologne R&D centre, the co-location of supplier engineers, which means that the Ford PDT effectively supervises the design and development process. Nevertheless, this is a significant departure from a process whereby the OEM hands over detailed designs to the supplier whose role was then limited to component assembly, this is one area where the Tier 0,5 vision is beginning to emerge. Another is that some big system integrator suppliers now take responsibility for external as well as internal sourcing and integration of some entire auto parts such as the entire door system (window regulators, door frame, closure system, glass, mirror and central control unit etc.) as investigated in the case of this thesis work, or cockpit (including the heating, ventilation and air conditioning systems plus ducting, cross car beams, steering member, airbag system and most electronics and the plastic mouldings), and the rest are bought in. By which sales of the suppliers have accordingly much more full responsibility for fixed assets and capital employed.

So in the new era, the Tier 0,5 suppliers will on one hand make certain percentage of the components, and on the other hand undertake logistics and management responsibility for all the rest in its new role as a big system supplier. It has to be responsible for integrating the efforts of a number of Tier 1 and Tier 2 suppliers, and totally or partially in charge of the commercial issues and engineering issues. In some existed experiences, a system supplier who is quite close to the Tier 0,5 concept supplier, has to deal with many upstream suppliers among which some are “imposed”, where the OEMs handle prices and commercial agreements while the “Tier 0,5” handles everything else (including parts ordering, expediting and QM), and some are “nominated”, where it handles the pricing and commercial agreements as well. These “imposed” or “nominated” suppliers however are somehow a barrier for the long good, since supply contracts for components are awarded on a global supply basis, the resulted imposed and nominated suppliers are mainly selected on price-down criteria but not others. The major benefits of modular construction and the Tier 0,5 integration can only be realized if full integration of the various components takes place at the design stage and the supplier QM targets are fulfilled at the same time when the price target are achieved.

Furthermore, increasing responsibility is not happening only in development and manufacturing. OEMs are also trying innovative approaches in terms of assembly, with some platforms, suppliers assemble a number of modules in final assembly at OEM plant and attach them directly to the vehicles on their own. The benefits that OEMs achieve are reduced asset intensity, reduced supply chain management costs, as well as improved quality and productivity.

In general, the Tier 0,5 concept is quite a promising trend of the automotive industry, and the 0,5 vision can be realized with the more and more cooperation between OEMs and system suppliers, and among suppliers. Only when a true integration is achieved, the Tier 0,5 vision is not far away from being successful.

6.4 The Future Automotive Supply Chain

Comparing to the automotive supply chain structure discussed before in chapter 2, a new structure based on the investigations done in this research work is then defined. As following in the figure, between the Tier 1 and OEM, there is a new tier, namely the Mega System Supplier， defined as Tier 0,5. And between every two adjacent tiers, another 3rd party service tier is introduced, which consequently is the Tier 1,5 and Tier 2,5 etc. These additional tiers are mostly consisting of the external engineering design companies and logistic providers. The introduction of the half tiers is defining the automotive supply chain more precisely.

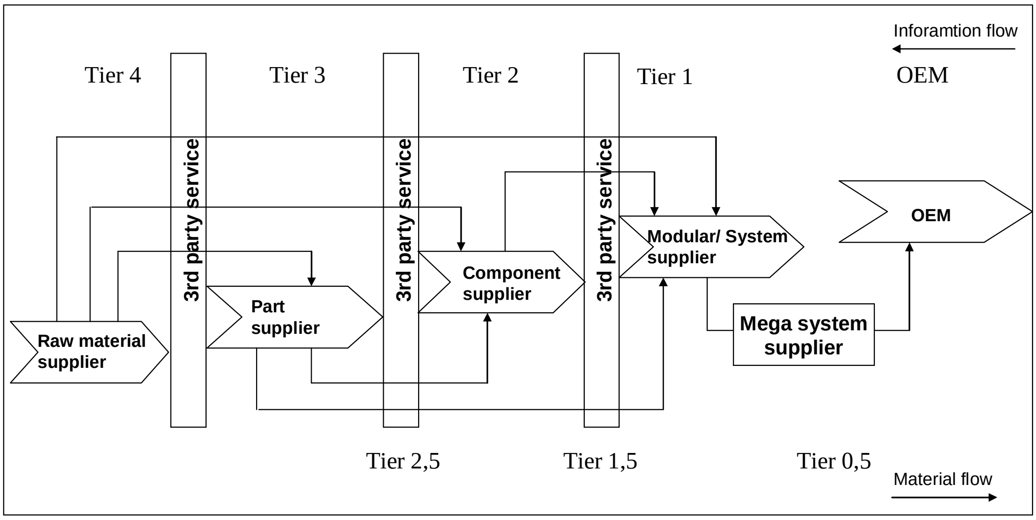

Figure 6- 1 New Automotive Supply Chain Structure

The reason of these two innovations is on one hand for the requirement of real situation, and on the other hand a suggestion to improve the automotive supply chain. The advantages of this new structure will be introduced in the following two sections.

6.4.1 Solution to Overcapacity

As is concluded by many experts and research institutes, one of the biggest problems in automobile industry is overcapacity, especially in the new booming areas like China and India, where the auto industry has been enjoying a double digit growth. Clever use of capacity and the capacity risk bound to it has become the central factor for success in the automobile industry. To balance with other concerns while keeping the industry competitive, the suggested scenario in this work will not only increase the supply chain participators' satisfaction degree, but also help to solve the over capacity problem from the following mentioned two aspects:

1. Vertical Integration

When the responsibilities are more transferred to suppliers, and big suppliers are more involved in R&D processes, the investments including fixed assets and human intelligence of the OEMs can be greatly reduced. For example the vehicle door supply, if the supplier is supplying the entire door, instead of building up the complete assembly line in their own OEM plants, only a test centre is needed for the inspection at the OEM. Even more than VMI, all the OEM should care is giving the requirements to a certain degree, no matter a black box design or grey box design, the mega suppliers will take care of all the activities in achieving the OEM target, including cooperation with external design companies, or managing the upstream suppliers for the door production, ect. Generally, this job transfer will greatly reduce the OEM assembly complexity, and increase the capacity utilization accordingly.

