A Systematic Architecting Approach for Supply Chains

by

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Abstract

Over the past two decades, the advent of information and communication technology has broken physical distance limits and enabled seamless collaboration models, real-time planning, and quick responses among participants in supply chain systems. Globalization, specification, and the use of technologies that pursue low costs with high services have been dominating the supply chain design for years. Since 9/11 in 2001, however, supply chain designs have shifted from concentrating on cost-competitive advantages to security, collaboration, robustness, and flexibility. After 2008, worldwide events such as fluctuating gasoline prices, increased labor costs in developing countries, volatile demand as a result of the economic recession, and environmental regulations and agreements have resulted in renewed scrutiny of supply chain design paradigms. These challenges not only have had an impact on supply chain operations, but also on its architecture: in the aspects of organization, culture, geography, and information.

Obviously, expanding globalization has made it difficult to consider a system locally and closely. The interactions between internal and external stimulus, multiple stakeholders' goals, along with corporate bottom lines: sociality, plant, and profits have conducted a supply chain a complex system. In order to resolve this complexity, to understand the supply chain holistically, and to avoid applying a complex solution on a complex supply chain system, a supply chain architecting framework, derived from Systems Engineering and System Architecture, is proposed in this research to simplify the supply chain architecting process into steps: modeling, mapping, and linking operational and architectural improvements.

In summary, the goals of this study are: (1) Eliminate the gaps between corporate (supply chain) strategy, design, and implementation; (2) Propose a framework consisting of previous research and best practices; (3) Develop a simple, easy-to-understand, planning modeling methodology that carries sufficient information for supply chains. The contributions of this study aligned with these three goals are: (1) Supply chain architecting framework, including the fulfillment and value chains and the three improvement cycles; and (2) Architecting methodology, including concept, form, and function, as well as three layers of views from which to represent a supply chain.

Thesis Supervisor: Charles H. Fine

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1. Introduction

In the past two decades, rapidly developing technologies and growing worldwide markets have led supply chains towards global. Companies outsourced their production to a number of low labor-cost countries and built logistics systems to fulfill customers' needs with competitive costs. At the same time, specialization in every segment of supply chains caused the increment of stakeholders, as well as extended and distended supply chain structure. Broader worldwide market coverage and a growing number of participants today have transformed supply chains into complex systems. This complexity has, in turn, created challenges for developing a comprehensive plan to satisfy all needs.

In addition to supply chains, exogenous environments have also changed dramatically over the past decade. Some long-hold beliefs and principles to supply chain design and operations, therefore, do not fit well into current situations as a way to effectively achieve desired performance goals. For instance, short product life cycles and subletting customers' preferences often drive companies to review their systems more frequently to ascertain that it is still on the right track.

However, when companies find that they need to redesign their supply chain, they will also find it's difficult to include all crucial factors, to communicate with stakeholders, and to arrive at a consensus. The conquering of these difficulties requires more than just traditional tried-and-true tools and methods. Rather a systematic approach for architecting supply chains must be developed. Moreover, new technologies such as RFID, GPS, mobile technology, and image identification have not only enhanced supply chains operations, but also enabled changes in both business organizations and cultures. Without a holistic analysis and a comprehensive solution, the benefit of these technologies is limited.

Taking into account the above issues, I find that the scope and aspects of supply chains today are both wider and more complicated than ever before. Designing a supply chain that meets all the stakeholders' needs, uses technologies efficiently, and aligns with corporate strategies is the goal of all supply chain managers. In order to resolve the challenges associated with supply chain design, I intend to develop an approach applying the skills in system architecting to resolve system complexity, for people who are going to analyze, design, and improve a supply chain especially at architectural level in this research. The tool is deigned for communication and is simple for use. I also intend to establish the links between the operational and the architectural improvements to support long-term supply chain evolutionary design.

1.1 Supply Chain Challenges

Among the growth paths of supply chain, it is not difficult to find its scope of definition has become wider, and the number stakeholders have increased, and a supply chain has turn into a complex system. System complexity incurs difficulties to come out a comprehensive plan to satisfy all needs.

Except a supply chain itself has evolved into a complex system, the externals have changed dramatically in the past decades, and caused some long-hold beliefs and principles won't able to fit in current situation to achieve performance goals well. Two of those most distinguished changes are energy prices and environmental concerns. In this section, the complexity issue, high oil prices, green concepts, and supply chain design are discussed.

Supply Chains are Complex Systems

According to Bernie Hart's observations (Hart, 2009), supply chain challenges in 2009 included:

1. Supply chain risk mitigation in an economic downturn.
2. Searching for working capital.
3. A resurgence in letters of credit
4. Shortening the supply chain

5. Improved speed and savings in Mexico
6. More free-trade agreements and more scrutiny
7. China clamps down on oversight
8. The Amended Lacey Act
9. A global eye toward consumer product safety

Lynch (Lynch, 2010) summarizes the supply chain challenges for 2010 including a fragile and weak economics leading weak volumes and cutthroat pricing, rising price of fuel, regulation, infrastructure, and outsourcing policy.

It gets me attention that those challenges cross operations, finance, supplier-customer relationship, regulations, global economics, etc. It implies that a single and straightforward solution isn't able to resolve supply chain challenges in all perspectives. Additionally, participants within a supply chain share a symbiotic relationship. Suppliers provide customers with values, and customers return suppliers with business. Among the supply chain, any organization is both a supplier and a customer. Although their goals align to the supply chain goal, there are conflictive objects internally. Finally, supply chain evolves, and its legacy systems highly affect its capability in the future. Those features of supply chains: multiple dimensions, multiple stakeholders, multiple objectives, and evolutionary cause supply chain a complex system.

Rising Energy Prices

Among supply chain challenges, low fuel prices before 2005 expedited the evolution toward to current supply chain design, a centralized production strategy. The design includes sourcing manufacturing to few low labor-cost countries, and utilizing transportation networks to fulfill demands from distant warehouses, to sustain competitive supply chain cost. However, from 2000, the oil prices gradually rise from less than $20/barrel, to the historical highest record $135 per barrel in the mid 2007 (Figure 1). The prices of gasoline were approximate six times in 2008 than it was in 1990s. Many companies start doubting whether prior paradigm manufacturing methods, for instance: JIT (just-in-time) and global offshore sourcing, is able to achieve desired performance goals as usual. Since these methods were designed and widely applied while the oil prices were low and could be ignored in 1980s and 1990s. Though the global economics recession resulted in demand decreasing, and caused the oil prices back to $40/barrel, the weak commercial activities and purchasing power remaining force companies cutting transportation costs. Today, Wal-Mart, nation's top grocery seller, highlights its purchases of "locally grown" produce. While companies are touting the community benefits, buying local produce is also a way to cut the companies' growing fuel costs millions of dollars each year.

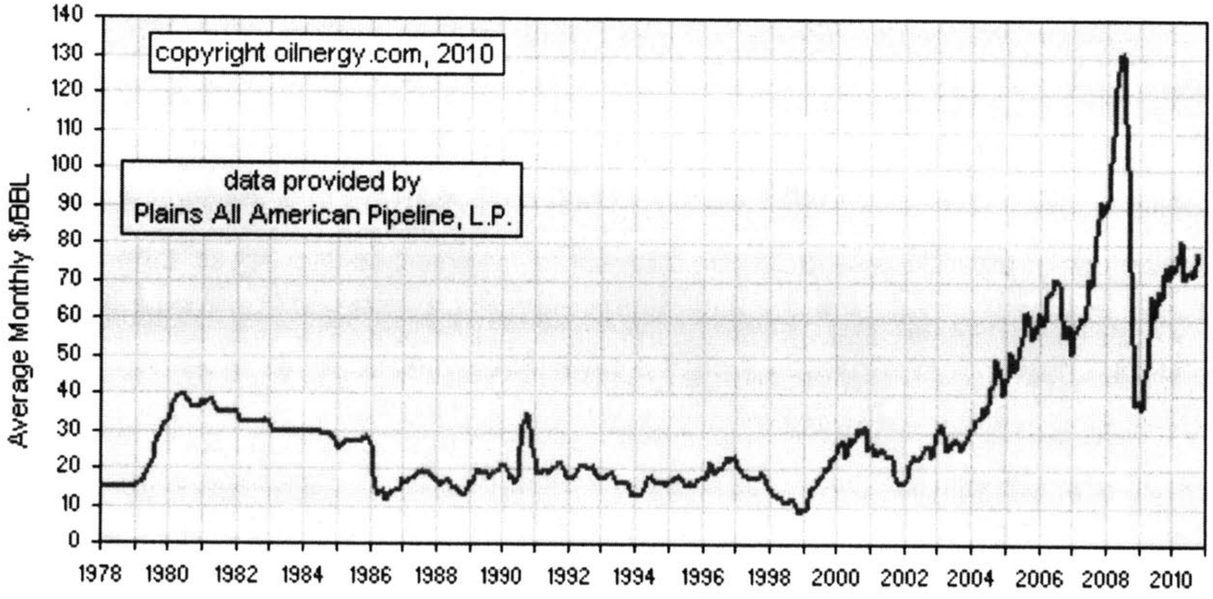

Figure 1: Average Monthly Price from 1978 through 2010[1]

Growing Environmental Concern

Since late 1990s, environment has been a consideration factor in supply chain design. In the past years, with more evidences of global warming, green supply chain, as other popular supply chain topics such as global sourcing, has been ranked in ten of the most discussed topics in supply chain management. The pressure of environmental requirements usually comes from widely external society and regulations to acquire

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[1] Data source: http://www.oilnergy.com/

companies to be in charge of their social responsibilities. These pressures force companies to totally review their supply chain. Particularly, while oil prices rise to history records, companies sought alternative and clean energy, and adjust their supply chain to decrease oil dependence.

Designing a green supply chain is not a single perspective task. It may widely change the supply chain from product design, which uses environmental friendly materials; process design, which decrease waste and poison by-products; and the moreover renews the ways of supply chain management and order fulfillments. It will not only have an impact on supply chain's operations, but also escalate to the whole supply chain level and change the supply chain architecture.

1.2 Research Objectives

In order to adjust a current supply chain system to deal with both long-lasting and new coming challenges, Cartland (2006)[2] proposed following eights steps:

1. Map your supply chain
2. Review each supplier's capability
3. Compare each supplier's capability with your maximum tolerable outage
4. Review each suppliers risk analysis for assumptions, impacts and likelihoods
5. Compare each supplier's ability to satisfy your continuity strategy
6. Develop improvement program
7. Implement improvement program
8. Document and test

Within these steps, mapping supply chain is the first step to understand current supply chain design, and to prepare for future improvement. At the previous section mentions, a supply chain is a complex and symbiotic system. Simply describing it from physical

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[2] http://www.husdal.com/2010/03/24/business-continuity-in-global-supply-chains/

or process respective is not sufficient to understand it. Hence a systemic approach is needed to understand, to analyze, and to design a supply chain system.

After studying systems courses at MIT, I found the concept of system architecting intriguing as it has developed supporting tools for design, collaboration, and evaluation in hardware and software industries. However, in supply chain management field, systems architecture is rarely mentioned. This phenomenon interested me, and I sought to answer these questions: Are there any frameworks and methods that can represent supply chain architecture well and support managers in making decisions? Design patterns have been widely used in the software industry to keep beautiful designs and prevent design failure, but are there any patterns that can be summarized and documented to avoid repeating the same bad decisions in the future?

In order to answer these questions, an architecting framework and a modeling method to represent existing supply chains are needed. With these thoughts, I explored architecting framework for government and enterprise, and modeling methods, SCOR (Chapter 2.3.1), UML (Chapter 2.3.2), and OPM (Chapter 2.3.3). I found they are either developed from information technology point of view, or from operations perspective, and lacking a system wide viewpoint to solve complex system problems.

Professor Ed. Crawley in MIT ESD.34 System Architecture class proposed a framework to design product architecture to meet customers' needs. He concluded that regulation, corporate and marketing strategy, customer' needs, competitive environment, downstream strategies, competence, and technology will affect the design of product architecture before architecture is made (Figure 2). On the other hand, downstream factors (Figure 3): implementation, operators, cost, legacy, and design will determine the success of an architecture design. In regard to modeling method, he modified OPM to meet the need of system architecting.

I found those concepts can be re-used, and the framework and the modeling methods can be abstracted, neutralized, and migrated in the filed of supply chain architecting. Therefore the objective of this research is to develop a systematic framework with a modeling method. The proposed framework will be able to help companies who have the needs to redesign supply chain systems to both meet stakeholders' needs and align with corporate strategies. In addition to proposing a method for architecting, I also intend to establish a link between architecture design and implementation, and make good use of previous research and best practices.

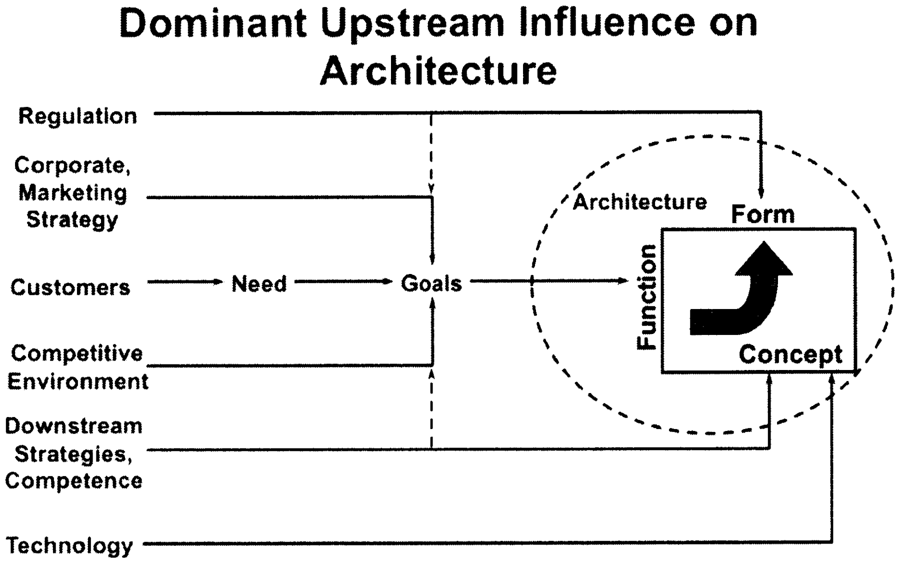

Figure 2: Upstream Influence on Architecture (Crawley, 2007)

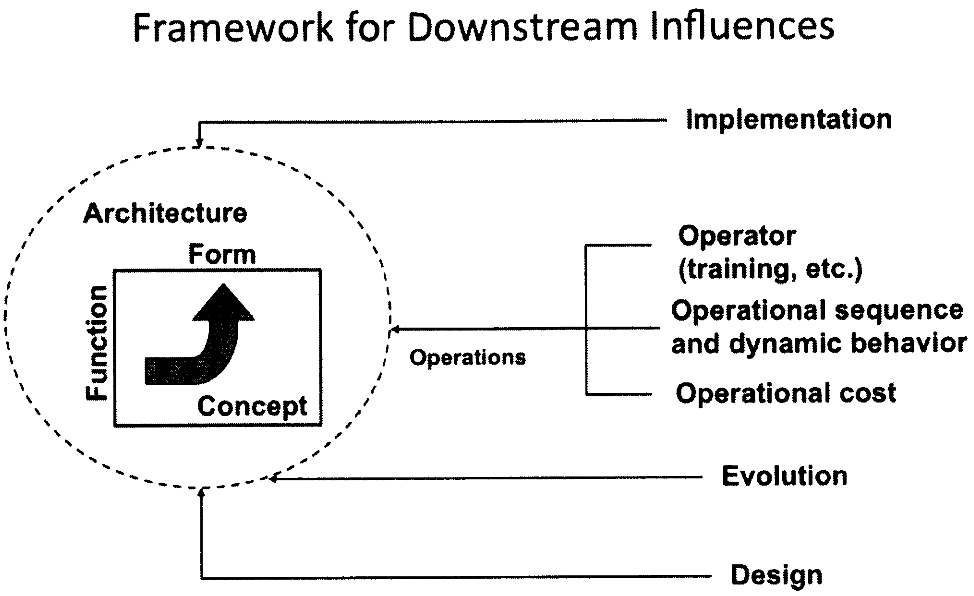

Figure 3: Downstream Influence on Architecture (Crawley, 2007)

1.3 Thesis Organization

This research will start with the discussion of supply chain challenges, where address the evolution of supply chain, why supply chain can be seen as a complex system, and how architects design a supply chain. Then an architecting framework, the iterations among supply chain architecture, corporate strategy, and operations will be proposed. In term of architectural improvement, a modeling methodology, derived from the concepts of System Architecture and Systems Engineering, is proposed, as the SCOR model will be used for operational improvement. Finally the iterations between these two types of improvement and the approach to integrate them are explained. Figure 4 shows the structure of the research. The dashed rectangles, operational improvement and SCOR model, are not covered in this article.

