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Packaging Design and Development for Supply Chain Efficiency and Effectiveness

Vahid Sohrabpour

LUND UNIVERSITY

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Lund, September 2014

Vahid Sohrabpour

Abstract

In the supply chain interactions with product and packaging systems, actors place various needs on packaging. Satisfying these needs eventually increases the supply chain efficiency and effectiveness. The aim of the research presented is to contribute to the packaging logistics body of knowledge on reducing the gap between the supply chain needs and satisfying them, through packaging design and development directed toward increasing supply chain efficiency and effectiveness.

This research was carried out in a university-industry collaboration on problems in industrial practice and then matched to the academic literature in the field. A pre-investigation and four main investigations were conducted. Investigations 1, 2 and 3 were primarily related to the physical function of the supply chain toward increasing its efficiency. Investigation 4 was based on the market mediation function of the supply chain toward increasing its effectiveness.

Toward increasing supply chain efficiency, this dissertation provides an expanded operational life cycle based on supply chain needs by exploring supply chain interactions with the product and packaging system. In addition, an improved packaging design and development method based on the expanded operational life cycle is provided to satisfy the actor's needs. This was achieved by exploring and analyzing an existing packaging design and development method for satisfying the supply chain needs. By identifying available models and software for corrugated board packaging design and development and exploring their use in industrial practice, this dissertation suggests using a p-diagram as a method to provide a holistic perspective for modeling corrugated board packaging in the improved design and development method. Toward increasing supply chain effectiveness, the dissertation further provides improvement to a model for matching supply chain strategy and product while highlighting the role of packaging by describing the current state of supply chain strategy research in relation to product and packaging in order to map the lack of consideration of packaging.

This dissertation concludes that packaging can contribute to both supply chain effectiveness and efficiency if it is matched to the supply chain strategy and if it is designed and developed to satisfy physical supply chain needs.

Populärvetenskaplig sammanfattning

När en konsument går längs en gång i en butik kan han eller hon enkelt ta ett mjölkpaket utan att tänka på allt som behövts göras för att det ska kunna hamna på hyllan. Många chefer och ingenjörer lägger ner oerhört mycket energi för att detta ska vara möjligt. För varje paket mjölk omfattar kedjan av olika aktiviteter processande, förpackning, transport och lagring, från mejeriet till butikshyllan.

Att ta hand om hela kedjan är en utmaning. Mjölkpaketen måste vara redo att skickas iväg exakt när kunden vill köpa dem. De måste vara av rätt storlek så att innehållet kan konsumeras innan bäst föredatumet och inte behöver kastas. En annan utmaning är att göra kedjan av aktiviteter så effektiv som möjligt för att undvika svinn så att man kan utnyttja transport och lagring på bästa sätt.

Världens befolkning väntas nå 9 miljarder år 2050, vilket kommer att innebära en högre efterfrågan på mat. När välståndet och köpkraften ökar blir efterfrågan på processad mat och mejeriprodukter större. Till år 2050 väntas efterfrågan på mat öka med 70-100 %. Ett sätt att ta sig an den här utmaningen är reducera matsvinnet, vilket uppskattas vara 30-50 % av allt mat som produceras globalt. Den direkta ekonomiska kostnaden för matsvinnet uppskattas till 750 miljarder U.S. dollar.

Förpackningar är ett sätt för livsmedelskedjorna att hantera dessa utmaningar. Den här forskningen undersöker några kompetens- och effektivitetsutmaningar. Den ger förslag på att hantera kedjan av aktiviteter och på bättre förpackningsutveckling. Föreslagna förbättringar inkluderar olika strategier för livsmedelsförsörjningskedjor, modeller, mjukvara samt design- och utvecklingsmetoder. Den här avhandlingen kommer att hjälpa chefer och ingenjörer att göra livsmedelskedjorna mer kompetenta och effektiva.

Appended papers

Paper I

Title: Packaging in Developing Countries: Identifying Supply Chain Needs

Authors: Vahid Sohrabpour[1], Daniel Hellström[1], Marianne Jahre[2]

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Citation: Sohrabpour, V., Hellström, D., Jahre, M. (2012) "Packaging in developing countries: identifying supply chain needs", *Journal of Humanitarian Logistics and Supply Chain Management*, Vol. 2, No. 2, pp.183-205.

