Designing Structural Supply Chain Flexibility

Mulinski, K.J.

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For my grandfather,
an accomplished geologist,
who taught me to dig deeper
at the age of eight

In memoriam
W.M. Sachs

Abstract

In a continuously changing business environment the role of supply chain flexibility is constantly increasing. A flexible supply chain can ensure survival in quickly changing market conditions as well as enable sustainable growth. This thesis explores the topic of supply chain flexibility with focus on structural flexibility due to scarcity of previous research in that area. The purpose of the research is to answer a question: *how can companies design structural supply chain flexibility*? In an attempt to answer this question design principles for designing structurally flexible supply chains are formulated and tested.

Chapter I introduces the topic of supply chain design and the challenges of designing for supply chain flexibility. The author commences with providing an array of definitions of what actually is a supply chain. What follows is an overview of concepts which have influenced and formed supply chain management: interorganizational relationships and industrial networks theory, Transaction Cost Economy with its view of a firm, and the virtual organization theory. After a review of the above-mentioned concepts the author proceeds to describe the concept of supply chain flexibility. Supply chain flexibility is defined on three levels: operational (i.e. supply and demand balancing), structural (i.e. evolutionary adaptation to the changes in the environment) and strategic (i.e. redesigning the value chain). The author then explores the concept of the enemies of supply chain flexibility. This concept is taken into account in the case study selection process. Since this thesis focuses on the success stories of supply chain flexibility the three cases which were selected for empirical research were screened for the presence of the supply chain enemies prior to selection. We focus on flexible supply chains in which the enemies of flexibility are not apparent.

Chapter II starts with a review of the new trends in organizational design. A notion of design science (van Aken 2004; van Aken 2005) is introduced and followed by the process of science based organization design. The architecture of the design principle is then explained following the logic of Context, Intervention, Mechanism, Outcome (CIMO). Finally, a design principle of incompleteness is examined as an enabler of organizational flexibility. This study employs the design principle of incompleteness (Garud, Jam, and Tuertscher 2008) to construct a logical chain of reasoning between Object Orientation and supply chain flexibility.

Chapter III builds on the concepts introduced in the previous two chapters to propose a framework of supply chain design principles for flexibility. The framework is built upon Object Orientation which is a concept brought into the field of supply chain design by analogy from the field of Computer Science. The chapter commences with an overview of the principles of Object Orientation, the latter being a concept conceived in order to deal with the complexity of information systems development. Object Orientation is based on four key design principles: modularity (that the system should be divided into self-contained objects), abstraction (that these objects should have well defined communication interfaces), encapsulation (that these objects should be treated as black boxes, without paying attention to what is actually inside), hierarchy (that the system should be decomposed into most basic objects, which are contained by other objects). The author through a series of analogies concludes that the application of Object Oriented design would contribute to designing flexible supply chains built on the idea of incompleteness. The rest of the chapter is devoted to exploring the four principles of Object Orientation in supply chain context. On the basis of

that exploration a list of Theoretical Design Principles for achieving structural supply chain flexibility is put forward.

Chapter IV is an overview of methodology employed in the empirical part of the study. The study uses literature research and analogical reasoning for the formulation of Theoretical Design Principles, which are verified in an exploratory case study conducted according to Yin's (2003) methodology. The Theoretical Design Principles are then subject to Alfa-testing in a developing multiple case study (van Aken 2004).

Chapter V is a case study of three companies which have endeavored a redesign of their supply chain organizations in search of flexibility. Company Alfa was a manufacturer of consumer products and tools, which decided to redesign its supply chain to benefit from increased operational and structural supply chain flexibility. Company Beta was a manufacturer of furniture components, which started a supply chain optimization project to gain the flexibility needed to survive in difficult market conditions. Company Gamma was an energy producer which launched a supply chain strategy design project aiming at an increased flexibility of its maintenance and repair supply chain. Alfa's case is a pilot used for exploring the Theoretical Design Principles in business context. The remaining case studies of Beta and Gamma are based on action research paradigm and thus are a ground for Alfa-testing the proposed design principles.

Chapter VI summarizes the conclusions from the study. It puts forward a suggestion for practitioners that supply chain organizations designed according to the principles of organizational modularity, abstraction and encapsulation are more likely to be structurally flexible. Afterwards a summary of the contribution to supply chain design, design science and Object Orientation is presented. Finally, implications for further research are presented.

This thesis presents original research in the field of supply chain management and contains interesting implications for supply chain practitioners and academics alike.

Contents

Introduction

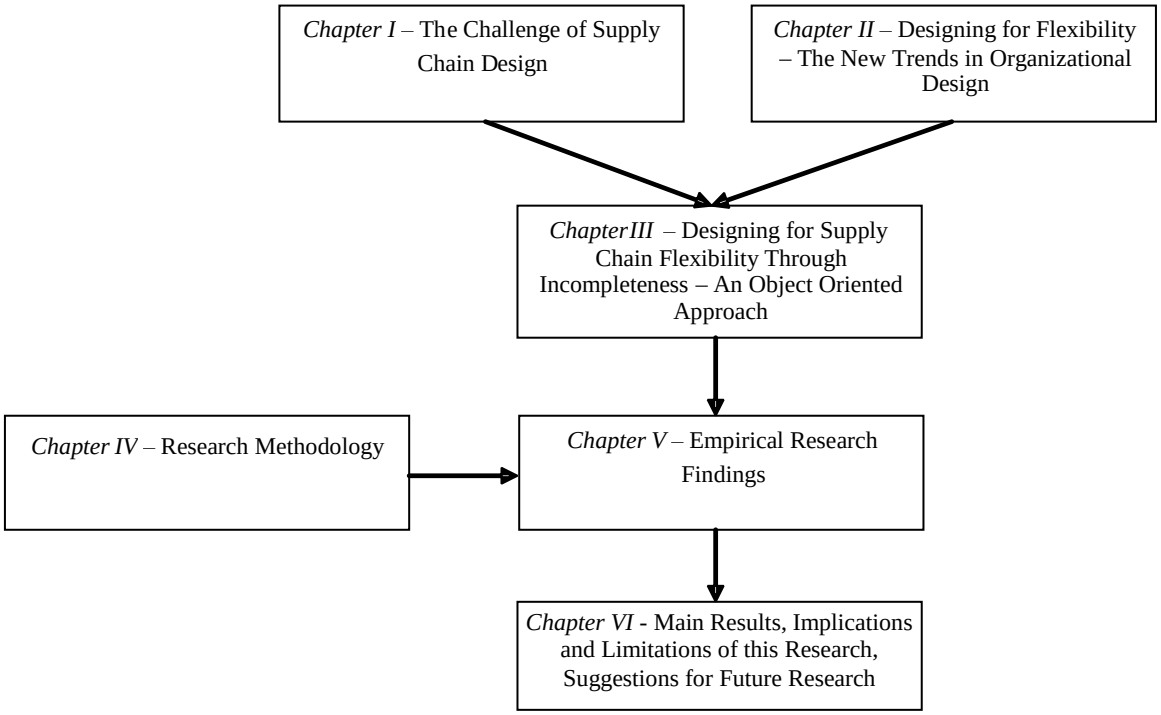
In a constantly changing business environment organizational flexibility gets a well deserved amount of executives' attention. There are two main reasons for flexibility to be on the top of executives' agendas. First, it enables the organization to adapt and survive in the changing environment and in the times of economic crises. Second, is that the flexibility as an organizational capability represents the last sustainable source of competitive advantage (Nadler and Tushman 1997).
Indeed, in a world shaped by an increasing globalization and an ongoing technological revolution the competitive advantages of the industrial era are but temporary in nature, whereas "the ultimate core competency is the ability to choose the capabilities well" (Fine 1998). Indeed, Miller (1996) observed that the ability to take action and adapt quickly is a key determinant of superior organizational performance in many industries.
Supply chains are of strategic importance to firms in the modern global business environment (Christopher 1998) and they are a key enabler of organizational flexibility. Supply chain design plays a crucial role in ensuring the ability of an organization to respond to change and meet the shifting customer demand for products and services. The capability of continuously redesigning the supply chain in a quest for temporary advantage is what constitutes the source of sustainable competitive advantage (Fine 1998; Nadler and Tushman 1997).
To illustrate the importance of supply chain flexibility let us reflect on the following hypothetical example. Consider a company producing consumer electronics which has entered the market on a wave of demand for portable CD players. Upon its startup the company has quickly assembled its supply chain from a range of component suppliers. When the customer demand shifted to portable MP3 players the company was able to reassemble its supply chain in a timely manner to deliver the new product and capture a significant portion of the market. If that company would manage to repeat its successful early market entry strategy in the future it would have a lasting competitive advantage. On the contrary, if it would not be able to turn this one time success into a lasting capability it would quickly lose its competitive edge.

As we have outlined above, much research has been done on the importance of organizational and supply chain flexibility. There is also a vast body of knowledge on solutions which are known to improve supply chain flexibility on the operational level, that is in supply and demand balancing - e.g. product modularity (Doran 2005; Danese and Filippini 2010; Jacobs et al. 2011; Lau and Yam 2005, 2007; Sanchez 2004; van Hoek and Weken 1998), Sales & Operations Planning practices (Milliken 2008; Piechule 2008; Pilger 2009, Sodhi and Tang 2011), Vendor Managed Inventory (Kastsian and Monningman 2011, Kristianto et al. 2012), Electronic Data Interchange (Machuca and Barajas 2004). Yet, we do not know how companies can improve their structural supply chain flexibility, i.e. their ability to evolutionarily adapt their supply chain organization to the changes in the environment. By that adaptation we mean the capability to "pick and choose" from the operational solutions and to implement them quickly and effectively. There is no comprehensive set of design principles for structurally flexible supply chain design.

This thesis attempts to define design principles for structural supply chain flexibility. More specifically, it attempts to answer a research question which is: *how can companies design structural supply chain flexibility*? This work is organized in a manner pictured below (see Picture 1). Chapter I introduces the topic of supply chain design and the challenges of

designing for supply chain flexibility. Chapter II introduces new trends in organizational design and designing for flexibility. Chapter III combines both of these approaches and supplements them with Object Orientation in order to propose a framework for building structurally flexible supply chains. This framework is empirically verified according to research methodology described in Chapter IV and empirically tested in Chapter V. Chapter VI presents the conclusions and implications of the undertaken research.

Picture 1. Graph of Relations Between Chapters



I. The Challenge of Supply Chain Design

This chapter lays the foundation for the whole thesis by reviewing the body of knowledge related to supply chain design. It explores the various forms of supply chains, the concept of supply chain flexibility and the challenges of flexible supply chain design.

1.1. Definition and Forms of Supply Chains

The concept of supply chain was developed in the 1980s in response to deregulation of industries, increasing globalization and advances in the information technology (Giannakis, Croom, and Slack 2004). It was used in so many contexts by academics and managers alike that its meaning became vague. Most organizations have since worked out their own definitions of boundaries and processes covered by the term. The table below revokes a few definitions from the literature.

Table 1. A Review of Definitions of a Supply Chain

Authors	Definition
Ganeshan and Harrison (1995)	A supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers.
Lee and Ng (1997)	A supply chain is a network of entities that starts with the suppliers' supplier and end with the customers' customers for the production and delivery of goods and services.
Christopher (1998)	A supply chain is a network of interconnected organizations co-operatively working together to control, manage and improve the flow of materials and information from suppliers to customers.
Lambert, Stock et al. (1998)	A supply chain is the alignment of firms that bring products or services to market.
Handfield and Nichols (1999)	The supply chain encompasses all activities associated with the flow and transformation of goods from the raw materials stage (extraction), through to the end-user, as well as associated information flows. Material and information flow both up and down the supply chain.
Peck and Juttner (2000)	A supply chain is a coordinated collective of interdependent companies and highly autonomous market-sensitive business units.
Chopra and Meindl (2001)	A supply chain consists of all stages involved, directly or indirectly, in fulfilling a customer request. The supply chain includes the manufacturer, suppliers, transporters, warehouses, retailers, and customers.
Waters (2003)	A supply chain is the series of activities and organizations that both tangible and intangible materials move through on their journeys from initial suppliers to final customers.

Supply chain management is based upon the idea that to achieve a competitive advantage the supply chain should be analyzed and managed in its entirety, from supplier's supplier to the end customer (Giannakis, Croom, and Slack 2004), since optimization of supply chain performance is only possible by considering the totality of costs and the end to end effectiveness.

The stream of supply chain management thought revokes many different concepts from the realm of organization theory. It seems that the most influential are: systems theory

(Giannakis, Croom, and Slack 2004; Helou and Caddy 2006; Lau and Yam 2007), game theory (Anon 2004; Cox 1999; Giannakis, Croom, and Slack 2004), interorganizational relationships and industrial networks theories (Dubois, Hulthen, and Pedersen 2004; Subramani and Venkatraman 2003; Talluri, Baker, and Sarkis 1999), Transaction Cost Economy (Anon 2004; Jaspers and van den Ende 2006; Mueller and Seuring 2007), and the virtual organization theory (Chandrashekar and Schary 1999; Rahman and Bhattachryya 2002; van Hoek 1998; Walker 2006). It is not the purpose of this study to comprehensively review their influence on supply chain management, since this has already been done in an impressive body of literature. Reviewed below are only those, which directly or indirectly influence the concepts put forward in this thesis: interorganizational relationships and industrial networks theory, Transaction Cost Economy with its view of a firm, and the virtual organization theory.

1.1.1. Interorganizational Relationships and Industrial Networks Approach to Supply Chains

Interorganizational relationships and industrial network theories all rely on the central concept of **interaction**, defined as a relatively enduring transaction that occurs between organizations in a given environment (IMP 1982). The **Interaction Model** developed by the Industrial Marketing and Purchasing group is a dynamic model of buyer-supplier relations in industrial markets in which the marketing and supply of industrial goods is described as an interaction between two parties (Giannakis, Croom, and Slack 2004). Interactions are influenced by four characteristics: **parties** involved in the interaction (organizations, groups, individuals), the **process of interaction** itself, the **environment** within which the interaction takes place, the **atmosphere** affecting and affected by the interaction (IMP 1982). It has been recognized that there is a continuum of relationship forms between the *obligational contracting relation* characterized by a long term approach to close collaboration and trust and *arm's length contractual relation* where parties are principally independent and possibly adversarial (Sako 1992).

1.1.2. Transaction Cost Economy's View of a Firm

Transaction Cost Economy also views the organizational structure of a firm and its value chain as experiencing tensions from two opposing trends, one being towards a market-based transactional model, and the other being towards a hierarchy-based model of close collaboration and supplier integration[1]. This seems to be a result of an unresolved dispute on the nature of the firm, started by Coase's seminal article (Coase 1937), and elaborated on by Williamson (Williamson 1971; Williamson 1973; Williamson 1979; Williamson 1985; Williamson 1993; Williamson 1996) and numerous other theorists (Alchian and Demsetz 1972; Demsetz 1968; Demsetz 1988; Klein, Crawford, and Alchian 1978). The following paragraphs will present the Transaction Cost Economy view of the boundaries of a firm and the transactions within the supply chain depending on the chosen organizational structure.

Since we cannot review the various forms of supply chain organizational structure without referring to the transactions which take place within the supply chain, we have to examine the basic transaction characteristics first.

[1] The hierarchy-based model covers both hierarchies and cooperative arrangements, which bear close resemblance to hierarchies due to the existence of a dominant controlling party.

An element which is inherent to every transaction is **cost**. Dyer (2000) defines four kinds of costs related to transactions: search cost – the cost of gathering information, supplier identification and evaluation; contracting cost – the cost of negotiating and writing a contract; monitoring cost – the cost associated with monitoring the fulfillment of a contract; enforcement cost – which is associated with ex-post bargaining and sanctioning a trading partner.
Every transaction is associated with a degree of **risk** which results from uncertainty. Williamson (1973; 1979) assumes uncertainty to be a critical factor affecting transactions and points out its effects to be "extensive and pervasive" (Williamson 1973). Williamson identifies two types of uncertainty: exogenous and behavioral, the first stemming from the impossibility of accurately predicting future states of the environment, and the second from the impossibility of hedging against "self interest seeking with guile" of the contracting parties.
The third characteristic of a transactions is **asset specificity** which develops when the parties that enter into the transaction invest in transaction specific assets – thus creating sunk costs, and assets which are not easy to deploy elsewhere, "since specialized investment cannot be redeployed without a loss of productive value" (Williamson 1996). What is more, writing and negotiating contracts for transactions which are highly asset specific is costly (Williamson 1981).
The fourth characteristic of a transaction is the **frequency** at which it is renewed or undertaken. Irregularities in the transaction frequency are induced by fluctuations either on the demand or on the supply side. A group of researchers (Hon, Tarng, and Chu 2000) states that "even when the customer demand is relatively stable, institutional and random factors tend to make the demand expressed at each subsequent stage upstream in the supply chain more cyclical and extreme in variation", a phenomenon otherwise known as the bullwhip effect (Lee, Padmanabhan, and Wang 1997). Irregularities in transaction frequency apply to the supply side as well, especially when the number of suppliers in the market is large (Dobrila, Rajat, and Radivoj 1998).
Having reviewed the four basic transaction characteristics, we can proceed with describing the various supply chain structures.

1.1.2.1. The Characteristics of the Market-based Transactional Model of the Supply Chain

A market-based transactional model of a supply chain is a value chain built from autonomous organizations contracted on the market, each focused on a set of activities in which they have core competences, in order to deliver value to the end customer. The relations between the parties in such a supply chain are reduced to transactions, thus economizing on management cost as well as benefiting from market competition.
Market based supply chains are based on a "self-interested owner allocation of resources in accordance with market prices" (Demsetz 1997). Therefore, firms in the supply chain are autonomous and atomized, connected through numerous weak ties and partners. Market based supply chains are relatively easy to enter or exit, at least for those who have the required skills and capital (Jones 1993). According to Williamson (1975; 1985) the market is a natural starting point form of a supply chain, which provides a more efficient mechanism of exchange than a hierarchy, due to the economies of specialization (Leiblein and Miller 2003). Market-based supply chain is a form which emphasizes "independence and enterprise" and enjoys the benefits of autonomous adaptation to market conditions, as opposed to hierarchy-based supply chains under which a need for cooperative adaptation accrues (Williamson 1999).

Market-based supply chains offer advantages over hierarchy-based supply chains in several fundamental aspects: cost-benefits, organizational flexibility and supply chain competitiveness.

Cost advantages of market-based supply chains stem from two areas: market production costs and management costs. Production costs under market procurement benefit from three factors (Williamson 1981):

- markets enjoy a more leveraged economy of scale, than a separate company,
- markets aggregate uncorrelated demands, thus realizing a risk pooling benefit,
- markets can enjoy economies of scope in supplying a related set of activities, of which a firm requires only one.

What is more, an advantage arises from competition among suppliers on the market and an ability to negotiate a better offer, provided that the supply side is sufficiently large.

Management cost advantage results from a lower cost of managing a transaction in a market based supply chain than that of managing an analogical operation under alternative form of governance. Management costs comprise the costs of coordinating and controlling the transaction resources.

Supply chains based on market procurement are more flexible and reconfigurable than the hierarchy-based supply chains. A reconfiguration of a market based supply chain can be achieved by simply swapping those participants which do not fit the new supply chain business model, whereas in the case of hierarchy-based supply chains this can only be achieved by organic change (Hagel III 2002). In established organizations, organic change meets with resistance, which usually is a cause of failures or at least a weakened impact of change efforts (Chandrashekar and Schary 1999).

Market-based supply chains can be designed to be more competitive as a whole, by choosing only those suppliers which exhibit a comparative advantage in their core competency. This approach seems to be significantly less expensive than developing analogical abilities in-house, which not only increases the cost of design for competitiveness, but also exposes the organization to a serious risk, that a developed competence may eventually become obsolete. A value chain composed from companies focusing on their core competences, not only provides superior value to the supply chain as a whole, but also offers (Honi, Tarng, and Chu 2000): economies of scale, learning curve effect and benefits from comparative advantages.

On the other hand, market-based supply chains also have their disadvantages, which are: potential misalignments of supply chain participants goals and operations, limitations to knowledge transfer and sharing, and relative ease of imitating the supply chain structure by competition.

The misalignments of goals and operations result from the fact, that each firm in the market-based value chain pursues its own goals under its own operational model, which could be conflicting with goals and operations of other value chain participants. Therefore one could argue that markets could operate significantly less effectively than hierarchies, which have an established set of goals, coherent business model and an overall "stronger mission orientation" (Williamson 1999). Operational model discrepancies between the chain participants can be observed relatively easily and early into the value chain organization lifecycle and can be remedied by swapping a participant with a more fitting one. Whereas goal misalignments seem to be virtually impossible to eliminate from market-based value chains, because of self interest seeking behaviors of chain members.

The limitations of knowledge transfer and sharing stem from the characteristics of market transactions. Market transactions are limited to the exchange of products without provisioning for the exchange of experience and knowledge. As long as codified knowledge such as documentation, blueprints and formulas are relatively easy to transfer, tacit knowledge "is difficult to articulate in a way that is meaningful and complete" (Teece 1998).

Those limitations could be a significant disadvantage, considering that knowledge is one of the key factors of production in modern economy and a source of competitive advantage (Leiblein and Miller 2003). Value chains based on market procurement do not promote joint R&D initiatives and the lack of knowledge sharing leads to a reduced competitive advantage of the whole supply chain.
The relative ease of imitating the supply chain structure by competition results from the transparency of supply chain and the fact that the market suppliers are not exclusively bound to one supply chain (Watson, Zinkhan, and Pitt 2004). Therefore the advantage of a unique supply chain structure can be stolen and the business model imitated if no other "competitive advantage from learning about its customers or (…) network effects" has been established (Watson, Zinkhan, and Pitt 2004).
According to Williamson (Williamson 1991) different governance structures are beneficial in different contractual situations. Transactions which are thought to benefit from being undertaken in market-based supply chains are characterized by:

- a sum of transaction and management costs of a purchase on the market that is smaller than a sum of transaction and management costs of an analogous exchange in a hierarchy (Demsetz 1988),
- low uncertainty, which results from a relatively stable and predictive environment or a degree of trust between the parties involved in a transaction,
- lack of asset specificity, which means that no transaction specific assets were invested in,
- low but regular transaction frequency, therefore there is no benefit to internalize the exchange,
- both the supply and demand side of the market are large, hence no market inefficiencies arise from small number bargaining.

1.1.2.2. The Characteristics of the Hierarchy-based Model of the Supply Chain

A hierarchy-based model of vertical integration is a value chain built through the integration of supply chain members either under a firm or under a cooperative arrangement between individual firms, bearing close resemblance to hierarchy due to the existence of a dominant controlling party. The relations between the links in the supply chain are governed by administrative rules and procedures. All the transactions within the chain are internalized, thus reducing the risk associated with market contracting and the costs related to high specificity of production assets.
Transactions within the hierarchy involve factors of production, which the hierarchy allocates to achieve its overall goals. Hierarchies exercise bureaucratic control over exchanges and impose authority roles, rules and procedures. What is more, they reserve certain critical legal rights such as "the right to audit, access to information, fiat of authority and forbearance from court interference in divisional disputes" (Jones 1993). Hierarchies feature cooperation and trust among its members and are characterized by greater compliance and stronger mission orientation (Williamson 1999). Ties within the hierarchy-based supply chains are strong and dense, thus entrance into the structure is tightly regulated.
According to Williamson, the hierarchy-based supply chain when compared to market-based supply chains "will never do worse (by replication) and will sometimes do better (by selective intervention)" (Williamson, 2005). On the other hand, implementing an efficiently functioning hierarchy is difficult, because of bureaucracy costs, which may lead to hierarchy failure like in the case of central planned economy (Williamson 1991).

Nevertheless, hierarchy-based supply chains offer several advantages over market-based supply chains. The advantage shifts to hierarchy-based supply chains when the need for cooperative adaptation accrues. Under hierarchy-based supply chains the incentive to pursue local goals is reduced, due to an aligned organization and a more holistic system orientation. A significant advantage of a hierarchy-based supply chain is a "wider variety and greater sensitivity of control instruments that are available for enforcing intrafirm in comparison with interfirm activities" (Williamson 1971). Hierarchy-based supply chains should resolve disputes, mitigate internal conflicts and avoid the impasses which may occur on the market, more easily and in a less costly manner, thanks to implemented rules and regulations. The risk of internalized transactions is reduced, due to the fact that they are based on trust and that the internal organization environment is not as volatile as the market. The quality of products and services being subject to internal exchange is under constant performance measurement, and whenever issues arise they can be collectively worked upon.
As a result of closer collaboration and a better flow of information more innovations can be created. Knowledge transfer is easier and more feasible when the relations within the value chain are close. What is more the hierarchy-based supply chain offers a basis for R&D cooperation between the functional departments and business units, further reinforced by aligned incentives for collaboration. New products can be 'designed for manufacturability' through close collaboration of R&D, marketing and production functions of internal suppliers (Fine 1998).
Hierarchy-based supply chains also have some disadvantages to their functioning, which are: cost detriment, bureaucratic inefficiencies, and lack of organizational flexibility.
Production costs in hierarchy-based supply chains can be higher than in the market competition environment. To offset this disadvantage and to get a quasi form of competition, internal markets along with mixed sourcing techniques have been introduced, but still it is questionable whether they are as cost effective as markets (Baldenius and Reichelstein 2006).
Management and bureaucracy costs in internalized supply chains tend to be higher than in market-based supply chains, because "the establishment of production linkages between operating divisions requires that the firm invest in bureaucratic controls to coordinate interdivisional exchange" (Jones and Hill 1988). Costs of internal management and coordination are usually not taken into account when conducting a make-or-buy analysis, nevertheless they constitute for a significant portion of alternative transaction costs. Managers' time consumed by meetings, conference calls and other close collaboration issues is higher compared to simplified transactions with market suppliers, or as Williamson puts it: "coordination through hierarchy leads to bureaucracy and inefficiency because of the lack of competitive pressure" which is alleviated by "market exchange (which) serves to attenuate the bureaucratic distortions to which internal exchange is subject" (Williamson 1981).
Hierarchy-based supply chains are less flexible and more difficult to restructure. Contrary to the market-based supply chain, parts of the organization cannot be simply replaced, but have to go through organic change, which is a long process which usually meets with resistance (Hagel III 2002), which in turn is a cause of failures or at least a weakened impact of change efforts (Chandrashekar and Schary 1999).
Williamson asserts that vertical integration within the supply chain is a generic strategy when faced with market failure (Williamson 1991). Transactions benefit from being internalized under the hierarchy when:

- a sum of transaction and management costs of a purchase on the market is bigger than a sum of transaction and management costs of an analogous exchange in a hierarchy (Demsetz 1988),
- moderate to high uncertainty, which results from an unpredictable environment or other sources of risk,

- moderate to high asset specificity, which means that a significant amount or highly specialized transaction specific assets were developed,
- recurrent transactions, therefore there is a benefit to internalize the exchange,
- the supply or demand side of the market are small, hence market inefficiencies arise from small number bargaining.
- hold up concerns are severe, the hierarchical governance aligns the interests and reconciliates the differences via rules and procedures, and permits a more effective, sequentially adaptive, decision making process (Leiblein and Miller 2003).

1.1.3. The Virtual Organization and its Supply Chain

Since the foundations of Transaction Cost Economics were laid by Williamson in 1970s, the business environment has changed and both the markets and hierarchies have evolved. Several forces have driven the direction of change, among them the most prominent were modern information technology, market globalization and ongoing product commoditization. Those factors have altered the basic characteristics of business to business transactions.
The overall **transaction costs** have been reduced. The search cost has been reduced due to a widespread use of the Internet for the means of communication, thus greatly facilitating the process of gathering information on suppliers and evaluation of their offers (Bartezzaghi and Ronchi 2003). The contracting cost has been reduced thanks to the standardized agreements and ongoing commoditization of products and services (Welker and Vries 2005). The monitoring and enforcement costs have been reduced thanks to the introduction of bodies, which establish and monitor product standards and quality.
Transaction **risk** has been significantly countered by standardizing, monitoring and quality assuring bodies. Product standardization and quality assurance eliminates risks related to product incompatibility and faultiness. A notable example is the automotive industry, which among few other most quality demanding industries, has established its own quality standards.
Asset specificity is less likely to develop when the market is commoditized and the products are standardized. Transaction specific assets, if any, are easily deployed at no or low cost in other transactions. As a result no lock in develops either at the supply nor the demand side.
Transaction **frequency** is high but the tendency to internalize the transactions is less likely to develop, the reasons being low transaction costs and buyers benefiting from supplier competition on global market. Last but not least, market inefficiencies which result from small number bargaining situations are less likely to happen on global markets, which are in prevalence today.

Those changes in the business environment have resulted in an emergence of a new form of organization which has been described in a growing stream of virtual organization theory (Chandrashekar and Schary 1999; Frigant and Talbot 2005; Hagel 2002; Hoogeweegen, Teunissen, Vervest, and Wagenaar 1999; Rahman and Bhattachryya 2002; van Hoek 1998; Walker 2006; Watson, Zinkhan, and Pitt 2004). A **virtual organization** is basically defined as an organization which has relatively few physical assets and which extensively uses information technology to manage its business. There is a belief that entire supply chains can be designed to be virtual and managed as such (Giannakis, Croom, and Slack 2004).

Several researchers have helped build a fairly accurate view of the virtual supply chain phenomenon (Chandrashekar and Schary 1999; Hagel 2002; Watson, Zinkhan, and Pitt 2004) describing its key characteristics.

The members of virtual supply chains are autonomous organizations, focused on a narrow set of activities in which they have truly distinctive capabilities. These organizations can be members of multiple supply chains. The virtual supply chain is coordinated by a dominant party – an orchestrator, which dynamically assigns temporary partners for a specific task or project in order to provide a customized product to a specified customer group. The orchestrator sets requirements and certification procedures for new companies entering the supply chain, either by imposing its own standards or by requiring adherence to those of already existing standard bodies. An important feature of virtual supply chains is that the relations within the supply chain are simplified, the number of transactions is reduced and the remaining transactions become routinized, which results in transaction cost economies. On the other hand the firms in a buyer-supplier relation are capable of long term close collaboration and alignment of their interests whenever it is perceived as mutually rewarding (e.g. joint R&D projects or cost optimization).
Virtual supply chains are flexible and operate analogically to pull systems in that they respond to customer orders in real time and adjust to customer and market requirements. The Internet plays a vital role in virtual supply chains as it is extensively used for communication and coordination purposes.
In one of his last works, *Management Challenges for the 21st Century*, Peter Drucker (1999) points out that a modern firm can no longer be thought of in terms of the span of control, as present day managers are increasingly called upon to produce results with resources over which they have no hierarchical control, be it in project teams or in supply chains.