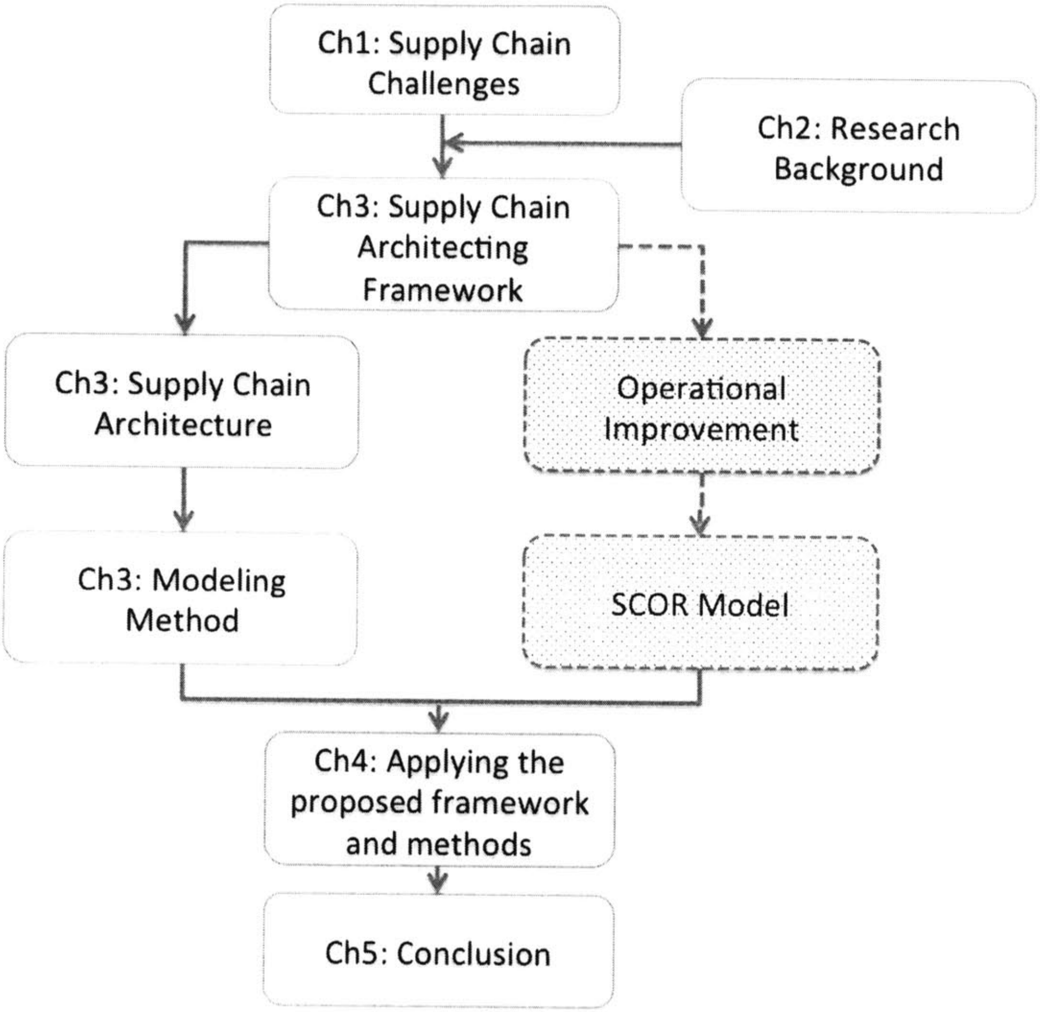

Figure 4: The Structure of the Thesis

Chapter 2 provides the background for this thesis; it starts with introducing the evolution of supply chain management. Then, system architecture and supply chain modeling methodology are addressed.

Chapter 3 explains the proposed supply-chain architecting framework and the modified Object-Process Methodology for modeling. Three elements, namely concept, form, and functions of supply chain architecture, and three views of supply chain architecture are presented as well.

In Chapter 4, the use of the proposed framework and modeling method is discussed and demonstrated by a supply chain security case. With the proposed model and case analysis, a conclusion is made and the future direction of study is discussed in Chapter 5.

2. Research Background

Supply chains are not born- they evolve. Evolution has been a unique feature of supply chains, and affects their behaviors. At the beginning of this chapter, I am going to discuss the evolution of supply chain management, and the reason why supply chain design needs a systematic approach including architecting framework, architecture, and modeling methods. Since a supply chain doesn't evolve alone, the phenomenon of co-evolution among the evolutions of supply chains, products, and process will be discussed, too. Then, the use of system architecture in software and enterprise design will be introduced. Finally, three modeling methods are discussed in the last section of this chapter.

With the challenges in the previous chapter, a supply chain has been a complex system, and required systematic approaches to analyze and design. Among the three system core courses, Systems Engineering, System Architecture, and Project Management, in the System Design and Management program at MIT, System Architecture is fundamental to systematic approaches. System Architecture has developed in hardware for hundreds of years, and quickly developed in the software industry in the pass decade. The widely use of the term causes the definitions of system, system architecture, and supply chain architecture are various in literatures, and they are discusses in Chapter 2.2.

Mark W. Maier (Maier, 2002) in "The Art of Systems Architecting" addressed the importance of modeling to architecting. It is used not only for understanding the system, but also for further communicating, while communicability is the first step to reach consensus and alignment among stakeholders. In Chapter 2.3, two popular modeling approaches, Supply-Chain Operations Reference-model (SCOR) and Unified Modeling Language (UML), as well as Object Process Methodology (OPM) are going to be introduced.

2.1 Supply Chain Evolution

Attributed to Oliver and Webber (Oliver, 1982), the term "Supply Chain Management" has been used with several different meanings since it was introduced in the early 1980s — from clear-cut definitions based on the idea of system-level optimization (Simchi-Levi, 2003), to broader definitions that use the terms "Supply Chain Management" and "Value Chain Management" interchangeably (Fine, 1998). The variety of ways the term is used is indeed so wide that even integrative efforts to track its historic use do not completely agree (Harland, 1996) (Chandra, 2000). The changes in the definition of supply chain represent the changes of its scope and content. In this session, the evolution of supply chain management is discussed from 1950s to present.

In the 1950s and 1960s, most manufacturers emphasized mass production to minimize unit production cost as the primary operations strategy, with little product or process flexibility. 'Bottleneck' operations were mitigated with inventory and in-process (WIP) inventory. In the 1970s, with the introduction of information technology and Manufacturing Resource Planning (MRP), managers realized the impact of huge WIP on manufacturing costs, quality, new product development, and delivery lead-time. In the 1980s, the needs of low-cost, high-quality, and reliable products with greater design flexibility encouraged manufacturers to utilize Just-In-Time (JIT) and other management initiatives to improve manufacturing efficiency and cycle time.

The relationship between customers or suppliers changes as well. In the 1950s and 1960s, sharing technology and expertise with customers or suppliers was considered too risky and unacceptable, and little emphasis appeared to have been placed on cooperative and strategic buyer–supplier partnership. Up to the 1980s, the fast-paced JIT manufacturing environment, with little inventory, raised production or scheduling problems, and manufacturers began to realize the potential benefit and importance of strategic and cooperative buyer-supplier relationships. The concept of supply chain management emerged as manufacturers experimented with strategic partnerships with their immediate suppliers.

After the 1990s, the emphasis of supply chain management extended to include strategic suppliers and logistical function in the value chain. Supplier efficiency was broadened to include more sophisticated reconciliation of cost and quality considerations. The relationship with suppliers and customers entered a strategic and long-term developing era. Manufacturers trusted suppliers' quality control by purchasing from only a handful of qualified or certified suppliers (Inman, 1992). Manufacturers now commonly exploit supplier strengths and technology in support of new product development (Ragatz, 1997), and retailers seamlessly integrate their physical distribution function with transportation partners to achieve direct store delivery or cross docking without the need for receiving inspection (Onge, 1996).

With the evolution of supply chain management, the changes also could be observed from its definition in past decades. The National Council of Physical Distribution Management (NCPDM), founded in 1963, changed its name to the "Council of Logistics Management" (CLM) in 1985. During this stage, it used to define SCM in the following way:

In 2005, the CLM changed its name to become the Council of Supply Chain Management Professionals (CSCMP). It clarified its earlier definition of supply chain management to become logistics management, and redefined Supply Chain Management as the following:

> ***Definition of Supply Chain Management***
>
> *Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.*
>
> ***Supply Chain Management – Boundaries and Relationships***

> *Supply chain management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance, and information technology.*
>
> ***Definition of Logistics Management***
>
> *Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements.*
>
> ***Logistics Management – Boundaries and Relationships***
>
> *Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers. To varying degrees, the logistics function also includes sourcing and procurement, production planning and scheduling, packaging and assembly, and customer service. It is involved in all levels of planning and execution--strategic, operational and tactical. Logistics management is an integrating function, which coordinates and optimizes all logistics activities, as well as integrates logistics activities with other functions including marketing, sales manufacturing, finance, and information technology.*

With these two definitions, it can be found that Supply Chain Management (SCM) has evolved into a larger scope with several functions in a strategic business domain. It has shifted its referred name from various terms like "distribution management" and "logistics management" to "supply chain management". The goal of SCM has also been revised from cost and efficiency to integration, coordination, and collaboration. It is not simply physical flow, but also information and business flow. Throughout the progress of SCM evolution, whether leaning toward traditional or current supply chain management, cost, efficiency, and flexibility are consistently the key performance indicators. However, after the terrorist attacks on September 11th, 2001, security has been a highlighted issue. Governments and companies worldwide are eager to secure supply chains without being threatened or forced to terminate services. In the Hurricane Katrina crisis in 2005, the issues of supply chain social responsibility have been raised. The $150/barrel oil prices in 2008 and increasing awareness of global warming caused companies, governments as well, to rethink long-standing supply chain design. Security, social responsibility, and environmental concerns began to involve more stakeholders in supply chain systems, broadening system boundaries, and thus, further complicating the problem. In order to develop a robust supply chain to meet these new requirements, past approaches are no longer sufficient, and a more systematic approach is needed.

Co-evolution

The concept of co-evolution was briefly described by Charles Darwin in "On the Origin of Species", and developed in detail in "Fertilisation of Orchids". In a broad sense, biological co-evolution is "the change of a biological object triggered by the change of a related object" (Yip, 2008). For instance, viruses and their hosts may have coevolved in a number of cases (Hogan, 2010). Co-evolution does not imply mutual dependence. The host of a parasite, or prey of a predator, does not depend on its enemy for survival. Such cyclic interaction between pairs of species could be found in bio-system, and also in supply chain systems.

Fine (1998) suggests that product, process and supply chain are interleaved and should be designed concurrently. He also proposed that three essentially different supply chains, Product/service Fulfillment (the "classic" supply chain), Product Development, and Capability Development are interrelated. Both of them can be regarded as supply chain co-evolution. From this standpoint, some work has been done in addressing the issue of matching products and supply chains (Fisher, 1997; Fine, 1998). F. Diaz

(CelaD´ıaz, 2005) proposed an integrative framework for architecting supply chains in a strategic view. However, the questions of how elements affecting one and another remain largely unresolved

2.2 System Architecture

System architecting research was first proposed by John Zachman in his 1987 article titled, "Framework for Information Systems Architecture", which discussed a classification schema for organizing architecture models. It provided a formal and highly structured way of viewing and defining an enterprise. Based on Zachman's framework, Matthew & McGee (1990), Evernden (1996), Schekkerman (2003), and Vladan (2006) modified and extended the framework to meet further needs.

2.2.1 System and Architecture

The term "system" has been widely used in many fields across science, nature, and business. There are several definitions of a system. Merriam-Webster defines a system as "a regularly interacting or interdependent group of items forming a unified whole." Crawley (2007) defines a system as "a set of interrelated elements, which perform a function, whose functionality is greater than the sum of the parts." Wikipedia states that a system is "a set of interacting or interdependent entities forming an integrated whole." Maier (Maier, 2002) gives another view of the definition of a system, claiming that a "system is a collection of different things, which together produce results unachievable by the elements alone." With these definitions, there are four common thoughts regarding a system: (1) a system consists of more than one element, (2) a system has a certain behavior, (3) a system interacts with its elements, and (4) a system performs a function, which is unachievable by the elements alone.

> *Architecture (from Greek word ἀρχιτεκτονική - arkhitektonike) is the art and science of designing and constructing buildings and other physical structures for human shelter or use. (Wikipedia)*

Similar to “system”, “architecture” is also widely used in many aspects, not only in hardware, such as buildings and products, but also in software (programming language and operation systems, etc.) and organizational structures (such as company organizations, governmental regimes). Architecture also can de defined from the viewpoints of a system:

> *"The structure, arrangements or configuration of system elements and their internal relationships necessary to satisfy constraints and requirements." (Frey)*
>
> *"The arrangement of the functional elements into physical blocks." (Ulrich &Eppinger)*
>
> *"The embodiment of concept, and the allocation of physical/informational function to elements of form, and definition of interfaces among the elements and with the surrounding context." (Crawley, 2007)*

Maier (2002) revised the definition of architecting as the art and science of designing and building systems.

> *"Systems architecting is the art and science of creating and building complex systems. That part of systems development most concerned with scoping, structuring, and certification."*
>
> *"The art of system architecting: The part of systems architecting based on qualitative heuristic principles and techniques; that is, on lessons learned, value judgments, and unmeasurables."*
>
> “The science of system architecting: That part of systems architecting based on quantitative analytic techniques; that is on mathematics and science and measurables.” (Maier, 2002)

He also proposed that (1) architecting is a systems approach with multiple disciplines, (2) it is purpose-oriented with useful purpose, affordable cost, and acceptable periods of time, and (3) modeling is the centerpiece of systems architecture.

Architecture is a way to simplify problems and manage complex systems. It is an abstract description of the entities of a system and the relationships between those entities (Crawley, 2005). The system architecture process combines basic aspects of the system: intent, concept, function, form, and context into an understanding of the system as a whole. Other properties are also important to architecture, often referred to as the "ilities;" they are durability, maintainability, flexibility, and manufacturability, which are related to the life cycle of the system (Eileen, 2007).

2.2.2 Enterprise architecture

A supply chain system can be broadly treated as an enterprise compositing companies located worldwide. The term "enterprise architecting" can be tracked to the 1980s when great strides were made in improving information technology. In general, enterprise architecting describes the interaction within subsystems and the relationship with external environments. It guides the design and evolution of an enterprise (Giachetti 2010; EARF 2009; Weill 2007).

National Institute of Standards and Technology (NIST), proposed a five-layered model. The five layers: business architecture, information architecture, information systems architecture, data architecture, and data delivery systems, are defined separately but are interrelated and interwoven (CIO-Council 1999). Chief Information Officers (CIO) Council adopted NIST's enterprise architecture model and Zachman's framework and then expanded on these foundations to meet the organizational and management needs of a federal to propose Federal Enterprise Architecture Framework.

Surveying these developed enterprise architecture frameworks, they were developed based on information design views, lacking the interactions with product design. As a result, suppliers and customers' relationships led to an insufficient description of a supply chain framework.

2.2.3 Supply Chain Architecture

The definition and views of supply chain architecture in terms of supply chain management are diversified. Some researches describe supply chain architecture from an operations viewpoint, and emphasize structure and interactions among these operations.

> *"A Blueprint for Networking the Flow of Material, Information, and Cash applies five crucial business principles to solve network problems for geographically separated workers who must team together to deliver products and services. These five principles, Velocity, Variability, Vocalize, Visualize, and Value, simplify the design and operation of complex, real-world supply chain networks for broad use throughout the manufacturing and service sectors." (William T. Walker, 2005)*
>
> *"Just as a blueprint describes the construct of a building and how each element fits together, your supply chain architecture should describe the construct of your process and how they interact." (Shoshanah Cohen, 2005)*

Others may see supply chain architecture at strategic level, and defined supply chain architecture is a set of high-level decisions such as make/buy decision.

> *"**A Supply Chain Architecture** is a set of high-level decisions taken over a number of design degrees of freedom of a supply chain reference model." "**A Design Degree of Freedom** is any feasible design decision the [Supply Chain] Architect wants to consider in any part of the reference model, as long as he has decision rights over it." (Fernando, 2005)*
>
> *"Supply chain development is divided into the supply chain architecture decisions and logistics/coordination system decisions. Supply chain architecture decisions include decisions on whether to make or buy a component, sourcing decisions (for example, choosing which companies to include in the supply chain), and contracting decisions (such as structuring the relationships among the supply chain members). Logistics and coordination decisions include the inventory, delivery, and information systems to support ongoing operation of the supply chain." (C.Fine, 2000)*

2.3 Supply Chain System Modeling Methods

Maier (2002) addressed the importance of modeling to architecting, which was used to not only understand the system, but also to further communicate, which became the first step to reach consensus and alignment among stakeholders.

Cartland (2006) suggested eight steps for reviewing and designing a supply chain. The first step in this process was mapping a supply chain, for which a modeling methodology is required. In the current context, a supply chain is not only able to serve as an analogy of a gigantic enterprise, but also a complex service-oriented system. Relying on simply describing the supply chain from a physical or process perspective without a systemic approach that includes analysis and mapping is not sufficient.

> *"A supply chain is a network of facilities and distribution entities (suppliers, manufacturers, distributors, retailers) that performs the functions of procurement of raw materials, transformation of raw materials into intermediate and finished products and distribution of finished products to customers."* [28]

Therefore, a supply chain is typically characterized by a forward flow of materials and a backward flow of information. The forward flow may consist of facilities, entities, and processes.

Beamon (1998) grouped proposed supply chain modeling methods into four categories: deterministic models where all the parameters are known; stochastic models where at least one parameter is unknown but follows a probabilistic distribution; economic game-theoretic models; and models based on simulation, which evaluate the performance of various supply chain strategies. These methods are steady-state models based on average performance or steady-state conditions, and are designed with predictable circumstance and quantifiable parameter assumptions. However, static models are insufficient when dealing with the dynamic characteristics of the supply chain system. In particular, they are not able to describe, analyze, and find solutions for emerging security, social and environmental responsibility problems. In addition, these models are designed for small, or relatively small, segment of process optimization, not for system-wide design, which includes qualitative and conflicted issues.

In the following, Supply Chain Operations Reference-model (SCOR), Object-Process Methodology (OPM), and Unified Modeling Language (UML) are introduced.