2. Horizontal Integration

It is always difficult to convince the competitors to cooperate with each other, especially when they are sharing the same market level. This competition is a main cause of the reduplicated investment of the OEMs besides the daily increasing variety and individualization requirements. But if we transfer more responsibilities into the mega suppliers, it will help the horizontal integration of OEMs in a significant way.

Since the mega system suppliers are not supplying one single OEM, and since products-like in our case the door systems, share actually many common parts and even common modules and subsystems, it is more possible to have the integration at the mega supplier level. For example the Tier 2 can supply only the stamping parts while Tier 1 combine them into different door modules with different combination of the same window regulator and ECUs, then the Mega system supplier can combine the door modules with different outer frames and then supply to different OEMs, by which the actual supply chain of doors is now reduced to a very simple line with greatly increased capacity utilization for the suppliers, especially compared with the previous multifarious intersectional supply chains.

In addition to the central production of like parts and platforms at Tier 0,5, the geographical advantage of the suppliers could also be better taken with the integration discussed above.

6.4.2 Solution to E- mobility

The research of new energy vehicles actually can be traced to the 50s last century, together with the booming production of traditional vehicles. After a long run of the R&D trail, the powertrain and fuel strategy goes through the phases of oil (diesel fuel/ gasoline), natural gas (SynFuel CNG), renewable (SunFuel/ Electricity/ Hydrogen), among which the electrotraction battery and electrotraction fuel cell are listed as the development target.

Besides the obvious effect in powertrain and fuel strategy, how the E- trend affects auto design, is a question to be answered. To cope with the green and sustainable target, when people are all focusing on the battery techniques, the E-trend is also challenging the vehicle body designs: the structure, materials, functions, will definitely be influenced as well, and if we come to the study of current published E-prototypes or the series produced E-autos, the huge differences from before the existing traditional autos can be noticed.

After all the success and failures, the industry has been sharing now the same opinion: The electricity is the most applicable power for the future vehicles. Although the high cost of battery and limitation of one-time charging continuation are still the biggest obstacles, compared to other concepts, the commercialization of E-auto is still quite promising. So even it is predicted the traditional vehicle will be still leading the market in the next 10 years, the auto companies should be prepared for the coming E-trend.

Then quite logically, the automotive companies are confronting the problem of designing appropriate logistic concepts to cope with the E-trend, both the infrastructures and the supply chain concepts. And if we look deeper into the market segmentation, besides the existing OEMs who are making a lot of efforts in the E-auto research, many other new auto makers come to this business and have already presented good results. The characteristics of those companies are that they are relative small, but flexible in production and management. They focus mainly on the body design and final assembly, and they have most of their systems outsourced for the limitation of their own capacities.

According to the investigation of this work, different companies focus currently in different areas, and the market pilots are working mainly in the pickups, shuttle buses, special vehicles, and low speed city autos suitable for the current urban system especially the “Mega Cities”. The different market orientations give those auto makers enough space to develop themselves. Based on the investigation of the current existing E-auto prototypes, people may very easily get appealed to the individualized design of the autos, either small and cute, or big and stylish, some vehicles totally changed people’s traditional auto image.

Accepted or not, the suppliers have to change their concepts to occupy the new niche market, and the SC designers have to design new supply chains to meet the requirements for this new market situation. Therefore the metal parts suppliers should consider how to change their material and design to cope with the light structure; cockpit suppliers should consider what kind of new functions are required in the new vehicles, and what others can be replaced; and the door system suppliers have to consider even, how a vehicle door should look like in the future when the auto itself looks no longer like an auto. And since the door systems used to be considered as one of the most complex systems, with different materials like steel, plastic, glass, textile, rubber, and applying different techniques like stamping, blanking ,welding, coating, joining, etc, it will be extremely difficult for the suppliers to solve the new supply chain dilemma.

In general, all the OEMs are confronted with two problems: how to ensure the efficiency when customers order totally different autos from each other (especially the outlook design), which requires high degree of BTO; and how to make the best utilization of the supply chain capacities and achieve biggest standardization when meeting individual customer’s needs. This situation challenges the upstream supply chain greatly, especially to the roles every company is supposed to play. Automotive companies have to define their position more clearly, since it is no longer a task located only to the OEMs, it is rather a task to the collaboration and integration of supply chain members.

Then based on the above analysis, the new structure defined in the previous section offers a good organization which makes the realization of E-Auto easier, and the actual supply more logic and efficient, since the work loads will now be spitted by different partners with an optimal utilization of their own strength and advantageous capability, and total resources of the E-automotive supply chain can be effectively utilized by appropriate collaboration of supply chain partners. In this solution, the mega system supplier, namely the Tier 0,5, will be playing an irreplaceable important role, and for the E-auto supply chain, keeping flexible by the functioning of Tier 0,5, is extremely important for the coming change.

7. Summary and Outlook

This research has been done under the automotive industry background and the researched period covers the recession time and recovery time. Therefore on one hand the work has its scientific contribution, and on the other hand, the conclusions also contribute to the real case problem solving. In this chapter, conclusions of the entire research will be presented, and some recommendations for the future research will also be proposed.

7.1 Research Summary

The summary of research can be elaborated in the following points:

1. The automotive industry is facing unprecedented chances and challenges than ever before. On one hand, the market is expanding with a dramatic speed, and high volumes are demanded by the markets, the entire automotive industry is experiencing a booming development; On the other hand, high requirements from the customers and fierce competition with the competitors are challenging this century-old industry. The design of the autos are supposed to be safer, greener, and more individual, meantime the delivery lead time are required to be shortened in every possibly way. Time is good but challenging.

2. The competition is no longer a simple competition among the different single companies, rather, it’s becoming the competition of supply chains. This requires not only the management of production and financial accounting, but every other aspect that is involved in the supply chain.

3. The automotive supply chain is one of the most complicated supply chain since the automotive industry is a global industry, and most of the supply chain issues are then global issues with large quantity of elements. This makes the automotive supply chain management normally cross big networks.

4. Collaboration between the supply chain members are highly required than ever before. Technology sharing and information sharing are especially required in the new supply chain environment.