Virtual supply chains are an evolutionary form of organization, which combines some of the advantages of both market and hierarchy-based forms:

- cost benefits, with additional gains of: economies of production and buyer costs owing to global market competition, reduction of transaction and management costs owing to the advances in information technology,
- relatively higher organizational flexibility than that of a hierarchy, ensured by: information technology enabling a real time global communication system, and access to a wide portfolio of suppliers available on the global market,
- relatively higher supply chain competitiveness, due to access to a wide portfolio of competencies available on the global market,
- the ability of cooperative adaptation - a more aligned supply chain organization and a more holistic system orientation than that in a market-based setting, though mutual trust is a *sine qua non* requirement,
- knowledge transfer is easier and more feasible when the relations within the value chain are close, virtual ties offer a basis for R&D cooperation between the functional departments and business units of buyer and supplier, further reinforced by aligned incentives for collaboration.

Virtual supply chains besides having numerous advantages do also have disadvantages:

- relative ease of imitating the supply chain structure by competitors, due to an increased transparency of virtual supply chains,
- management and bureaucracy costs in virtual supply chains, though not as high as in integrated supply chains, are typically higher than in market-based supply chains, because of the increased costs of coordination.

To emphasize the fact that the virtual supply chain is not "yet another academic fantasy" but a phenomenon deeply rooted in the business environment, it is worth noting that the trend has also been recognized by IBM Global Business Services in its study of the ongoing

enterprise specialization (Pohle, Korsten, Ramamurthy, and Foecking 2004). The study explores the emergence of highly competitive and flexible companies, which prosper in demanding and competitive environments, through use of modern information technologies to design and manage their value chains.

1.2. The Nature of Organizational and Supply Chain Flexibility

Academics and practitioners alike have invested significant effort into defining what constitutes flexibility. They have provided a diverse set of answers, which should not be surprising since flexibility appears to be a polymorphous concept (Evans 1991), which can be interpreted differently at different levels of the same organization (Toni and Tonchia 1998).

An exploration of the concept of flexibility and supply chain flexibility in particular shall commence with a review of contributions to the subject by different researchers. Various definitions of flexibility usually see it as a response to environmental uncertainty and to specific customers' expectations (Gupta and Goyal 1989; Halemane and Janszen 2004; Nilsson and Nordahl 1995). In relation to this definition, Volberda (1996) observed that most researchers oppose flexibility to stability, which seems to be a step in the wrong direction since "too great a reaction capacity or too short a reaction time may lead to overreaction, excessive information search, and wasted resources" (Volberda 1996). Only by ensuring stability in flexible organizational designs the organization can achieve lasting advantage (Adler 1988). This view is also encompassed by Hitt et al. (1998), who define flexibility as a capability to respond quickly or proactively to changing competitive conditions in order to maintain competitive advantage paired with ability to "balance stable and fluid states of the organization" (Hitt, Keats, and DeMarie 1998).
Another approach emphasizes the reversibility of the adaptive changes in the organization. Abott and Banjeri define flexibility as "the ability to adapt, in a reversible manner, to an existing situation, as opposed to evolution, which is irreversible"(Abbott and Banerji 2003).
Yet another approach is presented by Evans (1991) who defines flexibility as composed of a number of "senses" including "adaptability, agility, corrigibility, elasticity, hedging, liquidity, malleability, plasticity, resilience, robustness, and versatility", which are organizational responses to environmental uncertainties and pressures.
An extensive literature review by De Toni and Tonchia (1998) reveals that flexibility can indeed be classified in different dimensions, flexibility measurement is inherently difficult and its interpretation differs among different people within the organization.
Majority of researchers agrees to divide the concept of flexibility into several dimensions (Abbott and Banerji 2003; Halemane and Janszen 2004; Volberda 1996). This study focuses on a view developed by Volberda (1996) as it can be easily related to supply chain flexibility.
Volberda defines flexibility as "the degree to which an organization has a variety of managerial capabilities and the speed at which they can be activated, to increase the control capacity of management and improve the controllability of the organization" (Volberda 1996). He subsequently defines four types of organizational flexibility: steady-state, operational, structural and strategic.
Steady-state flexibility is a set of standard organizational procedures which are deployed to optimize firm's performance when the organization operates in a relatively stable environment.
Operational flexibility consists of routine capabilities which are based on current organization design. Those capabilities respond to changes in volume and mix of activities in familiar situations and lead to short term fluctuations in organization's level of activity.

Structural flexibility consists of managerial capabilities to evolutionarily adapt the organization design to changes in the environment. The scope of organizational change triggered by structural flexibility covers organization structure and processes.
Strategic flexibility consists of managerial capabilities to transform the organization strategy and design in the face of unfamiliar changes in the environment. This involves redefinition of the organization's strategic direction and activities.

Supply chain flexibility is often perceived solely at the operational level, as the ability to balance demand with supply and provide clients with products in the right place, time and quality (Gong 2008; Stevenson and Spring 2007; Wadhwa, Saxena, and Chan 2008; Wang, Tai, and Wei 2006). But supply chain flexibility should be viewed in the same four dimensions as is organizational flexibility since it spans more than just operational activities within an organization (Schary 1998).
Steady-state and operational supply chain flexibility consist of routine capabilities to adjust to fluctuations in supply and demand and maintain responsiveness and continuity in supply chain operations.
Structural supply chain flexibility consists of managerial capabilities to evolutionarily adapt the supply chain design in response to changes in the environment. The scope of activities covers for example: onboarding of new clients, business partners and suppliers; qualifying a new source of supply; adding a new manufacturing plant; enabling a new type of offering; introducing Just in Time philosophy.
Strategic supply chain flexibility consists of managerial capabilities to transform the supply chain strategy, dynamically reconfigure the value chain in order to respond to fundamental changes in the environment and provide new products and services to the customer through business design and structure. The scope of activities covers for example: responding to major supply chain disruptions, supporting acquisitions and divestitures within the value chain, fundamentally redesigning sourcing strategy, adding a new line of business.

To achieve flexibility within each of the dimensions mentioned above appropriate organizational designs and capabilities have to be developed. Yet, because of the complexity of supply chains and the plethora of factors which diminish supply chain flexibility, it is a very difficult task. There is a vast body of knowledge on solutions which are known to improve supply chain flexibility on the operational level, that is in supply and demand balancing - e.g. product modularity (Doran 2005; Danese and Filippini 2010; Jacobs et al. 2011; Lau and Yam 2005, 2007; Sanchez 2004; van Hoek and Weken 1998), Sales & Operations Planning practices (Milliken 2008; Piechule 2008; Pilger 2009, Sodhi and Tang 2011), Vendor Managed Inventory (Kastsian and Monningman 2011, Kristianto et al. 2012), Electronic Data Interchange (Machuca and Barajas 2004). There is also existing research on strategic shifts in the supply chain - e.g. launching completely new products (Terziovski 2002), choosing the right flexibility strategies (Candace et al. 2011) or strategic logistics outsourcing (Veerwal et al. 2008). Yet, we do not know how companies can improve their structural supply chain flexibility as there is no comprehensive set of design principles for structurally flexible supply chain design. On the forthcoming pages we will attempt to define and test the design principles for structural supply chain flexibility. More specifically, we will attempt to answer a research question which is: *how can companies design structural supply chain flexibility*?

1.3. Complexity and Other Organizational Enemies of Supply Chain Flexibility

Organizations and their supply chains do not exist in a vacuum. They are living organisms, subject to many internal and external influences and therefore likely to continually change.

What may start as a flexible supply chain with one kind of architecture may evolve over time towards another form. This evolution may reflect changes in the organizational strategy, but it seems that in most situations it is rather an undesirable drift. Indeed, it will be demonstrated that there are many natural organizational processes which militate against supply chain flexibility; let us call them "enemies" inspired in that by Churchman (1979). Below some of these enemies are presented and described in terms of their impact on supply chain flexibility.

Complexity is the foremost enemy of flexible supply chain design, is deeply rooted in all elements of supply chain architecture. Herbert Simon, in his classic *Architecture of Complexity* (1962), defines a complex system as "one made up of large number of parts that have many interactions… in such systems the whole is more than the sum of the parts in the weak but important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole". It is this very characteristic that makes supply chain design such a challenge.
Supply chain complexity can be further examined both within the organization and at its interfaces with the supplier.
Internal drivers of complexity include product characteristics, operational processes, and organizational structures. **Product innovation** can also drive complexity and lead to development of asset specificity, disruption of established product architecture, and require an additional amount of coordination. Reestablishing the product interfaces after an innovation takes a considerable amount of resources and supplementary quality controls to ensure that the product requirements are passed.
Indeed, one study shows that the leading driver of complexity is **product proliferation** (Hoole 2006). Striking the right balance between a revenue generating product innovation and a cost inducing increase in product complexity is particularly difficult (Baldwin and Clark 1997; Burkett 2006; Ernst 2005; Gottfredson and Aspinall 2005; Sturgeon 2002; Wilson, Carey, and Reynolds 2006). A fine example of a company which has fallen prey to product-driven complexity is LEGO. Company's product designers had proliferated the number of modules until it had 1,500 stock keeping units, whereas 80 percent of sales were generated by just 30 products (Oliver, Samakh, and Heckmann 2007).

Supplier-customer interface is understood as the relationship between the transacting parties, and the material flows and information flows. This interface also gives rise to numerous complexities.
Communication of **product requirements** and coordination of **production schedules** can also become a complex task due to an increasing intricacy of product requirements and geographical dispersion of supply networks.
The drive towards **supply chain transparency** also adds up to complexity. Suppliers revealing features of their operations to the buyers, with factory or laboratory tours, product improvement conferences, sharing of strategic information, and similar practices, all lead to the buyer not only having to tackle its own complexity but also that of its supply chain partners, as it must now acquire the competencies and the knowledge to make sense of the seller's operations.
Nevertheless, complexity is a fact of life in a rapidly changing business environment and companies have to learn to effectively manage it[2]. Indeed, one study (Heywood, Spungin, and Turnbull 2007) suggests that complexity should be treated not as a problem to be eliminated, but as a challenge which, if properly managed can be a source of economic value.

[2] Managing complexity involves facing a dilemma of complexity vs. reliability. Increasing the reliability of a design often translates to increasing its complexity, whereas increased complexity can signify reduced reliability.

Corruption is the next enemy of flexible supply chains. It is natural for people that repeatedly transact with each other to develop social relationships, and since the decision to purchase by a buyer may be perceived by the seller as a favor, it is only natural to reciprocate. At what point is the line of corrupted behavior crossed? The answer is largely a matter of taste, and will vary significantly from one culture to another. But it is necessary for the supply chain professionals to stay as objective as possible and approach each transaction or long term contract with only a narrow focus on the best interest of the firm.

The seller may not intend to corrupt the buyer, but merely pursue a legitimate strategy of developing **customer loyalty**. This can be done for example by volume discounts cumulated a posteriori over a period of time. When this is done, the buyer need not decide to commit to a higher volume of purchasing, having the option to forego in the future the opportunity to buy from the same purchaser. However, if volume discounts require prior commitment or some form of down payment, and therefore a longer term contract, special attention should be paid to the increase in transaction costs and risks. If the supplier cannot be called strategic for the supply chain, this kind of transaction should probably be avoided. Even though it is tempting for the buyer, because the decrease in unit costs may be significant. But proper supply chain management practices impose the obligation to consider the totality of costs, including a monetized value of risk and of intangibles like management attention required to the deal.

In recent years it is fashionable for companies faced with intense competitive pressures and commoditization of their wares to transform themselves from **product into service firms**, by marketing their goods as part of a complete package that includes consulting or R&D services for the client, after-sales services, economic and technological intelligence, training and so on. This approach requires a close and sustained relationship, and therefore companies that choose to implement it partially forego the flexibility of their supply chain, as they include the chosen supplier into the ranks of their partners and close collaborators. The buyer can no longer treat the seller as a "black box" that can be switched for another "black box" at will.

Lack of trust also negatively affects supply chains. Expecting that the supplier will fail to deliver on contractual terms results in a need to constantly monitor his actions and collect evidence in case of a need for juridical prosecution. This results in increased transaction costs through monitoring and enforcement, and a need for constant development and refinement of contingency plans.

When all other means of smoothing the cooperation with a strategic partner fail, close collaboration can assume a form of taking over **control of supplier operations**. This is often done by appointing resident on-site managers and engineers or implementing quality monitoring. This form poses a serious threat to the integrity of supply chain architecture, as it bears a moral hazard resulting from relations that are not arms length and sharing the responsibility for suppliers' economic well being, thus making it for example impossible to lower the buying prices.

Another two enemies are the supplier's **encouragement to buy customized products,** which naturally increases supplier dependency, and supplier tie-in related to a **large scale of production** when one supplier provides a significant portion of a certain good.

Social responsibility has also recently become a restraint to supply chain flexibility since there is a pressure to monitor the potential suppliers for issues like ethics or ecology.

Table 2 provides a summary description of the enemies of supply chains, of their impact and provides references to supporting literature.

Table 2. The Enemies of Supply Chain Flexibility

Enemy	Outcome	Sample References
Product complexity	Increase in coordination costs	Baldwin and Clark (1997); Burkett (2006); Ernst (2005), Wilson et al. (2006)
Product innovation and proliferation	Complexity driven by the disturbance of standardized module interfaces, loss of benefits from commoditization leading to asset specificity	Ernst (2005), Hoole (2006) ,Sturgeon (2002)
Communication of product requirements and production schedules	Complexity driven by the need to communicate intricate information and coordinate complex interactions	Hagel (2002), Chandrashekar and Schary (1999)
Supply chain transparency	Complexity driven by the need to acquire capabilities to evaluate supplier operations	Gunasekaran and Ngai (2004)
Corruption of buyers by sellers	Increased costs and loss of bargaining power	Millington et al. (2005); Steidlmeier (1999)
Customer loyalty tactics by suppliers	Increase in transaction costs and risks	Piercy and Lane (2007)
Bundling of products with associated services	Increased dependence on specific suppliers and loss of strategic independence	Wilson et al. (1990); Heide and John (1988)
Lack of trust	Monitoring of unreliable suppliers increases transaction costs	Chu and Fang (2006); Myhr (2001); Ratnasingam and Phan (2003); Violino (2002)
Interference with supplier operations	Increase of overhead and management costs, development of emotional ties with the supplier leading to moral hazard.	Williamson and Ouchi (1981)
Encouragement to procure customized products	Increased supplier dependency, increased buying costs with potentially marginal customization payoffs	Ganesan (1994); Gassenheimer and Manolis (2001); Gassenheimer et al. (1998); Heide and Miner (1992)
Size / Scale of production	Increased supplier dependency	Jacobs (1974)
Social and political pressures	Increased transaction cost and possibly management costs	Anon (2004); Barlett et al. (2006a); Littlefield (1996); Winstanley et al. (2002)

The presence of enemies in a certain supply chain should be assessed on a continuum from weak to strong. Companies whose supply chain suffers from the presence of enemies are naturally less likely to build a truly flexible supply chain. This thesis focuses on the success stories of supply chain flexibility to examine how that success can be achieved. In the selected cases we have focused on supply chains which are flexible, therefore the enemies of flexibility are weak and such is their impact on supply chain flexibility. For that reason, we place a more in depth discussion on the enemies of flexibility, their impact on the specific kinds of flexibility and enemy strength assessment in each of the case studies in Appendix 1.

II. Designing for Flexibility - The New Trends in Organizational Design

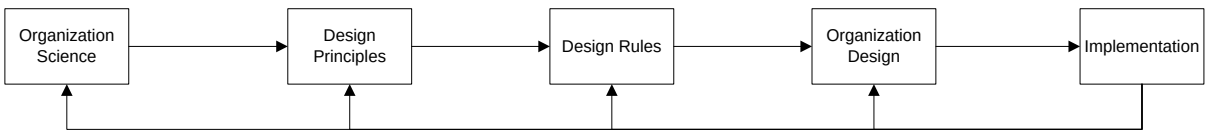
The first chapter has introduced us to the challenge of supply chain design and design for supply chain flexibility. This chapter reviews the new trends in organizational design and the emerging concept of design principles of organizational flexibility. This will allow us to build a theoretical framework of design principles for supply chain flexibility in Chapter III.

2.1. The New Trends in Organization Science – The Rise of Science for Design

Organization science has long been criticized for its lack of practical applicability (van Aken 2005). Academic efforts have been reduced to describing and evaluating recent development in organizational practice produced by the practitioners (Kaminska-Labbe and Sachs 2006). Yet amidst the cries for practical relevance of organization science, academics lately seem to be on the right track to rejoin the realms of practical significance. A new trend of *science for design* (also named *design science*) has emerged aiming to "seriously address the need for scholars and managers alike for better organizational forms and processes" (Jelinek, Romme, and Boland 2008).
Denyer et al. (2008) argue that *design science* as a term was coined by Van Aken (2004) who referring to the work of Simon (1996) distinguished between the *explanatory sciences* (according to Simon's natural sciences along with sociology and economics) and *design sciences* (Simon's sciences of the artificial). Whereas *explanatory science* aims to describe, explain and predict, it is *design science* that aims to develop knowledge applicable in solving real-life problems. *Design science* applied to management seeks to develop knowledge on how to solve problems faced by the organizations through their entire lifecycle.
Design science steps into the direction of developing design principles (Romme 2003) and propositions specific to certain situations, conditions and contexts (Jelinek, Romme, and Boland 2008). It embraces the complexity theory by accepting that a small change in inputs can have a major influence on outputs, thus avoiding the pitfalls of claimed scientific omniscience. Instead, *design science* advocates that a set of well chosen simple design rules can help build a range of resilient and productive processes (Eisenhardt and Sull 2001).
This approach is very close to the hearts and minds of consultants and organization design practitioners alike. Indeed, they often refer to the notion of 'best practice', which in most cases is a proven design principle, though often referred to without the scientific discipline (i.e. not taking into account the specific situations, conditions and contexts under which this principle was particularly successful).

Romme and Endenburg (2006) provide a general process of *science-based* organization design (see Picture below). They propose that the *science-based organization design* process ought to be composed of the following five liaised components.

Picture 2. Science-based Organization Design Process



Organization Science which is "the cumulative body of key concepts, theories, and experientially verified relationships useful for explaining organizational processes and outcomes" (Romme and Endenburg 2006). From this body of knowledge formulated in the form of prescriptions a set of *construction principles* is drawn.

Design Principles (or Construction Principles) are defined as "any coherent set of imperative propositions, grounded in the state-of-the-art of organization science, for producing new organizational designs and forms and redeveloping existing ones" (Romme 2003). They should be regarded as an extract from the body of organization science that will be applied in the specific design at hand. Design principles are translated from the language of theory which generally contains conditional propositions in the form "if A then B" into a set of prescriptive principles of the form "to achieve A, do B" (Kaminska-Labbe and Sachs 2006).

Design Rules are "elaborate solution-oriented guidelines for the design process" (Romme 2003). They constitute a high-level sketch of the design and serve to describe the intentions of the designers. Design rules constitute a coherent set and it is impossible to abstract one from the others. Practitioners use to develop several sets of design rules to help evaluate the alternatives and reach the final design decisions.

Organization Design is a visualization of a not yet implemented design developed using the design rules agreed upon in the previous step. It is represented by a chosen type of visualization (drawing, organization chart, narrative). Particular designs arise from an interaction between the chosen design rules, contingencies and constraints of the design process and the preferences of the design team (Romme and Endenburg 2006).

Implementation is a physical representation of the design. This phase of the design process enables to see whether the chosen design actually works and produces the intended outcomes. Observations gathered during this phase are a critical input for improving the chosen design in the next iteration of the design process. Healthy organizations are in a state of constant redesign in a quest for competitive advantage (Nadler and Tushman 1997).

Design science brings about a special attitude towards organization design initiatives which can be best resumed by Bolland and Collopy (2004): "A design attitude views each project as an opportunity for invention that includes a questioning of basic assumptions and a resolve to leave the world a better place than we found it."

2.2. The Architecture of a Design Principle

In this paragraph we focus on the architecture of *design principles* since they constitute an important building block in the construction of theoretical propositions. Prescriptive knowledge in the form of *design principles* plays a pivotal role in design science. A *design principle* is not a complete solution for a given problem. It is an input and a guideline to designing a working solution. Transforming the *design principles* into actual design requires professional knowledge and expertise. Denyer et al. (2008) have provided a very meaningful contribution to organization design science extending the notion of the prescriptive design principles through 'CIMO logic'. This approach enables to easily synthesize multiple disparate perspectives on the fuzzy and ambiguous organization issues.
According to Denyer et al. (2008) the 'CIMO logic' stems from the seminal work of Bunge who has formulated the following logic of prescriptive knowledge: "if you want to achieve

outcome O in context C, then use intervention type I". This logic can be further enriched by taking into account what kind of generative mechanisms are triggered to produce the outcome of the intervention (Denyer, Tranfield, and Van Aken 2008). Finally the 'CIMO logic' can be defined as follows: in this class of problematic Contexts, use this Intervention(s) type to invoke these generative Mechanism(s), to deliver these Outcome(s).
It is essential to note, that 'CIMO logic' does not advocate a simple mechanistic view of organizations and does not express its directives in the form of "if A then B" algorithms. In fact it offers a robust architecture for providing rich accounts of actual design interventions. Below each of the aforementioned components of the *design principle* is described.

Context is the field problem that is addressed by the design principle and its background in the form of endogenous and exogenous factors, and the nature of the human actors that influence the organizational change. Exogenous factors include for example: market position, competition or industry specifics; whereas endogenous factors include: technology, organizational design, stability, organizational knowledge. Human actors which influence the design intervention are characterized by their competencies, experience, politics and power.

Interventions are the specific actions which are undertaken in order to deliver expected results. The outcome of the intervention is strongly reliant on its implementation and the *mechanisms* which are triggered.

Mechanisms are the organizational phenomena triggered by the intervention. An example of such a mechanism would be the causal chain of effects of empowering the employees. Employee empowerment provides the opportunity to contribute beyond the normal operational tasks, which naturally increases the responsibility and employee participation, which in turn offers a potential of long term benefits.

Outcome is the result of the intervention in its quantitative and qualitative aspects, e.g. performance improvement, cost reduction, or increased employee satisfaction.

At a later stage these components will help to establish theoretical design principles of supply chain flexibility.

2.3. The Role of the Principle of Minimal Specification in Organizational Flexibility

The constantly evolving nature of the business environment sparked genuine interest among academics and practitioners alike for researching organization designs that would thrive and succeed in such conditions.
Scholars used to advocate design completeness as a necessary condition for successful designs. Design completeness allows for a priori identification of a problem in the design stage, cautious assessment of alternatives and a choice of the most optimal solution (Garud, Jam, and Tuertscher 2008). Yet, there are two main reasons for which this approach is bound to fail in a turbulent business environment. Firstly, in turbulent environment it is impossible to forecast all the possible situations and factors which the designed organization would encounter. For example the boundaries of the organization or the preferences of the stakeholders might change as a result of exogenous forces; therefore any attempt at design completeness is futile by definition. Secondly, because of the complexity of business ecosystem and the networked character of its economy, it is easy to develop a solution that

would satisfy the local optima, but would otherwise yield suboptimal results of the system as a whole. Such organization design would be at a competitive disadvantage.

Van Aken (2005) observed that design implementations have numerous hidden properties, which although present in the implementation itself are invisible in the design model. Consequently, he has formulated a *principle of minimal specification*, which states that the design should contain only the essential information that those who lead the design intervention should know to realize it. The minimal specification gives the intervention leader several degrees of creative freedom to adapt the design to the requirements of the specific intervention.
Consequently, academics which monitor recent developments in the field of organization design have observed an emergent trend towards intentional *design incompleteness*. Incomplete designs based on the principle of minimal specification provide certain unchangeable high level design rules into the system, but allow for flexibility of their implementation as long as the implementations follow the predefined rules. *Incomplete designs* allow to build organizations which change easily and naturally when the environment and its conditions shift (Garud, Jam, and Tuertscher 2008) therefore increasing organizations' competitive advantage. Garud et al. (2008) refer to a case of Wikipedia which has started with an incomplete set of rules for editing and adding new knowledge content. Those rules have later evolved into a more elaborate set of policies for managing a constantly growing community of contributors. Even though the main design rule (the freedom of contribution) did not change its implementation has been altered to reflect the changes in the environment (the growing number of contributors and the sometimes disputable quality of their contributions).
Simon metaphorically likens the *design for incompleteness* to painting in oil "where every new spot of pigment laid on the canvas creates some kind of pattern that provides a continuing source of new ideas to the painter" (Garud, Jam, and Tuertscher 2008).

One could argue that the notion of *design incompleteness* is to some extent similar to systemic phenomenon of *self-organization*, yet in fact those notions differ distinctly. *Self-organization* is a notion rooted in systems theory, which states that interactions within an organization will develop into „highly-ordered relating patterns that members of a system did not design or intend" (Henning 2007). *Self-organization* is characterized by unpredictability of its emergence without instructions or a priori plans. It refers to "the perplexing way in which a complex system itself creates completely un-led, un-designed, yet highly ordered behavioral patterns" (Henning 2007). In general, *design incompleteness* is an intentional design decision, whereas self-organization is an emergent and uncontrollable systemic phenomenon.

Intentional *design incompleteness* can also be observed outside the field of organization design. *Object Orientation*, a notion drawn from Computer Science can be observed as a good example of *design for incompleteness*. Chapter III will be devoted to constructing detailed design principles of supply chain flexibility based on Object Orientation principles.

III. Designing for Supply Chain Flexibility through Incompleteness – An Object Oriented Approach

This chapter builds on the concepts introduced in the previous two chapters to propose a framework of supply chain design principles for flexibility. The framework is built upon Object Orientation - a concept brought into the field of supply chain design by analogy.

3.1. The Principles of Object Orientation

Object Orientation is a concept which has been conceived in order to deal with the complexity of information systems development. It is based on the idea of an *object* which can be generally defined as a "tangible entity that exhibits some well-defined behavior" (Booch 1998)[3]. Definitions of an *object* can get more detailed when presented from different perspectives. From the cognitive perspective an *object* is something that is visible, can be apprehended intellectually and toward which some thought or action can be directed. From the computer science perspective *object* is an "entity that combines the properties of procedures and data since it performs computations and saves local state" (Stefik and Bobrow 1986).

The term *object*, a close relative to the term *entity* in systems thinking, has emerged in various fields of computer science in the 1970s and it referred to a group of concepts conceived to manage the complexity of information systems development by representing them as sets of objects, which "represented components of a modularly decomposed system or modular units of knowledge representation" (Yonezawa and Tokoro 1987).
There were several advancements in the field of computer science which contributed to the emergence of *Object Orientation*, namely: advances in computer architecture, programming methodology and database models, emergence of new programming languages, and research in the field of artificial intelligence (Booch 1998). The emergence of *Object Orientation* is also strongly rooted in philosophy. Greek philosophers had first developed the idea that the world can be perceived in terms of objects and processes, this view was later reinforced by Descartes who claimed that human perception is naturally based on object-orientation (Stillings, Feinstein, Garfield, Rissland, Rosenbaum, Weisler, and Baker-Ward 1987). Objectivism developed by Rand built upon the earlier thought and proposed a whole object-centric epistemology (Rand 1990). The concept of *Object Orientation* in system development was first introduced by Jones (1979).

There are four programming paradigms: imperative, functional, logic-oriented and object-oriented, out of which the object-oriented paradigm is thought to be the most appropriate to the broadest set of applications[4]. Each programming paradigm has its conceptual framework. *Object Orientation* provides guidelines for object-oriented programming and is based on four fundamental design principles, which are covered in details below.

Abstraction is one of the main principles of human cognition and is instinctively employed by human beings to cope with complexity. Dahl et al. suggest that "abstraction arises from a recognition of similarities between certain objects, situations, or processes in the real world,

[3] In this paragraph we will mostly refer to Booch, who is regarded as a thought leader and a writer of an influential book on Object Orientation (Booch 1998)
[4] For an overview of Object Orientation in comparison to other programming paradigms refer to Appendix 1

and the decision to concentrate upon these similarities and to ignore for the time being the differences" (Booch 1998). Graham defines abstraction as all "the essential features of something without including background or inessential detail" (Graham 1991). Whereas Shaw adds that it should emphasize the significant details while suppressing the details which are diversionary (Shaw 1984). It is worth noting that on a more metaphysical level Whitehead defined abstraction quite similarly, as the act of "being comprehensible without reference to some one particular occasion of experience"(Whitehead 1958). In systems thinking the principle of abstraction would translate to a one-way homomorphic[5] mapping between the concrete object and its abstract model. Booch (1998) comes with a unifying definition: *"An **abstraction** denotes the essential characteristics of an object that distinguish it from all other kinds of objects and thus provide crisply defined conceptual boundaries, relative to the perspective of the viewer".*
Therefore an abstraction focuses on the outside view of an object and serves to separate object's essential behavior from its implementation. The literature on the subject calls this the *abstraction barrier* achieved by applying the principle of least commitment, through which the interface of an object provides its essential behavior and nothing more (Abelson and Sussman 1985). The abstraction barrier is related to the notion of relevant and irrelevant information in systems thinking, as the barrier acts as filter for relevant information (Kramer, De Smit 1997). Meyer augments this view by introducing a notion of a *contract model* – a client-server architecture in which the interface of each object defines a contract upon which other objects may rely (Booch 1998). The contract establishes the assumptions a client may make about the server and thus encompasses the *responsibilities* of the server. The server's contractual commitments are delivered either internally or in collaboration with other objects. The entire set of operations that a client may perform upon an object along with this object's responses is called the *protocol*.