2.3.1 Supply Chain Operations Reference Model (SCOR)

Although there are many alternative methodologies to modeling a system, a dedicated design for supply chain systems is rare. The Supply Chain Operations Reference-model (SCOR) is a process reference model that has been developed and endorsed by the Supply Chain Council as the cross-industry, standard diagnostic tool for supply chain management. SCOR enables users to address, improve, and communicate supply chain management practices within and between all interested parties. The model is based on three major pillars: Process Modeling, Performance Measurements, and Best Practice. The Model itself contains several sections and is organized around the five primary management processes of Plan, Source, Make, Deliver, and Return. By describing supply chains using these process building blocks, the model can be used to describe supply chains that are either very simple or extremely complex using a common set of definitions. As a result, disparate industries can be linked to describe the depth and breadth of virtually any supply chain (Matthews & McGee 1990) (SCC, 2008).

It spans from the suppliers' supplier to the customers' customer, and includes all physical material transactions and market interactions.

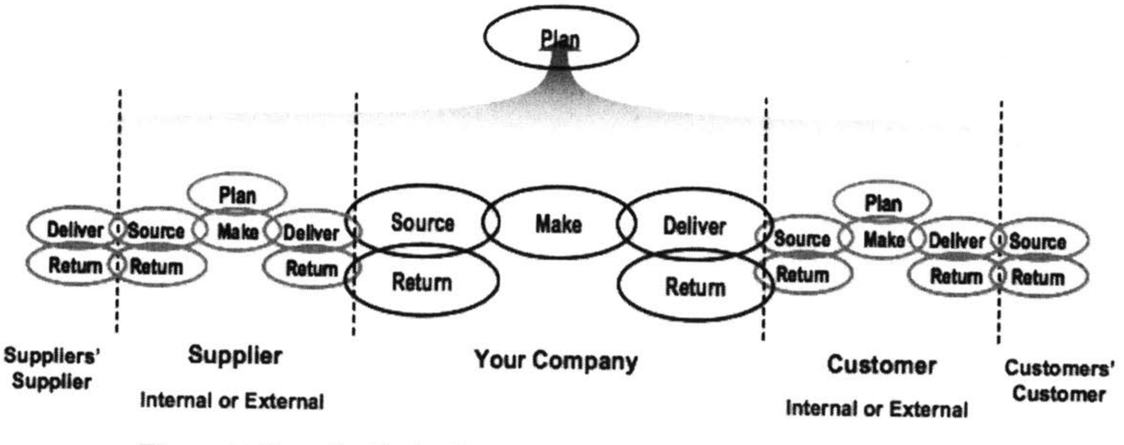

Figure 5: Supply Chain Operations Reference Model Scope (SCC, 2008)

Relationships between these processes can be made to the SCOR and some have been noted within the model. It provides three levels of process detail. Each level of detail assists a company in defining: scope (Level 1), configuration or type of supply chain (Level 2), and process element details, including performance attributes (Level 3). Below level 3, companies decompose process elements and start implementing specific supply chain management practices. It is at this stage that companies define practices to achieve a competitive advantage, and adapt to changing business conditions. (SCC, 2008)

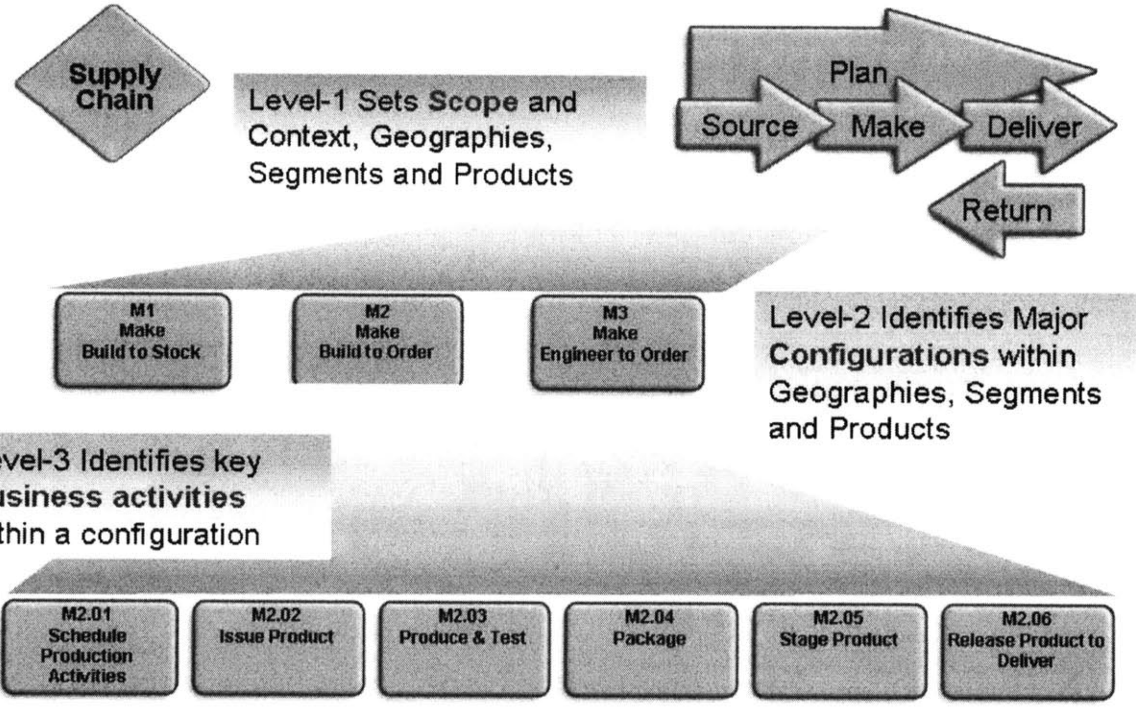

Figure 6: SCOR Framework Levels (SCC, 2008)

As an industry standard, SCOR facilitates inter and intra supply chain communication and collaboration. It also eases horizontal process integration by explaining the relationships between processes. SCOR is used to describe, measure, and evaluate supply chains in support of strategic planning and continuous improvement (SCC, 2008).

However, there are two issues to consider when one adopts the SCOR model to design supply chains. The first is the lack of ownership information. In some supply chain models, such as Vendor Managed Inventory (VMI), the ownership of goods changes at a very late stage, namely, when the goods are loaded into customer product lines. Since the ownership of goods is an attribute of the goods, not the process, the SCOR model, a process-oriented modeling approach, is not able to handle it properly. The second issue highlighting the weakness of using the SCOR model is the lack of customer/supplier relationship identification. In CSCMP's supply chain management definition in 2005, the supplier/customer relationship is included. Because the relationship is intangible and is not easily observed, the SCOR model does not provide an approach to address it.

In the context of the above two issues, SCOR would work properly when it is used in operational level design, but a complementary tool to enhance the business and strategic level is also necessary.

2.3.2 Object Process Methodology (OPM)

Object-Process Methodology (OPM) is a comprehensive approach developed by Dr. Doc Dori to tackle a complex system regardless of whether it is a technical, social, or an organizational system (Dori, 2002; Dori, 2003; Dori 2005). This methodology demonstrates its usefulness in its simplicity and generic features for analyzing a variety of complex systems. It explicitly uses building blocks *object*, *process*, and their complex system links into a single model.

From an OPM view, the world is composed of either physical or informational entities, where an entity is a generalization of an object, which has the possibility of achieving a stable form for a certain positive duration, and can be in physical or informational form, and a process, which is the transformation pattern, applied to one or more objects. An object is linked to nouns and has its own state while a process changes the state of the object and is generally linked to a verb. An object is exactly in one state at any specific point of time, and the state can be changed through process. The links can exist between pairs of objects to show to the structure of a system, or connect entities (objects, processes, and states) to describe the behavior of a system.

These building blocks constitute the Object-Process Methodology with a set of object-process diagrams (OPD) and object-process language (OPL), a group of descriptions for corresponding objects and processes. Figure 7 shows examples of object-process links (Kim, 2007).

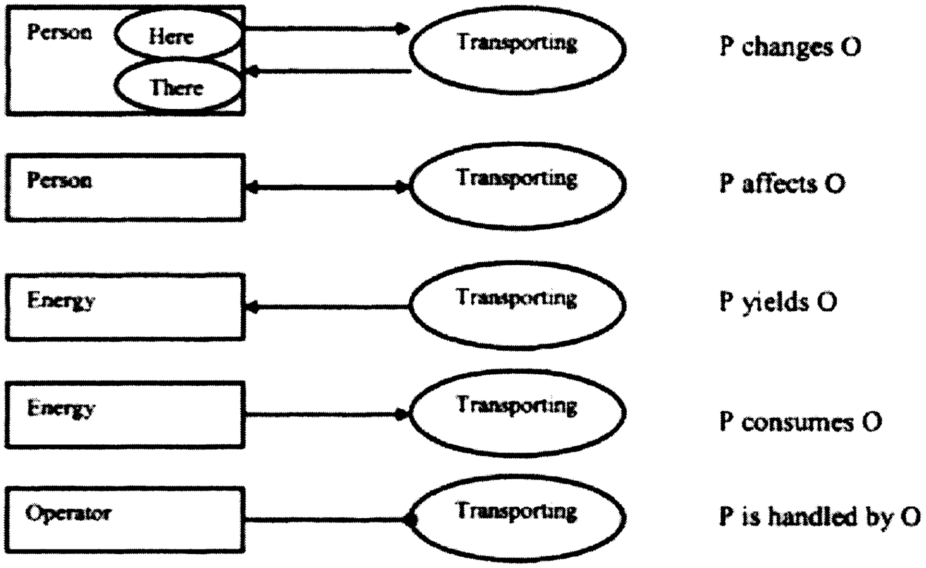

Figure 7: Examples of Object-process Links and Relational Structural Links. (Crawley, 2005)

As the inherent complexity and interdisciplinary nature of systems increases, the needs for universal modeling, engineering, and lifecycle support approaches become ever more essential. However, some modeling methodologies, such as UML, the current standard language in software engineering, are unnecessarily complex. Object-Process Methodology provides a simpler, formal, and generic paradigm for systems development.

2.3.3 Unified Modeling Language (UML)

Software architecture is an aspect of software engineering directed at developing large, complex applications in a manner that reduces development costs, increases the potential for commonality among different members of a closely related product family, and facilitates evolution, possibly at system runtime (Evernden 1996; Schekkerman 2003; Jovanovic, 2006; Garlan, 1993; Perry, 1992; Medvidovic, 2002). The Unified Modeling Language (UML), created and managed by the Object Management Group, is a standardized general purpose modeling language in the field of software architecture.

With a high dependence on IT support, UML is a de facto standard software design language used to model a supply chain. It is widely found in industry and helps to facilitate the process of system development. UML provides a variety of useful capabilities to the software designer, including multiple, interrelated design views, semiformal semantics expressed as a UML meta model, and an associated language for expressing formal logic constraints on design elements.

UML is used to specify, visualize, modify, construct, and document the artifacts of an object-oriented software intensive system under development. UML offers a standard way to visualize a system's architectural blueprints, including elements:

- actors
- business processes
- (logical) components
- activities
- programming language statements
- database schemas, and
- reusable software components[3]

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[3] Grady Booch, Ivar Jacobson & Jim Rumbaugh (2000) OMG Unified Modeling Language Specification, Version 1.3 First Edition: March 2000. Retrieved 12 August 2008.

UML employs three types of diagrams: behavioral, structural, and interactional. Behavioral diagrams emphasize what must happen in modeled systems and describe system functionality. Interactional diagrams, a subset of behavioral diagrams, emphasize the flow of control and data among the components modeled and are suitable for supply chain architecting.

Behavior diagrams including activity, State-machine, and Use-case diagrams. Interaction diagrams incorporate communication, interaction overview, sequence, and timing diagrams.

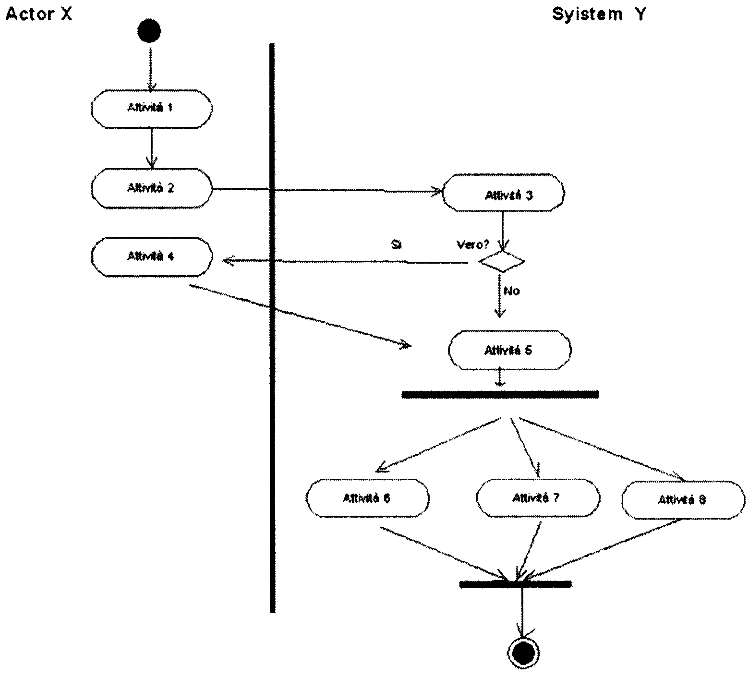

Figure 8: Activity Diagram: Represents Business and Operational Step-by-Step Workflows of System Components. Activity Diagram Shows overall Control Flow

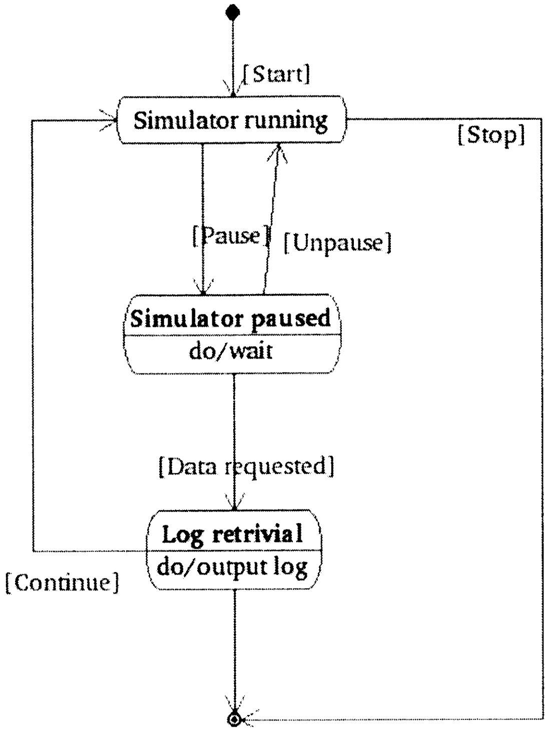

Figure 9: State-machine Diagram: Standardized Notation to Describe Many Systems, from Computer Programs to Business Processes

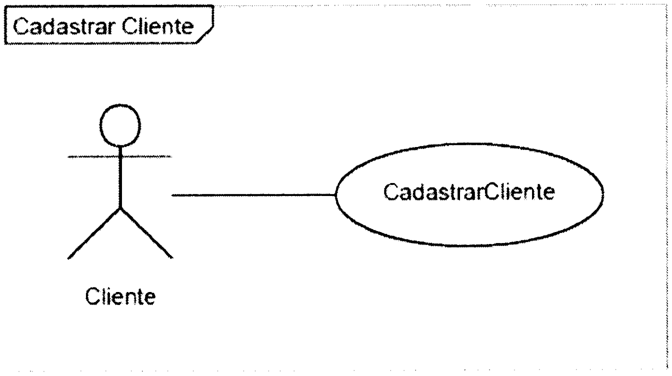

Figure 10: Use-case Diagram: Shows System Functionality in Terms of Actors, Their Use-case Goals, and any Dependencies among Those Use Cases

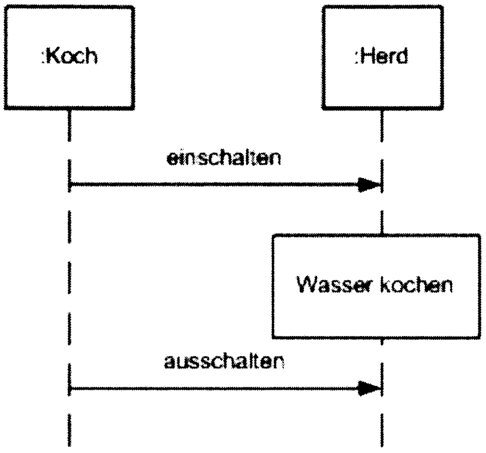

Figure 11: Sequence Diagram: Shows How Objects Communicate with Each Other in Terms of Message Sequencing. Indicates Lifespan of Objects Relative to Those Messages

The object-oriented approach has been advocated for business process reengineering (Jacobson, 1994). The basic advantage is that there is a better transition from modeling concepts to actual software implementation, since objects have a natural match in the real world. Therefore, some studies (Medvidovic, 2002) have been applied UML to model and design a supply chain, especially for further information system development.

However, the complexity of UML creates many challenges. It prolongs staff training times and drives participants away from joining supply chain design projects. People in an information department, who are familiar with UML, may implicitly dominate the supply chain design/improvement project, and lead the project toward a software-oriented project, and thus, overlook the importance of physical and business flow (the ownership flow). In addition, the freedom of object design in object-oriented approaches results in diversified views and distracts from the core issues. These drawbacks make UML an improper modeling approach, particularly for comprehensively designing a supply chain across multiple stakeholders where the partners are unlikely to collaborate and achieve consensus on a particular project.

3. Proposed Supply Chain Architecting Framework

With the growing globalization and specialization in industries, the decreasing life cycle time of products, the increasing frequency of product or process engineering changes and the number of transportation and warehousing options/combinations, supply chains have become more complex and difficult to manage. In this chapter, a systematic supply chain architecting framework is proposed to deal with the complexity for both designing a brand new supply chain and redesigning an existing supply chain to meet new requirements. As supply chain architecture is the core of the improvement framework and connects to other considerations, supply chain architecture and its three elements (function, concept, and form) are explained in Chapter 4. The structure of Chapter 3 and Chapter 4 is as Figure 12.