5. In order to better design the automotive supply chain, or improve the current supply chain, performance evaluations are needed. The evaluation can be done before a supply chain is established, which may offer good choices for the design; the evaluation can also be done during the supply chain operation, which offers real-time dynamic assessment and discover the bottleneck of the supply chain, meantime offer improvement solutions as well.

6. For certain cases, evaluation from certain interesting perspectives with conventional model might be enough. But for large and complicated supply chain system, integrated model for the overall evaluation is necessary.

7. The conventional model applied in this work well evaluated the performance of a door module supply case, and under that circumstances, localization supply is a good solution.

8. The integrated model applied in this work well evaluated the performance of a door system supply case, and under that circumstances, integration supply is a good solution.

9. The integrated model built up can be widely used in other cases as well, only with adjustment of the index system when needed.

10. The MDFIE method of fuzzy calculation solves the evaluation well, especially with the imprecise data resources. And this method can be used in other cases as well.

11. To improve the supply chain performance in practice, some new technologies such as the RFID etc. are suggested to be applied, which on one hand may increase the productivity, and on the other hand, may strengthen the information management and the collaboration of the supply chain partners.

12. Based on the analysis of current over-capacity problem, more out-sourcing of the non-core business from the OEMs is necessary, which also means a deeper integration of suppliers in the original OEM work is required.

13. E-mobility is a definite trend of the future automotive industry. Companies who catch up this opportunity and make the first foot print in E-mobile market, may have big advantage in the future competition. But the E-mobile has meantime many different characteristics compared with the traditional vehicle industry, market players have to make efforts in getting suitable in this new market.

14. In most of the cases, based on the deeper outsourcing/ integration and E-mobility requirements, new automotive supply chain structure is necessary. Where the integrated Tier 0.5 is supposed to play an important role and some other half-tiers are supposed to occupy the niche position in the automotive supply chain, meantime offer more efficient and qualified services.

7.2 Recommendations for Future Research

As in this work a research mainly concerning the automotive supply chain evaluation has been made, both conventional model and integrated model are proposed and analyzed by vehicle door system supply. The two models are applicable and able to generate reasonable evaluation results which help in the supply chain improvement and optimization, however, in the real industrial application, there is still space for model modification:

a) The proposed models require many manual work, the calculations are done manually with the help of Matlab. A user friendly evaluation software or system with easy interface should be probably developed, by which the engineers only need to input some basic data, and the results can be then automatically calculated by the software or system. This is to say, the algorighum behind the model especially the integrated model could be computaionalized, and all the manual calculation processes should be avoided and done by the computer.

b) The system developed in this work is suitable to the special case applied for this research, by adjusting the index system, the model could be used for evaluation of other cases as well. And the researchers may build up a software or system, where the indices could be defined freely by the user.

c) There are different kinds of algorithms which can be used for supply chain performance evaluation, besides the MDFIE method used in this work, some other methods could also be developed by using other algorithms like “gray correlation analysis method” or “genetic algorithms” and so on.

It is expected that the recommendations may enhance the usefulness of this research, and may contribute to the development of better supply chain performance evaluation systems, and help in the supply chain optimization.

8. References

[ABHT 95] Bruce C. Arntzen, Gerald G. Brown, Terry P. Harrison and Linda L. Trafton, Global Supply Chain Management at Digital Equipment Corporation (1995). Interfaces, Vol. 25, No. 1, Franz Edelman Award Papers (Jan. - Feb., 1995), Pp. 69-93.

[AKK 99] George Archibald, Nejat Karabakal and Paul Karlsson, Supply chain vs. supply chain: using simulation to compete beyond the four walls (1999). Proceedings of the 31st conference on Winter simulation: Simulation - a bridge to the future - Volume 2, Pp. 1207-1214.

[ARS 83] Ravi Singh Achrol, Torger Reve and Louis W. Stern, The Environment of Marketing Channel Dyads: A Framework for Comparative Analysis (1983). The Journal of Marketing, Vol. 47, No. 4 (Autumn, 1983), Pp. 55-67.

[BCW 08] Robert A. Burgelman, Clayton M. Christensen and Steven C. Wheelwright, Strategic Management of Technology and Innovation, 5th Edition (2008). Publisher: McGraw-Hill/Irwin.

[BC 06] Carliss Y. Baldwin and Kim B. Clark, Modularity in the Design of Complex Engineering Systems (2006).Understanding Complex Systems, Pp. 175-205, Springer Berlin, 2006.

[Bea 99] Benita M. Beamon, Measuring supply chain performance (1999). International Journal of Operations and Production Management, Vol.19, No. 3, 1999, Pp. 275-292.

[BGM 00] Ronald H. Ballou, Stephen M. Gilbert and Ashok Mukherjee, New Managerial Challenges from Supply Chain Opportunities (2000). Industrial Marketing Management, Vol. 29, Iss. 1, January 2000, Pp 7-18.

[BGT 04] Asbjoern M. Bonvik, Stanley B. Gershwin and Donald E. Troxel. Operating High Variability Manufacturing Systems (2004). Pp. 57-62.

[BKGST 08] Erkan Bayraktar, S.C. Lenny Koh, A. Gunasekaran, Kazim Sari and Ekrem Tatoglu, The role of forecasting on bullwhip effect for E-SCM applications (2008). International Journal of Production Economics, Vol. 113, Iss. 1, May 2008, Pp. 193-204.

[BM 05] W.C. Benton and Michael Maloni, The influence of power driven buyer/seller relationships on supply chain satisfaction (2005). Journal of Operations Management, Vol. 23, Iss. 1, January 2005, Pp. 1-22.

[BS 08] Kati Brauer and Thomas Seidel, Network Design for Build-to-Order Automotive Production (2008). Build To Order - The Road to the 5-Day Car, Pp.323-334, Springer London.

[BW 03] Rouman Boutellier and Stephan M. Wagner. Sourcing Concepts: Matching Product Architecture, Task Interface, Supplier Competence and Supplier Relationship (2003). Business Engineering: Auf dem Weg zum Unternehmen des Informationszeitalters, Pp 223-237, Springer Verlag.