Encapsulation refers to the opaqueness of an object, or its treatment as a "black box" according to systems thinking approach. Black box is a system of unknown internal contents but defined inputs and outputs. Therefore, encapsulation forbids the system architect to assume anything about the object other than what is in the "contractual" specification of its functionality and interface. In other words, an abstraction of an object should precede its implementation and should be treated as a secret, hidden from the client objects. Ingalls resumes that "no part of a complex system should depend on the internal details of any other part" (Ingalls 1976). This is achieved through *information binding* which hides all the non-essential information about an object. Encapsulation erects barriers between abstractions and leads to a separation of concerns between the implemented objects (Booch 1998). Liskov observes that encapsulation of object implementations is a sine qua non precondition of *Object Orientation* (Liskov 1988). Booch (1998) summarizes with the following definition: "***Encapsulation** is the process of compartmentalizing the elements of an abstraction that constitute its structure and behavior; encapsulation serves to separate the contractual interface of an abstraction and its implementation".*

Modularity refers to the notion that a complex system should be designed as an assemblage of loosely coupled reusable constituents, each of which is capable of independent evolution. Modularization helps to manage the complexity of a system and is closely related to both encapsulation and abstraction since "the connections between modules are the assumptions which the modules make about each other" (Booch 1998). It may be difficult to decide on a definite set of modules in the design stage when the final design is not yet known. There are

[5] Two systems are homomorphic when there is a many-to-one and onto mapping transforming one into the other with the conservation of relations (Kramer, De Smit, 1977).

two concepts which act as guidelines to modularization: cohesiveness (grouping of logically related abstractions) and loose coupling (minimizing the dependencies among modules). Therefore modularity can be defined as: "*a property of a system that has been decomposed into a set of cohesive and loosely coupled modules*" (Booch 1998).

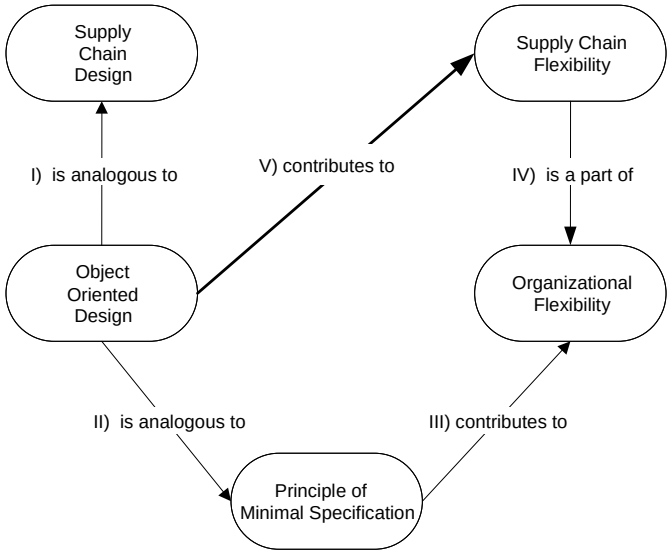
Finally **hierarchy** refers to the idea that complexity is best handled by decomposing abstractions into relatively few loosely coupled and opaque modules, which in turn can be further decomposed into other such modules, and so on, until one arrives at simple objects and operations. Booch defines hierarchy as a "*ranking or ordering of abstractions*" (Booch 1998).

Besides helping to manage the complexity of system development *Object Orientation* provides numerous other benefits (see Appendix 1 for comparison with other programming paradigms). Harmon et al. (Harmon and Peel 1997; Harmon and Taylor 1993) mention faster development due to more intuitive modeling and module reuse, increased quality due to module reuse and easier maintenance. Whereas Booch (1998) lists: reuse of software and frameworks, increased resilience to change, reduced development risks, and natural appeal of object-oriented architecture to human cognition. Wirth (2006) resumes the benefits of *Object Orientation* as follows: "This paradigm closely reflects the structure of systems 'in the real world', and it is therefore well suited to model complex systems with complex behaviors".

3.2. The Applicability of Object Orientation to Supply Chain Design

All the crucial conceptual entities have now been introduced into the thesis. We will now proceed with establishing the missing logical links and subsequently developing the main hypothesis of this study. The picture below illustrates the conceptual entities and relations between them.

Picture 3. Relations between the conceptual entities developed in this thesis



Relation I: Object Oriented Design is analogous to Supply Chain Design

There is an intuitive appeal to extending the *Object Oriented* design philosophy to supply chain architecture. The entities within the supply chain can exhibit very object-like characteristics which enable us to assume that the supply chain is a complex system of buying and supplying organizations which can be treated as objects. To elucidate this concept, let us elaborate on a hypothetical example of a company Teta entering the market of portable MP3 players. Teta had made a strategic decision that it would assemble its products from readymade electronic circuits differentiating them only by attractive external design. To establish its supply chain Teta needed to find the suppliers for the electronics (circuit board, LCD display, memory), batteries and headphones. To start things off Teta had sent requests for information (RFI) to a large group of potential circuit board suppliers, analyzed the responses and then issued requests for quotation (RFQ) to a few selected of them. Several highly standardized parts like batteries and headphones had been procured through an Internet based auctioning system. The steps taken by Teta to design the supply chain prove a point that suppliers have their clearly established, standardized communication interfaces. The exchange of information between Teta and its suppliers proceeded in a very defined and standardized way as the mechanisms of requests for information and quotation are well known business practices. The use of Internet based auctioning system further proves the point of standardized communications as these systems have strictly defined interfaces and codes of conduct for the parties involved in a transaction. Thus we have proved that supply chain design is analogous to object oriented design in applying the *abstraction* principle.

Teta's strategy was one of cost reduction. It attempted to reduce costs by reducing the relations with suppliers to arm's length and instilling frequent supplier changes. Basically, all that Teta cared about was the lowest possible cost of components which adhered to its specifications and quality standards. Teta treated its suppliers like "black boxes" and paid attention only to the contract (price, technical specification, service level, quality). This behavior proves that supply chain design is analogous to object oriented design in applying the *encapsulation* principle. Teta's supply chain was relatively simple because of its simple end product, the MP3 player. But even in a supply chain of such simplicity some degree of product modularity appeared. The memory that the player used was integrated into the electronic circuit board by Teta's supplier but in fact it was produced by the supplier's supplier. The fact that the product exhibited modular characteristics, i.e. was composed of modules provided by different suppliers (and those supplier's suppliers) proves that supply chain design is analogous to object oriented design in applying the *modularity* principle.

The above mentioned Teta's circuit board supplier had to manage its suppliers including the supplier of its memory chip. Thus Teta's supply chain exhibited *hierarchy*, where the lower tier suppliers are managed by the first tier of suppliers. This reduced some of the complexity for Teta which helped to manage the costs.

On the basis of a hypothetical example of Teta designing its supply chain we have shown all the four key principles of Object Orientation. Therefore we can establish a link that *Object Oriented Design* is related to Supply Chain Design by analogy.

Relation II: Object Oriented Design is analogous to Principal of Minimal Specification

When observed from a *design science* perspective *Object-oriented designs* are goverened by the principle of minimal specification and as such exhibit the key characteristics of *design for incompleteness.* The object model and its four fundamental concepts of abstraction, modularity, encapsulation and hierarchy constitute the high level design principles. These principles have to be implemented in their unaltered form in every *Object-oriented design*. The minimal specification founds an unchangeable framework on which the particular low level design is based. The low level design rules and their implementation retain the flexibility to

change according to the evolving needs of a particular system. The four key concepts of *Object Orientation* can be treated as the *design principles* since they are a "coherent set of imperative propositions". Therefore the analogy of *Object Oriented design* to *design for incompleteness* hints that the object oriented approach can be projected onto the field of organization design.

Relation III: Minimal Specification contributes to Organizational Flexibility

This relation was established in paragraph 2.3 where we have explored *minimal specification* and *design for incompleteness* as a design principle which increases organizational flexibility. To illustrate this relation we can recall the case of Wikipedia which has designed an incomplete set of rules for managing the input of new content on its pages. According to the old rules, everyone was able to contribute and the contribution appeared right after it was written. When the quality of new content became alarmingly low the founders of Wikipedia did not change the rules, because everyone is still able to contribute. Instead they have added more specific rules and policies for managing the increasing number of contributors. This case proves that the incompleteness of design increases the ability of the organization to adapt to changing environment.

Relation IV: Supply Chain Flexibility is a part of Organizational Flexibility

This relation was established in paragraph 1.2 where we have explored the nature of supply chain flexibility in relation to organizational flexibility. Supply chain flexibility constitutes an important part of the overall flexibility of the organization. The flexibility that the supply chain provides enables the company to withstand and adapt to major turbulences in the environment.

Relations I to IV that we have established thus far, enable us to establish a new logical link between the above mentioned conceptual entities and this link is:

Relation V: Supply Chain Design based on Object Orientation contributes to Supply Chain Flexibility

Indeed, there is an intuitive appeal to extending the *Object Oriented* design philosophy to supply chain architecture in an attempt to increase flexibility of supply chain operations and strategy. The remaining part of this thesis will be devoted to exploring this relation. First, as an immediate result of the concept exploration a set of theoretical design principles will be put forward. They will be rooted in supply chain and appropriate subject matter literature. Then, these theoretical design principles will be tested against the empirical design principles derived from case studies of supply chain design initiatives.

3.3. Object Oriented Design Principles – An Overview

Three types of supply chain flexibility have been introduced in the first chapter of this thesis: steady state and operational flexibility, structural flexibility, and strategic flexibility (see paragraph 1.2). In the following paragraphs we will examine their relation to Object Oriented design principles with emphasis on structural supply chain flexibility which has received the

least attention from researchers so far. This study focuses on establishing a link between the application of Object Oriented design principles and structural supply chain flexibility.

Before we proceed with establishing the relations between Object Oriented design principles and supply chain flexibility let us resume the very definition of structural supply chain flexibility. **Structural supply chain flexibility** consists of managerial capabilities to evolutionarily adapt the supply chain design in response to changes in the environment. The scope of activities covers for example: on-boarding of new clients, business partners and suppliers; qualifying a new source of supply; adding a new manufacturing plant; enabling a new type of offering; introducing Just in Time philosophy.

Below we will explore how the principles of modularity, abstraction, encapsulation and hierarchy applied to supply chain design improve its structural flexibility. The principles will then be presented in a Context – Intervention – Mechanism – Outcome (CIMO) format and will constitute the testable Theoretical Design Principles. The table below provides an overview of the supply chain design principles which will be discussed.

Table 3. An overview of supply chain design principles in a CIMO format

	Internal Organization Design Modularity	**Abstraction**	**Encapsulation**	**Hierarchy**
Context	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain			Appropriate supplier market structure for implementing a structurally flexible supply chain
Intervention	Implementation of a modular supply chain organization through aggregation of cohesive activities. Establishing a loosely coupled architecture between modules. Leveraging (reusing) modules across the organization. Automation and standardization of activities.	Implementation of standardized internal and external communication interfaces at the business and technological level.	Implement a centralized procurement organization which acts as a mediator between the suppliers and the rest of the organization.	Implementation of a tiered supply chain structure
Mechanism	Aggregation of activities enables for faster reconfiguration of processes and structural reorganization. Modular internal supply chain organization is flexible to accommodate structural changes within the entire supply chain.	Standard communication interfaces help to establish efficient information flow and the ability to remodel the supply chain organization when needed.	Centralized procurement organization reduces unnecessary information flows and facilitates implementation of new procurement rules & policies. Ensures encapsulation from the influence of *flexibility enemies* from outside the organization.	Tiered supply chain structure reduces unnecessary supplier relations by delegating them to first tier suppliers. Ensures encapsulation from the influence of *flexibility enemies* from outside the organization.
Outcome	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	Increase in structural supply chain flexibility Complexity reductions.	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.

3.4. The Design Principle of Modularity in Supply Chain Context

Even though in a software design context the four key concepts of *Object Orientation* are equally weighted, it seems that in a supply chain context it is modularity that plays the crucial role. Therefore we will start with exploring modularity and then proceed with other principles showing how they relate to each other.

3.4.1. Exploring Modularity in a Supply Chain Context

In software development parlance *modularity* is a characteristic of a system that has been decomposed into a set of cohesive and loosely coupled modules each of which is capable of independent evolution. Already, there is an extensive literature dealing with *modularity* in management (Arnheiter and Harren 2005; Asan, Polat, and Sanchez 2008; Baldwin and Clark 1997; Ernst 2005; Frigant and Talbot 2005; Guzman 2003; Hoogeweegen, Teunissen, Vervest, and Wagenaar 1999; Sanchez 1995; Sanchez 1999; Sanchez 2000; Sanchez and Mahoney 1996; Schilling 2000; Schilling and Steensma 2001; Sturgeon 2002; Wilson, Weiss, and John 1990; Worren, Moore, and Cardona 2002) and specifically in supply chain context (2006b; Doran 2005; Lau and Yam 2005; Lau and Yam 2007; Sanchez 2004; van Hoek and Weken 1998).
Management literature defines *module* as a "unit whose structural elements are powerfully connected among themselves and relatively weakly connected to elements in other units" (Baldwin and Clark 1999). There exist multiple typologies for modularity related concepts and applications. Baldwin and Clark (1999) identify *modularity* in design, in production and in use. Ernst (2005) defines technical, organizational, and market modularity, whereas Arnheiter (2005) proposes a new typology by identifying: manufacturing modularity, product use modularity, limited life modularity, and data access modularity. In this study we will build on the typology proposed by Sanchez and Mahoney (1996) which broadly identifies two types of modularity: *product design modularity* and *organization design modularity*.
Let us start with exploring the concept of **product design modularity** and what it brings to supply chain flexibility. The concept of product modularization emerges from the seminal work of Simon (1962), where he shows that a product is a hierarchical complex system of many interacting parts, which can be arranged into modules. Simon illustrates this concept with a parable of two watchmakers - Hora and Tempus. Tempus designed his watches in a way that if he were interrupted during assembly the watch would fall to pieces and would have to be reassembled again from elementary components. In comparison, Hora's design consisted of stable subassemblies composed of a few parts each. If interrupted during assembly, Hora would have to reassemble only the last unfinished subassembly. Tempus' product architecture did not possess a high degree of modularity, on the contrary to Hora's design which was highly modular. This parable also partially illustrates that product modularization decreases new product development and production lead time by enabling the potential of mixing and matching different modules (Simon 1962). Alexander observes that to facilitate concurrent development of new products the modules should perform pre-defined functions, so that the redesign of one module would not affect the others (Lau and Yam 2005). The term *modular production* has allegedly been used for the first time in 1965 by Martin Starr in his seminal paper, where he compared the traditional mass production system with modular production (Arnheiter and Harren 2005). *Product design modularity* is best defined as an approach to product design which relies on the use of generic interchangeable and reusable product modules in a range of finished goods (Lau and Yam 2005; Ulrich 1995). The main purpose of product design modularity is to increase product variety and production flexibility, while decreasing product complexity.
A single module within a particular product design is defined by its function and a specification of its inputs and outcomes, thus constituting its *interface*. The *interface* standardizes its functional, spatial and other relations with external modules and is intended

not to change for a defined period of time. Baldwin and Clark (1999) observe that modularity in product design has dramatically altered the mechanisms of design change. They identify six modular operators which they see as a basic repertory of actions applied in developing new product designs: *splitting* a system into modules, *substituting* one module for another, *augmenting* by adding a new module to an existing system, *excluding* a module from an existing system, *inverting* to create new design rules, and *porting* a module designed for one system into another system (Baldwin and Clark 1999). *Product design modularity* leads to the creation of a complex adaptive system, where design changes in one module can happen without permission from other modules, as long as the module interfaces remain unchanged (Baldwin and Clark 1999). This decentralization of design efforts has allowed for the subsequent development of **external organization design modularity**.

External organization design modularity results in a decentralized, autonomous and concurrent module design process and is enabled by the information structure established by the module *interface* specifications (Sanchez and Mahoney 1996). *External organization design modularity* in supply chain context translates to a network of suppliers from which a value chain is assembled according to their capabilities and the requirements of the consumer. The use of such networks to improve the ability to reconfigure the value chain and quickly launch new products and their variations is called leveraged growth (Hagel 2002). Sanchez (1995) introduces the notion of *resource chains* to describe the result of linking the resources and capabilities of many organizations for the sake of new product development. *Modular product design* provides a 'glue' for the coordination of the loosely coupled supplier network (Sanchez and Mahoney 1996) since coordination that had earlier required iteration and direct contact to resolve interdependencies now requires only a knowledge of the *interface* requirements (Hatch 2001).

The impact of product design modularity on supply chain design has been observed by Van Hoek and Weken (1998), Fine (1998), and Lau & Yam (2005). Fine (1998) suggests that product and supply chain architectures tend to be aligned along the integrality-modularity spectrum, i.e. integral products are developed by integrated supply chains, whereas modular products are developed by modular supply chains. Researchers suggest that product design modularity combined with modular design of the supply chain result in cost reductions (Ernst and Kamrad 2000; Sanchez and Mahoney 1996) and improved supply chain performance (Fine 1998). Schilling and Steensma (2001) suggest that modularity in product design and supply chain design result in an increased flexibility. Sanchez (1995) claims more specifically that modular product architectures can be an important source of strategic flexibility by enabling an organization to "respond more readily to changing markets and technologies by rapidly creating product variations based on new combinations of new or existing modular components" (Sanchez and Mahoney 1996).

Academics have focused their attention and research for supply chain related modularity on the outside of the organizations. But since a significant portion of supply chain management functions resides within the boundaries of the organization, I propose to look for **internal organization design modularity**. This search should especially focus on the emerging organization designs.

Globally integrated organizations encourage ongoing modularization of activities in order to gain economies of scale. We can observe two modularity related concepts in the emergent organizational designs: cohesiveness (grouping of logically related tasks) and loose coupling (minimizing the dependencies among modules). Aggregation of cohesive activities into organizational modules allows for their centralization across the organization thus reducing duplication and enabling "reuse". It is especially popular with parts of business which are labor intensive and require strict standards and policies. Activities aggregated within the organizational modules benefit from automation, consolidation and standardization which reduce costs and improve flexibility.

Each organizational module interacts in a loosely coupled manner with the rest of the organization which provides it with the flexibility to accommodate to structural changes, i.e. reconfiguration of the other modules. What is more each module by itself is able to evolve independently of other parts of the organization thus also increasing the flexibility of the organization as a whole. Supply chain organizations are increasingly often organized in a modular manner, aggregating cohesive processes across different dimensions, i.e. products, channels and geographies. This approach improves the flexibility of activities which would otherwise have to be replicated across different dimensions of the supply chain. This includes the structural flexibility of such activities as qualifying a new source of supply or supplier on-boarding.

In this paragraph three types of modularity were introduced: product design, external organization design, and internal organization design. Since the first two have been researched before the focus of this study is on the *internal organization design modularity* and its impact on structural supply chain flexibility. The next paragraph is devoted to defining the architecture of internal organization design modularity as a supply chain design principle.

3.4.2. Internal Organization Design Modularity as a Supply Chain Design Principle

The architecture of internal organization design modularity as a design principle will be elaborated utilizing the CIMO approach described in Chapter II. First the *context* in which it should be applied, then the details of the *intervention* or, what exactly should be done, next the *mechanisms* triggered by the intervention and finally the expected *outcome*. To illustrate this design principle, we will use Teta's example, which we have already mentioned in paragraph 3.2, when justifying the analogy between supply chain design and object orientation.

Context

In order to implement a structurally flexible supply chain by implementing internal organization design modularity the organization has to be sufficiently mature in terms of business and technological enablers. Most important internal criteria which have to be passed include: business process awareness, integrated information platform and readiness for change. Neither external factors nor human actors have significant influence on the implementation of internal organization design modularity. Let us now consider Teta to illustrate the right context for the implementation of internal design modularity as a design principle. As we can recall, Teta's supply chain exhibited product design modularity - demonstrated by the modularity of the circuit board and the memory chip. It has also exhibited external organization design modularity – visible in the two tiers of suppliers, as the circuit board manufacturer managed its memory chip supplier. Had Teta wanted to make the step further and make its supply chain organization internally modular, it would have to have a sufficient knowledge and awareness of its supply chain processes, process oriented management and assigned process owners. It would also have to have an integrated ERP system supporting its business processes and delivering reliable and exhaustive information.

Intervention

The internal organization modularity principle should be implemented by a general supply chain transformation approach (IBM 2007), starting from business review phase which defines detailed business requirements; through capability analysis phase which defines

capability gaps; vision development phase which sets out to create a compelling vision and value proposition; roadmap definition phase which defines specific actions and project plan; to finally reach the implementation phase. The implementation itself should consist of program management, change management, benefits realization, business design and IT solution design and development. The implementation of a modular supply chain organization should happen through the aggregation of cohesive activities in the supply chain area. The activities within the organizational modules should be consolidated, automated and standardized. The modules should be loosely coupled and thus independent. The developed organizational modules can be leveraged and reused across the organization. In Teta's case that would translate to the consolidation of all supply chain planning activities in one organizational module, standardizing the planning processes and applying information technology to support and automate as much processes as possible. The rest of the organization using the services of the supply chain planning module would only be interested in the inputs they are supposed to deliver and the outputs they expect to receive.

Mechanism

Aggregation of activities enables for faster reconfiguration of processes and structural reorganization. Modular internal supply chain organization is flexible enough to accommodate structural changes within the entire supply chain. Referring to Teta's case the module responsible for supply chain planning would be easier to redesign internally. For example any changes to the planning algorithms and tools would affect the internal workings of the module, possibly with only slight changes to the inputs and outputs of the module.

Outcome

Successful implementation of the internal organization design principle results in:

- Increase in supply chain structural flexibility
- Cost reductions
- Complexity reductions

3.5. The Design Principle of Abstraction in Supply Chain Context

As we have mentioned before *abstraction* is a principle which promotes focus on the essential characteristics of an object and it helps to define a contract between the client and the provider, specifying the accountability of both parties. In organization context an analogy to information and goods exchange between business entities is immediately obvious. Let us further explore this analogy to see where it will take us.

3.5.1. Exploring Abstraction in Supply Chain Context

Abstraction erects a barrier which separates the outside view of an object from its internal workings and acts as filter for relevant information. Supply chain processes should stand behind the abstraction barrier and exchange only the information relevant for other actors in the process. Outside the organization in a supply chain setting the principle is evidently in use when the buyer does not have to care for how a certain product or service is delivered, whether it is in its entirety a result of the supplier's operations or whether some parts of it were delivered by other parties. The principle of *least commitment* further reinforces the point by advocating that all the buyer should care about is the product or service specified in the contract. It may seem that this approach stands against the current trend towards the

integrated supply chains and increasing supplier collaboration (Bagchi and Skjoett-Larsen 2005; Boddy, Macbeth, and Wagner 2000; Grossman 2004; Holweg, Disney, Holmstrom, and Smaros 2005; McNichols and Brennan 2006; Mueller and Seuring 2007; Nussle Jr 2006; Simatupang and Sridharan 2004; Soonhong, Roath, Daugherty, Genchev, Haozhe, Arndt, and Richey 2005; Ulrich and Smallwood 2002; Wang, Tai, and Wei 2006). Yet, if we recall the Transaction Cost Economics (Williamson 1973; Williamson 1993; Williamson 2002; Williamson 2005; Williamson and Ouchi 1981) there are clearly some types of transactions which in certain market settings benefit from arm's length relations. Still, in an increasingly globally connected marketplace arm's length relations do not preclude introduction of standardized communication interfaces between the buyers and suppliers. No matter whether they take the form of extensive Electronic Data Interchange (EDI) or of simple internet-based product exchanges they serve to reduce transaction costs (Pohle, Korsten, Ramamurthy, and Foecking 2004), facilitate buyer-supplier coordination (Chandrashekar and Schary 1999) and help to reduce the complexity (Sivadasan, Efstathiou, Calinescu, and Huatuco 2004).

Inside the organization the principle is apparent in standardized communication interfaces between the departments. The development of organizational modules described in paragraph 3.4.1 usually leads to the development of internal communication interfaces. Standard communication interfaces help to establish efficient information flow which is an especially important issue in supply chain management.

Consequently, these improvements yield an increase in *steady state and operational supply chain flexibility*. Application of the *abstraction* principle also seems to increase *structural* and *strategic supply chain flexibility*.

When the organizational modules are connected with standardized abstract interfaces it is easier to restructure the supply chain by adding a new plant, business unit or product line. Redesigning the supply chain to follow the changes in business strategy is easier if the supply chain organization is resilient enough to accommodate major changes. This allows to increase the organization's competitive advantage as the supply chain can be optimized for required capabilities. It seems that this design principle acts as an enabler of organizational modularity, since it is difficult to conceive an efficiently functioning supply chain without clearly established communication interfaces.

In the next paragraph the architecture of *abstraction* as a supply chain design principle for flexibility will be developed.

3.5.2. Abstraction as a Supply Chain Design Principle

Analogically to internal organization modularity the architecture of the design principle of abstraction will be elaborated utilizing the CIMO approach described in Chapter II. We will also refer to the hypothetical example of Teta to illustrate this design principle.

Context

In order to implement a structurally flexible supply chain by implementing internal organization design modularity the organization has to be sufficiently mature in terms of business and technological enablers. An integrated and well developed information platform is the single most important enabler. Human actors have no major influence on the implementation of abstraction. Since the description of the context is virtually the same as in the case of modularity, please refer to paragraph 3.4.2 for the exemplary reference to Teta.

Intervention

The abstraction principle should be implemented with a general supply chain transformation approach (IBM 2007), which we have already referred to in paragraph 3.4.2. The intervention should aim at deploying standard codified communication interfaces both at the business and technology level. At the business level it should translate to a rule that the interfaces for information exchange be clearly defined as to the content, receivers and frequency of communication. At the technology level it should translate to an IT interface which would enable full supply chain visibility through codified information flows. In Teta's case of the supply chain planning organizational module it is illustrated by well defined content of inputs and outputs exchanged through the use of enterprise-wide information platforms and open standards like XML or SOAP.

Mechanism

By introducing standardized interfaces communication within and outside the organization is simplified through common visibility of the flow of products and information through the supply chain. It enables mutual information sharing and optimization of cross-enterprise processes, like joint supply and demand forecasting, and inventory management. Referring to Teta's case, the supply chain planning organizational module is able to efficiently exchange information with other parts of the organization and fulfill its planning tasks thanks to the codified, standardized interfaces.

Outcome

Successful implementation of the abstraction principle results in:

- Increased structural supply chain flexibility through reduced complexity and improved communication through standardized interfaces.

3.6. The Design Principle of Encapsulation in Supply Chain Context

The principle of *encapsulation* in terms of system development has already been introduced in paragraph 3.1. Let us explore what it translates to in a supply chain context.

3.6.1. Exploring Encapsulation in Supply Chain Context

Managing the supply chain operations on the basis of encapsulation implies no involvement with the suppliers from anyone other than the procurement organization. A centralized procurement organization acts as a mediator between the suppliers and the rest of the organization simplifying communication, reducing the information flows, and thus reducing complexity. It also helps to enforce procurement standards and policies, reduce "maverick" spending, and manage the supplier base facilitating the processes involved with supply chain expansion. The supplier transactions are preferably mediated through a computer network or a third party. When information about the suppliers is needed, for example on financial reliability, quality or fulfillment of ethical standards, use of third party certification is recommended. The use of third party certification helps to minimize the need to monitor quality and specifications of supplies, support sourcing decisions, and facilitate supplier assessment. Thus the principle of encapsulation ensures the internal supply chain organization from the negative influences from outside. In other words – it keeps the enemies of supply chain flexibility at bay.

3.6.2. Encapsulation as a Supply Chain Design Principle

Analogically to the two previously described design principles encapsulation will be elaborated utilizing the CIMO approach described in Chapter II and a reference to the hypothetical example of Teta will be made.

Context

The context in which encapsulation is expected to be implemented is the same as in the case of modularity and abstraction and focuses on an integrated information platform and business process maturity.

Intervention

Implementation of encapsulation should follow the very same guidelines as in the case of modularity and abstraction, and as these have already been described in paragraph 3.4.2 we will not repeat them here. The intervention should focus on implementing a centralized procurement organization which acts as a mediator between the suppliers and the rest of the organization. In Teta's case the intervention would be implementing a centralized procurement module, which would become responsible for all the relations with suppliers.

Mechanism

Processes within the encapsulated procurement organization are consolidated and standardized, which greatly facilitates any redesign efforts. Centralized procurement organization reduces unnecessary information flows and facilitates implementation of new procurement rules and policies. For example, if Teta had centralized procurement and altered the supplier assessment policy, only one organizational module would have to be trained in the new policy. Moreover, centralized procurement ensures encapsulation from the influence of flexibility enemies from outside the organization.

Outcome

Successful implementation of encapsulation design principle results in:

- Increase in supply chain structural flexibility
- Cost reductions
- Complexity reductions

3.7. The Design Principle of Hierarchy in Supply Chain Context

The principle of *hierarchy* in system development has already been introduced in paragraph 3.1. Let us explore what would hierarchy translate into in supply chain context.

3.7.1. Exploring Hierarchy in a Supply Chain Context

The hierarchy principle states that the supply chain should favor purchasing subassemblies, rather than more elementary components. This statement relates to Simon's (1962) parable of the two watchmakers which we have already mentioned in paragraph 3.4.1. One of the watchmakers designed his watches to be composed of subassemblies which reduced his production time and helped to manage the inherent complexity of the product.
Moreover, hierarchy promotes reduction in the number of suppliers. This principle translates to tiered supplier management, an approach which integrates an organization with its key first tier, second tier, etc. suppliers. The purpose is to improve customer response time and flexibility. It is a source of competitive advantage for companies that establish it as a standard practice. To reduce the complexity it is a frequent practice to delegate the responsibility of managing lower tiers to first tier suppliers. Tiered supply chain structure

reduces unnecessary supplier relations by delegating them to first tier suppliers. Similarly to encapsulation, this principle screens the supply chain from the influence of the enemies of flexibility from outside the organization.

3.7.2. Hierarchy as a Supply Chain Design Principle

The architecture of hierarchy as a design principle will be elaborated utilizing the CIMO approach described in Chapter II. What is more a reference to the hypothetical example of Teta will be made.

Context

In order to implement hierarchy as a step towards implementing a structurally flexible supply chain the supplier market has to be sufficiently developed. First tier suppliers have to posses the ability and willingness to manage the lower tiers. Neither internal factors nor human actors have influence on the context of the implementation. Teta's supply chain was evidently sufficiently developed for hierarchy to be implemented as the circuit board supplier naturally took on the responsibility for the memory chip supplier.

Intervention

Implementation of hierarchy should follow the very same guidelines as in the case of modularity and abstraction, and as these have already been described in paragraph 3.4.2 we will not repeat them here. The intervention should implement a tiered supply chain structure and make the supply chain benefit from supply chain hierarchy whenever possible by delegating supplier relations to first tier suppliers, thus lowering the transaction and production costs in case of limited supplier trust or high product complexity. In Teta's case, the decision to implement hierarchy was made at the supply chain design stage. The first tier circuit board supplier took on the responsibility for managing its memory chip supplier, even though Teta could procure and install it by itself.