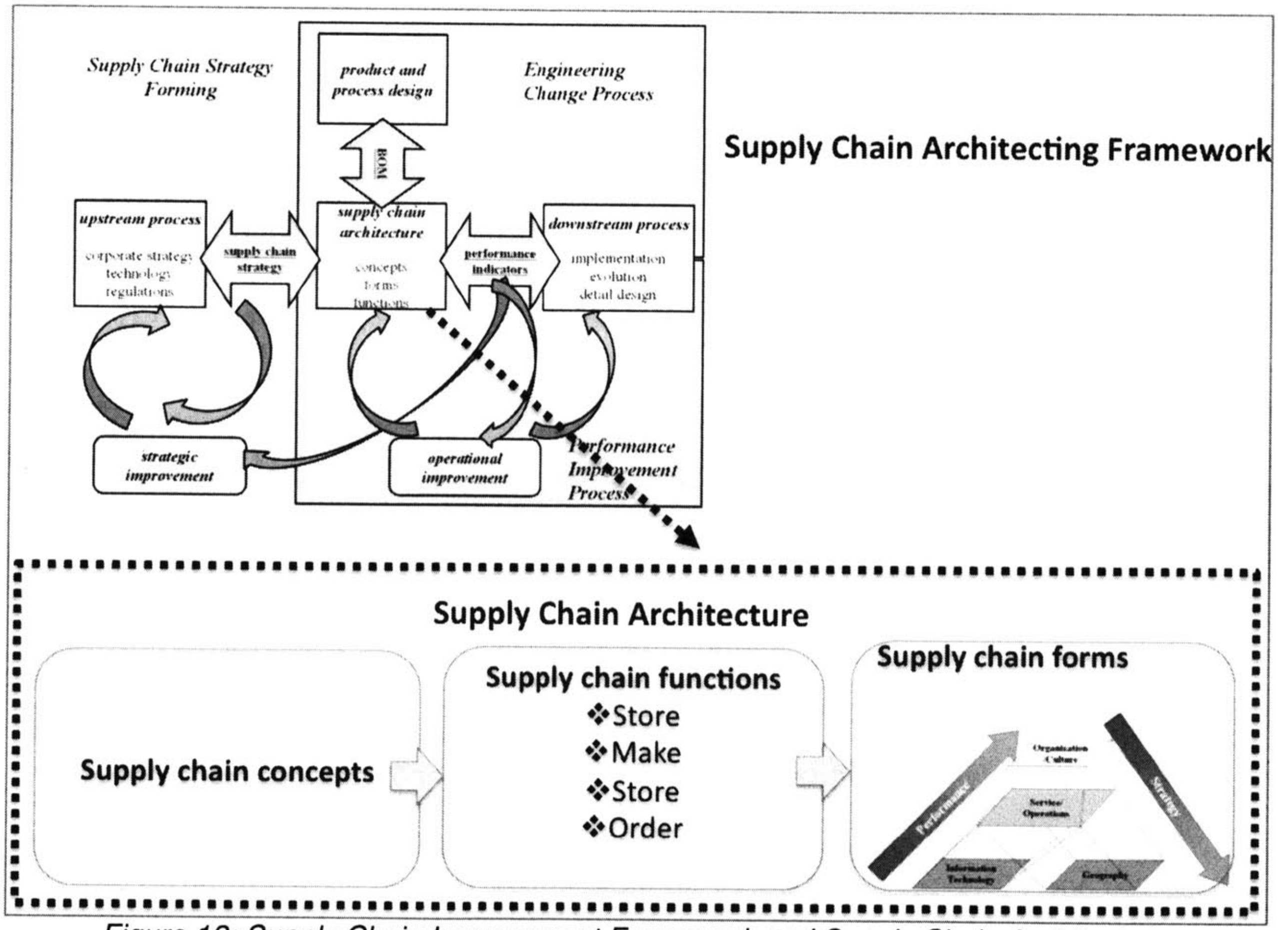

Figure 12: Supply Chain Improvement Framework and Supply Chain Architecture

3.1 Supply Chain Architecting Framework

The Federal Enterprise Architecture Framework defines a framework as:

> *"A logical structure for classifying and organizing complex information.* [4]"

In software development, framework is a guide for programmers to understand which, in an abstraction, should be produced and when. It is not a detail plan for functionalities, either not an instrument to direct a program what to do. It helps programmers to meeting software requirements rather than dealing with the more standard low-level details.

Supply chains are not born; they evolve. Evolution has been a unique feature of supply chains, and affects their behaviors. A supply chain doesn't evolve alone. Co-evolution can be observed among the evolutions of supply chains, products, and processes. Therefore, a well-designed framework for a supply chain system should be able to involve those dynamics and interactions.

Fine (2007) proposed a Three-Chain-Design model including *fulfillment*, *development*, and *capacity* chains. The *fulfillment* supply chain is the classic part described in SCOR and adds sell process to make a clear distinction between sourcing and supply procurement. The *capacity* supply chain, for instance knowledge, processes, and technology, can be transformed into *development* supply chain; the processes represent the product and process evolution. The model promotes a holistic view of architecting a supply chain by considering all the three chains. Based on the Three-Chain-Design model, and considering the effects of co-evolution, I propose a framework that includes the relationships of supply chain architecture to its upstream, downstream processes, product and process design, and performance feedbacks (Figure 13).

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[4] http://www.itstrategies.info/methodology-vs-framework-why-waterfall-and-ag

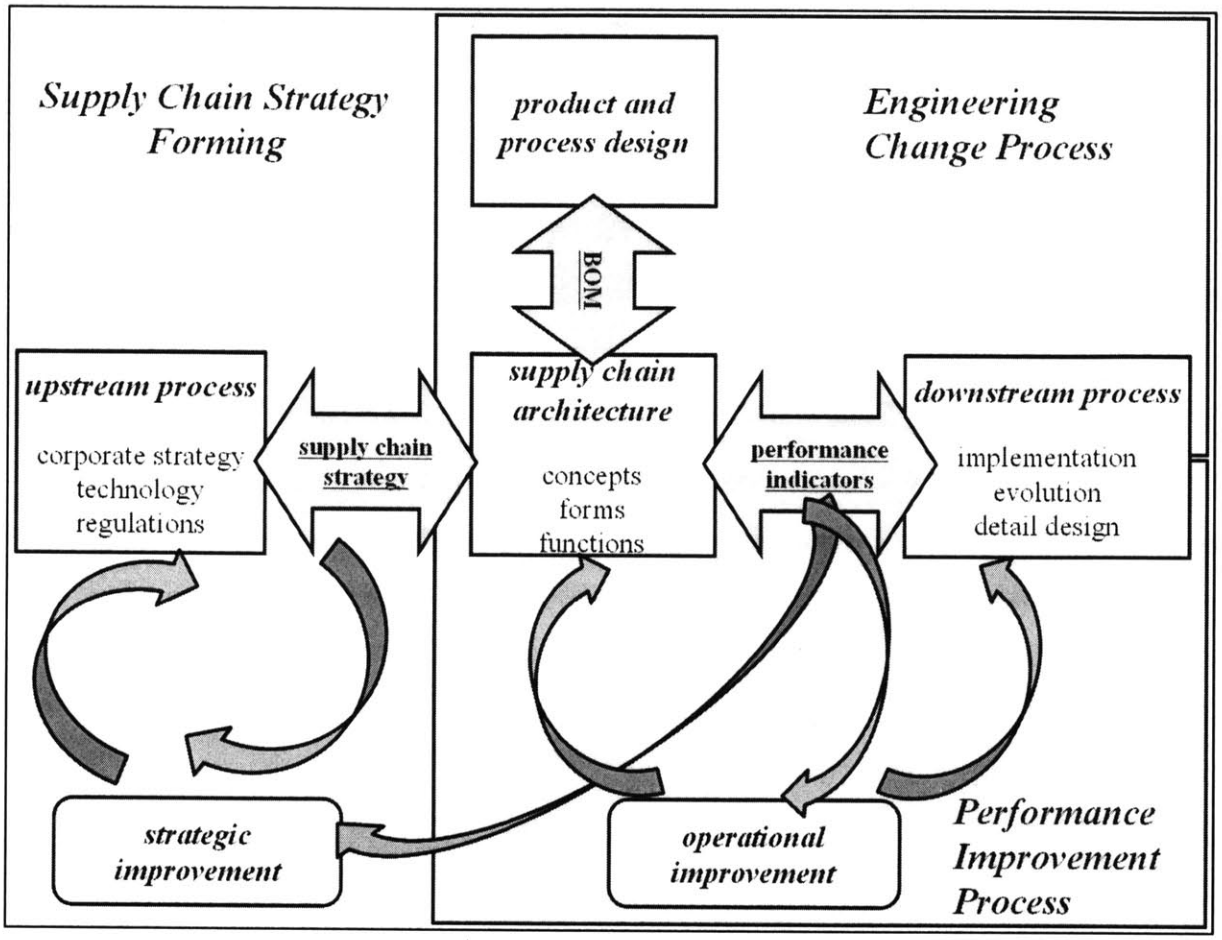

Figure 13: Supply Chain Architecting Framework

3.1.1 Four Segments of Supply Chain Architecting Framework

In the proposed supply chain architecting framework, there are four primary elements, namely (1) upstream process, (2) supply chain architecture, (3) downstream process, and (4) product and process design (Figure 13). Supply chain strategy, bill of material (BOM), and performance indicators are used to convert requirements from one to another element.

Upstream Process

The upstream process, the process prior to architecting, transforms beneficiary needs into corporate goals. The beneficiaries include customers, corporate marketing strategies, regulations, competitive environments, and technology. The output of an upstream process is supply chain strategy, which will be used as the concepts to design all consequent systems, such as product, process and operational systems. Without catching real beneficiary needs from stakeholders, a supply chain system will not able to perform in the right direction and produce desirable values to satisfy its stakeholders.

Supply Chain Architecture

As shown in Figure 13, supply chain architecture represents the core that links the other three aspects within this framework. It provides a common language and a single view of supply chain design for suppliers, customers, and product and process managers for further improvement. There are three basic elements of supply chain architecture: (1) *Concept*, derived from supply chain strategies that are the outputs of the upstream process, and is used to design performance indicators for the downstream process; (2) *Function*, influenced by concepts with implementation policies and is linked to the downstream process with performance indicators; and (3) *Form*, the aggregation of supply chain processes and corresponds to the bill of material (BOM) of the products. With the architecture principle "form and function being related through concept *within* the architecture", and upstream, downstream and product/process design connecting *to* the architecture, all pieces of the framework operate under the same goals.

Product and Process Design

Product, process, and supply chain concurrent engineering is able to solve the problems that occur by engineering changes in advance. However, product, process, and supply chain managers use discrepant views and languages, which easily create misunderstandings. Object-Process-Methodology (OPM), used for system modelling, is modified and used in supply chain architecture to solve the language issue. In addition, the Bill of Material (BOM) of the product is used as a bridge between product/process design and supply chain architecture. If there is any engineering change in product or process, the corresponding design in architecture could be found out and modified. Throughout the supply chain architecture, product/process design connects to corporate and implementation strategies as well.

Downstream Process

The downstream process is the detail design and implementation of the supply chain architecture. In order to properly connect supply chain architecture and the downstream process, the performance indicators should be related to architecture concepts and represent the outcome of the architecture.

Supply Chain Strategy, Performance Indicators, and Supply Chain Architecture

In this framework, supply chain strategies are transformed from corporate goals into the outputs of the upstream process, and are used as the inputs to supply chain architecture. Downstream processes, the process subsequent to architecting, include implementation, detail design, operational planning, cost consideration, and system evolution. In the proposed framework, performance indicators are derived from architectural concepts.

The following figure (Figure 14) shows supply chain architecture and its interfaces with upstream process, which is supply chain strategy, and downstream process, which is performance indicator. Within supply chain architecture, the architectural concept is derived from the supply chain strategy, and then it is used to design the implementing policy, an attribute of architectural function, and to select proper performance indicators, an attribute of architectural form. The SCOR model can help to choose performance indicators when the architectural concept is obtained. When the supply chain architecture is realized in real world, the SCOR model can provide best practices in industry for further improvement.

Figure 14 also shows the iteration of improvement processes among supply chain strategy, performance indicators, and supply chain architecture. While new supply chain strategy is made, current supply chain architecture should be reviewed to ascertain whether it still align to strategy. Then new performance indicators will be selected.

When the performance is below the expectation, will lead to either internal operational improvement, or external adjustments in supply chain architecture or strategy.

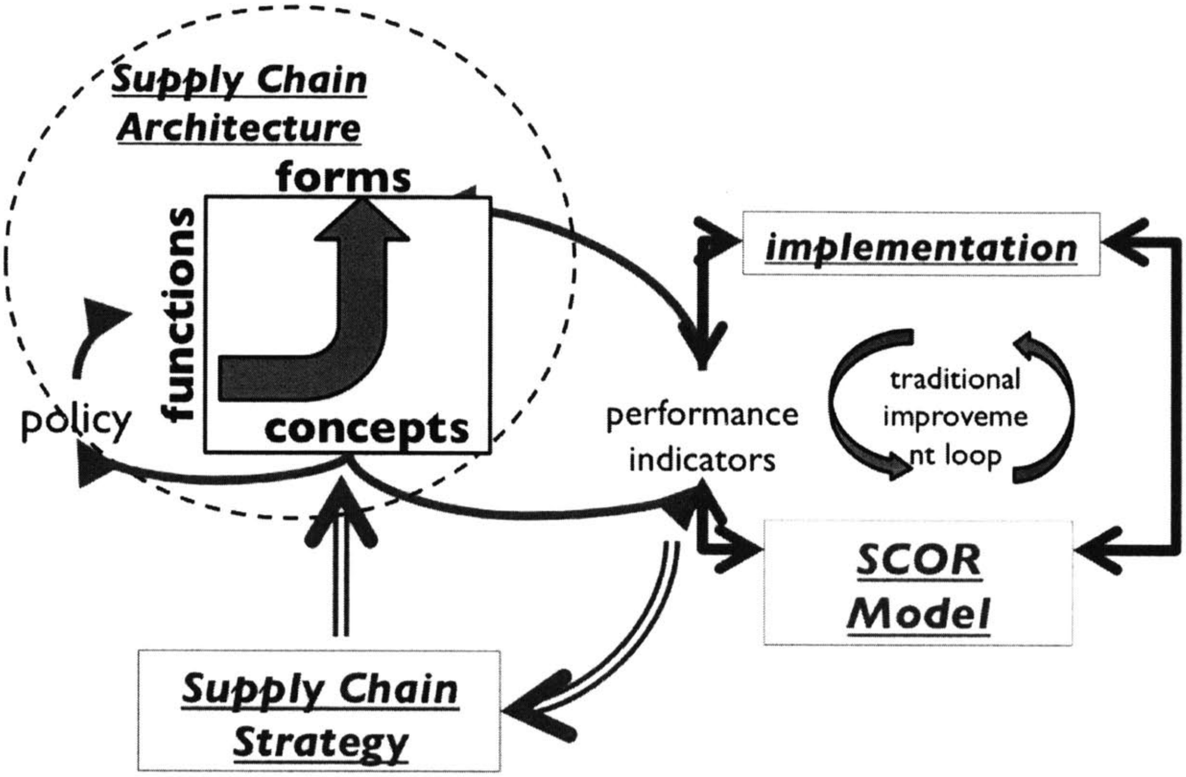

Figure 14: Supply Chain Architecture and Its Interfaces

3.1.2 Three Main Processes to Supply Chain Architecting Framework

In this framework, there are three processes across the four segments of the proposed architecting framework: they are supply chain strategy-forming, engineering-changing, and performance improvement processes. The supply chain strategy-forming process is the process triggered by any factors changed in the upstream process or in the poor quality in concerned performance indicators. Then a new supply chain strategy is made to meet new needs. The engineering change process is the process, which is triggered by product/process redesign, and then redesigns its corresponding architecture, detail design, and operations. Finally, the performance improvement process is the process that monitors performance in the real world and redesigns its architecture if needed.

In the previous discussion, the relationships and interactions of four segments (upstream process, architecture, downstream process, and product/process design) and three main processes (strategy-forming, engineering-changing, and performance improvement) are addressed. In the following sections, the three elements of system architecture, a mapping approach to obtain architecture concept, and the modified Object-Process methodology for modeling a supply chain system will be the focus.

3.2 Supply Chain Architecture

Systems architecture, which is the central part of the framework, is an artistic and scientific way to manage complex systems. It is also an abstract description of the entities of a system and the relationships between those entities (CIO-Council 1999).

Crawley (2007) defined architecture as "the embodiment of a concept: the allocation of physical/informational function to elements of form, and the definition of interfaces among the elements and with the surrounding context." With this definition, there are three basic elements to represent a system in abstraction: *concept*, *function*, and *form*. With the architecture principle of "form and function being related through concept within the architecture," all pieces of the framework operate under the same concepts.

These three elements are widely used in the system design field; however, different terms might be used. For instance, D. Nightingale[5] used purpose (function), structure (form) and top-level conceptual design (concept) in Enterprise Architecting. In this research, the terms concept, function, and form are used and discussed within the context of supply chain planning in the following sections.