[Cam 86] Kim S. Cameron, Effectiveness As Paradox: Consensus and Conflict in Conceptions of Organizational Effectiveness (1986). Management Science, Vol. 32, No. 5, Organization Design (May, 1986), Pp. 539-553.

[CBS 02] Leonardo Chwif, Marcos Ribeiro Pereira Barretto and Eduardo Saliby, Supply chain analysis: spredsheet or simulation? (2002). Proceedings of the 2002 Winter Simulation Conference, Pp. 59-66.

[CE 93] Martha C. Cooper and Lisa. M. Ellram, Characteristics of Supply Chain Management and the Implication for Purchasing and Logistics Strategy (1993). The international journal of logistics management, Vol 4, No. 2.

[CFMK 07] Dayana Cope, Mohamed Sam Fayez, Mansooreh Mollaghasemi and Assem Kaylani, Supply chain simulation modeling made easy: an innovative approach (2007). Proceedings of the 39th conference on Winter simulation, Pp.1887-1896.

[CG 07] Charu Chandra and Jānis Grabis, Supply chain configuration: concepts, solutions and applications (2007). Springer, 2007.

[CGLR 01] Keely L. Croxton, Sebastián J. García-Dastugue, Douglas M. Lambert and Dale S. Rogers , The Supply Chain Management Processes (2001). The International Journal of Logistics Management, Vol. 12, No. 2, 2001, Pp. 13-36.

[CH 99] Chen H. Chung, Balancing the Two Dimensions of Time for Time-Based Competition (1999). Journal of Managerial Issues, Vol. 11, 1999.

[Cha 95] S N Chary, Theory and problems in production and operations management (1995). McGraw-Hill, 1995.

[Che 97] Ching-Hsue Cheng, Evaluating naval tactical missile systems by fuzzy AHP based on the grade value of membership function (1997). European Journal of Operational Research, Vol. 96, Iss. 2, 24 January 1997, Pp. 343-350.

[Che 04] Chen Zhixiang, Model and Algorithms of Supply and Demand Coordination Performance Measurement Based on ANP Theory (2004). Computer Integrated Manufacturing Systems, 2004, 3.

[CJ 00] Martin Christopher, and Uta Jüttner, Developing strategic partnerships in the supply chain: a practitioner perspective (2000). European Journal of Purchasing and Supply Management, Vol. 6, Iss. 2, June 2000, Pp. 117-127.

[CL 08] Cao Qing-kui and Li Juan, Reliability Analysis and Evaluation on Member Enterprise of Manufacturing Supply Chain Based on BP Neural Network (2008). 2008 International Conference on Management Science and Engineering (15th), September 10-12, 2008, Pp. 474 - 479.

[CLH 02] Eddie W.L. Cheng, Heng Li, Danny C.K. Ho, (2002) "Analytic hierarchy process (AHP): A defective tool when used improperly", Measuring Business Excellence, Vol. 6, Iss. 4, Pp.33 - 37

[CLP 97] Martha C. Cooper; Douglas M. Lambert and Janus D. Pagh. Supply Chain Management: More Than a New Name for Logistics (1997). The International Journal of Logistics Management, Vol. 8, No. 1, 1997, Pp. 1-14.

[Cou 85] Anne T. Coughlan, Competition and cooperation in marketing channel choice: Theory and application (1985). Marketing Science, Vol. 4, No. 2, Pp 110 – 129.

[CR 04] Wen-Chyuan Chiang and Robert A. Russell, Integrating purchasing and routing in a propane gas supply chain (2004). European Journal of Operational Research. Vol. 154, Iss. 3, 1 May 2004, Pp. 710-729.

[CRG 00] Croom, S., Romano, P., and Giannalkis, M. (2000). Supply chain management: An analytical framework for critical literature review. European Journal of Purchasing and Supply Management, Vol. 6, No.1, Pp. 67 -83.

[CRG 00] Simon Croom, a, Pietro Romanob and Mihalis Giannakisa, Supply chain management: an analytical framework for critical literature review (2000). European Journal of Purchasing and Supply Management, Volume 6, Issue 1, March 2000, Pp. 67-83.

[CT 86] M. Reha Civanlar and H. Joel Trussell，Constructing membership functions using statistical data (1986). Fuzzy Sets and Systems，Vol. 18, Iss. 1, January 1986, Pp. 1-13.

[CT 04] A. Cakravastia and K. Takahashi, Integrated model for supplier selection and negotiation in a make-to-order environment (2004). International Journal of Production Research, Vol. 42, Iss. 21 , Pp. 4457- 4474.

[CTL 02] Felix T.S. Chan, Nelson K.H. Tang, H.C.W Lau and R.W.L. Ip, A simulation approach in supply chain management (2002). Integrated Manufacturing Systems, Vol.13, No. 2, Pp. 117-122.

[CZ 99] Gérard P. Cachon and Paul H. Zipkin, Competitive and Cooperative Inventory Policies in a Two-Stage Supply Chain (1999). Management Science, Vol. 45, No. 7 (Jul., 1999), Pp. 936-953. Published by: INFORMS.

[DBS 08] Michael Druml, Jörg Blechinger, G. Schuh et al (Hrsg.), Lieferantenmanagement in der Anlaufphase eines 0,5 - Tiers (MAGNA STEYR Fahrzeugtechnik AG& Co KG) (2008). Anlaufmanagement in der Automobilindustrie erfolgreich umsetzen, Springer 2008.

[Dia 06] Luis Martín Díaz, Evaluation of cooperative planning in supply chains: an empirical approach of the European automotive industry (2006). Detuscher Universitaets-Verlag, 2006.

[DM 95] Daniel R. Denison and Aneil K. Mishra , Toward a Theory of Organizational Culture and Effectiveness (1995). Organization Science, Vol. 6, No. 2 (Mar. - Apr., 1995), Pp. 204-223.

[Ebe 99] Mark Ebers, The Formation of Inter-Organizational Networks. Oxford University Press, 1999.

[EK 01] Dean Elmuti and Yunus Kathawala, An overview of strategic alliances (2001). Journal of Management Decision, Vol.39, No. 3, Year: 2001, Pp. 205-218.