Mechanism

Implementation of tiered supply chain structure and delegation of supplier relations to first tier suppliers reduces the complexity for the supply chain organization by offloading its responsibilities and workload. It improves supply chain flexibility by reducing the number of supplier relations thus enabling for more collaborative relations with strategic suppliers. Tiered supply chain structure reduces unnecessary relations with lower tier suppliers by delegating them to first tier suppliers. Hierarchy ensures encapsulation from the influence of flexibility enemies from outside the organization. For example, should Teta change the requirements of the circuit board and memory chip it would not have to manage both the circuit board supplier and the memory supplier.

Outcome

Successful implementation of hierarchy design principle results in:

- Increase in supply chain structural flexibility
- Cost reductions
- Complexity reductions from clear hierarchical picture of the supply chain

IV. Research Methodology

This chapter provides an overview of the methodology applied in this research, its conceptual framework, research objectives and the methods applied.

4.1. Research Framework and Objectives

The main objective of the study was to answer the question: *how can companies design structural supply chain flexibility*? The purpose of the study was to formulate design principles for designing structurally flexible supply chains.

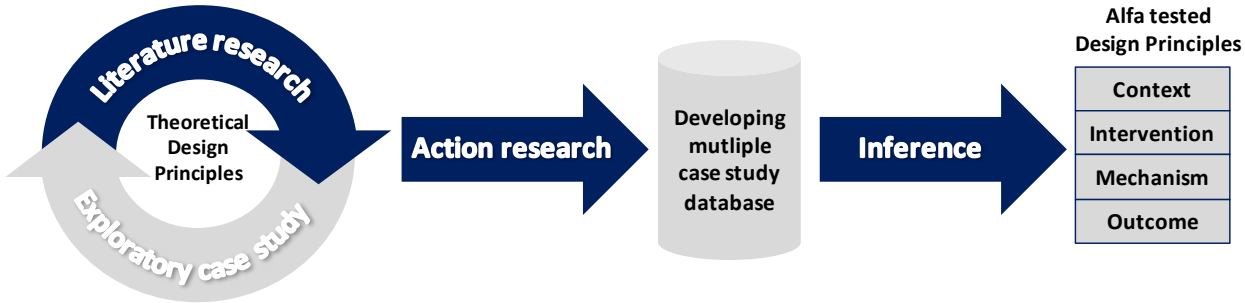
The study commenced by formulating the **theoretical framework** which was to be verified by empirical research. An exhaustive literature review on the subject of supply chains, supply chain management and supply chain flexibility was conducted. To supplement the subject matter literature an additional body of knowledge was acquired from the field of computer science or more specifically from complex system development based on Object Orientation. The literature review provided a solid foundation for building a set of testable theoretical propositions to be verified by the research. During the theoretical framework formulation the devices of analogical reasoning and metaphor were employed. It was decided that the testable propositions would be presented in the form of Theoretical Design Principles rooted in the Context-Intervention-Mechanism-Outcome approach to design principle structuring.

Empirical research was conducted in two phases. The first phase consisted of an exploratory case study (Yin 2003) which was used to further develop the Theoretical Design Principles formulated on the basis of the literature research. The second phase consisted of action research in the form of a developing multiple case study research (van Aken 2004) used to alfa-test and refine the Theoretical Design Principles.

On the basis of a cross-case comparison of Empirical Design Principles with Theoretical Design Principles **conclusions** and inferences were drawn which modified the theoretical framework to produce a set of Object Oriented Supply Chain Design Principles for Structural Flexibility. Finally, areas for further research are proposed.

The study framework is presented below in the Picture 4. Each part of the framework will be described in more detail in the forthcoming paragraphs.

Picture 4. Research Framework



4.2. Definition of Theoretical Design Principles through Analogical Reasoning

Besides standard literature research technique the study employed analogical reasoning in order to enrich the theoretical framework (see Chapter 3). Analogical reasoning is a core process of human cognition. It can be successfully and intuitively employed in the process of scientific discovery. Analogical reasoning facilitates drawing of ideas and inspiration from different, seemingly disparate fields, by providing a structured way of developing and exploring analogies. It naturally supports many of our thought processes: problem solving, decision making, perception, memory, creativity, emotion, explanation and communication. More generally analogy is an example of inductive reasoning, a broad family including also: metaphor, model, example, metonymy and synecdoche. Every form of reasoning within that family is based upon the principle of similarity. Philosophers of science emphasize the key role of analogy in scientific discovery not only in confirmation of the formulated theory (Carnap 1963) but also as a constant part of the newly formulated theory (Gibson 2008).

Analogical reasoning is a powerful tool which is often used in organization science research (Barry and Rerup 2006; Garud and Kotha 1994) and management practice (Gavetti and Rivkin 2005), as well as more generally in social studies research (Yin 2003).
Barry and Rerup (2006) have used metaphor to analyze the link between the aesthetic design features of mobile sculptures and effective organization design. They suggest the following approach to fruitful analogical reasoning: *"finding useful metaphors, working them into analogical systems by discarding nonessential attributes of objects in the two domains, transferring relational structures from one domain to another, and using the transferred structures to build a model that enables testable propositions"*. They believe that this process can be successfully used to improve the understanding of the target phenomenon as well as open up new lines of thinking.
Gavetti and Rivkin (2005) agree that analogical reasoning is a powerful tool for sparking breakthrough ideas. Yet, they identify two pitfalls in analogical reasoning which should be addressed in every successful analogical reasoning process. One of them is *confirmation bias* which is a natural psychological tendency to seek out information that confirms beliefs and to ignore contradictory data. In this study the confirmation bias was confronted by forming the theoretical propositions in an objective and empirically testable format, which was then verified on multiple case studies. The use of multiple sources of evidence and a multiple case study format in the second part of the research increased the veracity of the entire study.
The second pitfall is *anchoring* which is a cognitive phenomenon rooted in the fact that once a certain analogy or other idea anchors itself, it is notoriously hard to dislodge. This pitfall was remedied by an iterative approach to theoretical framework design in the course of which the framework was refined and consulted with independent experts.
Once the empirical framework was built on the basis of the two bodies of knowledge the Theoretical Design Principles were developed on the basis of the aforementioned CIMO approach (see Chapter 2).

4.3. Exploratory Case Study as an Augmentation to Theoretical Design Principle Definition

Designing a flexible supply chain is a complex and intertwined process. Multiple case study approach seems to be the optimal research strategy in such situation (Yin 2003) since it allows for a cross-case comparison of empirical accounts of supply chain design processes. Furthermore, case study approach bridges qualitative evidence with mainstream deductive research to allow theory development through developing constructs and testable theoretical propositions (Eisenhardt and Graebner 2007). We do follow the multiple case study format in

the second phase of empirical research, but for the sake of developing the Theoretical Design Principles we chose a single exploratory case study which augments the literature research.

The method is motivated by Yin's (2003) three essential criteria: (1) research questions defined in terms of 'how' (how companies can design structural supply chain flexibility); (2) relative novelty of the investigated field (no prior research in applying the Object Orientation to supply chain design); and (3) the emergent nature of the phenomena which makes analytical control of actors' behaviour inappropriate.

This single exploratory case study of company Alfa illustrates a supply chain design project involving organization and information system design. Data was collected from the two sources of evidence identified by Yin as viable: interviews and documentation. Multiple sources of information improve the level of 'completeness' and 'saturation', which are two key internal validity criteria proposed by Mucchielli (1991).
In the process of defining the Theoretical Design Principles the focus was placed on success stories of supply chain flexibility in order to extract the design principles which positively influenced the flexibility. The concept of enemies of supply chain flexibility was taken into account in the case study selection process. Alfa's case was chosen because of the lack of strong enemies of supply chain flexibility and the success that the project brought to the organization. A strong presence of the enemies of supply chain flexibility (see paragraph 1.3) would bias our study and invalidate the findings. For a more in depth discussion on the enemies of flexibility, their impact on the specific kinds of flexibility and enemy strength assessment in each of the case studies see Appendix 1.

The data collection framework was based on CIMO approach described in Chapter 2. Basically, the data was collected to shed light on four areas of the studied supply chain design projects: the **context** in which the project had taken place (relevant information about the company and the reason for undertaking the project), the **intervention** itself (the account of what actions had been taken during the project), the **mechanisms** which had been triggered by the intervention and the **outcome** (the actual results of the project). This approach was coherent with the Theoretical Design Principle definition .
The interviews were conducted with professionals directly involved in the analyzed supply chain design projects. Those professionals were either: external consultants specializing in the field of supply chain design, thus their view of the subject was well-constituted and objective; or executives from the analyzed organizations, whose opinions could be of course biased. To offset any possible biases, the information obtained from interviews was complemented by data gathered from internal project documentation and official company documentation (annual reports, organization charts, press articles).
Data collection was conducted in accordance with three principles listed by Yin: multiple sources of evidence were used, a case study database was created, and chain of evidence was maintained for every study finding. More detailed information about the case study data capture methods and techniques can be found in Appendix 3.

Validity of the case study was ensured by conforming to the four key criteria provided by Yin (2003). Below is described how each of these criteria was satisfied.
Construct validity requires that the operational measures be established for the concepts studied. This criterion was satisfied by employing the CIMO approach which helped to operationalize the theoretical framework in the form of Theoretical Design Principles. The use of multiple sources of evidence in data collection phase and the establishment of the chain of evidence had also ensured the integrity of the constructs enclosed in the study.

Internal validity requires that there are causal relationships between the concepts established in the study. It was ensured by a pattern matching approach in the case study analysis. The patterns described in the Theoretical Design Principles were sought for in the analyzed three cases. CIMO approach applied to case study analysis served to extract the Empirical Design Principles in a form which facilitated pattern matching and cross-case comparisons.
External validity requires that the study establishes a domain to which findings can be generalized. This was done in Chapters 1 - 3 through extensive literature research and later on in the empirical part by using the replication logic. Alfa's case study was analyzed for literal replication, i.e. yielding similar results to those predicted, and theoretical replication, i.e. yielding contrasting results but for predictable reasons. This case study did not produce statistically valid research results, due to limited sample but an attempt to maximize the validity of the research has been made through the use of developing multiple case study in the second phase of the empirical research.
Reliability requires demonstrating that the operations of the study such as data collection and analysis can be repeated by another researcher with the same results. This criterion was ensured by creating a case study database.

The analytical strategy applied to Alfa's case study analysis was that of reliance on theoretical propositions defined in the form of Theoretical Design Principles. Alfa's case report is presented in the CIMO format to facilitate verification of Theoretical Design Principles presented in the same form.
The case study analysis was conducted with the aid of *pattern matching*, which is "one of the most desirable techniques" for case study analysis (Yin 2003). This logic compares a theoretically predicted pattern with the empirically observed one. Yin (2003) states that if the two patterns exhibit symmetry then this result helps to strengthen the internal validity of the study. Once the symmetrical patterns are spotted, the goal is to identify and assess all the reasonable threats to validity by explaining why they cannot explain pattern replication.

4.4 Action Research and the Developing Multiple Case Study

The second phase of empirical research consisted of action research in the form of a developing multiple case study. In that phase, the Theoretical Design Principles (TDP) formulated and refined in a pilot exploratory case study, were applied in clinical research. The TDPs were treated as design exemplars, that is general prescriptions which had to be translated to specific design situations in the case of Beta and Gamma. Due to the indeterminate heuristic nature of the TDPs it was impossible to conclusively prove their veracity. Nevertheless it is deemed to be sufficient to present evidence supporting their applicability and usefulness in a given context (van Aken 2004). In both cases the design principles were refined and tested by their author in the context of their application. This kind of case study research is called alfa-testing. Van Aken (2004) also proposes a second kind of research called beta-testing, where the proposed design principles are field tested by independent third parties, which among other benefits reduces researcher's bias.
The choice of companies Beta and Gamma was driven by two factors. First and foremost, these two companies were looking specifically at increasing the flexibility of their supply chain. Since the research question was formulated as "*how can companies design structural supply chain flexibility*" they were a natural choice for researching the answer to that very question. The second key factor was of opportunistic nature – both companies turned to external consultants for help in reaching the objective of improved supply chain flexibility and one of the consultants participating in these projects was the author of that research. In each of the cases the author as a member of the intervention team had an opportunity to

translate the Theoretical Design Principles into actionable design principles which were later implemented by each companies' employees in the field.
More specifically, in Beta's case the author of the study was assigned as a leader of the Sales and Operations workstream. He was responsible for analyzing the as-is situation, designing the target solution and formulating its implementation plan. The citations from the interviews with Beta's managers were collected both in the early stages of the project and then in the post implementation phase. The outcome of the intervention was assessed and measured after the implementation of the target solutions had ended. The success story which illustrates the results in a qualitative manner happened nearly immediately after the intervention and the quantitative results were measured a year after the end of the project.
In Gamma's case the author of the study was directly involved with the process and organization design work streams and had an opportunity of translating the Theoretical Design Principles into the target supply chain organization design as he was responsible for the analysis of the as-is state, designing the target solution and defining the implementation plan. The snippets of interviews with Gamma's management which are cited in the case were collected during the course of the field research. Analogically to Beta's case the results of the intervention were collected after the end of the implementation phase. The qualitative success story happened a few months after the completion of the project and the quantitative results were measured a year after the end of the project. More detailed information about the case study data capture methods and techniques can be found in Appendix 3.
The case studies themselves are described in paragraphs 5.1 – 5.3 and the results of the case study research are recapitulated in paragraph 5.4. We then present the inferences and practical implications of the research.

4.4. Inference of the Alfa-tested Design Principles

As a result of alfa-testing the Theoretical Design Principles a case study database was created, which described important data about the studied companies and specific variants of the theoretical design principles used in each of the cases. It is impossible to conclusively prove the veracity of design principles, but they can be successfully tested in context. These variants are described in CIMO format which places emphasis on the Context they were used in, the description of the Intervention, the Mechanism employed and the Outcome. To analyze the results we have employed the analytical tool of *cross-case synthesis*. This method is directly analogous to cross-experiment interpretations, when they rely on a small sample of outcome data which thus does not allow for quantitative analysis (Yin 2003).
The case study data was presented in a word table to facilitate comparisons and conclusion drawing. The synthesis was led with the goal of identifying all the reasonable threats to validity and showing why such threats are not relevant.
This specific approach of combined analytical methods and approaches allowed for judging the results of the alfa-testing as sufficient supporting evidence and calling the study findings an interesting attribution to the science of organization design.

V. Empirical Research Findings

In this chapter we will present the analysis of empirical research concerning the supply chain design principles of flexibility. The cases were selected from a group of supply chain design projects which were aiming to improve supply chain performance through increased flexibility. Each of the selected cases tells a story of a supply chain design project which resulted in a significant increase in supply chain flexibility.
As mentioned earlier Alfa's case took the role of pilot exploratory case study, which was used to refine the Theoretical Design Principles. It is also the only case study which was conducted from the passive observer role. The cases of Beta and Gamma were conducted as clinical research from a design participant's perspective.
For each of the described cases we will first present the context, then describe the project approach and finally describe the object oriented design principles which manifested themselves in the analyzed case. The observed empirical design principles are compared to the theoretical design principles presented in the preceding chapters. Each case will also contain a short story on how the implemented design proved itself and improved the structural supply chain flexibility both in qualitative and quantitative terms.

5.1. Alfa - Tool Manufacturer

General context

Company Alfa is a supplier of consumer products and tools for professional, industrial and consumer use. It is a global company owning its production facilities in over 15 countries. Alfa is divided into three major divisions: Consumer Products, Industrial Tools and Security Solutions. The Consumer Products division focuses on hand tools, storage and hardware for the professional contractor and Do-It-Yourself market. Industrial Tools division focuses on hydraulic, pneumatic, specialty and measuring tools as well as storage systems like racks and shelves destined for industrial use. Security Solutions division includes production and installation of automatic doors, locks and related hardware. This case tells a story of supply chain redesign project which took place in the European part of the Consumer Products division of Alfa's business with an aim of improving the supply chain effectiveness and flexibility. Alfa was chosen for the study because of the undertaken redesign project and relative availability of data for an exploratory case study. For a more in-depth description of the research strategy please refer to paragraph 4.4. An overview of the approach to data collection used in the study can be found in Appendix 3.
Before we will investigate the details of the redesign intervention, let us first present an overview of the industry in which the Alfa's Consumer Products division operates, a few facts from its history, its key products, market position and financial information.

Industry overview

On the supply side tool manufacturers are dependent on steel and other metals, plastics and resins, and to a lesser degree electronics (the latter depending on the degree of sophistication of their products). Metals and resins are the main cost drivers, each accounting for 30 to 50% of overall material costs but this ratio differs between different tool types. Cost of the finished product is correlated with the price of materials, with metals and resins being the most volatile cost factors. The prices of metals are driven by the growing demand in BRIC countries, whereas the prices of some plastics and resins are driven by the price of oil and its derivatives.

The demand for tools is being driven by the housing business and to a smaller degree the manufacturing industry. When the housing market is up, that is the more houses are being built, renovated or demolished to make place for new ones, the more tools will be needed. The tools destined for the industrial market are of course reliant on the state of the manufacturing industry (this market is addressed by the Industrial Tools division). The Do-It-Yourself part of the tool market – is generally driven by the overall condition of the economy as it bears the characteristics of the consumer products market.

Brief history of the company

The company was started in the first half of the 19th century as a small tool shop in the United States. It has grown extensively in the post Civil War economy and sustained the growth until the end of the World War I, increasing its revenues from about 53,000 $ in 1860 to 11 million $ in 1919. In the interwar period the company had initially grown intensively through acquisitions in the US as well as it had expanded overseas to Europe. The Great Depression and the Second World War were a period of organizational decline and negative profits. In the post-war period Alfa's performance remained sluggish as its strategy of focus solely on manufacturing neglected the need for marketing of Alfa's products. Things changed in the 1960s as a new CEO brought on a broad revitalization and by the time when he was resigning in the late 1980s Alfa was an aggressive leader in the globally competitive tool and hardware industry. In the 1990s as the economy cooled down Alfa once again became stagnant. Looking for new possibilities for growth it has opened a new hand tools production facility in Central-Eastern Europe. The second half of the 1990s saw a new turnaround which was launched by an ex-General Electric CEO. It involved a reduction of workforce and shutting down of several factories and distribution centers. By the end of 2003 when the turnaround was completed the company was poised for further growth. In 2004 Alfa has made an important acquisition in France expanding its hand tool presence in Europe. Alfa is a company which has undergone many redesign efforts besides the one we will describe in more detail in this case.

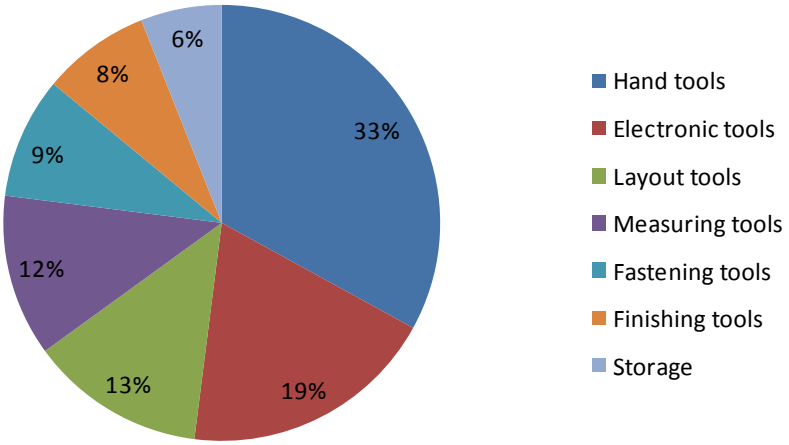
Product portfolio

The Consumer Products division manufactures and markets hand tools, consumer mechanics tools, storage and hardware. There are about 1500 Stock Keeping Units (SKU) sold by the division under several brands. Below we present the key product groups:

- Measuring tools – measuring tapes of varying length, strength and durability
- Layout tools – levels and squares ranging in size and durability
- Electronic tools – stud sensors detecting electrical wires and measuring the distance
- Wide assortment of hand tools – this category includes hammers, pliers, wrenches, knifes, blades, saws, screwdrivers and mechanics' tools - in all sizes and for all professional uses
- Fastening tools - this category includes four tool lines: manual and electric staplers, hammer tackers, hand riveters and electric glue guns
- Finishing tools – hand planes for all kinds of wood work
- Tool storage – bags, boxes, mobile storage and organizers
-

The best selling product group are the hand tools (33% of division's sales revenue in 2005), followed by the electronic tools (19% of division's sales revenue in 2005), layout tools (13% of division's sales revenue in 2005) and measuring tools (12% of division's sales revenue in 2005). These four product groups generate nearly 80% of revenues with the remaining 20% being generated by fastening, finishing and storage categories. The sales structure of the above mentioned product categories is presented in the picture below (see Picture 5).

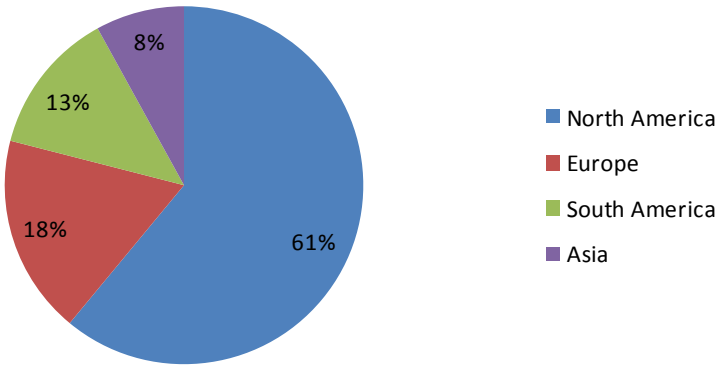
Picture 5. Sales structure of Alfa's Consumer Products (2005)



Market position and key customers

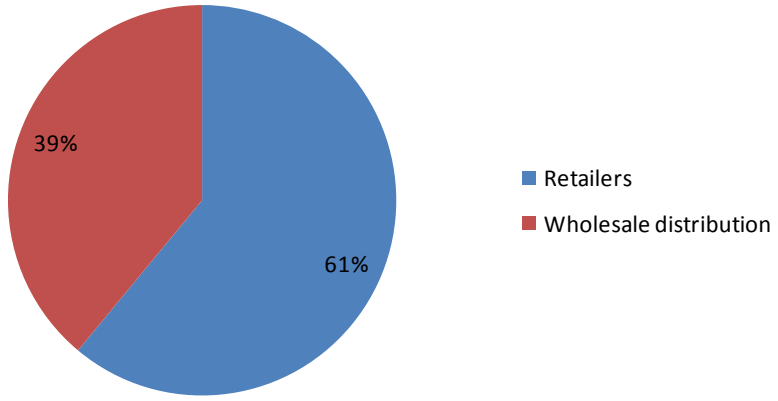
Alfa's main markets are North America (61% of division's sales revenue in 2005) and Europe (18% division's sales revenue in 2005) closely followed by Latin America (13% division's sales revenue in 2005), whereas the Asian market lags behind (8% division's sales revenue in 2005). This case focuses on the European part of the Consumer Products division. Alfa has an approximately 10% share in the European market. This market is a battleground with lower-cost manufacturers from Asia. Indeed, the DIY market sees an aggressive pricing strategy of unbranded products. Mainly Chinese companies are developing this market with no-name products that are 25 to 50% lower in cost than an European product. The breakdown of the sales by geography is presented in the picture below (see Picture 6).

Picture 6. Alfa's Consumer Products sales geography as a percentage of sales revenue (2005)



Alfa sells its products mainly through retailers including home centers, mass merchants, hardware stores, and lumber yards (58% of division's revenue in 2005) and wholesale distribution (39% of division's revenue in 2005). The key customers graph is presented below (see Picture 7).

Picture 7. Alfa's Consumer Products division key customer groups as a percentage of sales revenue (2005)



Alfa's pricing is higher compared to competition and especially to low-cost Asian manufacturers. Alfa's value proposition is based on premium quality, but it has also recently launched some more affordable tool brands.

Financial position

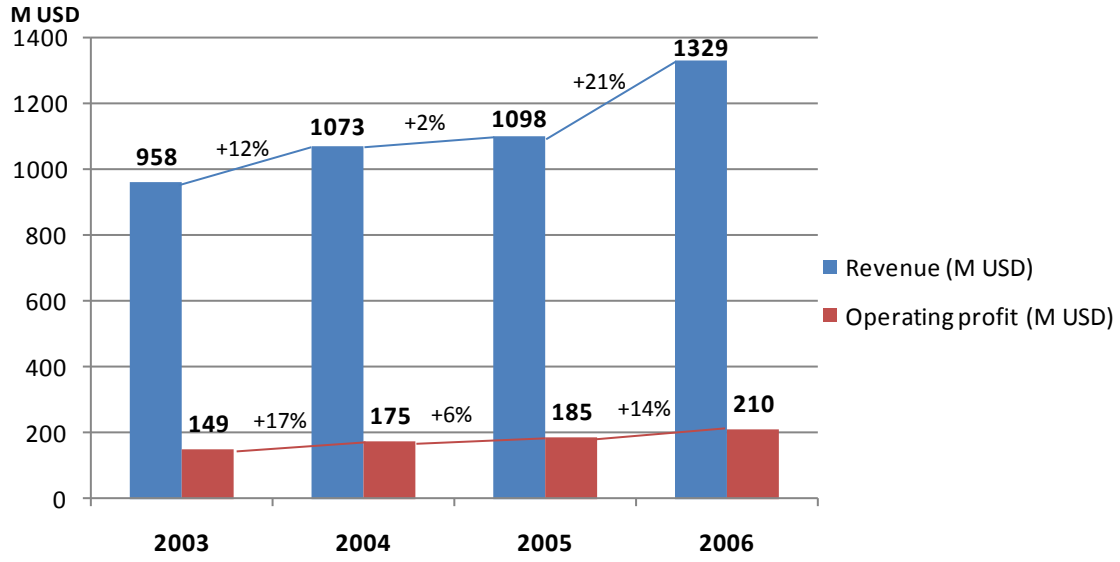
Since the turnaround which ended in 2003 Alfa's Consumer Products division was poised for future growth. In 2003 the division had a revenue of 958 million USD which was a 5% increase compared to 2002. The increase was mostly attributed to favorable currency fluctuations as well as a slight increase in volume in the US market. The operating profit was 149 million USD, which translates to a 16% operating margin.

In 2004 the revenue of the division rose by 12% to 1073 million USD. Of this 12% increase, volume represented 7% which was driven by growth in hand tools and storage units as a result of improved order fulfillment, increased brand support, and higher market demand. The operating profit rose by 17% to 175 million USD, which translates to a 16% operating margin.

In 2005 the Consumer Products revenue was 1098 million USD which represented a 2% increase from 2004. Of this 2% increase, 1% can be attributed to acquisitions while organic volume increased 1% driven by strong performance in the hand tools and consumer storage business associated with successful new product introductions. The operating profit rose by 6% to 185 million USD, yielding a 17% operating margin.

In 2006 the revenue of the division increased by 21% to 1329 million USD. Of this increase, acquisitions accounted for 18%, while organic volume and price rose 2% and 1%, respectively. The operating profit rose by 14% to 210 million USD translating to a 16% operating margin.

Picture 8. Alfa's Consumer Product's revenue and operating profit (2003-2006)



Issues identified by the management

Even though the Consumer Products division reported steady revenue growth between 2003 and 2005, most of that growth could be attributed to acquisitions. The company had faced some operational problems which were getting even more complex as new businesses were being acquired. By mid 2005 the Consumer Products division management has identified the following issues:

- High inventory levels – the division has experienced high levels of finished goods and raw material inventories due to unpredicted demand patterns and cancelled customer orders. Raw material overstock was a pressing problem as the material costs were increasing
- High supply chain costs – the division bore the costs of poor planning like the premium freight to expedite, costs of offsite storage and external distribution
- Low visibility of inventory – especially of the inventory being in-transit from the external suppliers or from own production sites
- Inconsistent processes across different businesses within the division – due to intensive non-organic growth different Consumer Products businesses had different approaches to supply chain planning and there was no organizational unit responsible for the entire integrated process

Alfa's management decided that the situation demands for action if the division was to sustain its good financial results. Thus they have asked external experts for guidance in solving the issues.

The solution

An initial project was carried out by a team of employees directed by external consultants experienced in supply chain management. The diagnosis was that the Consumer Products division experienced the symptoms of a supply chain lacking flexibility. As a result another project has been launched, which had a key objective of increasing the key drivers of supply chain flexibility. An increase in operational flexibility was sought through improving supply chain planning and execution, whereas an increase in structural flexibility was sought through developing a standardized Sales & Operations (S&OP) process model. It was decided to do a pilot project on the European part of the Consumer Products division.

The expected benefits of the project included:

- lower inventory levels (50% reduction) which were expected to be achieved through better supply and demand planning,
- significant reduction of associated inventory expenses and other operating costs through process optimization and organization redesign,
- maintenance of high customer service levels,
- improved supply chain visibility thanks to an improved IT support of the processes.

Intervention overview

Project management duties were jointly carried out by one of the consultants and Alfa's supply chain manager. At first the team struggled to get mid management support and involvement which was eventually secured through executives' involvement. The project commenced with a detailed analysis. Its purpose was to get a thorough understanding of the current organization, processes and technology. The analysis stage delivered process maps and business architecture overview. The next stage sought to define gaps between the existing sales and operations practices and those that are considered to be the best within the industry. As a result a detailed list of gaps was compiled along with the ways to close them. The following stage was of vision development. Vision for the target solution was drawn basing on industry trends and competitors' strategies. The vision comprised of creating a transparent supply chain with standardized processes executed by specialized business units. In the next stage a detailed roadmap of reaching the vision was created. It included defining the initiatives which contribute most value and their implementation plan, Alfa's change readiness assessment and the methods of progress measurement. The transformation stage included implementing the design and adjusting it wherever necessary to the changing external and internal constraints.

Detailed Design

Alfa's supply chain design project was a very complex and wide ranging effort. It included process and organization redesign supported by changes in the underlying information technology. The problem which interests us here is how did Alfa achieve its objectives of improving operational and structural supply chain flexibility. Theoretical Design Principles defined in paragraph 3.3. had been examined for pattern matching with the design principles which were used during the project. We will present the results of that analytical process below.

Observed patterns

The described case contains patterns which are close matches to *internal organization modularity* and *abstraction* principles. Alfa developed a vision to organize its Consumer Products supply chain planning organization in a modularized manner. To support this vision it planned to develop standardized communication interfaces. The key objective of that design was to achieve process modularity and standardization and thus greater flexibility. Because *internal organization modularity* and *abstraction* are closely interrelated in Alfa's case they will be analyzed jointly. Below is a CIMO analysis of these principles as observed in Alfa's case.