3.2.1 Concept of a Supply Chain

The concepts to a supply chain can be analogized as the business strategy to an enterprise. The supply chain concepts are derived from goals, and goals are transformed from beneficiary needs. The beneficiaries include customers, corporate marketing strategies, regulations, competitive environments, technology, downstream

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[5] D. Nightingale, ESD.38J Enterprise Architecting – lecture notes. MIT Engineering Systems Division, Spring 2008.

strategies, and downstream competence. The concepts of supply chain may vary in products and product life cycle stages even within a company. A product, which is in its growth stage, requires different supply chain concepts when it is in its saturation and decline stage. Therefore, the concept of a supply chain is highly product-oriented. In Fine's gears model (2003), there are six forces: *regulation*, *industry structure*, *capital markets*, *technology dynamics*, *business cycles*, and *customer preferences*, all of which should be considered in the upstream process. These forces are dynamic and interrelated; they are in continuous change and alterations, and each factor influences the others. A supply chain architect must understand not only the impact of each one in a supply chain but also be aware of their dynamic behaviour (CelaD´ıaz 2005).

3.2.2 Functions of a Supply Chain

Compared with hardware and software design, the diversity of supply chain functions is much more homogenous. In the SCOR model, supply chain operations are classified into: Plan, Source, Make, Deliver, and Return. In the proposed methodology, only the operations related to physical movement are involved. Hence, only make and move (deliver) are selected, while return could be seen as the combination of move and make (refurbish or disperse) in the reverse direction. Store, implicitly addressed in both source and delivers operations of the SCOR model, is extracted and considered as an individual function. In regards to information flows, order is used to represent submitting requests. To sum up, make, move, store, and order are four essential functions in the proposed supply chain architecting methodology.

In order to model a supply chain in graphic, Object-Process Methodology (OPM, introduced in Chapter 2.4.2) is modified and applied in this thesis. OPM basically uses two building blocks: object and process: an object is what has the possibility being stable for a certain period of time and can be in tangible physical form, such as inventory, material, and goods, or be in informational form, such as orders; a process is a transformation that is applied to the object.

A function (Figure 16) consists of an "*operand*(s)" and a "*processing*", and the "*processing*" is executed by an instrumental object. An operand is the object that the process operates on, and the changes in an operand are associated with the delivered value of the process. For example, when a pen is moved from location A to location B, the pen is the operand and the action "move" is the process in OPM. If the process is done by hand, a hand is an instrument object of the process. In addition, the process, "move", may have attributes such as "move two pens in every movement". In some cases, these attributes related to implementing policies in the processing determine the costs of the operation.

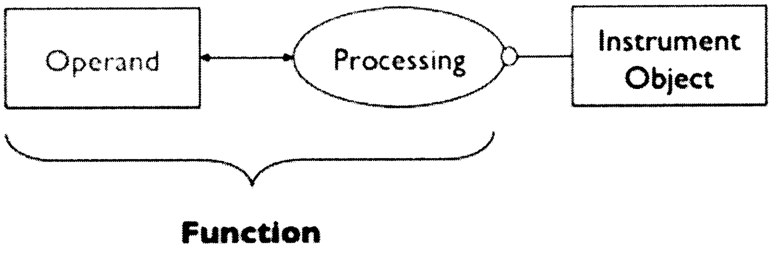

Figure 15: Function/Form and Benefit/Cost

Figure 16 shows the four essential functions by modified OPM. The move process changes the location of the inventory, but does not consume or create the inventory. Because the ownership of the inventory may differ from before moving and after moving, two inventory objects (inventory 1 and inventory 2) are used.

On the other hand, the store process only keeps the material and changes its status for a certain time, but does not consume or produce any materials. Hence, only one object to represent the operand (the material) is sufficient. The same situation can be observed on the order (submit) process. Hence, only use one object and order in the process.

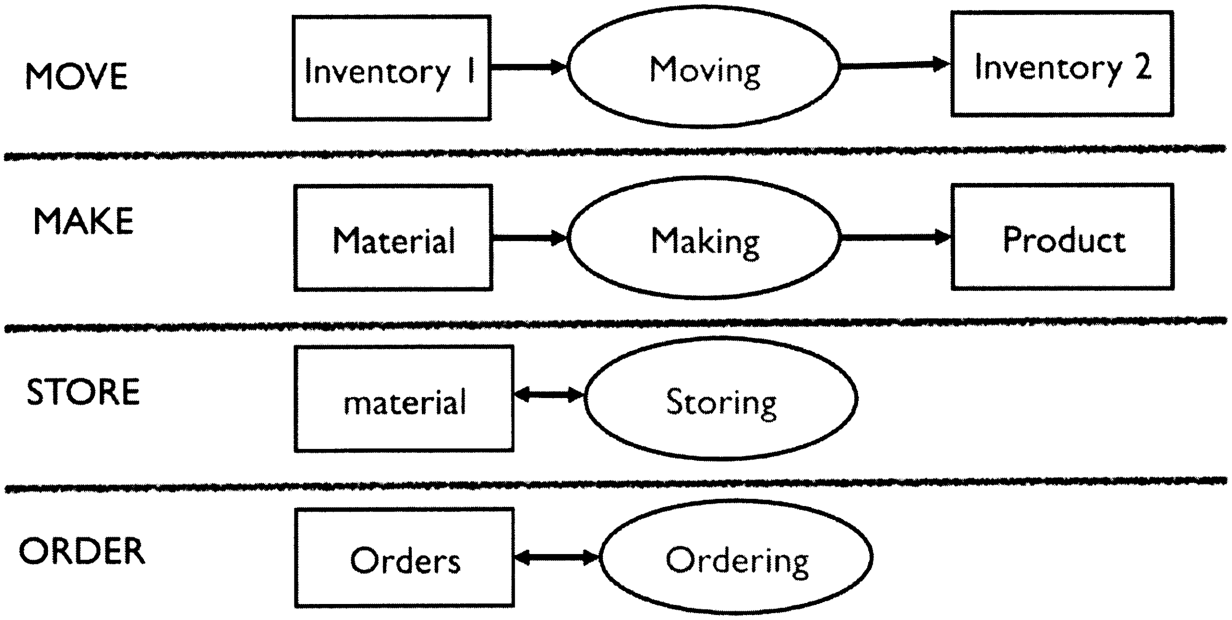

Figure 16: Functions of Move, Make, Store, and Order

3.2.3 Form of a Supply Chain

Fine's definition of the supply chain architecture (1998): "An integral supply chain architecture features close proximity among its elements. Proximity is measured along four dimensions: geographic, organizational, cultural, and electronic." A supply chain framework should be able to cover these four dimensions, and then the differences among supply chains can be observed in the design of architecture. The proposed definition introduced three and half layers of framework to represent supply chain architecture. They are organization, services, and information and geography. Supply chain is a collection of a sequence of services. In the proposed framework, services are central to the architecture that links the organizational, informational and geographic layers. The influence of corporate strategy is top-down. The design of services/operations layer will be able to sustain the business relationships in the organizational layer, while the configurations of information system and location selection will affect the performance of operations. On the other hand, performance merits cross these three layers and bottom-up trigger the evolution of the supply chain architecture.

Figure 17 shows the layers of form view in supply chain architecting. Any service or operation is fulfilled by a particular organization, and is located in a particular location. In the meantime, it may also be supported by a particular information technology application.

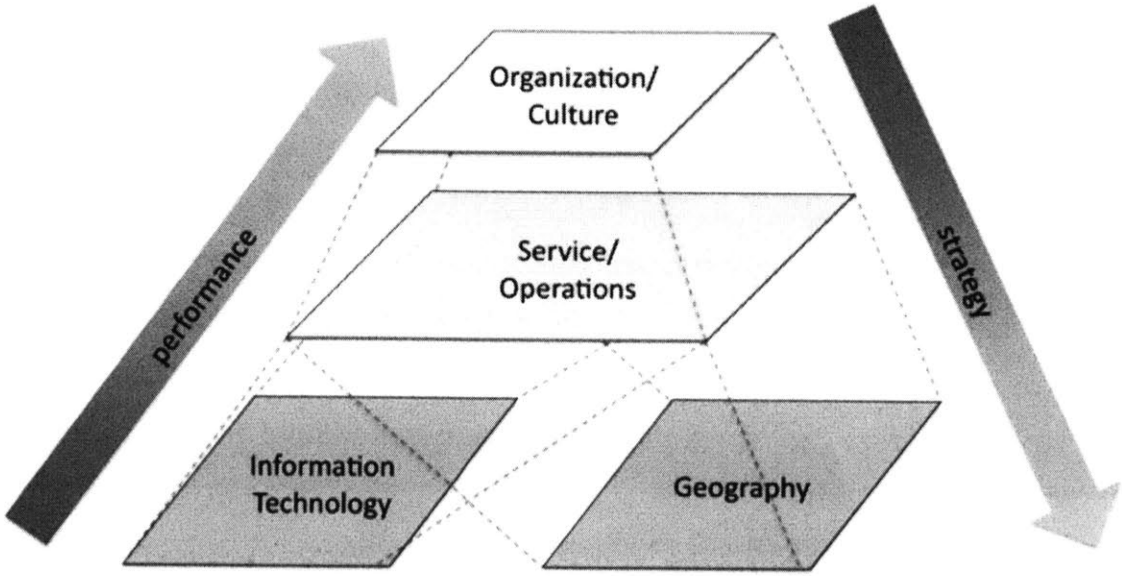

Figure 17: The Layers of Form View in Supply Chain Architecture

In order to communicate with stakeholders among a supply chain system without being hindered by learning modeling methods, Object-Process Methodology is modified and adopted for modeling purpose within each layer. A rectangle represents an object, an oval illustrates a process, an arrow stands for a type of relationship, and a dashed rectangle is used to show the scope of a system.

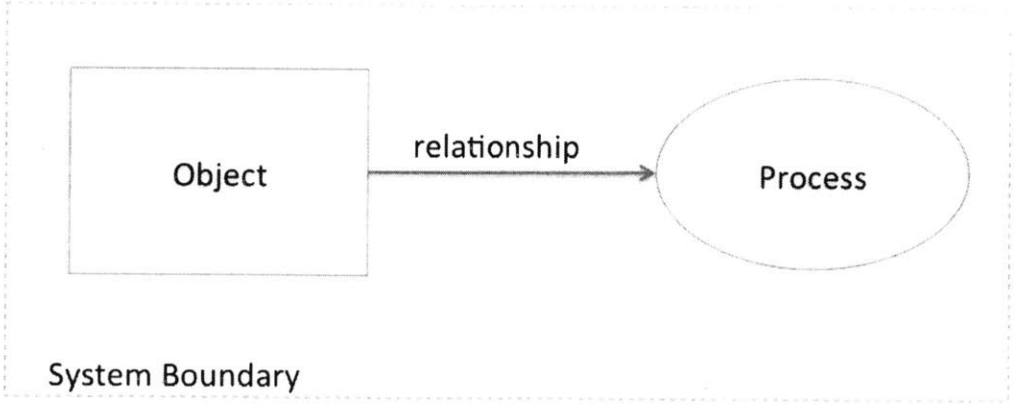

Figure 18: OPM

Organization/culture layer of Form

Supply chain culture is the "spiritual" part of a supply chain while the structure of organization is the "physical" part. The organizational view of form is used as the organizational/cultural perspective of architecture. In this layer, the participants (the stakeholders) of the supply chain and the relationships between customers and suppliers should be denoted. For instance, using "partner with" to represent a long-term and close relationship, "contract with" to represent a short-term and cost-oriented relationship, and "serve to" to represent providing services without any business relationships.

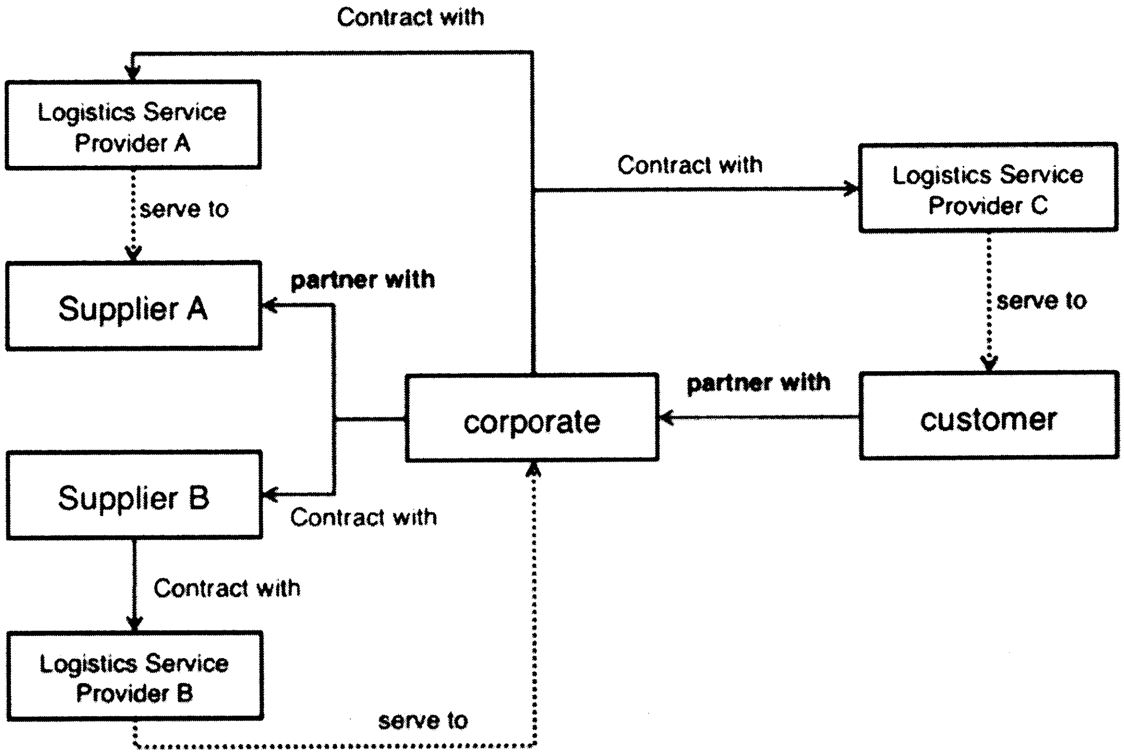

Figure 19: Organizational View of Form

Service/operation layer of Form

In the service/operation layer, in addition to operations, both the transition of physical goods and changeovers in ownership are critical to revealing the discrepancy of supply chain designs. Since all supply chains are the flow of physical goods, changeovers in ownership could definitely cause unique management methods and results. Take Vendor Managed Inventory (VMI) model for example. VMI is a sort of business model where the buyer of a product provides certain information to a supplier of that product and the supplier takes full responsibility for maintaining an agreed inventory of the material, usually at the buyer's consumption location (e.g., a store). The supplier is able to determine how much inventory is being stored in the warehouse; however, the inventory belongs to the supplier instead of the buyer. The ownership will shift to the buyer when the buyer consumes the inventory.

In addition, services/operations compose a supply chain; hence, the aggregation of operations is the form of a supply chain. In hardware architecture, form is believed as the source of cost. In supply chain management, cost is a discrete measurement, and is defined as the fixed, operational, and customer service cost in this research.

Fixed cost is the cost that is independent of production numbers, such as warehouse, land, and facilities. Oppositely, operational cost is the cost that is dependent of production numbers, such as oil/energy consumption and labor (per hour). Customer service cost might be tricky by not being as explicit as the previous two costs, and it associates the costs including entering customer orders, with the reserving inventory. With this classification, the instrumental objects of the process associate with the fixed cost, the agents affect the operational cost, and the attributes of the process, for instance the operational policy, will influence the customer service cost. Compared with the hardware design where *form* attracts cost, in supply chain architecture design, process occurs in all three types of cost.

Take *Move* function as example. The function itself, carrying inventory from location 1 to location 2, is value creation. The agent (driver), instrument object (truck), transportation policy, distance, and time attract cost; the moving process is cost creation. The transportation policy could be dedicated shipping or not, and constrains of delivery/arrival time, etc.

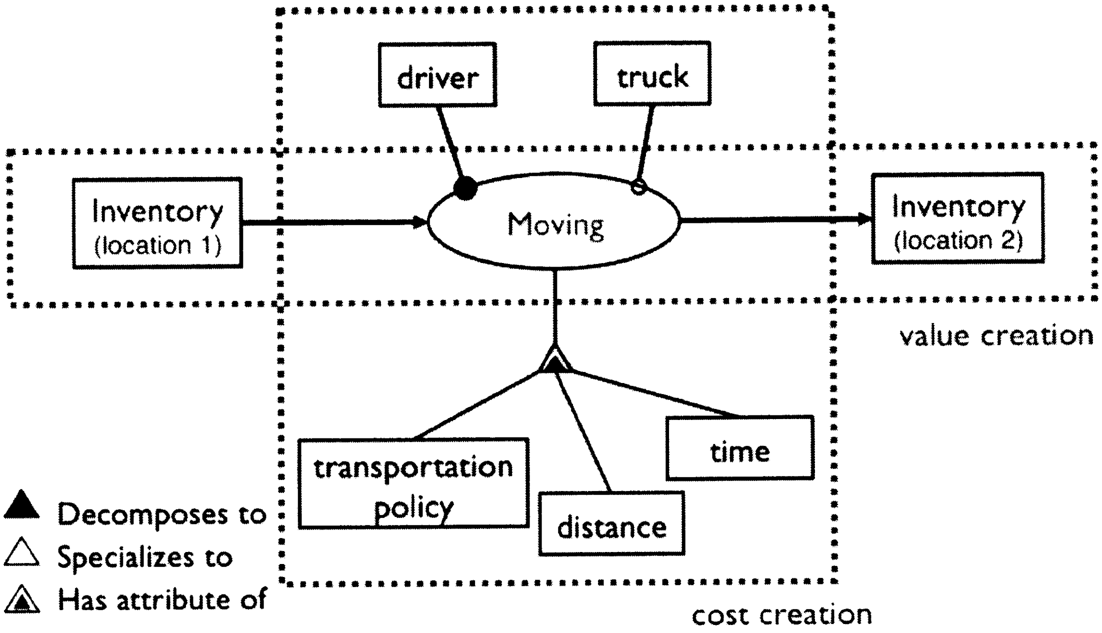

Figure 20: Form of Moving

Regarding *store* function, material/product undergoing the storing process to become inventory creates value. On the other hand, the labor, warehouse, facilities used to execute the storing process, inventory policy, such as the economic order quantity (EOQ) and newsboy models, and the desired customer service factor generate costs.