[EM 08] H. A. ElMaraghy and R. Majety, Integrated supply chain design using multi-criteria optimization (2008). The International Journal of Advanced Manufacturing Technology, Vol. 37, No. 3- 4, May. 2008, Pp. 371-399.

[EP 08] Daniel C. Esty and Michael E. Porter, Industrial Ecology and Competitiveness (2008). Journal of Industrial Ecology, Vol. 2, Iss. 1, Pp. 35 - 43.

[FM 02] Stanley E. Fawcett and Gregory M. Magnan, The rhetoric and reality of supply chain integration (2002). International Journal of Physical Distribution and Logistics Management, Vol.32, No.5, 2002, Pp. 339-361.

[FX 99] Shan Feng and Li D. Xu, Decision support for fuzzy comprehensive evaluation of urban development (1999). Fuzzy Sets and Systems, Vol. 105, Iss. 1, 1 July 1999, Pp. 1-12.

[FZHL 05] Fu Yu, Zhang Cunlu, Huang Peiqing and Luo Jianwen, Case-based Reasoning for Supply Chain Risk Assessment (2005). Journal of Forecasting, Vol.24, No.1.

[GB 96] Larry C. Giunipero and Richard R. Brand, Purchasing's role in supply chain management (1996). International Journal of Logistics, Vol 7, No. 1, 1996, Pp. 29-38.

[GD 08] Philipp Gneiting and Thomas Sommer Dittrich, An Overview of Modular Car Achitecture: the OEMS Perspective on Why and How (2008). Build To Order - The Road to the 5-Day Car, Pp. 101-107, Springer London.

[Geo 73] Petro Georgiou , The Goal Paradigm and Notes Towards a Counter Paradigm (1973). Administrative Science Quarterly, Vol. 18, No. 3 (Sep., 1973), Pp. 291-310.

[GM 05] Paolo Guerrieri and Valentina Meliciani. Technology and international competitiveness: The interdependence between manufacturing and producer services (2005). Structural Change and Economic Dynamics. Vol. 16, Iss. 4, December 2005, Pp. 489-502.

[GN 05] A. Gunasekarana and E.W.T. Ngaib, Build-to-order supply chain management: a literature review and framework for development (2005). Journal of Operations Management, Vol. 23, Iss. 5, July 2005, Pp. 423-451.

[GO 04] Christian Grönroos and Katri Ojasalo. Service productivity: Towards a conceptualization of the transformation of inputs into economic results in services (2004). Journal of Business Research, Vol. 57, Iss. 4, April 2004, Pp. 414-423.

[GO 98] S. H. Ghodsypour and C. O'Brien, A decision support system for supplier selection using an integrated analytic hierarchy process and linear programming (1998). International Journal of Production Economics, Vol. 56-57, 20 September 1998, Pp. 199-212.

[Göb 04] Christof Göbel, Flexible interorganisatorische Kopplung von Geschäftsprozessen: Simulative Flexibilitätsanalyse am Beispiel einer Automotive Supply Chain (2004). Zugl.: Bayreuth, Univ., Diss., 2004; Logos Verlag Berlin 2005.

[GPM 04] A. Gunasekaran, C. Patel and Ronald E. McGaughey, A framework for supply chain performance measurement (2004). International Journal of Production Economics, Vol. 87, Iss. 3, 18 February 2004, Pp. 333-347.

[Gra 02] Robert M. Grant, Contemporary strategy analysis: concepts, techniques, applications (2002). Wiley-Blackwell.

[GRD 98] Peter Gordon, Harry W. Richardson and Bill Davis, Transport-Related Impacts of the Northridge Earthquake (1998). Journal of Transportation and Statistics, May, 1998, Pp. 21- 37.

[GSD 08] Alexandra Güttner and Thomas Sommer-Dittrich, Current Issues at OEMs and Suppliers (2008). Build To Order: The Road to the 5-Day Car, Pp. 55-73 (Daimler AG; Group Research and Advanced Engineering; Materials, Manufacturing and Concepts).

[GW 05] Stephen C. Graves and Sean P. Willems, Optimizing the Supply Chain Configuration for New Products (2005). Management Science, Vol. 51, No. 8, August 2005, Pp. 1165-1180.

[Har 04] Alan Harrison, Outsourcing in the automotive industry inclusive Goal of Tier 0,5 (2004). Automotive industry, IEEE Manufacturing Engineer, February/ March 2004.

[Har 96] C. M. Harland, Supply chain management: relationships, chains and networks (1996). British Journal of Management, 7(special issue), Pp. 63- 72.

[Hes 77] James L Heskett, Logistics essential to strategy (1977). Harvard Business Review, Nov./Dec1977.

[HMG 06] Mickey Howard, Joe Miemczyk and Andrew Graves, Automotive supplier parks: An imperative for build-to-order? (2006). Journal of Purchasing and Supply Management, Vol. 12, Iss. 2, March 2006, Pp. 91-104.

[HRBT 98] Peter Hins, Nick Rich, John Bicheno and David Taylor, Value stream management (1998). The international journal of logistics management, Vol. 9, No. 1, 1998, Pp. 25-42.

[HSK 05] Samuel H. Huang, Sunil K. Sheoran and Harshal Keskar, Computer-assisted Supply Chain Configuration Based on Supply Chain Operations Reference (SCOR) Model (2005). Computer and Industrial Engineering, Vol. 48, 2005, Pp. 377-394.

[HT 02] Jens Leth Hougaard and Mich Tvede, Benchmark selection: An axiomatic approach (2002). European Journal of Operational Research, Volume 137, Issue 1, 16 February 2002, Pages 218-228.

[Inf 06] INFOR, Trends, Challenges, and Solutions for Success in the Global Automotive Industry (2006).

[JE 05] Sanjay Jain and Eric Ervin, Evaluation of supply chain business process improvements using simulation (2005). International Journal of Simulation and Process Modelling, Vol. 1, No. 3- 4 / 2005, Pp 138 -149.

[JHW 10] Zuhua Jiang, Yongwen Huang and Jinlian Wang, Routing for the Milk-Run Pickup System in Automobile Parts Supply (2010). Advances in Soft Computing, Volume 66/2010, Pp. 1267-1275.