Context – Modularity and Abstraction

Alfa's supply chain planning organization was fragmented. To a large degree it was a result of an intensive acquisition strategy. The Consumer Products division consisted of several brands and product lines, whose supply chain planning organizations were integrated to a different degree. This resulted in inconsistent, manual and labor intensive processes across the division's planning organization. The organization used disparate tools and technologies

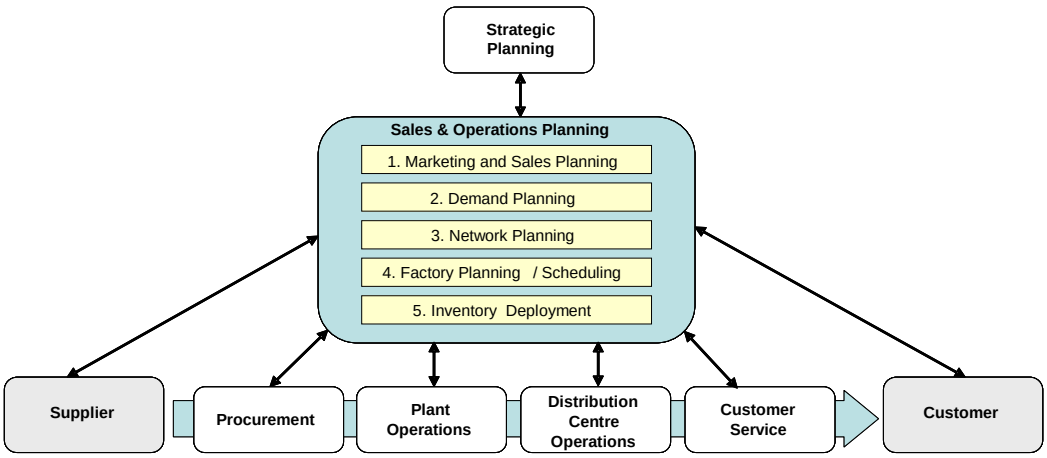
to produce inconsistent reports, which often could be little relied on. Because of delays in information delivery, most of the efforts went into data gathering rather than value added analyses and what-if modeling. The organization was unaware of its processes and lacked an integrated information platform. On the positive side, the organization was somewhat aware of its shortcomings and showed a degree of openness to change. One interviewee said "At the time, we were very aware of our pain points and a majority of management had a desire to improve. Yet, as usually, there were some opponents".

Intervention – Modularity and Abstraction

The project team developed a vision of an integrated supply chain planning department. The envisioned design was of a centralized supply chain planning department located on the Consumer Products division level. The department was to be responsible for the supply chain planning activities. It was to be integrated through developing its processes and shared human resources, as well as common IT systems, even though part of the team was planned to be geographically dispersed (localized in the factories or distribution centers). The planning department was to fulfill supply chain planning services and communicate with all the parties within the organization which relied on their plans and forecasts. One interviewee said "The design was meant to simplify the processes across the (Consumer Products) division. We have created a kind of a one stop shop for supply chain planning at the division level".

By creating an integrated department with clearly drawn boundaries and redesigned processes Alfa believed to achieve benefits in the form of: higher forecast accuracy resulting in lower inventory levels, an improvement in the post-acquisition integration process through simplified and unified organization design, increased visibility across the supply chain due to common information platform and standardized information flows. The detailed design can be found in the picture below.

Picture 9. To Be Supply Chain Planning Organization Design



The target supply chain planning organization design was that of an integrated department handling the following processes: Marketing and Sales Planning, Demand Planning, Network Planning, Factory Planning and Scheduling, and Inventory Deployment. The department was developed as a self-contained entity providing well-defined services to the functions which were directly responsible for the flow of materials and goods from the supplier to the customer. Thus a range of communication interfaces have been defined with

the Suppliers and Customers as well as the following internal entities: Procurement, Plant Operations, Distribution Center, Customer Service; support functions: Finance and Strategic Planning. These interfaces had also been defined and supported at the IT level where applicable. A summary of the interface specifications is presented in the table below (see Table 4).

Table 4. Interface descriptions

	Interface with Supplier	**Interface with Procurement**	**Interface with Plant Operations**	**Interface with Distribution Centre Operations**
Supply Chain Planning Interface Specifications	• Review supply plan and identify and communicate any constraints • Resolve supply constraints issues	• Deliver purchase orders in accordance with supply plan • Resolve supply limitations	• Deliver packing schedules • Receive production capabilities information • Coordinate demand management with production	• Deliver finished goods purchase orders • Resolve supply limitations • Coordinate supply management with distribution
	Interface with Customer Service	**Interface with Customer**	**Interface with Strategic Planning**	
	• Receive distribution capabilities information • Receive replenishment orders • Deliver real time stock availability data from supply planning • Monitor and coordinate stock availability and delivery priorities	• Receive customer forecast • Deliver posted demand plan and receive adjustments • Exchange information on promotion opportunities in a timely manner	• Receive business unit financial plans and budgets • Deliver supply and demand plans	

Implementation story

Vision of the design was developed during the visioning stage. It was later detailed during the roadmap definition stage and implemented during the transformation. The design consisted of business processes, roles and responsibilities, key performance indicators, and IT requirements. To develop consensus and facilitate acceptance of the design, the project ownership was placed on Alfa's representatives as the metrics of project's success were introduced into their Management By Objectives scorecards. External consultants' role was to provide the approach and subject matter expertise around supply chain planning processes. Relying on design implications from earlier stages, knowledge of leading practices, and understanding of technology capabilities, the project team worked together through iterative design work sessions with a focus on two of the Consumer Products division's business units to develop an initial design which was subsequently validated by other business units through a series of workshops. The design was initially validated with a proof of concept implementation approach – starting with two business units within the Consumer Products division. The proof of concept implementation was conducted with the help of change management and benefits realization techniques. The proof of concept proved to be a success and the design was rolled out to other business units within the division. The rollout of the organization design was supported by an implementation of an integrated information platform.

Mechanism – Modularity and Abstraction

The implementation of the design had triggered several organizational mechanisms which resulted in delivering the final outcome.

Process standardization and unification achieved thanks to the integration of the supply chain planning department and its processes has improved the internal information flows and process efficiency. Moreover the process blueprint has been created with future integration of acquired companies in mind. The standardized format of Alfa's supply chain planning inputs, outcomes and procedures would help to quickly establish efficient information flows and achieve process integration. What is more, a creation of an integrated department and concentration of supply chain planning competencies has helped achieve economies of specialization. An interviewee reported "The centre has proved to be so efficient that the accuracy of our forecasts and reports improved significantly, at the same time seriously driving down the operational costs".
Standardized and IT supported communication interfaces provide well defined inputs and outcomes. This has improved collaboration along the supply chain with both suppliers and customers, which has resulted in data exchange leading to an improved forecast accuracy. Once the communication interfaces had been implemented the quality and timeliness of information improved, resulting in improved supply chain visibility and forecast accuracy.

Outcome – Modularity and Abstraction

The project has delivered the desired objectives. Operational flexibility had increased due to more effective and coordinated planning processes and improved information flows within and outside the organization. Inventory levels were reduced thus lowering the working capital. Process costs were reduced due to process redesign and unification. Higher inventory visibility was achieved due to an implementation of an integrated warehouse management system.
Structural flexibility had increased due to standardized processes executed by an integrated department, which has allowed for smoother integration of new acquisitions. The complexity of planning the supply and demand of multiple product lines over several geographical regions has been reduced due to process unification.
The project was a success and the Sales & Operations Planning (S&OP) department design was replicated in other Alfa's divisions. One interviewee said "The design has proven to be so efficient that the Board has decided to roll it out to other divisions. We have become a kind of an internal best practice".

Structural Flexibility – A Success Story

Alfa's design team did not have to wait for long before the new design could prove itself. A few months after the completion of the project Alfa acquired a tool producer which closely resembled its existing operations. One of the major synergies sought after in the integration process was a far-flung supply chain integration. One of the goals was to incorporate the supply chain operations of the acquired company into the existing S&OP process. Thanks to modular design all the core activities were concentrated within the S&OP department thus the reconfiguration of process to accommodate a new business entity was much easier than in the case of processes dispersed all over the organization. The standardized interfaces also helped to define the information requirements from different functions of the acquired company. The integration process was also speeded up by the existing IT interfaces – new IT developments were only needed at the side of the acquired company. Thanks to the object oriented supply chain architecture Alfa was able to fully integrate the supply chain of the acquired company in three months. Clearly an outstanding result. Measures taken one year after the completion of the project implementation tell the rest of the story:

- Overall inventory level reduction by 54%,
- Supply chain cost reduction by 10%
- Improved On Time In Full service level from 98% to nearly 99%

Discussion

The case of Alfa redesigning its supply chain to achieve greater flexibility has exhibited two of the object oriented design principles in use – *modularity* and *abstraction*. *Modularity* was visible as a key design principle driving the design of the supply chain planning department. The modular, integrated architecture of the department was supplemented by standardized communication interfaces created according to the *abstraction* principle. A question arises where are the other two object oriented principles? Why were they not part of the supply chain design project? The answer is that they had already been implemented in Alfa's supply chain before.

Encapsulation which in supply chain context translates to the separation of organization from its suppliers through centralized procurement had already been implemented in Alfa. It had come about as a natural business decision to benefit from the purchasing power for the entire group. It has reduced the number of information flows between the company and the suppliers and has helped to manage procurement policies. Since the designed planning department had an interface with procurement, it is worth noting that its implementation might have been difficult if the procurement was not centralized. In that case it would have to interface with multiple fragmented organizations, thus significantly complicating the information flow, decreasing efficiency and increasing complexity.

Hierarchy which in supply chain context translates to a tiered supply chain structure was already existent in some parts of Alfa's Consumer Products division. It was existent specifically in the supply chains of products of significant complexity like pneumatic tools, where the first tier suppliers delivered power modules or engines. Thus we may formulate a cautious working hypothesis that the *hierarchy principle is implemented only there, were there is significant complexity to be reduced as a benefit (H2).*

Alfa's case provides some interesting observations on the relations between the object oriented design principles themselves. When we look at *abstraction* and *modularity* and the way the complement each other in Alfa's case one might be tempted to formulate another working hypothesis that *abstraction is an enabler of internal organizational modularity (H1).* Indeed the planning department developed in Alfa's case would not be functioning efficiently if it lacked defined interfaces with other parts of the organization. This hypothesis will be tested in the next cases.

Before we proceed into discussing alternative explanations let us first resume the observed Empirical Design Principles and confront them with the Theoretical Design Principles. The following table resumes the principles observed in Alfa's case.

Table 5. Comparative analysis of Theoretical Design Principles with Empirical Design Principles observed in Alfa's case

	Internal Organization Design Modularity		Abstraction	
	Theoretical Design Principle	**Empirical Design Principle**	**Theoretical Design Principle**	**Empirical Design Principle**
Context	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Fragmented, inefficient organization, lacking in terms of technological enablers.	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Organization lacked the information platform to provide the interfaces.
Intervention	Implementation of a modular supply chain organization through aggregation of cohesive activities. Establishing a loosely coupled architecture between modules. Leveraging (reusing) modules across the organization. Automation and standardization of activities.	Implementation of a modular supply chain planning department. Standardization and aggregation of processes. Providing supply chain planning services to the rest of the organization. Part of the department centralized, part localized.	Implementation of standardized internal and external communication interfaces at the business and technological level.	Implementation of business and technology interfaces for the modular supply chain planning department.
Mechanism	Aggregation of activities enables for faster reconfiguration of processes and structural reorganization. Modular internal supply chain organization is flexible to accommodate structural changes within the entire supply chain.	Process standardization and organizational modularization enabled for easier integration of acquired companies. Centralization of supply chain planning capability resulted in improved personnel skills.	Standard communication interfaces help to establish efficient information flow and the ability to remodel the supply chain organization when needed.	Better information flow improved process efficiency and integration of acquired companies.
Outcome	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	Increase in supply chain structural flexibility. Achieving economies of specialization, cost reductions and complexity reduction.	Increase in structural supply chain flexibility. Complexity reductions.	Increase in operational supply chain flexibility Complexity reductions
	Encapsulation		**Hierarchy**	
	Theoretical Design Principle	**Empirical Design Principle**	**Theoretical Design Principle**	**Empirical Design Principle**
Context	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Principle already implemented to improve the efficiency of procurement function.	Appropriate supplier market structure for implementing a structurally flexible supply chain	Principle already implemented in selected supply chains of products of sufficient complexity.
Intervention	Implement a centralized procurement organization which acts as a mediator between the suppliers and the rest of the organization.		Implementation of a tiered supply chain structure	
Mechanism	Centralized procurement organization reduces unnecessary information flows and facilitates implementation of new procurement rules & policies. Ensures encapsulation from the influence of *flexibility enemies* from outside the organization.		Tiered supply chain structure reduces unnecessary supplier relations by delegating them to first tier suppliers. Ensures encapsulation from the influence of *flexibility enemies* from outside the organization.	

Outcome	Increase in supply chain structural flexibility. Complexity reductions Cost reductions.		Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	

Rival explanations

Object oriented design principles are properly replicated in Alfa's supply chain design case. But can we find rival theories explaining the design principles used?

One rival theory is that it is process approach that is the key idea behind the design principles at work in Alfa's case. Process approach would explain the strong process focus of Alfa's design project. But the key design principles of process approach (Hammer and Stanton 1999): creation of end to end processes, process standardization and introduction of the role of a process owner do not explain the entire design conceived in Alfa's case. Indeed, the process approach does not explicate neither the creation of a modular, loosely coupled S&OP department nor the standardized interfaces created between it and the rest of the organization. While the project team responsible for the design must have been influenced by the process approach to organization design, they have clearly made their design unique in terms of the clearly defined boundaries and department team. The topic of the relationship between the process approach and the object oriented design principles is explored more in depth in paragraph 5.4.

Another rival theory is that the design was in fact based on the principles of virtual organization (see paragraph 1.1.3). This theory would explain the strong focus on the creation of standardized communication interfaces, but due to the lack of operationalized design principles of virtual organization it is rather difficult to argue that it was this theory that drove the design in Alfa's case.

Even though an extensive literature search was conducted no other rival explanations could be formulated. What explains this fact is that the phenomenon of flexible supply chain organizations is relatively new and so far not researched.

Thus this discussion concludes the pilot exploratory case. The next cases will be described below in the same format, aiming to collect sufficient context-rich evidence to support the theoretical claims of Theoretical Design Principles.

5.2. Beta - Furniture Components Manufacturer

Introduction

Company Beta is a manufacturer of materials for the furniture industry operating in Central Europe. Beta is a part of a capital group which has over 20 production sites in North America, Western and Central Europe. The entire capital group specializes in manufacturing materials dedicated to furniture and interior design. Beta operates four factories in Central Europe focusing on the production of raw and finished chipboard for the furniture industry. This case presents an overview of the industry in which Beta operates, a few facts from Beta's history, its key products, market position and financial information. Beta was chosen for the case study because it tells a story of a supply chain optimization project which had an objective of improving supply chain flexibility through the supply chain planning process. Moreover the choice was driven by the participation of the author of the study in that optimization project which gave him an opportunity to field test the design principles formulated earlier in the study. For a more extensive justification of the research strategy please refer to paragraph 4.4. An overview of the approach to data collection used in the study can be found in Appendix 3.

Industry overview

On the supply side the chipboard manufacturers are dependent on wood, paper and chemicals. Wood is the main ingredient of chipboards, and it is responsible for about 40% of material costs, paper for about 30% of material costs and the remaining 30% of material costs belongs to chemicals like glues, resins and paints. Cost of the finished product is strongly correlated with the price of the materials, with the cost of wood being the most volatile cost driver. On the local Central European markets the supply of wood is still to a large degree dependent on the national forest exploitation monopolies, which drives the volatility of prices.

On the demand side the chipboard manufacturing industry serves as a supplier to furniture industry, as chipboards constitute the main component of modern furniture. The furniture manufacturing industry in the region is dispersed with only a few locally important players. The furniture manufactures are in turn dependent on the situation in housing and renovation. Therefore the chipboard producers are also strongly dependent on the situation in housing and renovation. When the housing market goes up, that is more houses are built and as the demand for furniture increases so does the demand for chipboard. These markets are equally correlated when the housing industry is on the downturn. Overall, the changes in demand for chipboard and related products can be truly dramatic. In Beta's case the market demand can swing from roughly 25% to 125% of the monthly production capacity and the move between the extremes can take about 3 months. In such an industry those players which have developed strong demand planning capabilities have higher chances of success.

Brief history of the company

The history of Beta dates back to 1970s, when it was established as a state-owned enterprise. Since its beginnings it has specialized in chipboard manufacturing. Upon its commercialization in the 1990s, it was transformed into a joint-stock company, which had been listed on a local stock exchange since the late 1990s. By the end of the 1990s the company was acquired by a global manufacturing group focusing on the materials dedicated to furniture and interior design. The parent company currently operates over 20 highly specialized plants in North America, Central and Western Europe and consistently expands its sales to new markets. At the time of the research Beta operated two production sites locally and had another two in the construction process. By the time the research was finished Beta was operating four factories in Central Europe.

Product portfolio

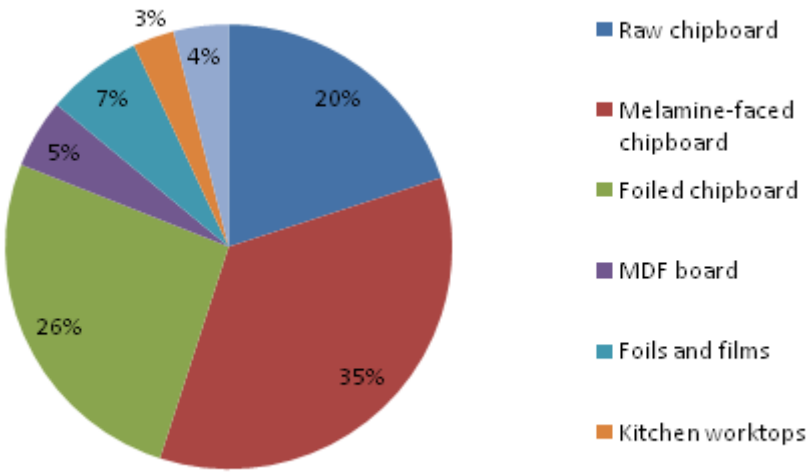
Beta's key products include:

- Raw chipboards – the basic product which serves both as a finished good, as well as a semi-finished product which can be further processed, i.e. laminated or foiled. The basic raw chipboard is a key component in the production of furniture fronts (e.g. cupboard fronts) and upholstery (construction of sofas and armchairs).
- Melamine-faced and foiled chipboards – finished chipboards imitating wood, stone and other materials, used for furniture fronts and interior design
- Thin MDF boards – thin boards used as the backsides of the furniture
- Furniture foils and melamine films – wood imitation foils and films used for finishing the raw chipboards into melamine-faced and foiled ones
- Kitchen worktops – cut to size, toughened worktops from chipboards covered with thick HPL film

The production sites operated by Beta act like a manufacturing cluster which is able to satisfy the local market and its own internal demand. Two sites produce raw chipboard and one of them also produces foils and films. The third site exclusively produces thin MDF boards and the fourth produces the glues and resins necessary for chipboard manufacturing.

Beta's revenue in 2008 was 307 million Euro and the sales structure graph is presented below (see Picture 10). Over 80% of that figure came from the sales of the three of its major products: melamine-faced chipboard (35% of sales revenue in 2008), foiled chipboard (26% of sales revenue in 2008) and raw chipboard (20% of sales revenue in 2008). The rest of the products generates less than 20% of revenue, with foils and films being the best-selling of the group (7% of sales revenue in 2008). This does not mean that Beta's product mix is homogenous. Quite to the contrary, as the melamine-faced and foiled chipboards come in a wide variety of colors and structures imitating various kinds of wood, stone or other materials. This translates to around 3500 Stock Keeping Units (SKU) in these two product categories alone. Such proliferation of SKUs in the best-selling category places a significant strain on the production department as it is supposed to deliver lots of different products in short lead times, which in turn results in shorter production runs and higher production costs.

Picture 10. Sales structure of Beta's products (2008)



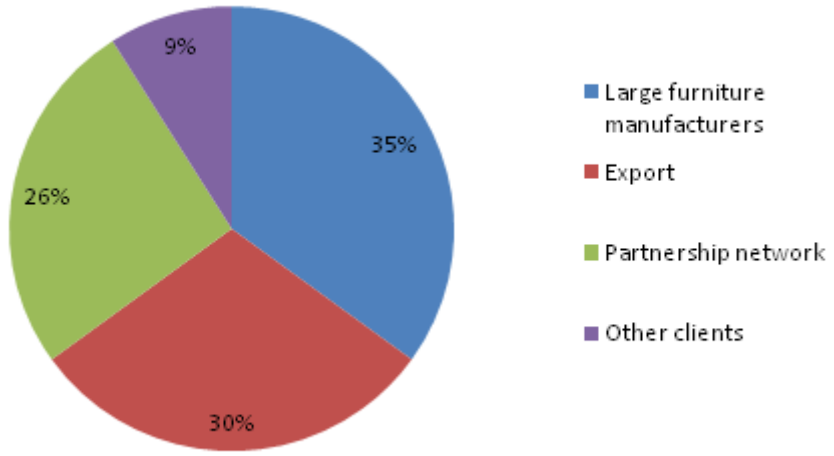
Market position and key customers

Beta has an approximately 25% share of the local market in Poland, with its two major competitors having a similar market share and the rest of the market being dispersed between smaller manufacturers.

Beta sells its products to customers from the local furniture industry (70% of sales revenue in 2008) as well as to other countries mainly in Eastern Europe (30% of sales revenue in 2008). Beta's local customers include large furniture manufacturers, which are supplied directly by the company (35% of sales revenue in 2008), and small and medium-sized manufacturers, which are supplied by Beta's official partnership wholesale network (26% of sales revenue in 2008). The wholesale network consists of around 30 distribution centers working in exclusive partnership with Beta. In addition to offering a wide range of materials for the furniture industry, the partnership network also provides formatting, coating and other more advanced material processing services. The key customers graph is presented below (see Picture 11).

Beta's pricing is higher to that of the competition but according to customer surveys the customers most value the level of Beta's service, i.e. uninterrupted availability of products, reliable distribution system adopted to the industry's specific needs, and the willingness to meet the customer requirements.

Picture 11. Beta's key customer groups as a percentage of sales revenue (2008)



Financial position

Since Beta was acquired in the late 1990s its financial results rose steadily as the local economy was on the incline. Especially, between 2001 and 2005 Beta's sales revenue rose consecutively year after year.

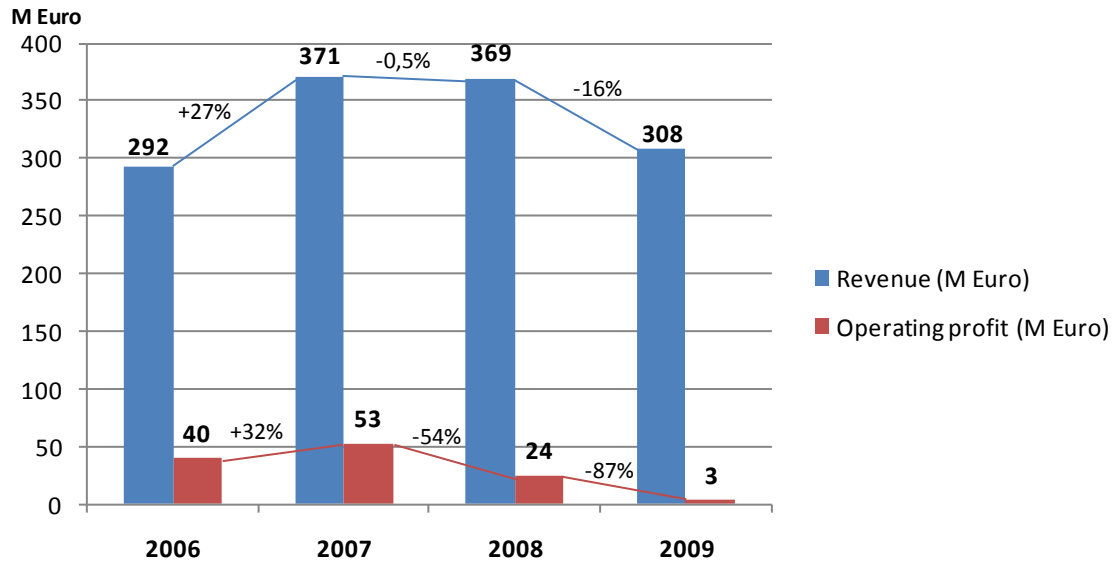
In 2006 Beta had its best year to date. The sales peaked at 292 M Euro with a healthy net profit of 40 M Euro yielding an operating margin of 14%. Things were so good that the company decided to build a new manufacturing plant in one of its major export locations.

In 2007 Beta had its best year ever. Sales revenue rose by 27% to 371 M Euro, mainly due to an increase in sales volume (23 pp) thanks to higher exports and strong activity in the housing industry. Operating income rose by 32% to 53M Euro yielding an operating margin of 14% for a second year in a row. Yet, it is worth noting that at the same time the net income was down due to investment costs into the new factory.

In mid 2008 the entire housing market in the region received a blow from the credit crunch. As we have discussed earlier the chipboard manufacturers are ultimately dependent on the

housing market which drives furniture manufacturers orders. Sales revenue at 369 M Euro was nearly the same as the year earlier but the operating profit was down by 54% to 24 M Euro what meant a 7% operating margin. This was due to increased cost of sales (i.e. marketing activities and promotions to offset the market decline) and higher production costs. Beta's production costs increased considerably due to higher material costs and short production runs as the plants were not operating at their full capacity. Material stocks for Make To Order products increased due to less customer orders. Whereas, the finished goods stocking costs rocketed as the clients refused to accept deliveries of the ordered products. Yet in 2008, the company decided to launch another investment project due to a perceived market gap in thin MDF boards. Sadly, two of the major competitors have perceived that gap and launched their investments into thin MDF plants at the same time.
Results in 2009 continued to worsen. Sales slumped by 16% to 308 M Euro and the operating income dropped by 87% to 3 M Euro, which means an operating margin of 1%. The top line suffered from lower sales volume (9 pp) and lower prices (7 pp). Operating costs were even more affected by increased cost of sales and production then in the previous year.

Picture 12. Beta's revenue and operating profit (2006-2009)



Issues identified by the management

By the middle of 2008 Beta's management observed that the deterioration of company's results is not a onetime experience but a beginning of hard times. The market prospects had not been really optimistic. The housing industry worldwide was still experiencing the aftershocks of the credit crunch. The market had been declining for two years in a row and the following year was probably going to follow suit.
Beta's management team had observed that to survive in new market conditions the company had had to overcome several internal problems and limitations. They had had identified the following issues:

- The company overinvested - indeed Beta had invested a significant amount of money into two new production sites. Neither of them was finished and the financing costs were eating up a significant portion of the profit as the banks had increased the

interest rates. Beta had a rate of return from its net assets[6] which was lower than the cost of its capital.
- The willingness to meet the customer needs comes at a price – the costs of cancelled orders, short production runs and finished goods overstock accumulate to serious amounts, which are not recuperated in profit margins.
- Production and procurement need to be better planned – in order to decrease production costs and avoid material overstocks

Beta's management decided that its supply chain needs to be better managed to achieve more flexibility and efficiency both on the demand and supply side. They have called in management consultants to help them in that very task.

The solution

A group of consultants was selected to support the company in improving its supply chain flexibility and efficiency. It was decided that in order to reach these goals the company had to improve its supply chain planning process by designing and implementing: Sales and Operations Planning, Vendor Managed Inventory and a few other operational improvements. The benefits were to be realized from business redesign supported by the implementation of new functionalities within the Enterprise Resource Planning (ERP) system.

The project was expected to bring benefits in the form of:
- increased operational flexibility, i.e. higher adaptability to changes in supply and demand,
- increased structural flexibility, i.e. the ability to launch new products, production sites, onboard new strategic clients,
- lower inventory levels - lower materials and finished goods stock.

Intervention overview

The project started with a **preparation and mobilization** phase during which specific project teams were formed and project responsibilities were assigned. Beta has decided to focus the project efforts on three key areas and has organized the project teams accordingly. The teams and their objectives were as follows:
- Sales and Operations Planning – an implementation of a Sales and Operations Planning process aligned with Beta's strategy. This included design or redesign and implementation of: sales planning, production planning, inventory planning and new product planning. The main gap to be bridged was the implementation of the sales forecasting process executed by the sales persons in cooperation with their clients. The expected benefits of this project stream included: higher operational and structural flexibility, and higher forecast accuracy due to incorporating client insight about his business plans and thus more accurately forecasting the demand. It is worth noting that the author of the study was a leader of that team.
- Manufacturing Resources Planning – implementation of a manufacturing resources planning process based on sales forecasts. The expected benefit of this project stream was to reduce the material inventory levels due to more reliable resource requirement plans.
- Vendor Managed Inventory – an implementation of consignment stock located at the client site owned and managed by Beta. As a result Beta should become responsible for stock replenishment and would bear the inventory holding costs. The benefits for

[6] Return on Net Assets (RONA) - metric used for measuring the efficiency of supply chain management calculated as *Net Income / (Fixed Assets + Net Working Capital)*

Beta were included more flexibility in stock management (possibility of moving desired products between VMIs at different locations) and what is more Beta believed it could more efficiently forecast the demand for the products held on stock than the client itself.

It was also during the preparation and mobilization phase that Key Performance Indicators (KPIs) were designed and baseline measures were taken for assessing the success of the project.
During the ensuing **analysis and design** phase the organization was thoroughly analyzed and the principles of new processes and organization were designed. Moreover the system functionalities supporting new processes were elaborated in detail.
The **implementation** phase commenced with a proof of concept of the new processes and organization design with only marginal ERP system support. It was launched to prove that the design was working well. In the next step the necessary modifications were made to the ERP system expanding its functionality. The entire project was concluded after a **go-live** of the ERP system supporting the new processes and organization design.
During the entire lifecycle of the project there were **change management** activities going on. The project entailed a significant change in the way of work of the sales people, as they were supposed to prepare sales forecasts and their clients, which were supposed to participate in the sales forecasting process. The clients were also intended to accept and adapt to a change in the way that part of the inventory was handled due to the implementation of Vendor Managed Inventory.