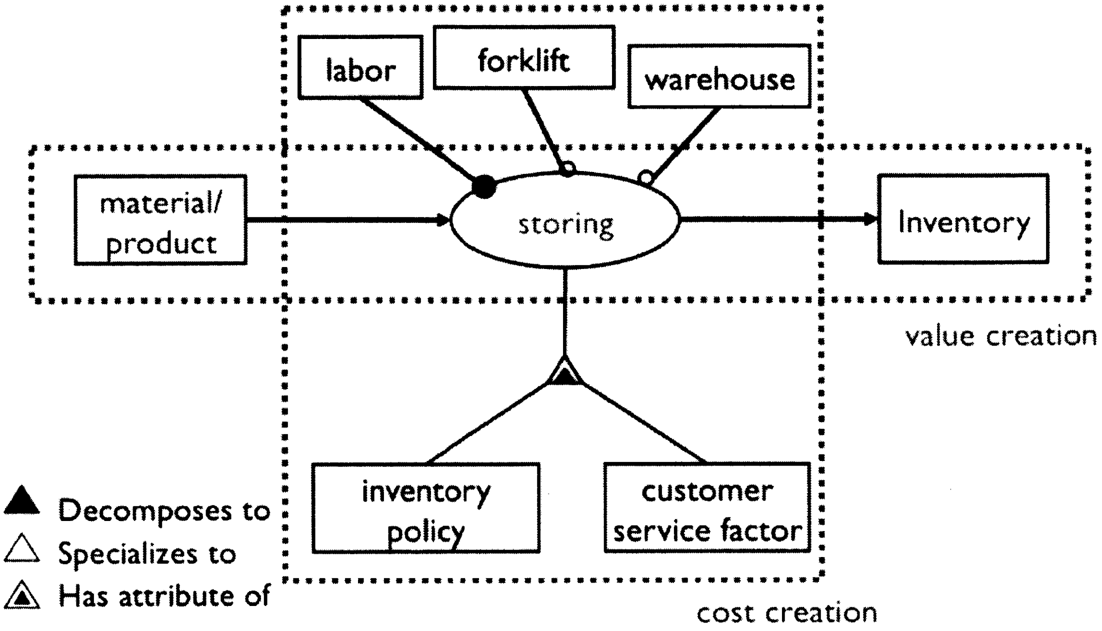

Figure 21: Form of Storing

In terms of make function, material going through the making process to become product is value creation. The labor and facilities used to execute the making process, the manufacturing policy, such as lot size, and the facilities settings, such as maintenance, are cost creation.

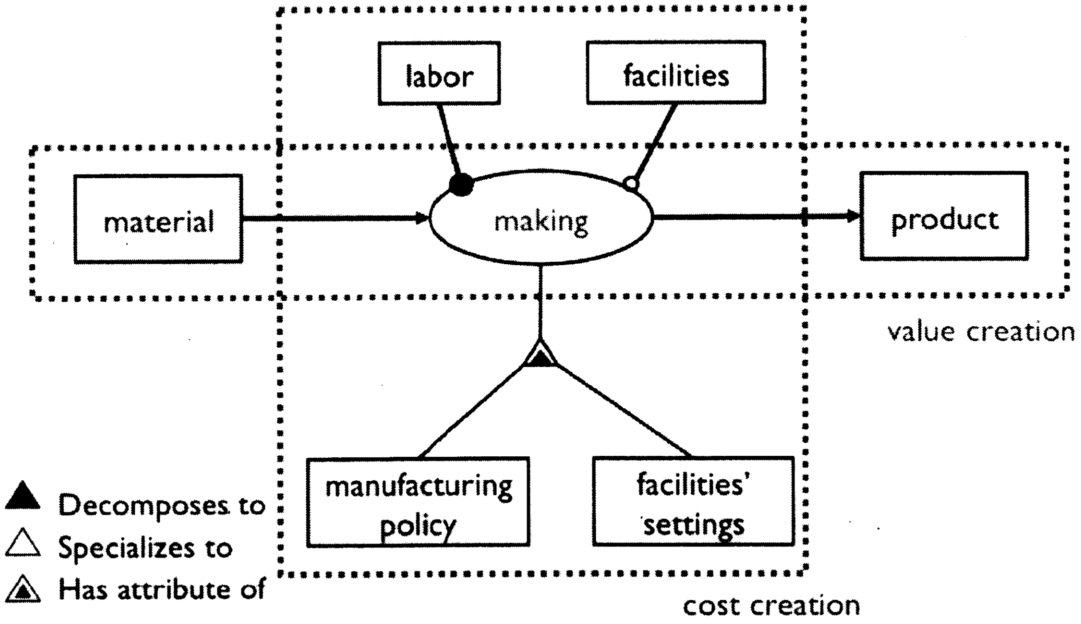

Figure 22: Form of Making

For the *order* function, the change of order status through the ordering process is value creation. The staff, facilities, and infrastructure used to execute the ordering process, and the ordering policy, such as minimal order quantity, are cost creation.

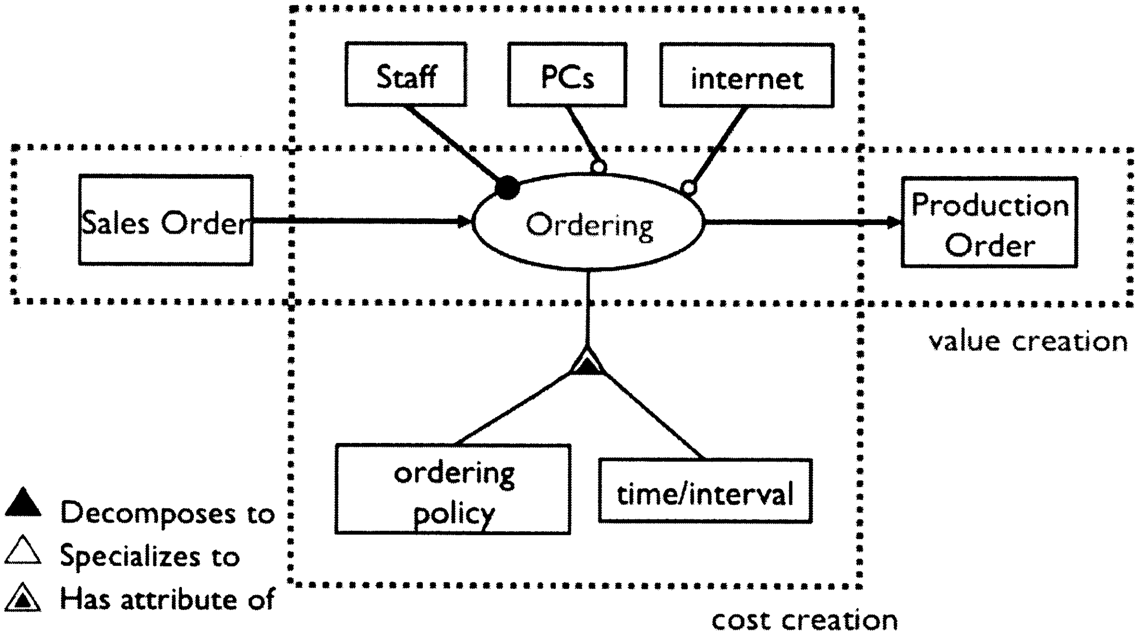

Figure 23: Form of Ordering

Geography and information technology layer

Selecting a good location can benefit the performance of services, such as well-established distribution centers that can locally decrease overall inventory and maintain customer satisfaction. Information technology (IT) is also well understood as a tool that can transcend physical distance limitation, while supporting services/operations. Hence geography and information technology are considered as two individual views in the same layer in this framework, and is seen as one and half layer. The IT and service layer connections indicate monitoring points, and a corresponding mechanism that collates informational and physical flows. Similar to noting ownership in the services/operations layer, the owner of the application should be shown in this layer as well.

4. Applying the Proposed Architecting Framework

Supply Chain Consul's SCOR model is widely treated as the industrial standard with well-designed performance indicators. It can be applied to assist architecting a supply chain and furthermore bring the architecture design into practice.

There are two directions within the architecting procedure: 1) Forward (from concept development) functions and form designs: this type of architecting is used for traditional and brand new supply chain designs; and 2) Backward, which starts from form analysis, function review, and ends with concept identification. The Backward procedure facilitates supply chain performance improvement and reengineering. Architecting is not a single-trip process, and several iterations are needed to evaluate and acquire the best architecture under specific time and requirements.

A framework only provides the guide of how to think, and it is inevitable to make different choices and results even applying the same framework. People are not compelled and guided to produce specific artifacts according to a process. In the following sections, I would like integrate the use of SCOR model into the proposed architecting framework in its three elements: concept, function, and form. Finally, a supply chain security case is applied to demonstrate the use of architecting framework and modeling methods.

4.1 Concept Formation

Supply chain architecture concepts should align with corporate supply chain strategies. Only then, functions and forms that are being designed based on concepts allow supply chain strategies to penetrate downstream processes.

Figure 24 shows that architecture concept is the median that connects supply chain strategy (upstream process output) and performance indicators (downstream process input). In the proposed framework, architecture concepts are derived from corporate supply chain strategies, and are used to determine proper performance indicators in real practice. When poor performance emerges, either execution or architecture should be revisited to solve those issues. In the following section, the approach to deriving concepts from supply chain strategy and obtaining performance indicators is discussed.

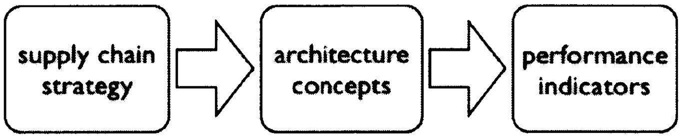

Figure 24: Strategy, Concept, and Metrics

4.1.1 Supply Chain Strategy to Architecture Concepts

Shapiro (Shapiro, 1984) concluded that there are three generic competitive strategies in business, and these strategies are:

- Competition in Cost
- Competition in Customer Service
- Competition in Innovation

These generic competitive strategies' commensurate supply chain characteristics are summarized in Table 1. The correspondent characteristics, as known as "ilities", are used as architecture concepts.

Table 1: Aligning Supply Chain Characteristics and Competitive Strategy (CelaD´ıaz , 2005)

Competitive Strategies	Required Characteristics on Supply Chain	SCOR 9 Metrics Sets	Suggested Performance Indicators in SCOR 9 (Level 1)
Cost	Efficiency	Cost	• SC management cost • Cost of goods sold
Service	Reliability Responsibility	Reliability Responsiveness	• Perfect order fulfillment • Order fulfillment cycle time
Innovation	Flexibility Sensibility Adaptability	Agility Responsiveness	• Upside SC flexibility • Upside SC adaptability • Downside SC adaptability • Order fulfillment cycle time

4.1.2 Architecture Concepts to Performance Indicators

In order to expand the architecture concepts to the downstream process, the SCOR model, which categories supply chain metrics in four sets (cost, reliability, responsiveness, and agility) is adopted as a switch. Taking advantage of the metrics set in the SCOR model, in which apposite performance indicators of these four categories are well-designed and defined, we can not only transform architecture concepts into performance indicators, but also further benchmark them to best practices and improvement.

In Table 1, taxonomy and mapping are used to transform strategies into architecture concepts, and then concepts are used to identify appropriate metrics sets. The performance indicators of the SCOR 9 metrics set, namely reliability, responsibility, agility, and cost are shown in Table 1.

4.1.3 The Weakness of the Transformation

In the late 1990s, several serious pollution calamities and gradually serious global warming raised ecological issues in supply chain design. In 2001, the terrorist attacks caused supply chain shut down. These events brought about some research that explored the drawbacks of profit-oriented enterprise systems, and proposed triple bottom lines ("TBL", "3BL", or "people, planet, profit") to measure business performance. In the previous section, the three generic competitive strategies all belong to the financial bottom line. When companies redesign their supply chain to improve social and environmental responsibility, Table 1 will not provide desirable information.

On the other hand, the development of SCOR model is usually behind the real needs, and the metrics set and best practice cannot always be found. When the required information is not in Table 1, supply chain architects have to develop the architecture concept and its corresponding performance indicators with the supply chain improvement team.

The form-function-concept principle stating form and function are related through concept (or pattern) represents the core of the architecture. With the proposed methodology, concept connects to form through performance indicators, concept affects function by way of policy, and then concept is widely spread to the entire supply chain. In addition, architects are required to highlight concepts and continually review to monitor whether the design and implementation adhere to the supply chain concepts.

4.2 Services/operations layer of the form of supply chain architecture

Here, the processes compose a supply chain; hence, the aggregation of processes is the form of a supply chain. As mentioned in Chapter 3.2.2, *move*, *make*, *store,* and *order* are the essential functions adopted to assemble a process in a supply chain. In hardware architecture, form is believed as the source of cost. In supply chain management, cost is a discrete measurement, and is defined as the fixed, operational, and customer service cost in this research.

Fixed cost is the cost that is independent of production numbers, such as warehouse, land, and facilities. Conversely, operational cost is the cost that is dependent on production numbers, such as oil/energy consumption and labour (per hour). Customer service cost might be tricky by not being as explicit as the previous two costs. Rather it associates the costs of entering customer orders with the reserving inventory. With this classification, the instrumental objects of the process are associated with the fixed cost, the agents affect the operational cost, and the attributes of the process, (e.g., operational policy influence the customer service cost). Compared with the hardware design where form attracts cost, in supply chain architecture design, process occurs in all three types of costs. Take the Move function for example. The function itself, which carries inventory (operand) from location 1 to location 2, is value creation. The agent (driver), instrument object (truck), transportation policy, distance, and time attract cost; the moving process is cost creation. The transportation policy could be dedicated shipping or not, and may have constraints of delivery/arrival time, etc.

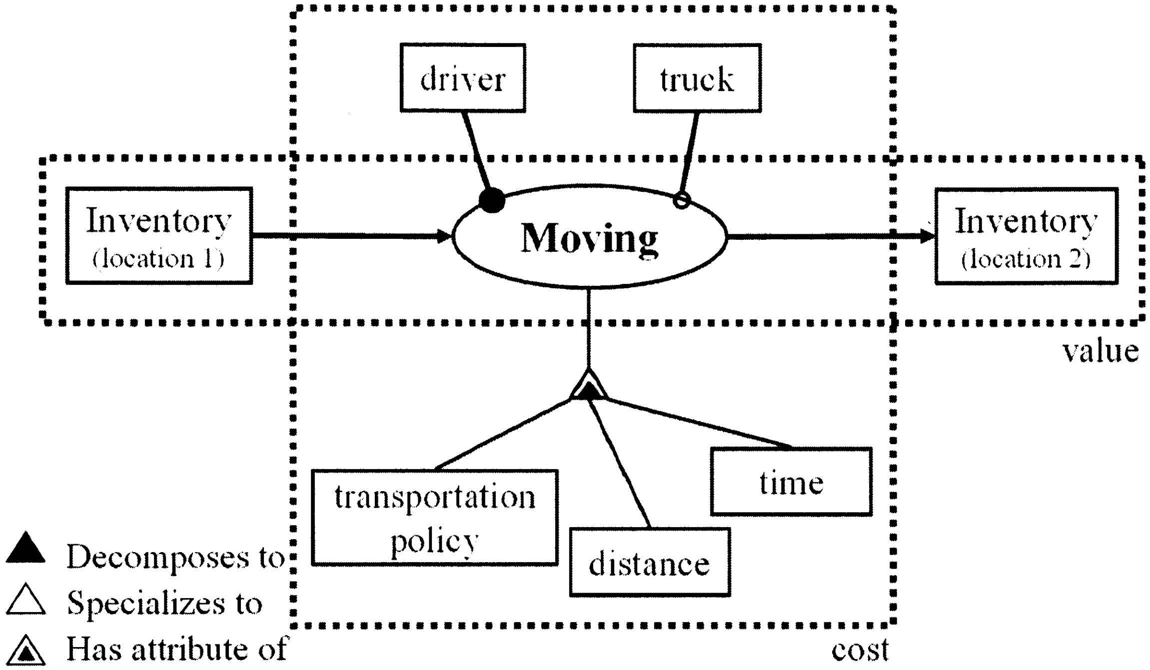

Figure 25: Form of Moving Function

With regards to the store function, materials/products undergoing the storing process to become inventory help create value. On the other hand, the labour, warehouse, and facilities used for executing the storing process, the inventory policy (such as the economic order quantity (EOQ) and newsboy models), and the desired customer service factor—all go to generating costs.

In terms of making function, material that goes through the making process to become a product is considered as value creation. The labour and facilities used to execute the making process, the manufacturing policy (e.g., lot size), and the facilities settings (e.g., maintenance) are termed as cost creation.

In terms of the order function, the change of order status through the ordering process is value creation. The staff, facilities, and the infrastructure used to execute the ordering process and the ordering policy, such as minimal order quantity, are considered as cost creation.

4.3 Two-ways transforming

Architecting can be either forward, backward, or both. The forward architecting is the process that includes supply chain strategy formation, architecture design, detail activities, management mechanism planning, performance monitoring, and feedback. In the case of a new product launch, forward architecting may be possible. However, companies may have existing products in market and existing supply chain implementations. As a result these legacy systems may result in making forward architecting unfeasible. The following figure (Figure *26*) shows the forward architecting while the SCOR model is used to assist performance indicators selection and management. Backward architecting, on the other hand, is constrained by existing legacy systems, which cause reduced freedom in supply chain architecture and strategy.