[JLT 01] Gary K. Jones, Aldor Lanctot JR. and Hildy J. Teegen, Determinants and performance impacts of external technology acquisition (2001). Journal of Business Venturing, Vol. 16, Iss. 3, May 2001, Pp. 255-283.

[JT 05] Alberto Jose and Michel Tollenaere, Modular and platform methods for product family design: literature analysis (2005). Journal of Intelligent Manufacturing, Vol. 16, No. 3, June 2005, Pp. 371-390.

[Jut 04] Uta Juttner, Supply chain risk management: Understanding the business requirements from a practitioner perspective (2004). The International Journal of Logistics Management, Year: 2005, Vol. 16, Iss. 1, Pp. 120-141.

[JWD 04] Juliang Jin, Yiming Wei and Jing Ding, Fuzzy comprehensive evaluation model based on improved analytic hierarchy process (2004). SHUILI XUEBAO, Vol. 3, March. 2004, Pp. 65-71.

[KGR 00] Nejat Karabakal, Ali Günal and Warren Ritchie, Supply-Chain Analysis at Volkswagen of America (2000). Interfaces, Vol. 30, No. 4, Supply-Chain Management (Jul. - Aug., 2000), Pp. 46-55.

[KYK 08] Stephen Keysuk Kim, Tetsuya Yamada and Hyunchul Kim, Search for Alternatives and Collaboration with Incumbents: Two-Sided Sourcing Behavior in Business Markets (2008). Decision Sciences Volume 39 Number1 February 2008.

[LCK 04] A.C. Lvons, A.E. Coronado-Mondragon and D.F. Kehoe, Factors influencing the design of build-to-order supply chains (2004).

[Lee 08] Thomas Yew Sing Lee, Supply Chain Risk Management (2008). International Journal of Information and Decision Sciences, Vol. 1, No. 1, 2008, Pp. 98-114.

[LHK 01] Eon-Kyung Lee, Sungdo Ha, and Sheung-Kown Kim, Supplier Selection and Management System Considering Relationships in Supply Chain Management (2001). Transactions on Engineering Management, Vol. 48, No. 3, August 2001, Pp.307-318.

[Li 01] Xueping Li, A study of scaling method to obtain index weight by analytic hierarchy process (2001). Journal of BUPT (Social Sciences Edition), Vol. 3, No. 1, Jan．2001, Pp. 25-27.

[LPW 97] Hau L. Lee, V. Padmanabhan and Seungjin Whang, Information Distortion in a Supply Chain: the Bullwhip Effect (1997). Management Science, Vol. 43, No. 4, Frontier Research in Manufacturing and Logistics (Apr., 1997).

[LQ 08] Quanxi Li and Yibing Qi, Computer science. A Framework for Assessing Supply Chain Flexibility (2008). 2008 International Conference on Information Management, Innovation Management and Industrial Engineering.

[LRB 02] Arnold Looman, Frans A.J. Ruffini and Frans A.J. Ruffini, Designing Ordering and Inventory Management Methodologies for Purchased Parts (2002). The Journal of Supply Chain Management: A Global Review of Purchasing and Supply, Copyright © May 2002, by the Institute for Supply Management, Inc. Pp 22-29.

[LSG 02] Kim Langfield-Smith and Michelle R Greenwood, Developing Co-operative Buyer–Supplier Relationships: A Case Study of Toyota (2002), Journal of Management Studies, Vol. 35, Iss. 3, Pp. 331- 353.

[LSW 89] Luxiang Liu, Qixin Song and Shiyun Wang, A Preliminary Study on Multifactorial Evaluatioin of New Crop Varieties with the Application of the Grey System Theory (1989), Scientia Agricultura Sinica, 1989-03.

[Lu 02] Lu J.W. Intra- and Inter-organizational Imitative Behavior: Institutional Influences on Japanese Firms' Entry Mode Choice (2002). Journal of International Business Studies, Vol. 33, No. 1, March 2002, Pp. 19-37.

[LWL 08] Yuanhong Liu, Haiyan Wu and Ming Luo, A Reliability Evaluation of Supply Chain: Indicator System and Fuzzy Comprehensive Evaluation (2008). Research and Practical Issues of Enterprise Information System II, 2008, Pp. 1515-1521, Springer Boston.

[Lyn 09] Kerry Lynch, Idle Capacity in the Auto Industry Hits a Record High (2009). American Institute for Economic Research.

[Ma 04] Ma Shihua. The Study for Elements and Characters of Integrated logistics capability (2004). Chinese Journal of Management, Vol. 1, 2004.

[MAD 01] C. Muralidharan, N. Anantharaman and S.G. Deshmukh, Vendor rating in purchasing scenario: a confidence interval approach (2001). International Journal of Operations and Production Management, Vol.21, Iss.10, 2001, Pp.1305-1326.

[MAD 06] C. Muralidharan N. Anantharaman and S.G. Deshmukh, A Multi-Criteria Group Decisionmaking Model for Supplier Rating (2006). Journal of Supply Chain Management, Vol. 38, Iss. 4, Pp. 22 - 33.

[Mcl 01] Ronan Mclvor, Lean Supply: the design and cost reduction dimensions (2001). European Jounal of Puchasing and Supply Management, Vol. 7, 2001, Pp. 227-242.

[MCL 94] Don-Lin Mon, Ching-Hsue Cheng and Jiann-Chern Lin, Evaluating weapon system using fuzzy analytic hierarchy process based on entropy weight (1994). Fuzzy Sets and Systems, Vol. 62, Iss. 2, 10 March 1994, Pp. 127-134.

[MH 08] Joe Miemczyk and Mickey Howard, Automotive Supplier Park Strategies Supporting Build-to-Order, Build to order: the road to the 5-day car, 2008, Srpinger.

[Mik 00] Juliana Hsuan Mikkola, Modularity, outsourcing, and inter-firm learning (2000). DRUID Summer Conference 2000.

[MK 91] John T. Mentzel and Brenda Ponsford Konrad, An efficiency/ effectiveness approach to logistics performance analysis (1991). Jounal of Business Logistics, Vol. 12, No. 1, 1991, Pp 33-63.