Detailed Design

Beta's supply chain organization was experiencing inefficiencies due to the lack of aligned supply chain planning process. Lack of proper planning resulted in an accumulation of high inventory stocks and Beta did not possess the flexibility to dynamically respond to changes in supply and demand. What is more, several core processes, like introducing new products or onboarding new clients, were suffering long lead times due to lack of clearly assigned responsibilities and proper communication between the departments.
The redesign project aimed at alleviating the organizational issues found in the supply chain planning process. As a result of the project new processes have been designed, existing responsibilities have been clearly assigned, the communication gaps have been bridged through new system mediated interfaces. The resulting supply chain design has proved to be more flexible. Below we will analyze how Beta reached this objective. For this we will use the Theoretical Design Principles defined in paragraph 3.3. and examine them for pattern matching with the principles employed by Beta. The results of this analysis can be found below.

Supporting evidence

The described case contains evidence supporting the *internal organization modularity, abstraction* and *encapsulation* principles. Beta has redesigned its supply chain planning process relying on modularity and augmented it with system mediated communication interfaces. The project has also increased the degree of procurement encapsulation. Below we will analyze those principles using the CIMO framework.

Context – Modularity, Abstraction, Encapsulation

In order to illustrate the design work that was done during the project we will first review the situation as it was prior to the beginning of the project. Since the project focused on the supply chain planning process it will be our main unit of analysis. The overall picture of the process is presented in the table below.

Table 6. An overview of the supply chain planning process before the project

Activity	Responsibility	Comment
Sales Forecasting	None	No responsibility assigned, actually performed by customer service with unsatisfying results
Sales and Operations planning	Customer Service department	Based on inaccurate sales forecasts prepared in separation from the customer, without access to historical data at a level of detail insufficient for production planning
Demand optimization	Sales department and Customer Service department	Unclear responsibilities and division of work
Production scheduling	Production department	Well executed but does not receive an optimal demand plan
Manufacturing resource planning	Production department and Procurement	Unclear responsibilities and division of work
Procurement	Procurement	Procurement does not receive detailed material demand plans which results in material overstock
Inventory Management	Logistics	No problems encountered
Business Analytics and Budgeting	Controlling	No problems encountered

The supply chain planning process was organized in an interconnected, looped manner. This means that the last activity in the process – Budgeting – fed into Sales Forecasting to initiate another iteration of the process. We will start the description of the process from the first activity within the loop and that is Sales Forecasting.

No responsibility for **Sales Forecasting** was assigned within the organization. Actually it was performed by the Customer Service department and only at an aggregated level, without direct contact with the customer or access to historical data sufficient for meaningful statistical prediction. Due to lack of customer contact it was, as one of Beta's employees resumed it, "an exercise in futility". **Sales and Operations Planning** also performed by the Customer Service in practice boiled down to matching the predicted sales volume with an expected level of production costs. **Demand Optimization**, the third activity in the planning loop was to analyze the high level sales and operations plans delivered by the Customer Service and then match them with the sales targets to see whether there is a market possibility of volume and pricing adjustments. Finally the plans were transferred to the production planning department for scheduling and manufacturing resource planning. Effectiveness and quality of work at this stage suffered from an unclear split of responsibilities and division of work between the Sales and Customer Service departments. As a result the plans transferred to Production department were inaccurate and incongruent.

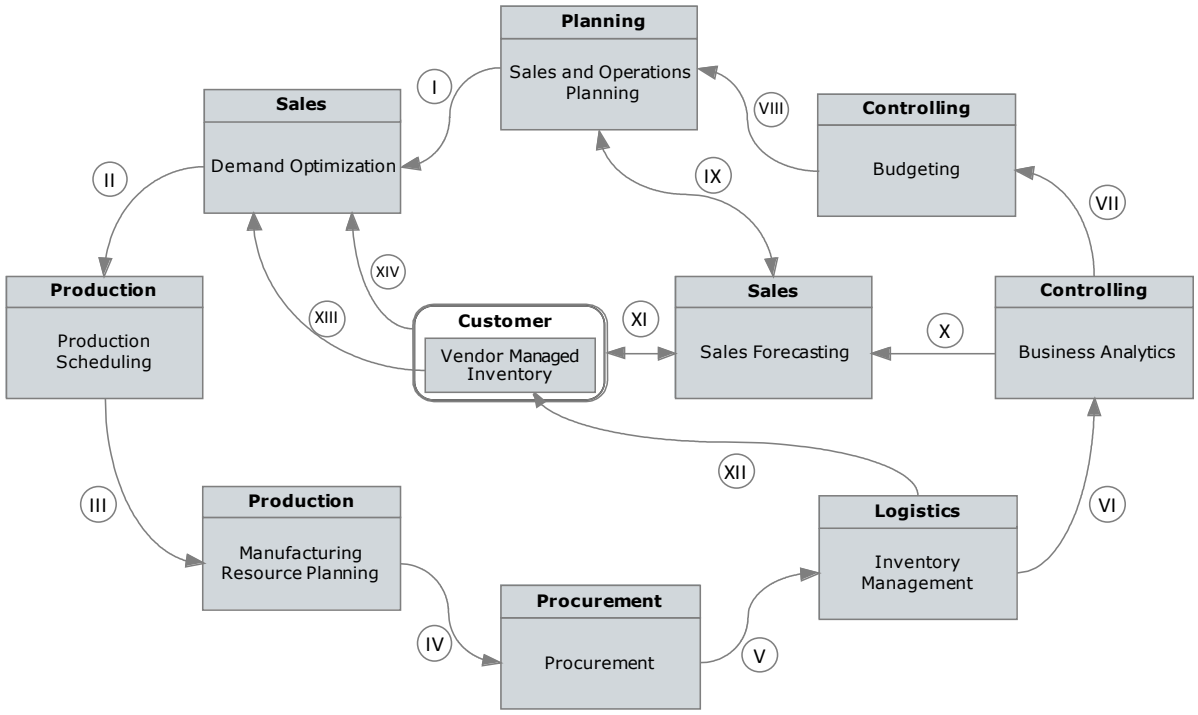
Production Scheduling, the next activity in the loop, did not face any direct organizational problems but had to rely on the aforementioned unreliable demand plans, which decreased the quality of the production plan. **Manufacturing Resource Planning**, which was the following activity within the loop had also suffered from unclear responsibilities and division of work. There were no clearly assigned responsibilities as to who was responsible for creating a detailed material demand plan. **Procurement** suffered from the lack of detailed material demand plans, thus it was prone to subjective planning and external influences, which resulted in material overstocks. **Inventory Management** was flawlessly executed by the Logistics department. **Business Analytics and Budgeting** both carried out by Controlling experienced no organizational issues as they provided sufficient management information.

The project team developed a comprehensive design of the target process. We will now describe the intervention which has put in place the design being a close match to modularity, abstraction and encapsulation. The new supply chain planning process was designed according to the following principles:

- grouping of similar activities within one department,
- creation of a single department responsible for the Sales and Operations Planning process,
- assigning responsibility for each activity to exactly one department within the planning process,
- standardization and automation of activities through system implementation,
- presence of communication interfaces between the departments, and with the customer.

Below is an overview of the supply chain planning process after the redesign.

Picture 13. Redesigned Supply Chain Planning Process at Beta



The most important change to the process was a creation of a Planning department which was made responsible for the Sales and Operations Planning process. The Customer Service department was relived of this duty because of the lack of coherence of that responsibility with the rest of its activities as well as a lack of sufficient competence. It was decided that the Planning department would be centrally coordinating the entire supply chain planning process for all the production sites.

Another important redesign was an implementation of the Sales Forecasting process which involved coordination with the customer. The process was designed to be carried out by the Sales department. Each sales representative was made responsible for contacting his key customers and verifying the Planning department generated forecasts together with them (see interface XI in the table below). Thus the sales representatives served as a communication interface between the Planning department and the customer.

The third major redesign was an implementation of Vendor Managed Inventory (VMI). On the basis of VMI Beta has made itself responsible for maintaining accurate inventory levels of selected stock categories at its customers' sites. As a result, there arose a need for two new system mediated interfaces with the customer (see interfaces XIII and XIV in the table below). They allowed for efficient management of VMI stock at customer sites involving demand forecasting and stock transfers between different locations.
As a result of making Production department responsible for creating a detailed material demand plan and providing an interface for transferring it to Procurement, the encapsulation of the procurement organization improved. Having a detailed material plan Procurement was enabled to fully take on a role of mediator between the organization and the suppliers.
All other issues within the process have been solved by: clearly assigning all of the responsibilities between the departments, so that each activity is handled by exactly one department, and by building efficient communication interfaces between the departments. All organizational and system mediated interfaces are described in the table below.

Table 7. Process interface descriptions

Interface	Interface description
I	Allows for transfer of sales plans from Customer Service to Sales department. EDI mediated.
II	Allows for transfer of demand plans from Sales to Production department. EDI mediated.
III	Allows for transfer of production schedules within the Production department. EDI mediated.
IV	Allows for transfer of detailed material demand plans from Production to Procurement department. EDI mediated.
V	Allows for transfer of Purchased goods specifications from Procurement to Logistics department. EDI mediated.
VI	Allows for transfer of inventory data from Logistics to Controlling department. EDI mediated.
VII	Allows for delivery of historical data analyses for budgeting purposes. EDI mediated.
VIII	Allows for transfer of an approved budget to feed the sales plan. EDI mediated.
IX	Provides Forecasts, sales targets, pricing information to sales representatives. EDI mediated.
X	Provides necessary information (current stock levels, historical data) to prepare sales forecast. EDI mediated.
XI	Allows for direct contact with the customer in order to verify the automatically generated sales forecasts. EDI mediated.
XII	Allows for transfer of information related to physical transfer of VMI ordered goods. Human mediated
XIII	Allows for automatic placement of VMI orders through a web portal, EDI mediated
XIV	Allows customers to place orders for products not covered by the VMI. EDI mediated

The principles involved in grouping the activities and assigning responsibilities are a close match to the pattern of *internal organization design modularity*. In Beta's design each group of activities on the planning loop is aggregated in and executed by one department. What is more, the activities are automated and standardized by SAP implementation. The resulting process blocks are reused across the organization, as all of the activities are executed centrally for multiple production sites.

The principles involved in the design of standardized communication interfaces are a close match to the pattern of *abstraction*. In the analyzed case the redesign project included an implementation of standardized internal and external communication interfaces at the business and technological level. The interfaces allowed for efficient information flow between the departments and seamlessness of the supply chain planning process as a result.

Design and implementation of a new interface for the Procurement department has improved the information flow between Procurement and the rest of the organization. It has also facilitated Procurement taking on a role of the mediator between the organization and the suppliers more fully. This very much goes in line with the pattern described in the principle of *encapsulation.* It also helps to establish a relation between *abstraction* and *encapsulation*. This topic is further elaborated in the paragraph devoted to a discussion on Beta's case.

Implementation story – Modularity, Abstraction, Encapsulation

The new supply chain planning process was conceptualized during the analysis and design phase. The design consisted of a detailed blueprint of the processes, roles and responsibilities, as well as elaborate IT requirements. Executive project ownership belonged to the Vice-president of Sales and Operations. Operational project management was given to the Director of Logistics. Change management played a significant role in successful roll out of the project as there were two major groups of stakeholders who were against any change. It was the salespeople who were to be assigned new responsibilities liaised with sales forecasting, as well as the customers who were to accept the change brought about by VMI. Luckily, the proactive approach to change management and senior management support helped to realize the project without major difficulties. As a means of tracking the benefits and measuring the degree of realization of objectives of the project a key performance indicator (KPI) measurement tool was used. Selected KPI measures were taken before the project to establish a comparative baseline. During the project cycle selected KPIs were monitored and corrective actions were undertaken to diminish the risk of not meeting the project objectives.

Mechanism – Modularity, Abstraction, Encapsulation

In Beta's case the clearly defined, reusable organizational modules with automated activities allowed for quicker dissemination of information. The modularity has also allowed for easier structural redesign in the future. The interfaces enabled the information to flow more efficiently allowing for seamless supply chain planning processes. Whereas, the implementation of the interface further improved the encapsulation of the Procurement department. The Director of Logistics thus described how the project provided the benefits: "Redesigning the processes and organization into interconnected 'modules' has removed the organizational bottlenecks from the information flow between departments. "

Outcome – Modularity, Abstraction, Encapsulation

The implementation of *modularity* in the form of modular supply chain planning process has improved the ability to launch new products and onboard new clients/suppliers faster, it has thus increased structural supply chain flexibility. Furthermore, through arranged activity responsibilities the degree of organizational complexity has been reduced.

The implementation of *abstraction* in the form of standardized communication interfaces has resulted in faster reaction time to market information which signifies an increase in operational flexibility. What is more, the complexity of the planning process has been reduced through standardized communication interfaces. In the long run abstraction attributed to an increase in structural flexibility as it was easier to connect new business entities to the existing processes.

The improvement of the degree of *encapsulation* has resulted in reduced organizational complexity as the Procurement department had a single and reliable source of material demand information.

The Vice-president of Sales and Operations resumed the results of the project in the following words: "We have succeeded at building a more flexible and cost effective supply chain organization at Beta. In the short term we have been able to significantly reduce the levels of working capital invested into inventories. In the long run, we have built a more agile organization able to dynamically adapt to the swings in supply and demand, as well as introduce new products to the market and onboard new strategic clients more quickly".

Structural Flexibility – A Success Story

A proof of the newly acquired structural flexibility was on the occasion when Beta launched a new plant producing an entirely new product line and the goal was to enable them in the supply chain planning process. Thanks to modular architecture Beta was able to quickly redesign the existing planning function to accommodate the new production capacity and product line. Since everything was organized within one department the change was not that far flung from the planning point of view. Thanks to standardized communication interfaces Beta quickly "plugged in" the new product scope. The encapsulation of procurement reduced the complexity of resource planning and procurement. The new product line was enabled in the supply chain planning processes on Day 1 of its go-live. All in all an outstanding result. Metrics related to the issues that Beta's management had identified before the project tell the rest of the story:

- Improved Return On Net Assets – 2% increase over the year
- Reduced production costs – 5% improvement over the year
- Reduced stocks – lower material stocks by 13% and lower finished goods inventory by 10%

Discussion

Beta's case has shown three of the design principles in use: *internal organization design modularity, abstraction* and *encapsulation. Modularity* could be observed as a design principle behind the new division of responsibilities and aggregation cohesive of activities into departments. *Abstraction* was manifested in the standardized communication interfaces between the departments. The redesign resulted in an increased *encapsulation* of the Procurement department.

In Beta's case the hypothesis H1, that the *abstraction* is an enabler of internal organizational *modularity* is confirmed. A successful redesign of the supply chain planning process would not be feasible without implementing standardized communication interfaces which are a manifestation of *abstraction*. This is also confirmed by Beta's project manager who described the implementation of interfaces as "crucial to the success of the project".

The principle of *hierarchy* was not observed, which confirms our hypothesis H2 formed on the basis of Alfa's case. In Beta's case the supplier market structure was not complex enough for *hierarchy* to be implemented with benefit. Beta procured simple products (e.g. wood, paper, chemical ingredients), which could not be organized into meaningful hierarchical structures.

The increase of the degree of *encapsulation* experienced by the Procurement department as a result of the implementation of *abstraction* suggests that there might be a positive correlation between the degree of *abstraction* and *encapsulation.* We will therefore formulate a new tentative working hypothesis H3 that *abstraction is positively correlated with encapsulation (H3).*

Before we proceed into discussing alternative explanations for the observed principles let us first resume the observed Empirical Design Principles and confront them with the Theoretical Design Principles. The table below resumes the principles observed in Beta's case.

Table 8. Comparative analysis of Theoretical Design Principles with Empirical Design Principles observed in Beta's case

	Internal Organization Design Modularity		Abstraction	
	Theoretical Design Principle	**Empirical Design Principle**	**Theoretical Design Principle**	**Empirical Design Principle**
Context	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Joint responsibility for some planning processes. Unclear roles and duplication of work between departments.	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Lack of interfaces and information flow between some departments.
Intervention	Implementation of a modular supply chain organization through aggregation of cohesive activities. Establishing a loosely coupled architecture between modules. Leveraging (reusing) modules across the organization. Automation and standardization of activities.	Each group of activities on the planning loop is aggregated in and executed by one department. Activities automated and standardized by SAP implementation. All the activities are executed centrally for multiple production sites.	Implementation of a modular supply chain organization through aggregation of cohesive activities. Establishing a loosely coupled architecture between modules. Leveraging (reusing) modules across the organization. Automation and standardization of activities.	Implementation of the lacking interfaces between the departments concerned with supply chain planning on business and technological level. Introduction of a SOP planning interface with suppliers mediated through salespeople. Introduction of VMI and appropriate interfaces with the supplier.
Mechanism	Aggregation of activities enables for faster reconfiguration of processes and structural reorganization. Modular internal supply chain organization is flexible to accommodate structural changes within the entire supply chain.	Clearly defined, reusable organizational modules with automated activities allow for quicker dissemination of information and organizational redesign.	Aggregation of activities enables for faster reconfiguration of processes and structural reorganization. Modular internal supply chain organization is flexible to accommodate structural changes within the entire supply chain.	Information can flow efficiently through the interfaces allowing for seamless supply chain planning processes. Common and full information database allowed for a faster reaction time.
Outcome	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	The ability to launch new products and onboard new clients/suppliers faster - increased structural supply chain flexibility. Reduced organizational complexity through arranged process responsibilities.	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	Faster reaction time to market information - increased operational and structural flexibility. Reduction in the complexity of the planning process
	Encapsulation		**Hierarchy**	
	Theoretical Design Principle	**Empirical Design Principle**	**Theoretical Design Principle**	**Empirical Design Principle**
Context	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Centralized procurement was already implemented but lacked some interfaces with the rest of the organization.	Appropriate supplier market structure for implementing a structurally flexible supply chain	No signs of suppliers' hierarchy due to simplicity of products procured.
Intervention	Implement a centralized procurement organization which acts as a mediator between the suppliers and the rest of the organization.	Implementation of a technological interface allowing for material demand planning.	Implementation of a tiered supply chain structure	
Mechanism	Centralized procurement organization reduces unnecessary information flows and facilitates implementation of new procurement rules & policies. Ensures encapsulation from the influence of *flexibility enemies* from outside the organization.	Implementation of the interface further improved the encapsulation of the department.	Tiered supply chain structure reduces unnecessary supplier relations by delegating them to first tier suppliers. Ensures encapsulation from the influence of *flexibility enemies* from outside the organization.	

Outcome	Increase in supply chain structural flexibility. Complexity reductions. Cost reductions.	Cost reductions. Complexity reductions.	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	

Rival Explanations

Three out of four Theoretical Design Principles were replicated in Beta's case. The question is whether there are alternative explanations for the evidence we have collected.

Similarly to Alfa's case, both process approach and virtual organization are the candidates for rival explanations. In Beta's case both of these alternatives are unlikely and the arguments against are virtually the same as in Alfa's case. Another explanation is that Beta's case is an implementation of a regular S&OP model as described in subject matter literature (Milliken 2008; Piechule 2008; Pilger 2009). And to a degree it is, but in the S&OP reference model there is no mention of the necessity of creating a modular organization with standardized interfaces supported by centralized procurement.

5.3. Gamma - Energy Distributor

General context

Gamma is a part of a major group producing and distributing energy on the Polish market. It distributes energy to over two million households and industrial users. Its distribution network covers 20% of the country. The power that Gamma distributes is generated by other companies within the group, including two conventional coal fired and over twenty hydroelectric power plants. Gamma's role within the group is solely one of an operating distributor as it does not settle the bills with its end users. This case focuses on a project which was conducted in Gamma's Maintenance & Repair supply chain. First it presents an overview of the industry in which Gamma operates, a few facts from Gamma's history, market position, financial information and a brief characteristic of the Maintenance & Repair supply chain. Gamma was chosen for the case study because it tells a story of a redesign project which had an objective of improving the supply chain operation. Moreover the choice was driven by the participation of the author of the study in that redesign project which gave him an opportunity to field test the design principles formulated earlier in the study. For a more extensive justification of the research strategy please refer to paragraph 4.4. An overview of the approach to data collection used in the study can be found in Appendix 3.

Industry overview

Energy producers like Gamma make use of coal and other fuels, running water or nuclear fuel. The price of fuel is to a significant degree the main driver behind the attractiveness of different energy production technologies. Gamma is a conventional energy producer and nearly exclusively uses coal in its main power plants. The price of coal constitutes about 50% of operational costs of Gamma's coal fired power plants. The demand for coal prices are globally rising due to a constantly increasing demand from India and China, but otherwise coal is easily available on the local market. There are a lot of local and global suppliers and they do not exercise any special power.

On the demand side the energy is consumed by the households and industry. The demand for energy in Poland is continuously rising and is quite inflexible, i.e. the energy will be consumed regardless of the economic situation. The increased demand puts a strain on the infrastructure and significant investments are necessary. The market is regulated as a special anti-monopoly body acts to oversee the prices and tariffs to the end users.

Brief history of the company

The company was created as a result of a wide restructuring program of the local energy sector. It was created in 2003 by an integration of five energy producing and distributing state owned companies. All of these companies had their origins in the 1950s and were later commercialized in the early 1990s. The integrated company was partially privatized via a public offering on the Warsaw Stock Exchange.

Key spare parts portfolio

Since this case focuses on the maintenance and repair supply chain restructuring we will present the key spare parts that the company uses to maintain its 130,000 kilometers of power network and 34,000 power stations. The maintenance and repair supply chain mainly uses the following categories of spare parts:

- Cables and wiring – for low, medium and high voltage, different lengths and materials
- Electric pylons – for low, medium and high voltage in different heights
- Transformers

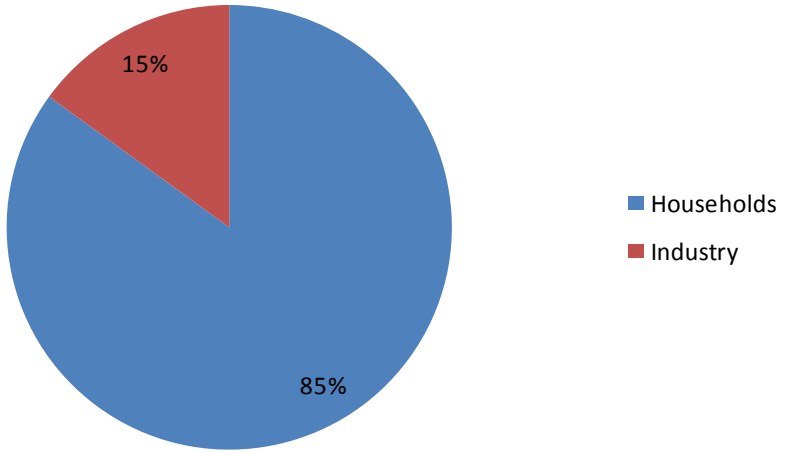
- Accessories for low, medium and high voltage lines
- Electricity meters and steering mechanisms

Before starting the project Gamma had about 5000 spare part Stock Keeping Units. The exact number was not known because the company did not have a common SKU index due to disparate legacy warehousing systems. Usage statistics of different part categories were also unavailable at the time because of the same reason.

Market position and key customers

Gamma provides electricity to over 2 million users. The company has a good standing on the Polish market and its distribution network delivers energy in 20% of the country. In 2008 when the project described in this case was conducted Gamma had an approximately 15% market share. There were also two larger competitors which had shares of about 30% of the market each and one company of a comparable size with similar market share to Gamma. The remaining 10% of the market were smaller companies, often subsidiaries of international energy groups. Gamma delivers energy mainly to households (85%) and to a lesser degree to industrial clients (15%, see Picture 14).

Picture 14. Gamma's key customers structure (2008)



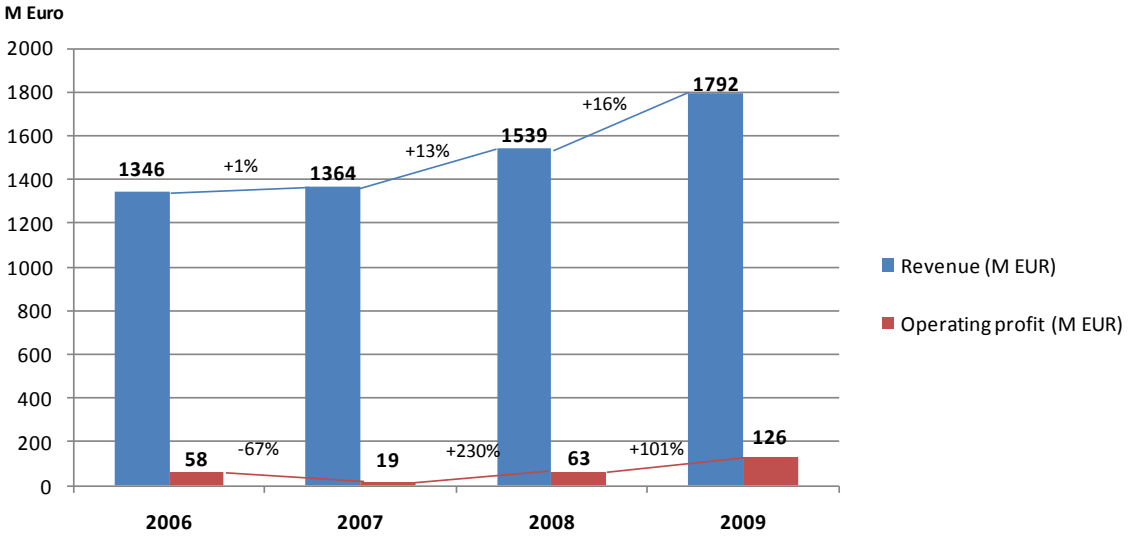
The household part of the market is quite specific. In fact, the households are by default assigned to geographically most suitable energy operator and the majority of household users does not change the operator even though they have a legitimate power to do so. Because of that fact the demand is quite constant and the pricing between market players does not differ much.

Financial position

In 2006 Gamma had a sales revenue of 1346 M Euro and an operating profit of 58 M Euro, which yields an operating margin of only 4%. In 2007 the sales remained stable at 1364 M Euro and the price vs. volume did not change. But at the same time the operating profit dropped by 67% to 19 M Euro which meant a 1% operating margin. It was mainly due to two factors: higher coal prices with energy prices fixed by the regulator at a lower level, and one-off restructuring costs like severance packages for employees on early retirement. In 2008 Gamma had a revenue of 1539 M Euro which was a 13% increase and an operating profit of

63 M Euro which was a 230% increase. The increased sales revenue was due to an increase in energy prices approved by the regulatory body (12 pp) and an organic growth in sales volume (1 pp). The operating margin came back to 4% thanks to the effects of partial workforce restructuring. In 2009 the revenue rose by 16% to 1792 M Euro. The rise was driven by another price rise approved by the regulator (15 pp) and a slight volume increase (1 pp). The improved sales and reduced operating costs resulted in an over 100% increase of operating profit to 126 M Euro and a 7% operating margin.

Picture 15. Gamma's revenue and operating profit (2006-2009)



Issues identified by the management

Gamma's management team has long struggled with low operational profitability of the company. It was caused by multiple factors:

- High costs of the back-office and support functions – functions like maintenance and repair, procurement, warehousing and accounting were overgrown and ineffective. They were regionally dispersed and the responsibilities were unclear. The problem was rooted in the fact that Gamma was created from five different organizations and never really integrated.
- Low operational reliability – the distribution network suffered from frequent shortages and breakdowns which were not resolved quickly by the Maintenance and Repair unit
- Inefficient spare parts supply chain – the spare parts warehouses were holding high stock of unidentified materials due to lack of an integrated approach to warehousing as well as a supporting IT system

Gamma's management started a project to remedy the above mentioned issues. They called for external experts for help.

The solution

The project had a primary objective of designing a flexible, cost-effective and reliable supply chain of the maintenance and repair organization. An increase in supply chain flexibility was sought through a wide ranging organization restructuring. The second objective of the project was to improve cash-flow and reduce costs while simultaneously driving significant operational performance improvement. The project was carried out by a cross-functional

team of external consultants and company employees with expertise in asset management, procurement, capital planning, supply chain and inventory management.

The expected benefits of the project included:

- improved flexibility of the maintenance and repair supply chain,
- significantly reduced operational costs of related functions,
- reduced spare parts inventories,
- improved supply chain processes,
- reduced power station down-time due to higher availability of the right spare parts.

Intervention overview

Project management duties were jointly carried out by one of the external consultants and Gamma's head of supply chain. The project was well received thanks to a strong understanding of a need for change among senior management. The project was divided into 9 work streams (strategic procurement, category management, capital planning, processes, spares and inventory, supplier quality, organisation design, performance management and asset management) and was realized in several phases. It must be noted that the author of the study was directly involved with the process and organization design work streams and had an opportunity of translating the Theoretical Design Principles into the target supply chain organization desing. The project commenced with a **diagnostic assessment** of the supply chain as a whole. It took into account the processes and technologies in the context of Gamma's business strategy and opportunities of employing best practices. This phase allowed for an identification of improvements in costs and working capital reduction. The project team then set out to develop a **strategic vision** of the supply chain. The vision was confronted with the results of the diagnosis to identify the gaps between the vision and reality. The **gaps** were analyzed and potential initiatives for plugging them were devised. Next, an overall strategy **implementation plan** was established taking into account the benefits, time critical priorities and costs. The plan was then implemented and the new organization was put in place.

Detailed Design

Gamma's supply chain strategy design project was a complex effort, which involved nearly all areas of the business. The resulting supply chain design was intended to be more flexible. The problem which interests us here is how Gamma did achieve this objective. Theoretical Design Principles defined in paragraph 3.3. had been examined for pattern matching with the design principles which were used during the project. We will present the results of that analytical process below.

Supporting evidence

The described case contains evidence which supports the principles of *internal organization modularity, abstraction* and *encapsulation*. Gamma has introduced supply chain organization strongly relying on modular architecture, reinforced with abstract communication interfaces and encapsulated procurement. Below we will analyze those principles using the CIMO framework.