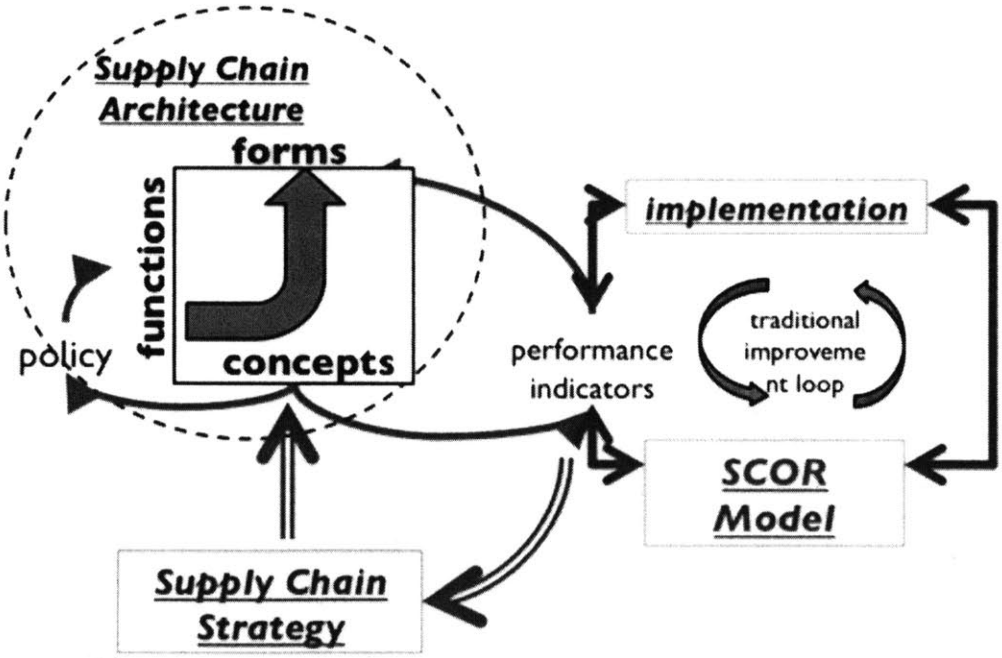

Figure 26: Supply Chain Architecture and Its Interfaces

It is rare that one is required to design a brand new supply chain. More likely, in the current competitive environment one may need to stick to one supply chain strategy.

Hence, the most reasonable architecting approach is reiterative. Both the forward and backward architecting is applied to ceaselessly adjust a supply chain. The backward architecting is used to improve operational performance while the forward is used to adapt corporate supply chain strategies to meet new needs as shown in Figure *27*.

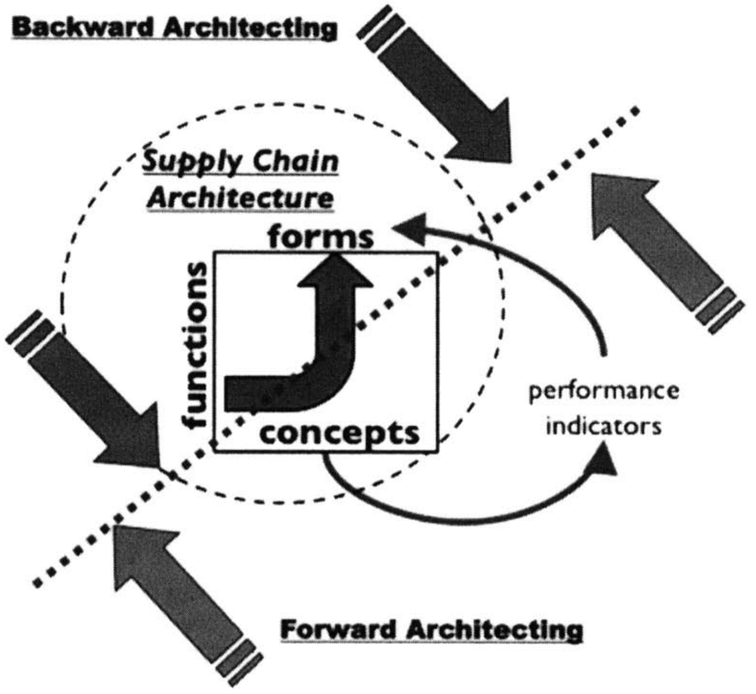

Figure 27.Backward (Upper-side) and Forward (Down-side) Architecting

4.4 Applying the Proposed Architecting Framework on a Supply Chain Security Project

The proposed architecting framework provides supply chain managers a way to think how to design a supply chain system, instead of restricting them what to think. Supply chain managers can find the most suitable parts of the framework and the methods to be used in their supply chain projects. In this section, I would like to apply the proposed framework and methods to deal with a maritime transportation issue.

Supply chain security has become a spotlighted issue since the aforementioned terrorist violence in 2001. With the suspended supply chain, governments worldwide realized vulnerable supply systems could ruin society and economics in all aspects. Hence, supply chain managers were asked to securitize their supply chain systems for possible attacks in the future and develop recovery plans to minimize the effects of stopping supply chains. However, pursuing security improvement based on existing supply chain design may lead to increased costs, process complexity, and low fulfillment efficiency. Eventually, it will hurt profits among supply chain members. Therefore, without strong incentives, such as preferential duties or allocating duties to customers, companies will be reluctant to conduct such an improvement. On the other hand, supply chain managers who are asked to conduct security projects will struggle to find acceptable trade-offs among corporate strategy, overall costs, security, and operational performances.

Some studies pointed out that reviewing the fulfillment process helps companies to gain supply chain visibility and to eliminate wastes. However, in practice, we found that companies who look forward to improving security either by process-oriented approaches, (e.g. imposing additional audits, check points) or by device-oriented approaches, (e.g. installing RFID or inspecting facilities), sacrifice cost-competitiveness and efficiency for security when fundamental system design revision from the kernel system architecture was absent. In addition, utilizing multiple participants worldwide makes it difficult to define the boundaries of security improvement projects; the impact and side-effects of new technologies and processes to legacy systems are not measurable. These issues addressed the need of a systematic approach to deal with uncertainty and complexity in order to achieve success among multiple goals: security, low costs, efficiency, and all other considered aspects.

This chapter explores how proposed architecting framework and modeling methods applied to design a secure supply chain through architecting, option evaluation, option selection, and prototyping.

Project Background

In this section, an international cargo transportation process, namely shipping cargo from a manufacturer's warehouse in Singapore to its customer's offshore warehouse in Taiwan, is used to demonstrate the use of the proposed architecting framework. The manufacturer's supply chain design and implementation will align with the new requirement: security. Then, the modified OPM is used in this case to model its "as is" status for further analysis, and resulted in several possible improvement options. Taguchi's Orthogonal Arrays were used in the following phase to design an experiment for selecting the best configuration set.

After a discussion with the shipper, security became a new requirement for the existing supply chain, since proving supply chain security can accelerate its custom-cleaning process. However, there was no corresponding performance indicator in this case to monitor the quality of security. Lacking an overall map of the existing supply chain and number of legacy systems makes developing an improvement project a tough job.

The stakeholders of the target system include manufacturer (the shipper), inland transportation operators, customs, carriers, foreign inland transporters, and customers. Each stakeholder has physical and informational legacy systems.

Architecture Analysis

Even when security was the purpose of the supply chain improvement project, the shipper did not want to sacrifice cost and efficiency advantages. As "security" was added to the supply chain strategy, visibility got consensus to be used as the architecture *concept* to redesign the supply chain. Moreover, cost and efficiency were the trade-off considered while visibility was increasing. Unfortunately, there is no counterpart performance indicator in the SCOR model to assess visibility. Hence, a definition of visibility and how it is evaluated were needed. The definitions of visibility, cost, and operational efficiency are described in the following section.

A backward architecting process is applied to analyze the current system. The analysis process starts from "*form analysis*" by observing the exterior attributes. Next, reverse engineering is undertaken by mapping *function* to *form*. These bottom-up (from form to function, compared with top-down, from function to form) steps (the upper side of Figure 28) can help capture original design knowledge and prevent original concepts from being infringed. Then, the new concept, visibility, is used to review the implementing policy, which affects the function design, and to select the key performance indicators, which affect the form design (the down side of Figure 28); with several iterations of backward and forward architecting, the new function and form are added to or replace legacy systems.

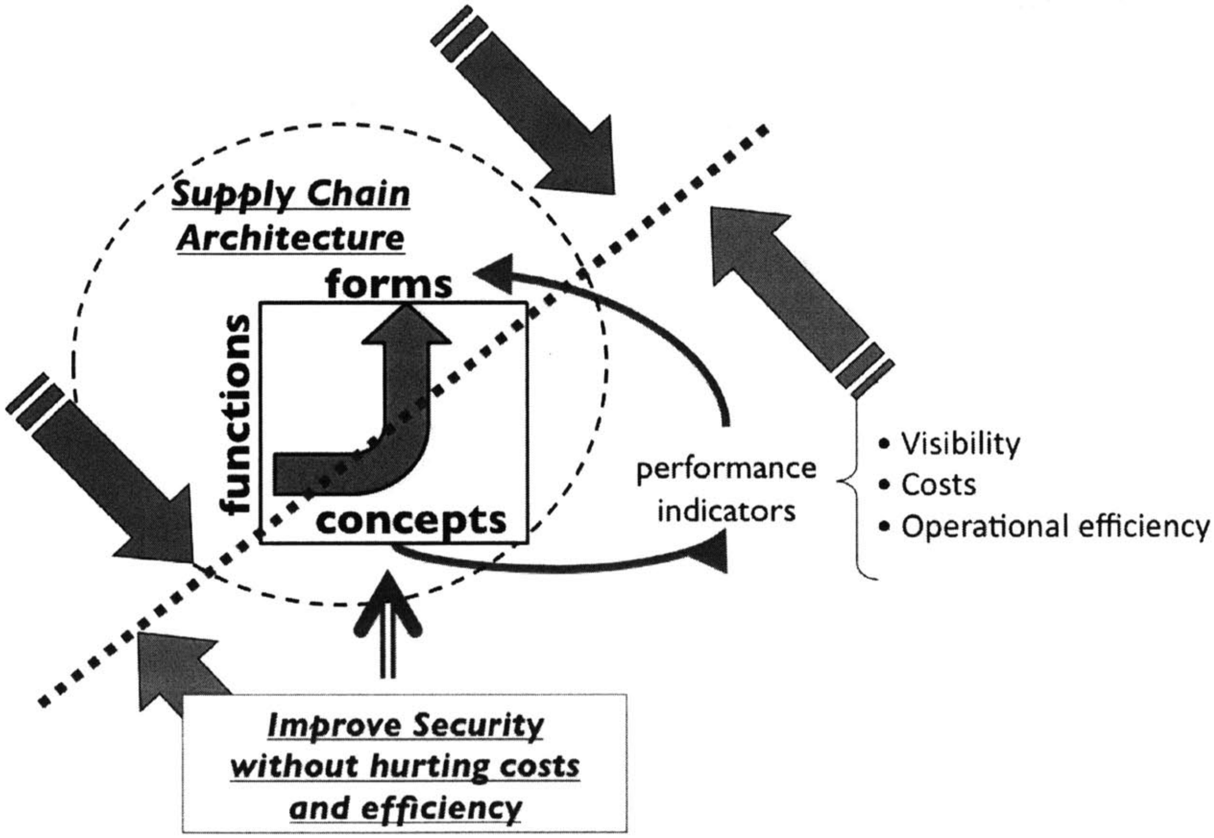

Figure 28: Backward (Upper-side) and Forward (Down-side) Architecting

In order to understand the current system, the modified OPM introduced in Chapter 3 is applied for architectural analysis and system design. In this case, because the design target is a segment of an international transportation process with information system, the functions (move, store, make, and order) proposed in Chapter 3 won't be fully suitable. The observable objects in the physical movement flow and the standalone software systems are seen as OPM objects, and the activities related to these OPM objects are arranged as OPM processes.

Figure 29 shows the architecture of the target transportation system by the object-process diagram. Informational and physical transporting systems are the two views and the interactions of these two views are shown as well. The top of Figure 29 represents the informational flow, which consist of two tiers of objects. Three databases, the Warehouse Management System (WMS), Transportation Management System (TMS), and carrier-system databases are in the first tier. These databases perform individually, but there exist sequential relations, and any security defects will be carried to all succeeding processes.

The second tier of the informational flow consists of Customs-EDI-system databases. Unlike the first tier objects, which directly communicate with the physical flow, the second tier objects retrieve information from the first tier databases with specific protocols.

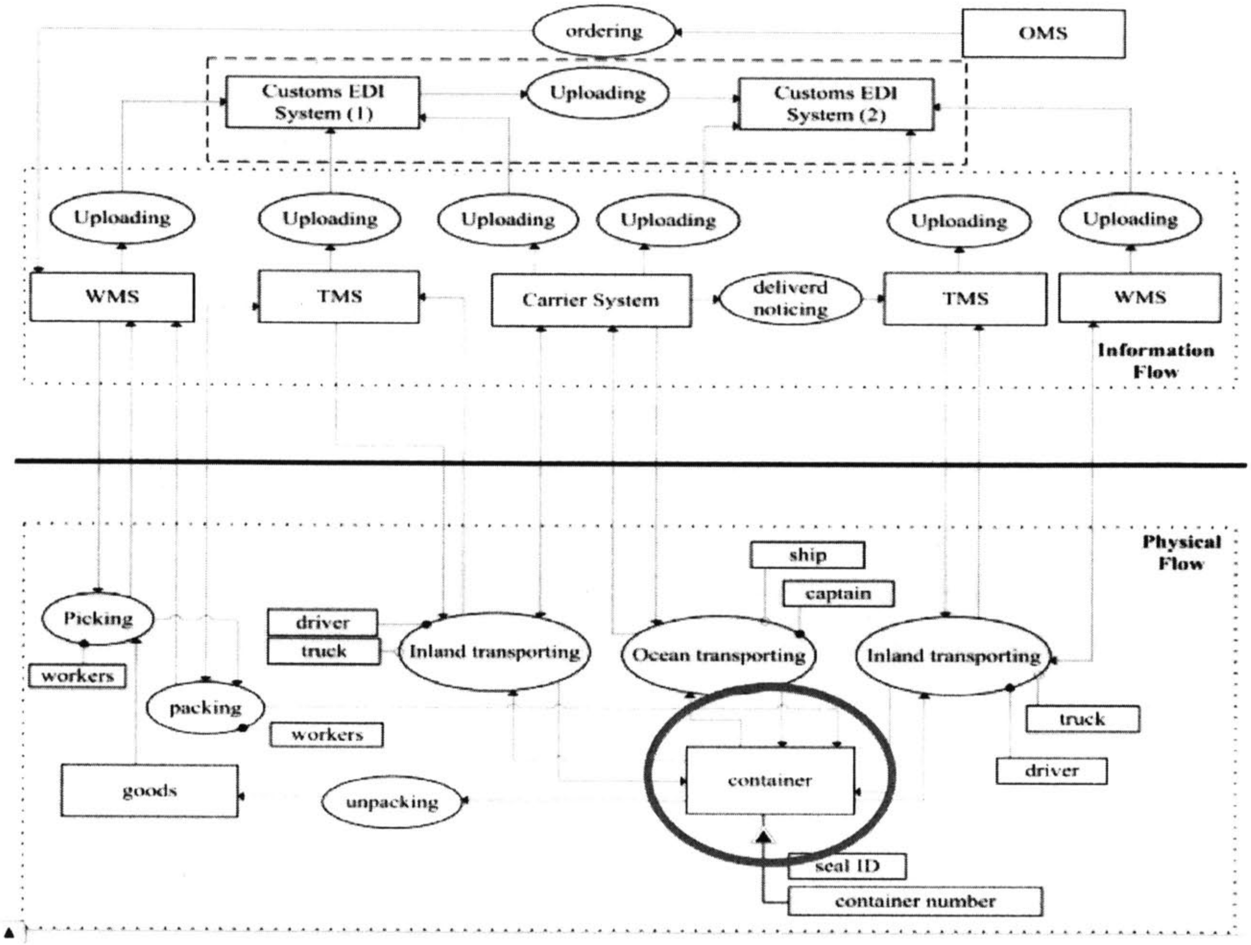

Figure 29: The Physical and Informational Views of the International Cargo Transportation Process

On the other hand, the bottom of Figure 29 represents the physical movement flow. Containers, connected to the majority of the processes in this system, are the value-related operands. Proper design to those processes related to containers can enhance entire system performance significantly. Particularly, the packing process incurs the longest waiting time and incorrect packing list data will inevitably result in failure no matter how secure the following tasks are.

The linkages between informational and physical movement flows are the most noticeable in the object-process diagram. Figure 29 shows that a process in the physical movement system not only affects objects in the physical and corresponding objects in the informational, but activates the following objects in the informational segment as well. For example, “inland transporting” in the physical segment sends feedback to “TMS” in the informational segment and also activates the “Carrier’s System”. Hence, the agents, drivers, and trucks of inland transporting processes play critical roles in connecting physical and informational segments, and transportation progress check points are needed to support the operations.

In understanding the OPM analysis system, three results are summed up: (1) the container is the *value-related operand* of the physical system; (2) well-educated drivers, equipped trucks, and more checking points to confirm transportation status and to activate following processes are needed; and (3) a standard data format among information systems can decrease total complexity.

Metrics Definition for Physical System Improvement

Security is the core concept in the system improvement project. Because it is not a solid and assessable merit, it is difficult to evaluate and select potential improvement options. Governments tend to be heavily concerned with security issues whereas private-sector companies focus on cost and operational efficiency rather than security. Hence, security, cost, and operational efficiency should all be considered at the same time. In the following, the definition of these three indicators and how to assess them are explained.