[MKH 02] Chiung Moon, Jongsoo Kim and Sun Hur, Integrated process planning and scheduling with minimizing total tardiness in multi-plants supply chain (2002). Computers and Industrial Engineering, Vol. 43, Iss. 1-2, 1 July 2002, Pp. 331-349.

[MMRC 01] John A. Muckstadt, David H. Murray, James A. Rappold and Dwight E. Collins, Guidelines for Collaborative Supply Chain System Design and Operation (2001). Information Systems Frontiers, Vol. 3, No. 4, December 2001, Pp 427-453.

[MT 04] L. Mikhailov and P. Tsvetinov, Evaluation of services using a fuzzy analytic hierarchy process (2004). Applied Soft Computing, Vol. 5, Iss. 1, December 2004, Pp. 23-33.

[NB 97] Barry J. Nalebuff and Adam M. Brandenburger，Co-opetition: Competitive and cooperative business strategies for the digital economy (1997), Strategy and Leadership,1997, Vol. 25, Iss. 6, Pp. 28-35.

[NCDZ 05] Anna Nagurney, Jose Cruz, June Dong and Ding Zhang. Supply chain networks, electronic commerce, and supply side and demand side risk (2005). European Journal of Operational Research, Vol. 164, Iss. 1, 1 July 2005, Pp. 120-142.

[NE 01] Sharon Novak and Steven D. Eppinger, Sourcing by Design: Product Complexity and the Supply Chain (2001). Management Science, Vol. 47, No. 1, Design and Development (Jan., 2001), Pp. 189-204.

[NW 89] J. L. Nevins, D. E. Whitney, Concurrent Design of Products and Processes (1989).

[OS 93] Cheri Ostroff and Neal Schmitt , Configurations of Organizational Effectiveness and Efficiency (1993). The Academy of Management Journal, Vol. 36, No. 6 (Dec., 1993), Pp. 1345-1361.

[Pen 06] Junsong Peng, Automotive Supply Chain: Strategy, Management and Information System (2006), Publishing house of electronics industry.

[Per 97] Göran Persson, Organization design strategies for business logistics (1997), International Journal of Physical Distribution and Logistics Management, Vol. 27, Iss. 5/6, Pp.282 - 291.

[PH 04] Frits K. Pil and Matthias Holweg, Linking Product Variety to Order-Fulfillment Strategies (2004). Interfaces, Vol. 34, No. 5 (Sep. - Oct., 2004), Pp. 394-403.

[PHR 04]Kenneth J. Petersena, Robert B. Handfieldb, and Gary L. Ragatzc, Supplier integration into new product development: coordinating product, process and supply chain design(2004). Journal of Operations Management,Vol. 23, Iss. 3-4, April 2005, Pp. 371-388.

[Por 07] Michael E. Porter, Towards a dynamic theory of strategy (2007). Strategic Management Journal, Vol. 12, Iss. S2, Pp. 95-117.

[PRW 08] Arnold Picot, Ralf Reichwald and Rolf Wigand, Information, organization and management (2008). Springer, 2008.

[LQ 07] A Framework for Implementing and Managing Supply Chain Flexibility under Environmental Uncertainty, 2007, Pp. 83-88.

[Rom 03] Pietro Romano, Co-ordination and integration mechanisms to manage logistics processes across supply networks (2003). Journal of Purchasing and Supply Management, Vol. 9, Iss. 3, May 2003, Pp. 119-134.

[RRN 97] Donna Retzlaff-Roberts and Ernest L. Nichols, Jr. Using Computer Simulation to Reduce Supply Chain Cycle Time (1997). Journal of Center for Supply Chain, 1997, Pp. 69-78.

[RT 04] Gerald Reiner and Michael Trcka, Customized supply chain design: Problems and alternatives for a production company in the food industry. A simulation based analysis (2004). International Journal of Production Economics, Vol. 89, Iss. 2, 28 May 2004, Pp. 217-229.

[RU 98] David Robertson and Karl Ulrich, Planning for Product Platforms (1998). Sloan Management Review, Summer 1998. Pp. 19-32.

[Saa 90] Thomas L. Saaty, How to make a decision: The analytic hierarchy process (1990). European Journal of Operational Research, Vol. 48, Iss. 1, 5 September 1990, Pp. 9-26.

[San 00] Ron Sanchez, Modular architectures, knowledge assets and organisational learning: new management processes for product creation (2000). International Journal of Technology Management, Volume 19, Number 6 / 2000, Pp. 610-629.

[SC 01] Ron Sanchez and Robert P. Collins, Competing and Learning in Modular Markets (2001). Long Range Planning, Vol. 34, Iss. 6, December 2001, Pp. 645-667.

[Sch 08] Torsten Schonert, Interorganisationaler Wertschöpfungsnetzwerke in der deutschen Automobilindustrie (2008). Pp. 193-229, Gabler Verlag.

[Sch 08] Michael Schwarz, Trends in the Automotive Industry - Implications on Supply Chain Management (2008). Cisco Internet Business Solutions Group (IBSG).

[SH 09] A.H.M. Shamsuzzoha and Petri T. Helo , Reconfiguring product development process in auto industries for mass customization (2009), International Journal of Productivity and Quality Management, Vol. 4, No. 4 / 2009, Pp. 400-417.

[SHK 05] M. Stevenson; L. C. Hendry; B. G. Kingsman， A review of production planning and control: the applicability of key concepts to the make-to-order industry

(2005). International Journal of Production Research, Vol. 43, Iss. 5, March 2005, Pp. 869-898.

[SHK 08] AHM Shamsuzzoha, Petri Helo, and Tauno Kekäle, Literature Overview of Modularity in World Automotive Industries (2008). PICMET 2008 Proceedings, 27-31 July, Cape Town, South Africa (c) 2008 PICMET.

[SKZDT 08] Mehmet Sevkli, S.C. Lenny Koh, Selim Zaim, Mehmet Demirbag and Ekrem Tatoglu, Hybrid analytical hierarchy process model for supplier selection (2007), Industrial Management and Data Systems, Vol. 108 No. 1, 2008, Pp. 122-142.