Context – Modularity, Abstraction & Encapsulation

Gamma's supply chain organization was suffering in several aspects due to its immaturity. The organization was not performing effectively and the job roles defined within the structure were vague. Gamma lacked proper supply chain planning processes and as a result the reliability and flexibility of the supply chain suffered greatly. Moreover, the organization was at odds with the core concept of supply chain management – it lacked the holistic

perspective and instead each power station had its own local perspective. It resulted in excessive inventory levels and poor procurement practices. The decentralized, local procurement lacked a clear procurement policy, supplier qualification and categorization processes. To that problems compounded was the fact that the IT Systems were poorly integrated which severely impaired efficient information flow locally, between departments of each power station and organization wide between the power stations. The supply chain organization was far from operational excellence and it was unable to react quickly to any operational and structural demands. One of the interviewed managers resumed it that way: "Our supply chain is fragmented between the sites and thus completely unable to adapt to the changes in internal and external environment. If we are to survive we need to devise a new flexible and resilient organization".

Intervention – Modularity & Abstraction

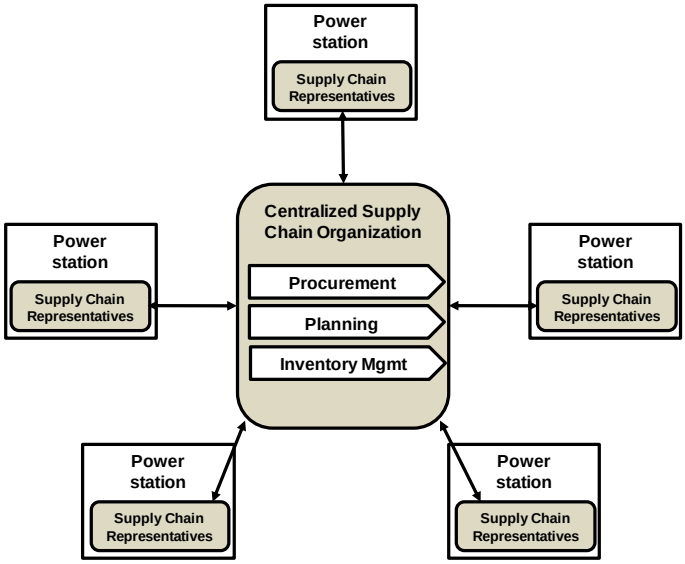
The project team developed a comprehensive design of the target organization. We will now describe the intervention which has put in place a design based on the principles which were a close match to modularity and abstraction (which we describe jointly like in the other cases because of close relationship observed between the two).

The supply chain organization within Gamma has been designed in a centralized manner. A centralized approach was chosen in an attempt to capture the economies of scale and functional specialization. The main principles guiding this design were:

- concentrating the value added management activities within the headquarters – development of a supply chain competence center,
- centralizing all of the repetitive, site-independent transactional processes and executing them in an automated manner,
- locally executed are only those processes which are site specific or require direct contact with other on-site personnel,
- communication interfaces between the supply chain function and the rest of the organization are human-mediated but in the future will be extensively supported by information systems ,
- introduction of coherent cross-site processes and improving the efficiency of information flow.

The core of the organization has been placed within the headquarters (to increase communication with other corporate functions). At each power station one or more supply chain specialists have been placed to act as representatives of the supply chain organization. Their role is to act as an on-site communication interface between the central supply chain organization and the local organization. The supply chain organization representative's role is to handle the non-routine tasks which have to be carried out onsite (like supply monitoring, quality assurance) as well as collect and analyze the needs and requirements of the local organization. The supply chain representatives also serve as change agents, increasing the local awareness of supply chain management philosophy and the implemented organization design. Thanks to the existence of human mediated communication interfaces, marginally supported by information systems the relative immaturity of IT has been remedied. Communication with suppliers and other parties outside the organization was designed to be handled by the centralized organization with the help of standardized guidelines and roles. Yet, the management of some external contacts was designed to be handled on-site – because of their local character and relatively small spend value. The picture below shows the relation between the local sites and the centralized supply chain organization.

Picture 16. To Be supply chain organization design



The interfaces between the sites and the centralized organization are described in the table below.

Table 9. Communication interface specifications

	Interface Power Station – Centralized Procurement	Interface Power Station – Centralized Planning	Interface Power Station – Centralized Inventory Management
Supply chain organization interface Specifications	**Power Station:** • Internal demand management • Local procurement needs analysis • Purchase order creation **Centralized Organization:** • Sourcing strategy development • Supplier relationship management • Market analysis • Cost management • Supplier enablement • Purchase order sign-off	**Power Station:** • Local demand planning **Centralized Organization:** • Supply chain strategy development • Supply chain performance management • Supply and demand plan consolidation	**Power Station:** • Local warehouse management **Centralized Organization:** • Cross site virtual inventory management • Safety stock management

Intervention - Encapsulation

The principles of *encapsulation* find their close match in the centralization of procurement. The key principles guiding the design process were:

- Introducing an organization acting as a mediator between the business and the supplier,
- Creating a standardized procurement policy,
- Focusing on high value added work by automating or outsourcing the low value added work.

The organization design which emerged as a result of the design effort is depicted above in Picture 6 and Table 7. The organization has been placed with other centralized supply chain functions within the headquarters. Just as it was the case with other functions, procurement

has its representative at each power station. The representative's role is to act as an on-site communication interface between the central procurement and the local organization. The on-site procurement is responsible for managing the internal demand for goods and services, analyzing and formulating the needs and requirements and creating draft purchase orders which are to approved by the central organization before being sent to the supplier. The central procurement organization act as a mediator between the business and the supplier – organizing Requests for Information/Proposal/Quotation, qualifying and assessing suppliers, negotiating and managing contracts. It also facilitates the process of supplier enablement – that is on boarding of a new supplier into the supplier panel. Therefore by overtaking all contacts with the supplier it acts as a screening device – verifying the requirements provided by the business and the proposals sent by the supplier. Such organization design improves the efficiency of uniform procurement policy and processes.

Implementation story

The new supply chain organization was designed and built simultaneously in all of the areas: procurement, planning and inventory management. Vision of the design was developed during the strategic visioning stage, it was later refined during the implementation of the plan. The design consisted of business processes, roles and responsibilities, key performance indicators, and IT requirements. Immaturity of the IT infrastructure posed a constraint in some areas – for example implementing centralized procurement required a certain level of IT enablement for routine tasks like purchase order processing. Project ownership was placed on Gamma's senior management which helped to develop consensus and facilitate acceptance of the design,

Mechanism – Modularity & Abstraction

Aggregation of common activities in a central organization and placing well informed representatives on-site resulted in a simplification and standardization of cross-site supply chain processes. A supply chain manager described: "The on-site SC professionals serve as efficient communicators of the needs and wants of their specific sites". Coherent supply chain planning consolidated at an enterprise level resulted in a more holistic view taking into account a totality of costs within the Gamma's supply chain. Standardized process interfaces have also improved the information flow – since all of the supply chain organization employees had a common approach to task realization. On the softer side a creation of the centralized supply chain organization helped in building supply chain competence within the developed organization and awareness in the rest of the Gamma's business.

Mechanism – Encapsulation

Centralized procurement organization resulted in screening the business from the suppliers thus helping to coherently manage supplier relations. This design eliminated unnecessary information flows and social ties between the business and suppliers. Treating suppliers in terms of their contractual interfaces and product requirements resulted in a greater possibility to orchestrate the supply chain from a portfolio of suppliers. Singularizing the buying entity within Gamma has improved its bargaining power towards its suppliers.

Outcome - Modularity & Abstraction

The implementation of a centralized supply chain organization resulted in an increased supply chain flexibility at a operational and structural level. At an operational level the coherent supply chain planning processes helped to better manage the demand of each of the power stations and match it with available supplies. A supply chain manager resumed: "This solution has improved our reaction time to unforseen demands and reduced the time of securing the time-critical supplies". At a structural level it has helped to increase the ability

to adapt the organization to new internal challenges. Introduction of new supply chain related processes and business rules, implementation of new information systems have been facilitated thanks to operating on a single organization entity.
What is more, the well defined organization interfaces have resulted in reduced complexity and improved communication. Besides it has delivered significant operational cost reductions.

Outcome - Encapsulation

Successful implementation of the centralized procurement organization as a part of the supply chain redesign initiative resulted in an increase in supply chain structural flexibility. The processes performed by the organization are much more easily managed and altered whenever a need arises. A procurement professional resumed it thus: "Due to centralized procurement we have been finally able to introduce a uniform procurement policy and be able to significantly reduce our costs and spend. "

Structural Flexibility – A Success Story

A true verification of the flexibility of designed supply chain organization was when it was decided to outsource the local procurement processes. The supply chain as well as the rest of the organization had to quickly adjust to the new way of dealing with procurement located at the power stations. Yet, thanks to the existence of the centralized supply chain organization and heightened awareness of the standardized communication interfaces the transition ran smoothly and completed within 3 months.
The rest of the goals that were set before the project as measured one year after the completion of the project:

- significantly reduced operational costs of related supply chain functions – 20% reduction
- reduced spare parts inventories – 40% reduction of stock, shutting down of 15% of warehouses
- reduced power station down-time due to higher availability of spare parts – 10% down-time reduction.

Discussion

The case of Gamma redesigning its supply chain design and strategy to achieve greater flexibility and cost savings has shown three of the object oriented design principles in use – *modularity, abstraction* and *encapsulation*. *Modularity* was visible as a key design principle driving the design of the centralized supply chain organization. The modular, integrated architecture of the organization was supplemented by standardized communication interfaces created according to the *abstraction* principle. The overall design was further reinforced by a centralized procurement function which was an implementation of the *encapsulation* principle.

Gamma's case confirms the working hypothesis H1 from Alfa's case that *abstraction* is an enabler of *internal organizational modularity*. Indeed, implementing a centralized supply chain organization would be impossible without properly defined and well functioning communication interfaces. This hypothesis proved true in all of the studied cases and thus is a candidate for a generalization – as such it will be further analyzed in paragraph 5.4.

The fourth principle – *hierarchy* – was not present in this case, which provides us with a confirmation of our working hypothesis H2 from Alfa's case. Indeed, the supplier market structure was not appropriate to implement *hierarchy*. Gamma's key sourcing categories were

composed of relatively simple, non complex products. Thus the hierarchy was not implemented due to insufficient complexity of procured products.

Gamma's case supports the working hypothesis H3. Indeed a*bstraction* is positively correlated with *encapsulation* since the implementation of centralized procurement was only possible after establishing organization-wide communication interfaces. Even if the resulting degree of *encapsulation* is not very high because of the human element left in the interfaces, still they act as an enabler for procurement centralization resulting in *encapsulation*.

Gamma's case also helps to build another working hypothesis that *encapsulation is strongly related to modularity (H4)*. In fact one might be tempted to say that *encapsulation* is a special case of *modularity*. An organization designer wishing for an encapsulated procurement seems very likely to build it in a modularized manner, which would facilitate the encapsulation principles compliance monitoring.

Before we proceed into discussing alternative explanations let us first resume the observed Empirical Design Principles and confront them with the Theoretical Design Principles. The table below resumes the principles observed in Gamma's case.

Table 10. Comparative analysis of Theoretical Design Principles with Empirical Design Principles observed in Gamma's case

	Internal Organization Design Modularity		Abstraction	
	Theoretical Design Principle	**Empirical Design Principle**	**Theoretical Design Principle**	**Empirical Design Principle**
Context	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Organization lacking mature IT architecture. Lack of full understanding of supply chain concepts.	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Organization lacking mature IT architecture.
Intervention	Implementation of a modular supply chain organization through aggregation of cohesive activities. Establishing a loosely coupled architecture between modules. Leveraging (reusing) modules across the organization. Automation and standardization of activities.	Supply chain organization within Gamma has been centralized into a central headquarters and local representatives on site.	Implementation of a modular supply chain organization through aggregation of cohesive activities. Establishing a loosely coupled architecture between modules. Leveraging (reusing) modules across the organization. Automation and standardization of activities.	Communication interfaces being developed. On-site supply chain staff serve as communication interfaces. External communications served by standardized guidelines and roles.
Mechanism	Aggregation of activities enables for faster reconfiguration of processes and structural reorganization. Modular internal supply chain organization is flexible to accommodate structural changes within the entire supply chain.	Competence building, awareness building. Aggregation of common activities in central unit, specialized staff at sites. Introduction of coherent SC planning processes increases flexibility and reliability.	Aggregation of activities enables for faster reconfiguration of processes and structural reorganization. Modular internal supply chain organization is flexible to accommodate structural changes within the entire supply chain.	Efficient information flow established by standardized processes/interfaces. (easier to introduce new processes on the basis of the old blueprint)
Outcome	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	Increased flexibility due to introduction of coherent planning. Complexity reduction due to introduction of specialized staff, simplification of procedures/processes.	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	Increased structural flexibility. Reduced complexity of communications (one point of contact per site).
	Encapsulation		**Hierarchy**	
	Theoretical Design Principle	**Empirical Design Principle**	**Theoretical Design Principle**	**Empirical Design Principle**
Context	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Decentralized and fragmented procurement function. Organization lacking mature IT architecture.	Appropriate supplier market structure for implementing a structurally flexible supply chain.	Supplier market structure not appropriate due to insufficient complexity of procured products.
Intervention	Implementation of a modular supply chain organization through aggregation of cohesive activities. Establishing a loosely coupled architecture between modules. Leveraging (reusing) modules across the organization. Automation and standardization of activities.	Implementation of a centralized procurement organization with unified policy	Implementation of a tiered supply chain structure	

Mechanism	Aggregation of activities enables for faster reconfiguration of processes and structural reorganization. Modular internal supply chain organization is flexible to accommodate structural changes within the entire supply chain.	Centralized procurement rationalized the spend and facilitated standardization of procurement policy.	Tiered supply chain structure reduces unnecessary supplier relations by delegating them to first tier suppliers. Ensures encapsulation from the influence of *flexibility enemies* from outside the organization.	
Outcome	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	Cost reductions. Complexity reductions.	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	

Rival explanations

Three out of four Theoretical Design Principles are properly replicated in Gamma's case. This provides a good support for the existence of Object Oriented design principles. Since no other rival theories than these discussed in the previous two cases can be presented, we will thus conclude this case study. A summary of rival explanations discussed is provided in the next paragraph.

It was the last of the researched case studies. Next paragraph will be devoted to a cross case analysis, results presentation and implication building.

5.4. Cross-case Findings and Implications

This paragraph analyses the results of the case studies, builds implications and formulates the results of the study in the form of Object Oriented Supply Chain Design Principles. The design principles are formulated on the basis of the field evidence collected in the case studies. Thus the resulting design principles are strongly context specific. We allow ourselves a cross-case generalization on the basis of an assumption that all the three case studies represent similar context.

To commence, we will analyze the first of the formulated design principles, which is *modularity.* The table below confronts the Theoretical Design Principle with Empirical Design Principles observed in each of the three cases. The last column in the table represents an attempt at generalizing the Empirical Design Principles into an Object Oriented Design Principle for Supply Chain Flexibility.

Table 11. A Summary of Theoretical and Empirical Design Principles of Modularity

	Internal Organization Design Modularity				
	Theoretical Design Principle	**Alfa Empirical Design Principle**	**Beta Empirical Design Principle**	**Gamma Empirical Design Principle**	**Result OOSC Design Principle for Flexibility**
Context	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Fragmented, inefficient organization, lacking in terms of technological enablers.	Unclear responsibility for some planning processes. Unclear roles and duplication of work between departments.	Organization lacking mature IT architecture. Lack of full understanding of supply chain concepts.	Internal Organization Design Modularity favors more process and technology developed organizations but should accept lower levels in the transition period.
Intervention	Implementation of a modular supply chain organization through aggregation of cohesive activities. Establishing a loosely coupled architecture between modules. Leveraging (reusing) modules across the organization. Automation and standardization of activities.	Implementation of a modular supply chain planning department. Standardization and aggregation of processes. Providing supply chain planning services to the rest of the organization. Part of the department centralized, part localized.	Each group of activities on the planning loop is aggregated in and executed by one department. Activities automated and standardized by SAP implementation. All the activities are executed centrally for multiple production sites.	Supply chain organization within Gamma has been centralized into a central headquarters and local representatives on site.	Internal Organization Design Modularity creates an organizational module based on standardization and aggregation of processes. The module is then leveraged across the organization. If possible, the processes within the module are automated.
Mechanism	Aggregation of activities enables for faster reconfiguration of processes and structural reorganization. Modular internal supply chain organization is flexible to accommodate structural changes within the entire supply chain.	Process standardization and organizational modularization enabled for easier integration of acquired companies. Centralization of supply chain planning capability resulted in improved personnel skills.	Clearly defined, reusable organizational modules with automated activities allow for quicker dissemination of information and organizational redesign.	Competence building, awareness building. Aggregation of common activities in central unit, specialized staff at sites. Introduction of coherent SC planning processes increases flexibility and reliability.	Internal Organization Design Modularity improves structural flexibility by facilitating supply chain redesign efforts (e.g. post merger integration) through the creation of modules aggregating cohesive activities.
Outcome	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.	Increase in supply chain structural flexibility. Achieving economies of specialization, cost reductions and complexity reduction.	The ability to launch new products and onboard new clients/suppliers faster - increased structural supply chain flexibility. Reduced organizational complexity through arranged process responsibilities.	Increased flexibility due to introduction of coherent planning. Complexity reduction due to introduction of specialized staff, simplification of procedures/processes.	Internal Organization Design Modularity provides benefits in the form of: increased structural flexibility and reduced supply chain complexity

From the confrontation of Theoretical Design Principle of internal organization design modularity with Empirical Design Principles observed in the analyzed cases emerged a proposition of Object Oriented Design Principle for Supply Chain Flexibility. That proposition is discussed below.

Context - ***Internal Organization Design Modularity favors more process and technology developed organizations but should accept lower levels in the transition period.***

Cross case analysis reveals that the context of implementation of modularity does in fact rely on the maturity of processes and information technology within the organization. But the study also shows that lower levels of maturity are acceptable for the transition period. That is during the implementation of modularity based designs it is possible to start with less sophisticated designs (see Gamma's case) and to gradually approach the desired solution.

Intervention - ***Internal Organization Design Modularity creates an organizational module based on standardization and aggregation of processes. The module is then leveraged across the organization. If possible, the processes within the module are automated.***

Cross case analysis supports the theoretical principle that the modules are built upon standardized and aggregated processes. If the maturity of information technology allows, the aggregated processes are automated (see Beta's case). The modules created upon these processes are then used where applicable in the organization. This reduces the costs of implementation and helps to achieve more value.

Mechanism - ***Internal Organization Design Modularity improves structural flexibility by facilitating supply chain redesign efforts (e.g. post merger integration) through the creation of modules aggregating cohesive activities.***

Cross case analysis reveals that modularity indeed improves structural flexibility. The mechanism behind is the aggregation of cohesive processes. In simple terms it translates to: when the change is needed instead of changing the same process executed in several places in the organization, you do it in one place – the module. This is well observable in the success stories cited in the cases: Alfa's successful post-merger integration, Beta's new plant and product launch, Gamma's procurement outsourcing.

Outcome - ***Internal Organization Design Modularity provides benefits in the form of: increased structural flexibility and reduced supply chain complexity.***

All of the analyzed cases support the fact that modularity increases structural flexibility and reduces supply chain complexity. An increase in supply chain structural complexity results from the mechanism of aggregating the cohesive processes. Whereas reduction of complexity results from other outcomes of the intervention like arranged process responsibilities and simplification of processes.

Table 12. A Summary of Theoretical and Empirical Design Principles of Abstraction

	Abstraction				
	Theoretical Design Principle	**Alfa Empirical Design Principle**	**Beta Empirical Design Principle**	**Gamma Empirical Design Principle**	**Result OOSC Design Principle for Flexibility**
Context	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Organization lacked the information platform to provide the interfaces.	Lack of interfaces and information flow between some departments.	Organization lacking mature IT architecture.	Abstraction favors more process and technology developed organizations but should accept lower levels in the transition period.
Intervention	Implementation of standardized internal and external communication interfaces at the business and technological level.	Implementation of business and technology interfaces for the modular supply chain planning department.	Implementation of the lacking interfaces between the departments concerned with supply chain planning on business and technological level. Introduction of a SOP planning interface with suppliers mediated through salespeople. Introduction of VMI and appropriate interfaces with the supplier.	Communication interfaces being developed. On-site supply chain staff serve as communication interfaces. External communications served by standardized guidelines and roles.	Abstraction creates standardized communication interfaces both within and outside the organization. If the maturity of the information technology is insufficient then human-mediated interfaces are used.
Mechanism	Standard communication interfaces help to establish efficient information flow and the ability to remodel the supply chain organization when needed.	Better information flow improved process efficiency and integration of acquired companies.	Information can flow efficiently through the interfaces allowing for seamless supply chain planning processes. Common and full information database allowed for a faster reaction time.	Efficient information flow established by standardized processes/interfaces.	Abstraction improves the information flow by providing standardized interfaces. Standardization and efficient flow of information aid in the process of supply chain redesign.
Outcome	Increase in structural supply chain flexibility. Complexity reductions.	Increase in structural supply chain flexibility. Complexity reductions.	Faster reaction time to market information - increased structural flexibility. Reduction in the complexity of the planning process.	Increased structural flexibility. Reduced complexity of communications (one point of contact per site).	Abstraction provides benefits in the form of structural supply chain flexibility and reduced complexity of communication.

From the confrontation of Theoretical Design Principle of abstraction with Empirical Design Principles observed in the analyzed cases emerged a proposition of Object Oriented Design Principle for Supply Chain Flexibility. That proposition is discussed below.

Context - ***Abstraction favors more process and technology developed organizations but should accept lower levels in the transition period.***

Cross case analysis reveals that the context of implementing an abstraction depends on the maturity of organization and its technology. But it has also revealed that it is a barrier that is possible to overcome in medium term (see Alfa's and Gamma's case).

Intervention - ***Abstraction creates standardized communication interfaces both within and outside the organization. If the maturity of the information technology is insufficient then human-mediated interfaces are used.***

Cross case analysis supports the theoretical design principle that the intervention based on the principle of abstraction aims to create standardized communication interfaces. These interfaces are either internal, between the supply chain organization and other departments in the supply chain, or external with customers or suppliers. Analysis reveals that human-mediated interfaces can also be used in cases where the information technology maturity is insufficient (see Gamma's case).

Mechanism - ***Abstraction improves the information flow by providing standardized interfaces. Standardization and efficient flow of information aid in the process of supply chain redesign.***

Cross case analysis reveals that abstraction indeed improves the flow of information within the organization by introducing standardized interfaces. In effect interface standardization and efficient information flow increase the ability of the supply chain to be redesigned. It translates to simple terms: when your communication channels are well defined, simplified and standardized you can more easily add, subtract, or modify elements of your supply chain.

Outcome - ***Abstraction provides benefits in the form of structural supply chain flexibility and reduced complexity of communication.***

The outcome of implementing abstraction in all of the analyzed cases was that the structural flexibility increased. This increase results from the mechanism of abstraction which improves the ability of a supply chain to be redesigned.

Table 13. A Summary of Theoretical and Empirical Design Principles of Encapsulation

	Encapsulation				
	Theoretical Design Principle	**Alfa Empirical Design Principle**	**Beta Empirical Design Principle**	**Gamma Empirical Design Principle**	**Result OOSC Design Principle for Flexibility**
Context	Sufficiently mature organization in terms of business and technological enablers wishing to implement a structurally flexible supply chain.	Principle already implemented to improve the efficiency of procurement function.	Centralized procurement was already implemented but lacked some interfaces with the rest of the organization.	Decentralized and fragmented procurement function. Organization lacking mature IT architecture.	Insufficient field evidence support
Intervention	Implement a centralized procurement organization which acts as a mediator between the suppliers and the rest of the organization.		Implementation of a technological interface allowing for material demand planning.	Implementation of a centralized procurement organization with unified policy	
Mechanism	Centralized procurement organization reduces unnecessary information flows and facilitates implementation of new procurement rules & policies. Ensures encapsulation from the influence of *flexibility enemies* from outside the organization.		Implementation of the interface further improved the encapsulation of the department.	Centralized procurement rationalized the spend and facilitated standardization of procurement policy.	
Outcome	Increase in supply chain structural flexibility. Complexity reductions. Cost reductions.		Cost reductions. Complexity reductions.	Cost reductions. Complexity reductions.	

From the confrontation of Theoretical Design Principle of encapsulation with Empirical Design Principles observed in the analyzed cases a conclusion is drawn that the provided empirical support is insufficient for practical grounding (see table above).
Even though the data is incomplete it allows for an observation that encapsulation probably does not provide benefits in the form of increased structural flexibility, for it did not appear in any of the analyzed cases.
Insufficient field evidence support should not be seen as a flaw of the case selection processes, but rather a result of strict and objective analysis. An implication for further studies on the role of encapsulation is that more cases should be analyzed. Probably the best method for further research would be a broad survey among companies which have a centralized procurement organization. The aim of the survey would be to verify whether the organization of supply chain of these companies exhibits the characteristics of encapsulation, as listed in the Theoretical Design Principles.

Least of all the Object Oriented Design Principles can be inferred about the nature of the *hierarchy* principle (see table below). On the basis of hypothesis H2 which has been formed during the study of Alfa's case it can be said that *hierarchy* principle is implemented only there, were there is significant complexity to be reduced as a benefit. In Alfa's case the hierarchy principle was existent in some parts of the product range supply chain - specifically in the supply chains of products of significant complexity, where the first tier suppliers delivered important product modules. Since none of the supply chain designs observed in other cases entailed such complexity the *hierarchy* principle needs further research. It is proposed to conduct a multiple case study focused on the *hierarchy* principle but a prerequisite would be a case screening process based on the criteria of sufficiently complex supply chain.
Last but not least it seems that *hierarchy* is not closely related to other Object Oriented principles but this subject is covered later on in this paragraph.

Table 14. A Summary of Theoretical and Empirical Design Principles of Hierarchy

	Hierarchy				
	Theoretical Design Principle	**Alfa Empirical Design Principle**	**Beta Empirical Design Principle**	**Gamma Empirical Design Principle**	**Result OOSC Design Principle for Flexibility**
Context	Appropriate supplier market structure for implementing a structurally flexible supply chain	Principle already implemented in selected supply chains of products of sufficient complexity.	No signs of suppliers' hierarchy due to simplicity of products procured	Supplier market structure not appropriate due to insufficient complexity of procured products.	*Hierarchy* principle is implemented only there, were there is significant complexity to be reduced as a benefit.
Intervention	Implementation of a tiered supply chain structure				
Mechanism	Tiered supply chain structure reduces unnecessary supplier relations by delegating them to first tier suppliers. Ensures encapsulation from the influence of *flexibility enemies* from outside the organization.				

Outcome	Increase in supply chain structural flexibility. Cost reductions. Complexity reductions.				

During the case studies four working hypotheses have been formed to be later tested on other cases. These hypotheses were formulated to gain a better understanding of the relations between the studied principles.

Hypothesis H1 was that *abstraction is an enabler of internal organizational modularity*. This hypothesis was formulated on the basis of Alfa's case, where the planning department would not be functioning efficiently if it had lacked defined interfaces with other parts of the organization. This hypothesis was confirmed in Beta's case where successful redesign of the supply chain planning process would not be feasible without implementing standardized communication interfaces. In Gamma's case hypothesis H1 was also confirmed since implementing a centralized supply chain organization would be impossible without properly defined and well functioning communication interfaces.

Hypothesis H2 was that *the hierarchy principle is implemented only there, were there is significant complexity to be reduced as a benefit.* This hypothesis was formulated on the basis of Alfa's case, where a tiered supply chain structure was already existent in the supply chains of products of significant complexity like pneumatic tools, where the first tier suppliers delivered important assembly modules. This hypothesis was also supported by the Beta's case where the supplier market structure was not complex enough for *hierarchy* to be implemented with benefit. Beta procured simple products (e.g. wood, paper, chemical ingredients), which could not be organized into meaningful hierarchical structures. In Gamma's case H2 also held true since the supplier market structure was not appropriate to implement *hierarchy* as Gamma's key sourcing categories were composed of relatively simple, non complex products.
One more observation relating to *hierarchy* is that it seems to be a concept unrelated to other object oriented design principles in supply chain context. On the basis of case studies one may form a hypothesis that neither modularity, encapsulation nor abstraction have any implications for the presence of hierarchy. It is worth noting that this hypothesis convenes with hypothesis H2 which relates the presence of *hierarchy* to factors external to supply chain organization. This newly formulated hypothesis needs further empirical verification on a wider sample of empirical data.

Hypothesis H3 was that *abstraction is positively correlated with encapsulation*. This hypothesis was formulated on the basis of Beta's case where an increase of the degree of *encapsulation* experienced by the Procurement department as a result of the implementation of *abstraction* suggests that there might be a positive correlation between the degree of *abstraction* and *encapsulation.* In Gamma's case a*bstraction* was positively correlated with *encapsulation* since the implementation of centralized procurement was only possible after establishing organization-wide communication interfaces. Even if the resulting degree of *encapsulation* was not very high because of the human element left in the interfaces, still the interfaces act as an enabler for procurement centralization resulting in *encapsulation*. Alfa's case revisited from the perspective of H3 provides further support. The centralized procurement department implemented prior to the project described in this paper was designed with extensive focus on establishing standardized interfaces.

Hypothesis H4, formulated on the basis of Gamma's case states that *encapsulation is strongly related to modularity*. In fact, one might be tempted to say that *encapsulation* is a special case of

modularity, since an organization designer wishing for an encapsulated procurement seems very likely to build it in a modularized manner, which would facilitate the encapsulation principles compliance monitoring. The case of Alfa revisited from the perspective of H4 provides further support since the centralized procurement department implemented prior to the project described in this paper was designed as a modular entity. The case of Beta revisited from the perspective of H4 is also supportive. The procurement department exhibited the full characteristics of an organizational module.

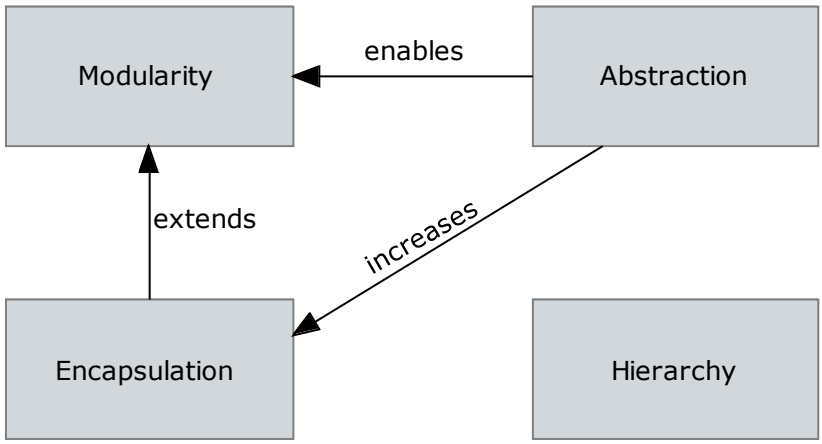
A summary of the hypotheses discussed above is provided in the table below.