Security

Visibility is used to assess the degree of security in the supply chain project, and is adopted as an additional concept to redesign existing supply chain architecture. In order to quantify visibility, the following approach of measurement is applied. When a truck is fully equipped and the status of its containers (usually either one or two) can be monitored in real time, the visibility is set as 1.0. If discrete checkpoints are used to substitute real-time tracking, an exponential decreasing function based on environmental factors such as region and transportation type with input variable “duration” is developed to estimate the degree of visibility. Given ten days without auditing, for example, an ocean-transported container is securer than when transported inland. Hence, ocean transportation visibility is higher than land transportation.

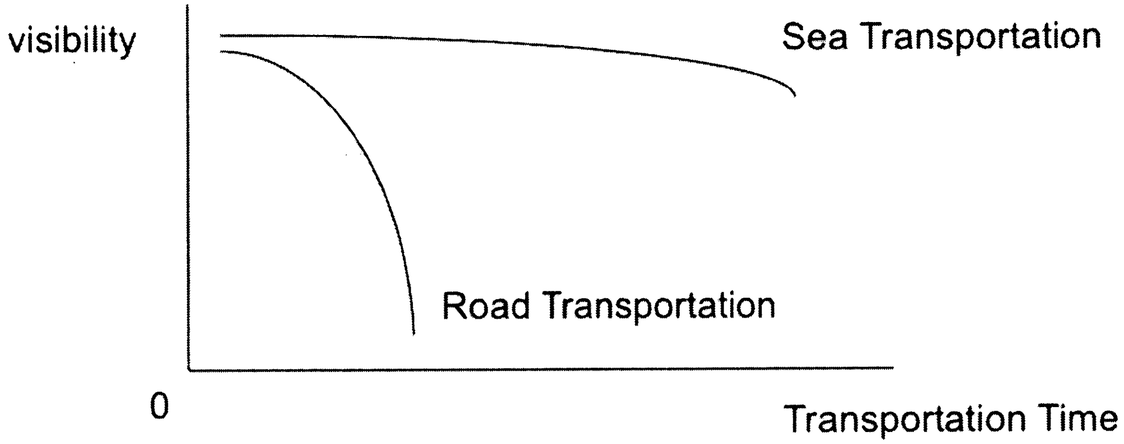

Figure 30: Visibility, Transportation Type, and Time

Costs

Personnel and equipment costs are both considered. Personnel costs include recruitment, education, monthly salaries, and other incurred costs, while equipment costs consist of purchases, installations, operations, and maintenance. The managers of the shipper are asked to estimate the amount of costs for each option.

Operational Efficiency

Because containers are the value-related operands, the processes connected to containers are critical to entire system performance. Hence the total time required for container status inspection, especially the operations requiring human involvement, is investigated to measure operational efficiency. In order to avoid the affect of external factors such as scheduling and traffic, only the inspecting time is measured. If there are multiple checking points, all of the inspecting time should be summed up.

Option Selection for Physical System Improvement

After meeting with the shipper, three control factors (1) number of checking points, (2) manual or automatic monitor, (3) and equipment (e.g. trucks and drivers) are considered in Taguchi's Orthogonal Arrays (L4: two level factors) to adjust the level of security.

Table 2: Experiment Design[6]

Factors / Experiment	Number of checking points	Manual or automatic monitor	Equipping trucks and drivers
1	FEW	Manual	Yes
2	FEW	Auto	No
3	MORE	Manual	Yes
4	MORE	Auto	No

These four experiments are evaluated by the considerations of security, estimated total costs, and operational efficiency. The option of fewer checkpoints with automatic container status checking is selected from the previous analysis for physical system improvement.

Figure 29 shows that the operations in physical flow not only perform their own jobs but also enable informational flow. Hence, after serious consideration, RFID technology is applied to achieve automatic inspection and to activate the information system. In the aspect of informational flow with regards to the requirement of standard data formats and protocols for data sharing, Unique Consignment Reference (UCR) is adopted to enhance existing systems.

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6 Fewer check points means setting up inspection at the beginning and end of any transportation process; fewer check points means adding one extra check point in the process.

RFID Technology

Radio Frequency Identification (RFID) has emerged as part of a new form of inter-organizational system that aims to improve the efficiency of supply chains (Floerkemeier, 2004). RFID is not only a data-capturing technology, but it enables technology (Wamba, 2008) and is able to achieve ubiquitous computing, seamless system integration (Soni, 2008), and improved supply chain sustainability (Turban, 2006). Research (Angeles, 2005; Ton, 2005) show that RFID can help supply chain partners to improve logistics efficiency, responsiveness, value-added services, reduce labor costs, out-of-stock rates, and reduce inventory levels. It is unique and contactless, and these features make RFID widely accepted in security applications.

A typical RFID system consists of tags and readers, and application software (Ngai, 2008). A Tag, which is memory-embedded and has a unique identity code, is categorized as either active (with batteries) or passive (without batteries). RFID readers are the devices that collect data from and write data to compatible RFID tags, and pass retrieved data to a server through a network and enrich applications, such as inventory control real-time tracking, and business intelligence (Heinrich, 2005). To ensure communication compatibility, the tag and reader must work at the same specified working frequency and comply with specific regulations and protocols.

Cargo Data Structure-UCR

Unique Consignment Reference (UCR) is a reference number for Customs use and is required to Customs at any point during a Customs procedure. The main objective of the UCR is to define a generic mechanism that has sufficient flexibility to cope with the most common scenarios that occur in international trade and to satisfy the need for Customs authorities to facilitate legitimate international trade. UCR is used to establish a unique reference to the commercial layer of the transaction between the consignor (customer) and the consignee (supplier). In addition, its standard format also make it possible to share information with stakeholders among the whole process

In the UCR framework, there are five layers of identification from a shipment, containers, pallets, boxes, packages, to a specific item (Ahn, 2005). Embedded RFID tags are used to recognize an object, to match its layer information, and to associate with its dependent objects. In this research, RFIDs are tagged on ocean containers (e-seal), pallets, and boxes that are used in the supply chain (as depicted in Figure 31).

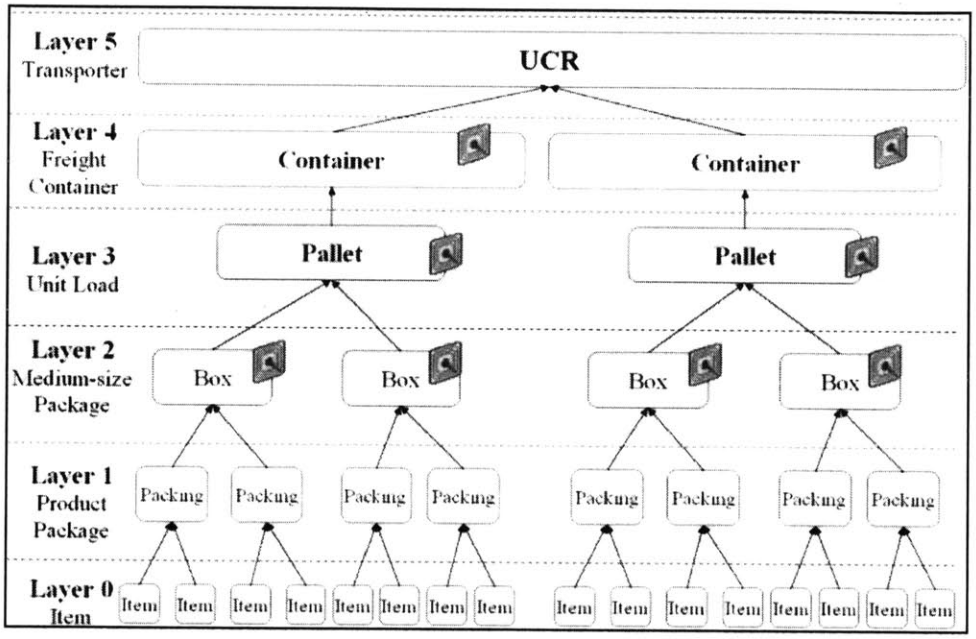

Figure 31: Integrated RFID with Logistics Layer

A Pilot Test

In this pilot test, RFID tags, Ultra-High Frequency (UHF) tags, are applied on boxes, pallets, and containers. A supporting system to match these three types of units was developed, and the matching process is invoked in the packing process in the physical system.

Two types of RFID readers, mobile and fixed, were used in the pilot test. Mobile RFID readers, with wireless communication ability to send data to back-end systems, are used at the consignor's packing/unpacking field to update the reactions between boxes and pallets and pallets and containers to WMS. On the other hand, fixed RFID readers were placed at the access gates, such as receiving/shipping points at a bonded warehouse or container yard and the receiving point at the consignee's warehouse. These fixed readers record the combination data set of driver, truck, and containers, and update them into information systems, and triggered subsequent systems.

System Modules

In order to efficiently integrate physical and information systems, three new modules are introduced: picking and packing information collecting/sharing, container inspection, and UCR code-generating.

(A) Picking and packing information collecting module

This module is designed to gather all goods' exit/entry events at the warehouse to help the supply chain managers to track and manage goods movements. The module also maintains the relations between containers and pallets, and pallets and goods automatically. When a stuffed container leaves the warehouse, a detailed list of the good, container ID, and its UCRs can be generated for Customs authorities without delaying and furthering efforts. In addition, in the container consignee-side warehouse, the detailed package list can be acquired for checking and updating to the warehouse management system by container IDs and UCRs. This module also provides a protocol for inventory managers to understand their real-time and accurate status of inventory for applications such as picking/packing errors prevention or new inventory models such as VMI (Vendor Managed Inventory).

(B) Container Inspection module

Each container in the pilot run was sealed with an RFID-embedded e-seal. When a container was detected by a gate RFID reader, the status of the e-seal when incorporating the UCR code was retrieved and uploaded. This model not only helps to add checkpoints without hiring more staff but also decreases total inspecting time.

(C) UCR code-generating module

The module centralizes the UCR codes for the shipping in the pilot project. Although each company can define their UCR code following some specific rules, UCR codes should be unique and maintain a consistent format within a corporation.

Project Conclusion

The pilot project demonstrated the use of proposed architecting framework and the modeling methodology to design an international security trading system while multiple goals (security, efficiency and cost) and legacy systems were considered. Then RFID technology and the UCR framework were selected to implement the design and provide feedback for further improvement. Through architecture analysis, the system boundary, legacy systems, and key components are identified, and such identification can prevent either device-oriented or process-oriented improvements.

Regarding what was learnt from the demonstration: RFID works well as an enabler and causes physical flow to communicate with information flow. Standard data format such as UCR strengthens the impact of RFID by removing barriers of data sharing. With comprehensive design and proper technology, the win-win among cost, efficiency, and security (or the win-win between the public and private sectors) is achievable.

5. Conclusion

A supply chain is a system of systems. It consists of numerous subsystems, which are designed with various conflicting or non-conflicting goals to other subsystems. If any one participant does not adhere to the goals, other elements are affected thereby diminishing the competitiveness of the system as a whole. However, aligning operations with corporate goals is not as easy as expected because of the involvement of a broad spectrum of new technologies, mandates, and legacy systems (both operational and informational). This complexity produces improper designs and unsuitable technology applications, which weakens the competitiveness of the entire supply chain system. One way to overcome this obstacle is to design an effective architecture that simplifies the complexity and helps managers in decision-making tasks. A properly designed architecture serves as the medium in product, process, and supply-chain concurrent engineering, thus shortening the response time needed for engineering changes.

In chapter 2, the evolution of supply chain management, enterprise architecting, and modelling methods are reviewed. It shows that the use of system architecture on an entire supply chain planning is rare; as a result, no widely recognized and simple modelling methodology is readily available. Therefore, a system architecting framework designed for supply chain planning and its three major cycles (reengineering, strategy, and implementation) are proposed in Chapter 3. A methodology derived from Object-Process-Methodology is used to abstract a supply chain and an approach to transforming supply chain strategy into architecture concepts, and influencing architecture form and function is used to align the architecture with strategy.

The use of proposed architecting framework and modeling methods, and a supply chain security project in Chapter 4 demonstrates that the supply chain architecture could be used to analyze a novel supply chain problem.

In summary, the goals of this study are: (1) Eliminate the gaps between corporate (supply chain) strategy, design, and implementation; (2) Propose a framework consisting of previous research and best practices; (3) Develop a simple, easy-to-understand, planning modelling methodology that carries sufficient information for supply chains. The contributions of this study aligned with these three goals are:

(1) Supply chain architecting framework, including the fulfilment and value chains and the three improvement cycles; and

(2) Architecting methodology, including concept, form, and function, as well as three layers of views from which to represent a supply chain.

Future Work

After studying the use of system architecture on supply chain, I have found there are difficulties to apply it in real world. The difficulties are the mainly caused by the qualitative requirements of architecture and lacking an approach to transforming those requirements into quantitative design. In addition, the description of architecture is static, which is similar to a snapshot at specific time. However supply chain evolves. Static view will limit the contributions of architecture framework. In the following, I listed two supply chain architecture topics, which will contribute long-term supply chain design, for future research. They are transforming path and design pattern.

Architecture Transforming Path

In Fine's three-dimension concurrent engineering, the evolution of product, process, or supply chain affects any other two. The evolution of product from the integral to the modular alters the number of suppliers of a supply chain. For instance, Intel bundled chip sets, wireless cards, and CPUs, which decreased the number of suppliers by two. The number of supplier affects the width of a supply chain shown in Figure 32. On the other hand, process evolution affects the number of layers of a supply chain. Take Dell for example. When Dell sells its products through its website, it eliminates the middle person (the retailer) and shortens the length of its supply chain. When Dell started selling its products via Staples, the length of its supply chain increased. Hence, product evolution influences the width of a supply chain while process evolution affects supply chain length (as shown in Figure 32).

Regarding speed, it is possible to predict the evolutions of product and process as well as the supply chain. However, it raises questions: Should companies prepare for the evolution? How do companies choose a proper transforming path from their current stage to future stages?

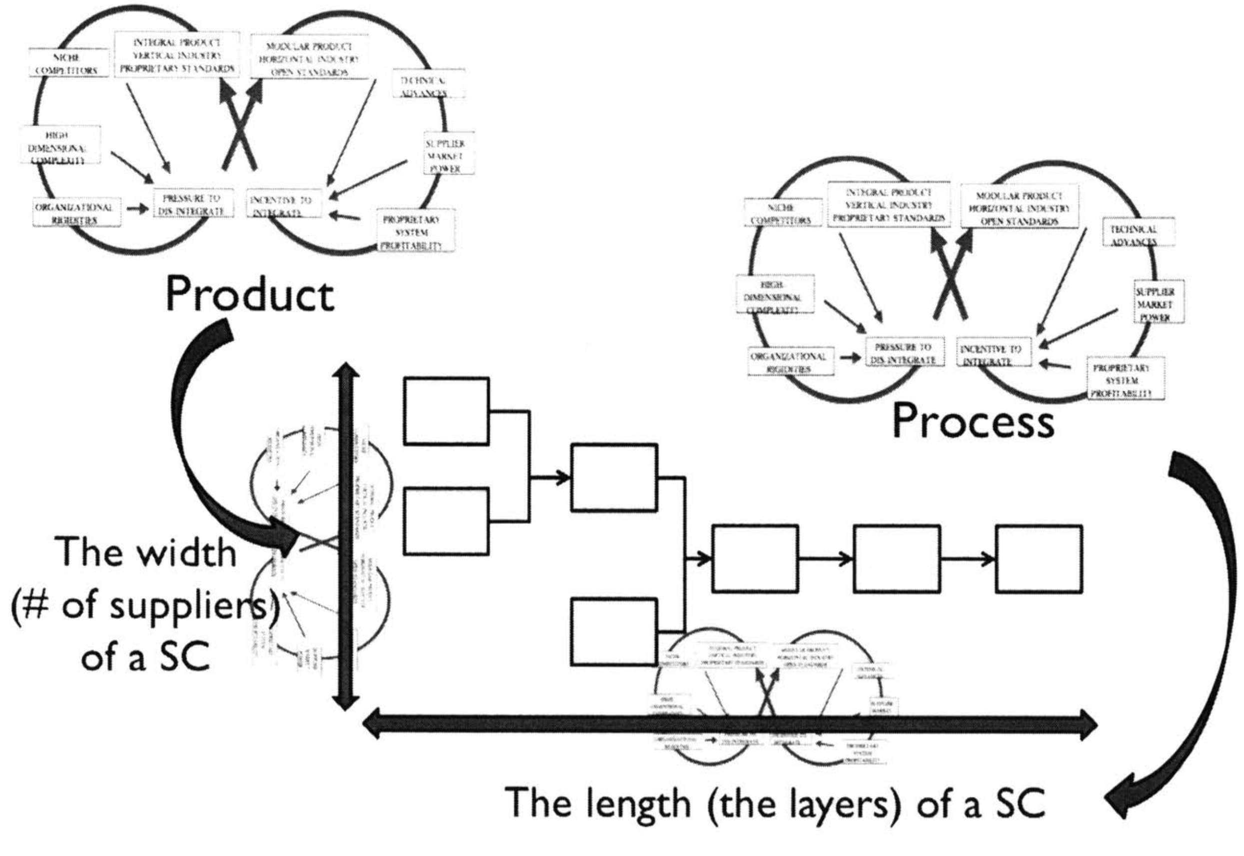

Figure 32: Double Helix, and Product, Process, and Supply Chain

6.3.2 Design Patterns

Architecting a supply chain needs a common language suitable for expressing the design problem. The Architecting Methodology modified from Object-Process Methodology presented in Chapter 3, is a starting point, but it is not sufficient.

With the proposed graphic modeling methodology, obtaining design patterns, which are used in disciplines such as civil architecture and software engineering to convey design decisions, becomes possible. In general, design patterns are appropriate whenever the system is complex. As supply chain management moves into the new view, we believe that patterns are more appropriate for simplifying a complex system. Some known design patterns already exist, although possibly not with that name (e.g. postponement and push/pull boundary); however, as of yet, no one appears to have attempted to build a body of knowledge of supply chain design patterns.

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