[SL 03] Nigel Slack and Michael Lewis,Operations Management: Critical Perspectives on Business and Management(2003), Routledge press.

[SMO 96] Richard A. Spreng, Scott B. MacKenzie and Richard W. Olshavsky, A Reexamination of the Determinants of Consumer Satisfaction (1996). The Journal of Marketing, Vol. 60, No. 3 (Jul., 1996), Pp.15-32, Published by: American Marketing Association.

[SSS 98] Jayashankar M. Swaminathan, Stephen F. Smith and Norman M. Sadeh, Modeling Supply Chain Dynamics: A Multiagent Approach (1998). Decision Sciences, Vol. 29, Iss. 3, Pp. 607 - 632.

[Tan 06] Keah Choon Tan, Supply Chain Management: Practices, Concerns, and Performance Issues (2006). Journal of Supply Chain Management, Vol. 38, Iss. 1, Pp. 42-53.

[TF 07] Barbara G. Tabachnick and Linda S. Fidell, Using multivariate statistics (2007). Boston [etc.], Pearson : Allyn & Bacon, cop. 2007, 5th, Pearson international edition.

[TLW 02] Keah Choon Tan, Steven B. Lyman and Joel D. Wisner, Supply chain management: a strategic perspective (2002). International Journal of Operations and Production Management, Vol. 22, No. 6, 2002, Pp. 614-631.

[Tow 96] Denis R. Towill, Industrial dynamics modelling of supply chains (1996). International Journal of Physical Distribution and Logistics Management, Vol. 26, Iss. 2, Pp.23 - 42.

[TPS 98] David J. Teece, Gary Pisano and Amy Shuen, Dynamic capabilities and strategic management, Strategic Management Journal, Vol. 18, Iss. 7, Pp. 509-533.

[TQ 08] Dunbing Tang and Xiaoming Qian Product lifecycle management for automotive development focusing on supplier integration (2008). Computers in Industry, Vol. 59, Iss. 2-3, March 2008, Pp. 288-295.

[TYW 04] Jiafu Tang; Kai-Leung Yung; Andrew W H Ip, Heuristics-based Integrated Decisions for Logistics Network Systems (2004). Journal of Manufacturing Systems, Vol.23, No.1, 2004, Pp. 1-13.

[Ulr 95] Karl Ulrich, The role of product architecture in the manufacturing firm (1995). Research Policy, Vol. 24, Iss. 3, May 1995, Pp. 419-440.

[VCJ 05] Guilherme E. Vieira and Osmar Cesar Junior (2005). A conceptual model for the creation of supply chain simulation models, 37th Winter simulation conference, 2005, Pp. 2619-2627.

[Vel 00] Francisco Veloso, The automotive supply chain organization: Global Trends and Perspectives (2000).

[VK 02] Francisco Veloso and Rajiv Kumar, The Automotive Supply Chain: Global Trends and Asian Perspectives (2002). Asian Development Bank.

[Voi 08] Kai-Ingo Voigt, Flexibilität und Stabilität in der automobilen Supply Chain - Anforderungen und Lösungsansätze (2008). Operations Management in Theorie und Praxis, Pp. 185-201, Verlag Gabler.

[WHD 03] Ge Wang, Samuel H. Huang and John P. Dismukes, Product-driven supply chain selection using integrated multi-criteria decision-making methodology (2003). International Journal of Production Economics, Vol. 91, 2004, Pp.1-15.

[Whi 90] Daniel E. Whitney, Designing the design process (1990). Research in Engineering Design, Volume 2, Number 1 / March 1990, Pp. 3-13.

[Wil 99] Sean Peter Willems, Two Papers in Supply Chain Design: Supply Chain Configuratioin in Multigeneration Products (1999). Massachusetts Institute of Technology, 1999.

[WKK 10] P. Wangphanicha; S. Karaa and B. Kayisa, Analysis of the bullwhip effect in multi-product, multi-stage supply chain systems - a simulation approach (2010). International Journal of Production Research, Vol. 48, Iss. 15, January 2010, Pp. 4501-4517.

[WYRX 04] Wang Zhe, Yu Bo, Rong Yihong and Xu Dianguo. TOCO total assessment tool for decision-making on IP supplier selection (2004). Journal of Harbin Institute of Technology (New Series), 2004, Vol 11, No. 1.

[XMC 00] Xu Xianhao, Ma Shihua and Chen Rongqiu, Key Performance Evaluating Index and Its Optimization in Supply Chain (2000). Journal of Huazhong University of Science and Technology, Vol. 3.

[Yi 07] Qingfeng Yi, Supply Chain Performance Evaluation Research Status and Question Investigation (2007). Commercial Times.

[Zad 65] L.A. Zadeh, Fuzzy sets (1965). Information and Control, Vol. 8, Pp. 338-353.

[ZH 06] Cunlu Zhang and Peiqing Huang, Supply Chain Risk by Structure (2006). Service Operations and Logistics, and Informatics, 21-23 June 2006, Pp. 300 – 303.

[ZL 08] Pei Zheng and Kin Keung Lai, A Rough Set Approach on Supply Chain Dynamic Performance Measurement (2008). Agent and Multi-Agent Systems:

Technologies and Applications, Pp. 312-322, Lecture Notes in Computer Science, Vol. 4953/ 2008.

[Zsi 06] George A. Zsidisin. Managerial Perceptions of Supply Risk (2006). .Journal of Supply Chain Management, Vol. 39, Iss. 1, Pp. 14-26.

[ZSMK 07] George A. Zsidisin, Michael E. Smith, Regina C. McNally and Thomas J. Kull, Evaluation criteria development and assessment of purchasing and supply management journals (2007). Journal of Operations Management, Vol. 25, Iss. 1, January 2007, Pp. 165-183.

[ZWHL 05] Zhang Cunlu, Wang Ziping, Huang Peiqing and Luo Jianwen, Supply Chain Structure Optimization Based on Risk Control (2005). Journal of Shanghai Jiaotong university, Vo l. 39 No. 3, Mar. 2005, Pp. 468-478.