Table 15. A Summary of Working Hypotheses Formed and Verified in the Study

	Working hypothesis	**Alfa**	**Beta**	**Gamma**
H1	*Abstraction* is an enabler of internal organizational *modularity*	formulated	confirmed	confirmed
H2	*Hierarchy* principle is implemented only there, were there is significant complexity to be reduced as a benefit	formulated	confirmed	confirmed
H3	*Abstraction* is positively correlated with *encapsulation*	confirmed	formulated	confirmed
H4	*Encapsulation* extends *modularity*	confirmed	confirmed	formulated

On the basis of these hypotheses a map of relations between the object oriented supply chain design principles emerges (see Picture 17). Below these relations are described in more detail.
On the basis of the studied cases it seems that **modularity** is the most important of all the object oriented supply chain design principles. It seems to have a pivotal role in the concept as the other principles relate to it.
Indeed, the relation between **encapsulation** and **modularity** is one of *extension*. This means that the concept of encapsulation is based on the concept of modularity – i.e. for an entity to be encapsulated it first has to be modular.
What is more, the relation between **abstraction** and **modularity** is one of *enablement.* That is the presence of abstraction is a sine qua non condition for the successful implementation of modularity since without standardized interfaces the modular organization would not be able to function.
The relation between **abstraction** and **encapsulation** is one of *positive correlation*. That is the higher the abstraction, the higher the degree of encapsulation. This means that the better the standardization of the interfaces, the more encapsulated the module can get.
No support for the fact that **hierarchy** relates to any of the three other design principles has been found. Therefore this principle has been mapped in some distance from the core three design principles.

Picture 17. A Map of Relations between the Supply Chain Design Principles



Summary of rival explanations discussion

During the case studies alternative explanations were suggested and discussed. Three rival theories were proposed and evaluated in the case studies. Below is a summary of these rival theories and the reasons of their dismissal.

Table 16. A Summary of Rival Theories Discussion

Rival theory	Justification	Reasons for dismissal
Process organization	Strong process focus (creation of end to end processes, process standardization and introduction of the role of a process owner)	Does not explicate neither the creation of a modular, loosely coupled S&OP department nor the standardized communication interfaces
Virtual organization	Focus on the creation of standardized communication interfaces	Lack of operationalized design principles of virtual organization – impossible to validate
Sales & Organization Planning organization	Best practice supply chain planning process model which must have influenced the studied designs	The S&OP reference model does not mention the necessity of creating a modular organization with standardized interfaces supported by centralized procurement

Since all of the rival theories were dismissed, the Object Oriented Design Principles are supported by all of the studied cases. This concludes chapter V devoted to case studies and brings us to chapter VI which presents the conclusions from the study.

VI. Main Results, Implications and Limitations of this Research, Suggestions for Future Research

The objective of this final chapter is to present the main results of the research, resume its practical and theoretical implications, recall its limitations and present the contribution it provides to Organization Science.

6.1. Main Results of the Research

The question posed at the beginning of that study was: *how can companies design structural supply chain flexibility*? To answer that question we have conducted an extensive research in supply chain management literature and thanks to analogical reasoning we have borrowed a concept of Object Orientation from Computer Science. Focus was placed on structural supply chain flexibility, because among the identified kinds of supply chain flexibility (i.e. operational, structural, and strategic) it has received the least amount of research and attention, yet it translates to very practical and tangible advantages like the ability of quickly launching a new production site or effectively implementing Lean Manufacturing principles. The formulated design principles were then refined on the basis of an exploratory case study. In the next step, the resulting design principles were alfa-tested in a multiple developing case study. In the table below we present the key findings of the research, that is the design principles which worked in the field and the links to field evidence supporting them.

Table 17. Main Results of the Study - The Design Principles of Structural Supply Chain Flexibility that Work

	Object Oriented Supply Chain Design Principle for Structural Flexibility		
	Internal Organization Design Modularity	**Abstraction**	**Link to Field Evidence**
Context	Internal Organization Design Modularity favors process oriented and technology developed organizations but should accept lower levels of maturity in the transition period.	Abstraction favors more process oriented and technology developed organizations but should accept lower levels of maturity in the transition period.	▪ Beta's case ▪ Gamma's case
Intervention	Internal Organization Design Modularity creates an organizational module based on standardization and aggregation of processes. The module is then leveraged across the organization. If possible, the processes within the module are automated.	Abstraction creates standardized communication interfaces both within and outside the organization. If the maturity of the information technology is insufficient then human-mediated interfaces are used.	
Mechanism	Internal Organization Design Modularity improves structural flexibility by facilitating supply chain redesign efforts (e.g. post merger integration) through the creation of modules aggregating cohesive activities.	Abstraction improves the information flow by providing standardized interfaces. Standardization and efficient flow of information aid in the process of supply chain redesign.	
Outcome	Internal Organization Design Modularity provides benefits in the form of: increased structural flexibility and reduced supply chain complexity	Abstraction provides benefits in the form of structural supply chain flexibility and reduced complexity of communication.	

An important relation between these two design principles has been observed. It was found that *abstraction* enables *modularity*. That is the presence of abstraction is a sine qua non

condition for the successful implementation of modularity since without standardized interfaces the modular organization would not be able to function.
There are good reasons to think that *hierarchy* is important for designing supply chain flexibility, because it may reduce the complexity of managing several tiers of suppliers by delegating that responsibility to first tier suppliers. Unfortunately, our test cases did not provide evidence for that design principle because the supply chains of these companies were not complex enough to observe tiered supplier management.
The remaining design principle of *encapsulation* has not been proved to increase the structural flexibility of the supply chain because of lack of supporting field evidence.

6.2. Practical Implications of the Research

The findings of this research can be formulated in a set of prescriptive design principles for achieving structural supply chain flexibility. There are several implications for supply chain practitioners from this research:

Supply chain organizations built with the design principle of organizational modularity are more structurally flexible.
Modularity is a design principle advocating an organization design based on standardization, aggregation and automation of cohesive processes. Ideally, the organizational modules are leveraged across the organization, i.e. they execute all instances of a given group of processes within the organization. Modularity of the supply chain organization facilitates the redesign efforts thanks to the aggregation of cohesive processes. Organizations covered in the case studies which have applied modularity to their supply chain organization experienced increased structural flexibility in situations like post merger integration of supply chains, outsourcing of procurement processes or launching a new production site. It is also worth noting that organizational modularity reduced supply chain complexity due to the simplification of modularized processes.

The design principle of abstraction is an enabler of successfully implemented organizational modularity.
Research implies that modularity, in order to be implemented successfully, needs presence of the design principle of abstraction. Abstraction is a design principle advocating that the supply chain processes stand behind the abstraction barrier and exchange only the information relevant for other actors in the process which signifies standardized communication interfaces both within and outside the organization. In cases when the maturity of the information technology is insufficient, human-mediated interfaces can be used. Standardized communication interfaces are essential for the successful implementation of modularity since without them the modular organization would not be able to function efficiently. Organizations which have implemented abstraction along with modularity have experienced increased structural supply chain flexibility. Abstraction acts as an enabler for the efficient functioning of modular organization.

The design principle of encapsulation supplements the modularity of the supply chain organization.
Encapsulation is a design principle advocating a certain way of managing the supply chain operations which involves the creation of a centralized procurement, acting as a mediator between the organization and its suppliers. This principle is an extension of the principle of organizational modularity, which means that the procurement department, in order to be encapsulated, has to be designed in a modular manner. It is hypothesized that encapsulation improves structural supply chain flexibility by facilitating implementation of new

procurement rules & policies. This principle needs some caution since it has not been fully empirically verified.

The principles of organizational modularity, abstraction and encapsulation applied to supply chain organization create a foundation for designing structurally flexible supply chain.
None of these principles is revolutionary, each has been applied in practice and described before under various names. The implication that we would like to convey is that these three principles should be implemented together to realize the full benefits. It is due to the fact that these principles create a positive feedback between each other – abstraction enables modularity, encapsulation extends it and higher abstraction increases the degree of encapsulation. Supply chain organization designed according to these principles has a solid foundation to be structurally flexible and fully supportive of even a blue ocean strategy.

6.3. Contribution to Organization Science

From the academic point of view this study contributes to several domains of Organization Science. First, it complements the literature on supply chain design and flexibility. Second, it explores the concept of design for incompleteness from a supply chain point of view. Third, it explores the concept of Object Orientation and investigates its applicability to organization design, especially to supply chain design. These three areas of contribution are reviewed in more detail below.

Contribution to Supply Chain Design

This study introduces a new concept to the literature on supply chain design. This concept is a set of design principles for designing structurally flexible supply chains. The study focused on structural supply chain flexibility due to the scarcity of previous research on that kind of flexibility despite its importance to the management practice.
The design principles were formulated on the basis of literature research and supplemented by the concept of Object Orientation borrowed from the domain of computer science. Object Orientation provided a framework based on its foundational principles of modularity, abstraction and encapsulation and hierarchy. The theoretical design principles were then empirically tested in multiple case study. A result of the study is a set of design principles presented in a detailed format, i.e. describing the context in which a given principle should be applied, then the details of the intervention (what exactly should be done), next the mechanisms triggered by the intervention and finally the expected outcome. Of course, more empirical research (preferably beta-testing) should be done before arriving at a sufficiently practically grounded set of design principles for designing structurally flexible supply chains, but this study already presents some interesting and actionable findings.
This study does also present a concept of the enemies of supply chain flexibility. Even though they were not the subject of empirical research, since the case selection process screened the supply chains which were most vulnerable to their attacks, they offer a potential for further research.

Contribution to Design Science

This study employs the design principles of minimal specification (Van Aken 2005) and incompleteness (Garud, Jam, and Tuertscher 2008) to construct a logical chain of reasoning between Object Orientation and supply chain flexibility. As a result the Object Oriented Design Principles are constructed according to the principle of incompleteness.
Moreover, this study has employed and tested a novel approach to architecting design principles and that is the CIMO approach (Denyer, Tranfield, and Van Aken 2008). This approach proved to be very useful for formulating and validating the design principles.

This study uses the concept of Object Orientation borrowed from computer science as a source of general inspiration and analogical reasoning, i.e. more disciplined approach to developing the Theoretical Design Principles. Research has proven that the concept of Object Orientation which is intuitively attractive for supply chain design has indeed several implications for it. This study demonstrates the applicability of three out of four of the core design principles of Object Orientation.

6.4. Limitations of the Research

This study has the limitations inherent to case study and qualitative research in general. We have attempted to mitigate these limitations by applying a developing multiple case study methodology. Findings from case studies of complex organizational phenomena can be difficult to replicate and generalize to other environments. On the basis of the chosen methodology we present our findings in a context-rich manner. Even though the sample size of three cases is not sufficient for generalization this study provides meaningful results to be further tested in the beta-testing mode.
Even though precautions were taken to ensure objectivity and reduce potential biases it is still possible that some biases exist in the study, which is inherent to the chosen methodology.

6.5. Suggestions for Future Research

This study raises new questions regarding supply chain design principles and it puts forward several suggestions for future research. The broadest area for further study is in beta-testing the proposed Object Oriented Design Principles. Since the studied sample was too small for any generalization the findings would have to be tested on a wider array of companies in different industries. This would allow to validate and expand them further.
Since the empirical part of this research was conducted before the economic crisis, another interesting topic for research would be testing the proposed design principles in the times of economic turmoil to see whether the proposed concepts still hold true.
This study leaves the concept of the enemies of supply chain flexibility empirically untouched. The concept of enemies was not tested because of their absence in strong form in the researched cases (see Appendix for the enemy assessment matrix). The enemies of supply chain flexibility could become a main subject of another study.
This study also suggests some very specific research questions trying to resolve the dilemmas faced in this study. One of them would be a study on the role of the encapsulation principle. Probably the best method for further research would be a broad survey among companies which have a centralized procurement organization. The aim of the survey would be to verify whether the organization of a supply chain in each of these companies exhibits the characteristics of encapsulation, as listed in the Theoretical Design Principles. Another suggested study would be a multiple case study focused on the *hierarchy* principle. A prerequisite of such study would be a case screening process based on the criteria of sufficiently complex supply chain.

6.6. Conclusions

Supply chain design is making its way to the top of executives' agendas. The flexibility the supply chains are expected to provide is a sine qua non condition for survival in a highly competitive and turbulent environment. The usual focus of supply chain operations was on delivering the right product, at the right place, at the right time, regardless of changes in

supply and demand. But supply chains can also deliver more strategic flexibility. In the era of virtual organizations when the transactional costs decreased considerably and companies are anything but vertically integrated, the role of supply chain management changed from mere operations to coordinating the entire value chain. This is supported by the newest research from MIT where Melnyk et al. (2010) propose a new paradigm of strategically coupled and value driven supply chain management focusing on strategic outcomes instead of a purely price driven approach. Indeed, supply chain management becomes a key enabler of strategy when it delivers the flexibility needed to implement roadmaps driving the company in strategically new directions. This study focused on the topic of structural supply chain flexibility for a good reason. Companies with more structurally flexible supply chains can effectively adapt their design to changes in the business environment and corporate strategy. These companies can effectively adapt to new clients' needs, launch products with short time to market, enable new production sites, or implement the principles of Lean Manufacturing. This study outlined the landscape of designing structurally flexible supply chains, the dilemmas they cause and the enemies they face, and finally posed questions which set directions for further research.

The author of this study was involved in several supply chain design projects initiated at the board level where supply chain management was seen as a significant enabler of corporate strategy.

VII. Appendices

Appendix 1 – A Discussion on the Enemies of Structural Supply Chain Flexibility

Enemy's Impact and Strength Assessment

The table below presents an assessment of the impact of each of the enemies defined in Chapter 1 on structural supply chain flexibility. The strength of each of the enemies judged as having an impact of structural supply chain flexibility is then assessed in the cases.

Table 18. Supply Chain Flexibility's Enemy Impact and Strength Assessment

Enemy	Outcome	Impact on Structural Supply Chain Flexibility	Enemy's Strength Assessment		
			Alfa	Beta	Gamma
Product complexity	Increase in coordination costs	**No**	N/a	N/a	N/a
Product innovation and proliferation	Complexity driven by the disturbance of standardized module interfaces, loss of benefits from commoditization leading to asset specificity	**Yes** Impacts structural flexibility by disturbing the standardized interfaces and developing asset specificity	Weak	Weak	Weak
Communication of product requirements and production schedules	Complexity driven by the need to communicate intricate information and coordinate complex interactions	**Yes** Impacts structural flexibility by increasing the complexity of on/off-boarding suppliers	Weak	Weak	Weak
Supply chain transparency	Complexity driven by the need to acquire capabilities to evaluate supplier operations	**Yes** Impacts structural flexibility by increasing the complexity of on/off-boarding suppliers	Weak	Weak	Weak
Corruption of buyers by sellers	Increased costs and loss of bargaining power	**Yes** Impacts structural flexibility by increasing the organizational resistance to redesigning the supply chain	Not observed	Not observed	Not observed
Customer loyalty tactics by suppliers	Increase in transaction costs and risks	**Yes** Impacts structural flexibility by increasing the organizational resistance to redesigning the supply chain	Weak	Weak	Weak
Bundling of products with	Increased dependence on specific suppliers and loss of	**Yes** Impacts structural	Weak	Weak	Medium

associated services	strategic independence	flexibility by increasing the organizational resistance to redesigning the supply chain			
Lack of trust	Monitoring of unreliable suppliers increases transaction costs	**No**	N/a	N/a	N/a
Interference with supplier operations	Increase of overhead and management costs, development of emotional ties with the supplier leading to moral hazard	**Yes** Impacts structural flexibility by increasing the organizational resistance to redesigning the supply chain	Weak	Weak	Weak
Encouragement to procure customized products	Increased supplier dependency, increased buying costs with potentially marginal customization payoffs	**Yes** Impacts structural flexibility by increasing the complexity of on/off-boarding suppliers	Weak	Weak	Weak
Size / Scale of production	Increased supplier dependency	**Yes** Impacts structural flexibility by increasing the complexity of on/off-boarding suppliers	Weak	Weak	Not observed
Social and political pressures	Increased transaction cost and possibly management costs	**Yes** Impacts structural flexibility by increasing the resistance to redesigning the supply chain	Weak	Weak	Weak

It can be observed that nearly all enemies which can impact structural supply chain flexibility have been assessed as weak or not observed. The one exception is bundling of products with services observed in Gamma's case where it is assessed at medium strength. The situation behind that case being one of the spare parts suppliers acting also as a warehousing services provider. This reduces structural flexibility due to more difficult process of changing the spare parts supplier. Redesigning the warehousing function is also more difficult because of the dependence on specific service provider which has developed.
On the basis of such limited research sample one might be tempted to formulate a working hypothesis that the possibility of the emergence of an enemy of structural supply chain flexibility is more likely in supply chains more complex due to the nature of the product they are providing. Such hypothesis should be thoroughly researched in a separate study on a properly constructed research sample.

The Limits of Structural Supply Chain Flexibility

Another topic which has not been touched upon in the main body of the thesis is a discussion on when is the structural supply chain flexibility truly desired. To answer that question one would have to conduct a research focusing solely on answering that inquiry

and it is not the purpose of the current study. As we have outlined in the table above our case studies exhibited too weak enemies to make meaningful inferences. Thus our discussion on that topic can only be theoretical in its nature.

In our opinion structural flexibility is always desired as it brings benefits in the form of increased ability to adapt the supply chain design in response to changes in the environment. On the other hand, the enemies of structural flexibility also offer some benefits. Supply chain transparency, bundling of products with associated services or interference with supplier operations are all well known under a collective name of close collaboration with suppliers. Close collaboration provides an opportunity to foster continuous improvement in terms of costs, quality and service levels as well as encourage innovation though involvement of suppliers in the R&D processes. What we are thus facing is a text book example of a management dilemma. Management dilemmas are problems without a golden ratio solution and management practice involves facing them on an everyday basis. Indeed, Sachs et al. (2006) have observed that static balance is not a solution to a dilemma since both opposites constantly coevolve. What is proposed instead is a irregular oscillation between the poles which is likened to maintaining balance whilst riding a bike. When translated into the terms of structural supply chain flexibility vs. close collaboration it turns into a task of oscillating between the benefits of structural flexibility and the benefits of "flirting" with the enemy. The exact design "mix" between the two opposites can be affected by multiple external forces since no management dilemma exists in a vacuum. We may thus envision that the choice can be affected by e.g. the complexity of the supply chain and its products, characteristics of the supplier market or a company's product strategy – whether it wants to sell cheaper, lower quality products for which materials can be procured from any supplier or higher quality, more expensive and innovative products which in order to be built need supplier involvement.

This thesis will not give definitive answers on that very topic, but it definitely sets a direction for further research.

Appendix 2 – An Overview of Object Orientation vs. Other Programming Paradigms

The table below presents an overview of the object-oriented programming paradigm in comparison to other paradigms. The table was compiled on the basis of the works of Harmon, Peel and Taylor (1993, 1997), Booch (1998), Normark (2003), Wirth (2006).

Table 19. A Comparative Overview of Object Orientation vs. Different Programming Paradigms

	Imperative programming	Functional programming	Logical programming	Object Oriented programming
Philosophy	• *"First do this and next do that"* • Incremental change of the program state as a function of time • Similar to description of everyday routines (food recipes, repair instructions) • Abstracts actions into a procedure, which can be called as a single command	• *"Evaluate the expression and use the resulting value for another operation"* • Based on the theory of functions • Abstracts a single expression to a function which can be evaluated as an expression • Atemporal, i.e. the state does not change in time	• *"Answer a question through search for a solution"* • Program execution becomes a systematic search in a set of facts, making use of a set of inference rules • Based on axioms, inference rules and queries	• *"Send messages between objects to simulate the temporal evolution of a set of real world phenomena"* • Data and operations are encapsulated in objects • Abstracts the key characteristics of an object to facilitate message passing • Objects can be organized into modules • Objects can be organized into hierarchies
Benefits	+ Relative simplicity	+ Clear structure of functions and variables + Fits need-driven computations + Easy to use for solving simple problems	+ An elegant way of solving logical problems	+ Faster development due to more intuitive modeling and module reuse + Increased quality due to module reuse + Easier maintenance + Reuse of software and frameworks, increases resilience to change + Natural appeal of object-oriented architecture to human cognition
Shortcomings	- Lacks clear structure - Difficult to understand and maintain the code of complex programs	- Functions have no state, i.e. the newly computed values cannot be assigned to the same variable overwriting its old value	- Programs need user intervention and support - Usability limited only to logical problems	- Needs careful design of object architecture - Too complex for solving relatively simple problems

Appendix 3 – Case Study Data Collection – Key Interviewees, Interview Guidelines and Other Sources of Evidence

The table below details the case study data capture. It mentions the key interview respondents, the number of interviews conducted and how structured they were. The table also mentions other sources of field evidence used.

Table 20. Data Collection through Interviews and Other Sources of Evidence

Company	Key interviewees	Type of contact	Other sources of evidence
Alfa	Supply Chain Manager, Local project manager	One formal semi-structured interview, email follow-up	Internal and external documents, project deliverables (detailed design), website, analysts' reports
	External expert leading the project	Two formal semi-structured interviews	
Beta	Vice-President of Sales and Operations, Project sponsor	Two formal semi-structured interviews	Raw data, internal and external documents, project documentation and deliverables (detailed design), website, analysts' reports
	Director of Logistics, Project Manager	Two formal semi-structured interviews, casual encounters during the project	
	Beta's project team (incl. operational managers and process owners)	Day-to-day cooperation during the project incl. joint work on the concept and its implementation	
Gamma	Director of Finance, Project sponsor	Two formal semi-structured interviews	Raw data, internal and external documents, project documentation and deliverables (detailed design), website
	Supply Chain Operations Manager, Project Manager	One formal semi-structured interview, one informal interview, casual conversations	
	Gamma's project team (incl. process owners)	Day-to-day cooperation during the project incl. joint work on the concept and its implementation	

The structured interviews were led according to the following generic guidelines:

First round of interviews
Strategic context:

- What are your key customers and key products?
- How is the industry evolving?
- What are the characteristics of your main markets?
- What is your company's market position (market share, competitors)?
- What is the company's history?

Issues identified:

- When did you identify that your company is suffering from supply chain related issues?
- What have you identified as the main pain points that you would like to solve with this project?
- What are the objectives for this project?
- What kind of benefits do you expect from this project?

Current state:

- How does the supply chain organization work in terms of key processes and organizational structure?
- What are the key IT tools you are using to support your business processes?
- How does your supply chain planning / logistics / transportation / procurement work?
- What is the supplier market structure?

Supply chain flexibility:

- How would you assess the flexibility of your supply chain on the operational level? Can your supply chain adjust to major swings in supply and demand in a short period of time?
- How would you assess the flexibility of your supply chain on the structural level? Is your supply chain capable of quickly onboarding new clients, business partners and suppliers; qualifying a new source of supply; adding a new manufacturing plant; enabling a new type of offering?
- How would you assess the flexibility of your supply chain on the organizational level? Is your supply chain capable of responding to major supply chain disruptions, supporting acquisitions and divestitures within the value chain, fundamentally redesigning sourcing strategy, adding a new line of business?

The second round of post-implementation interviews after the end of the project was focused on assessing the results of the intervention:

- Was there a tangible improvement in the flexibility of the supply chain after project completion?
- How was it measured?
- When did it materialize?
- Can it be attributed to different factors than the project itself?

In the case of Alfa the interviews were conducted after the end of the project. In the case of Beta and Gamma they were conducted either before or shortly after the kickoff of the project. The project work that was conducted in-between the interviews comprised of close collaboration with employees of company Beta and Gamma, which was a great opportunity to gather more information about the organization and its challenges.

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Samenvatting

In continu veranderende bedrijfsomgevingen wordt de rol van een leveringsketen ("supply chain") steeds belangrijker. Een flexibele leveringsketen kan maken dat een bedrijf overleeft in snel veranderende marktomstandigheden en ook dat een bedrijf op een gezonde manier kan groeien. Dit proefschrift verkent de flexibiliteit van leveringsketens met een nadruk op structurele flexibiliteit. Het doel van het onderzoek is om de volgende vraag te beantwoorden: *hoe kunnen bedrijven een flexibele structurele leveringsketen ontwerpen?* Om deze vraag te beantwoorden worden principes voor het ontwerpen van flexibele structurele leveringsketens geformuleerd en getest.

Hoofdstuk I introduceert het onderwerp: het ontwerp van leveringsketens en de uitdagingen in het maken van flexibele leveringsketens. De flexibiliteit wordt op drie niveaus gedefinieerd: operationeel (i.e. het balanceren van vraag en aanbod), structureel (i.e. evolutionaire aanpassing aan veranderingen in de omgeving) en strategisch (i.e. herontwerp van de waardeketen). De auteur verkent daarna het concept van vijanden van flexibele leveringsketens. Omdat dit proefschrift zich richt op succesverhalen over flexibele leveringsketens wordt geconcentreerd op flexibele leveringsketens waarin de vijanden van flexibiliteit niet goed zichtbaar zijn.

Hoofdstuk II start met een overzicht van nieuwe trends voor ontwerp binnen organisaties. Ontwerpwetenschap wordt geïntroduceerd en gevolgd door de introductie van het proces van wetenschappelijk gefundeerde ontwerpen van organisaties. De architectuur van het ontwerpprincipe wordt uitgelegd aan de hand van de logica van CIMO "Context, Intervention, Mechanism, Outcome". Ten slotte wordt het ontwerpprincipe van onvolledigheid bekeken als iets dat flexibiliteit mogelijk maakt in organisaties. Deze studie gebruikt het ontwerpprincipe van onvolledigheid om een logische redeneerketen te construeren tussen object- oriëntatie en flexibele leveringsketens.

Hoofdstuk III bouwt voort op de concepten die geïntroduceerd zijn in de eerste twee hoofdstukken. Een raamwerk voor ontwerpprincipes voor leveringsketens wordt voorgesteld. Het raamwerk is gebaseerd op object-oriëntatie, in analogie met het concept object-oriëntatie uit de Informatica. Object-oriëntatie is gebaseerd op vier principes: modulariteit (het systeem moet opgedeeld worden in op zichzelf staande objecten), abstractie (de objecten moeten helder gedefinieerde koppelvlakken hebben), inkapseling (de objecten moeten behandeld kunnen worden als zwarte dozen, i.e. zonder aandacht voor wat zich in de dozen bevindt), hiërarchie (het systeem wordt opgedeeld in basiscomponenten, die weer bevat zijn in andere objecten). Door een serie van analogieën concludeert de auteur dat de toepassing van object-georiënteerd ontwerp helpt in het ontwerp van flexibele leveringsketens gebaseerd op het idee van onvolledigheid. De rest van dit hoofdstuk is gewijd aan het exploreren van de vier principes van object-oriëntatie in de context van leveringsketens. Op basis hiervan wordt een lijst met theoretische ontwerpprincipes voor het bereiken van structurele leveringsketen flexibiliteit opgesteld.

Hoofdstuk IV geeft een overzicht van de methodologie die gebruikt wordt in het empirische gedeelte van dit proefschrift. De studie gebruikt literatuuronderzoek en het redeneren met analogieën voor het formuleren van theoretische ontwerpprincipes, die geverifieerd worden een exploratieve case studie. De theoretische ontwerpprincipes worden dan "alpha" getest in voortschrijdende case studie.

Hoofdstuk V geeft case-studies over drie bedrijven die hun leveringsketens wilden herontwerpen om ze flexibeler te maken. Bedrijf Alpha was een producent van consumentengoederen en gereedschappen, die besloten had om de leveringsketen te herontwerpen om te profiteren van de toegenomen flexibiliteit van de operationele en structurele leveringsketens. Bedrijf Beta was een producent van onderdelen voor meubilair dat een project gestart was met als doel om de leveringsketens te optimaliseren om te overleven in moeilijke marktomstandigheden. Bedrijf Gamma was een energieproducent die een leveringsketen strategieproject gestart was om grotere flexibiliteit te verkrijgen voor de leveringsketens binnen onderhoud en reparaties. De case van bedrijf Alpha is gebruikt om the theoretische ontwerpprincipes te testen in een bedrijfscontext. The overige twee case-studies van Beta en Gamma zijn gebaseerd op het actie onderzoek paradigma en zijn daarom een goede basis voor de alpha testing van de gekozen ontwerpprincipes.

Hoofdstuk VI poneert de suggestie dat leveringsketen organisaties ontworpen volgens de principes van organisatorische modulariteit, abstractie en inkapseling een grote kans hebben om structureel flexibel te zijn. Daarna wordt een samenvatting gegeven van de contributies van dit proefschrift aan leveringsketenontwerp, ontwerpwetenschap en object-oriëntatie. Als laatste worden richtingen van verder onderzoek beschreven.

Curriculum vitae of the author

As a reflective practitioner of management science I am actively involved in helping organizations reach their strategic and operational goals. I specialize in the field of supply chain management, strategy implementation and operational improvement. My research interests include design science and management in virtual organizations. My objective is to narrow the gap between academia and business practice by designing and implementing solutions to business problems, writing papers and lecturing.

Date and place of birth

1 December 1982 in Kraków, Poland

Education

2001 – 2006 - Cracow University of Economics, Poland - Master in Information Management

2003 – 2004 - Ecole Supérieure de Commerce CERAM, Sophia-Antipolis, France – Master in Management programme

1997 – 2001 - II Secondary School, Cracow, Socio-economical profile

Career history

From June 2012 – Logistics Manager at Intersnack Poland
Managing the logistics department of a fast growing consumer products company, subsidiary of a European food producer.

2009 – 2012 – Manager at Ipopema Business Consulting, Poland
Engaged in a consulting company offering innovative business services. Responsible for project management and delivery of business transformation projects in the field of supply chain management. Worked for the company since its startup.

2006 – 2009 – Business Transformation Consultant at IBM Global Business Services, Poland
Member of the Strategy & Change team. Delivered business transformation projects. Recognized as an Early Innovator for his work on supply chain strategies. Worked in multinational teams on both domestic and travel assignments in client facing roles. Facilitated workshops, managed work streams and led junior team members.

2003 – 2005 – Internships during studies
Business background in a variety of industries, both in local and international companies including Philips Lightning and Hewitt Associates.