This paper was published after a double blind peer review in the *Journal of Humanitarian Logistics and Supply Chain Management*. The data collection and analysis were performed by Sohrabpour. Hellström contributed with his research knowledge through guidance in the methodology and contributed with the literature review. The results, discussion and propositions were conducted conjointly by Sohrabpour and Hellström. In the writing process, drafts were written by Sohrabpour and reviewed by Hellström and Jahre. Based on the drafts and review, Sohrabpour and Hellström conjointly wrote the paper.

Paper II

Title: An Improved Supplier Driven Packaging Design and Development Method for Supply Chain Efficiency

Authors: Vahid Sohrabpour[1], Pejvak Oghazi[2], Annika Olsson[1]

Affiliations: [1]) Division of Packaging Logistics, Department of Design Sciences, Lund University, Lund, Sweden. [2]) School of Business and Economics, Linnaeus University, Växjö, Sweden.

This paper is under second review in *Packaging Technology and Science*. The data collection, the data analysis as well as the writing of the draft were performed by

Sohrabpour. Oghazi and Olsson were responsible for the review of the drafts. Olsson contributed with research experience through advice, suggestions and revision of the paper. Based on the drafts and reviews, Sohrabpour and Olsson conjointly finalized the paper.

Paper III

Title: Models and Software for Corrugated Board and Box Design

Authors: Vahid Sohrabpour[1], Daniel Hellström[1]

Affiliations: [1]) Division of Packaging Logistics, Department of Design Sciences, Lund University, Lund Sweden.

Citation: Sohrabpour, V., Hellström, D. (2011), "Models and software for corrugated board and box design", in the *Proceedings of the11th Biannual ICED Conference,* pp. 392-401, Copenhagen, Denmark.

This paper was published after a double blind peer review in the *Proceedings of the 11th Biannual ICED Conference*. The literature review, data collection and analysis were performed by Sohrabpour. Hellström contributed with research experience through reviews, advice and suggestions. The results, discussions and propositions were developed conjointly by the authors. In the writing process, drafts were written by Sohrabpour and reviewed by Hellström. Based on the drafts and reviews, the authors conjointly wrote the paper. Sohrabpour presented the paper at the conference.

Paper IV

Title: Supply Chain Strategy Interrelations with Product and Packaging – A Literature Review

Author: Vahid Sohrabpour

Affiliation: Division of Packaging Logistics, Department of Design Sciences, Lund University, Lund, Sweden.

Citation: Sohrabpour, V. (2013), "Supply chain strategy interrelations with product and packaging – a literature review", in the *Proceedings of the 25th Annual NOFOMA Conference,* Gothenburg, Sweden.

The paper was presented and published after a double blind peer review in the *Proceedings of the 25th Annual NOFOMA Conference*, 2013.

Other papers

These papers were published in the course of the Ph.D. studies but are not included in the dissertation since they are only peripherally related to its scope and focus.

1. Oghazi, P. Hellström, D. Mostaghel, R. Sohrabpour, V. (2013), "Social responsible supply chain and packaging – A conceptual framework", in the *Proceedings of 25nd Annual NOFOMA Conference,* Gothenburg, Sweden.

2. Sohrabpour, V. Pazirandeh, A. Brad, D. Negreira, J. Zhang, J. (2013), "Teaching and learning adaptation of international students in Sweden", in the *Proceedings of SEFI Conference*, Leuven, Belgium.

3. Nazarpour, A. Fischl, M. Sohrabpour, V. Fynes, B. (2014), "The impact of investments in innovation practices on competitive advantage", in the *Proceedings of EurOMA Conference,* Italy.

Contents

1. Introduction

1.1 Background

Traditionally, packaging did not receive the attention it deserved and it was mostly considered as a necessary cost that had to be minimized (Saghir, 2004). It was further identified as being an under-researched area in logistics and supply chain management (Stock, 2001). This was based on a general consideration of packaging as a minor issue with limited influence on the overall performance of the supply chain (Hellström, 2007; Saghir, 2004). However, if packaging does not receive enough attention it can have a devastating impact on supply chain costs and performance (Azzi et al., 2012).

In response to the neglect of packaging, a research trend started in the 1990s in the field of logistics to recognize and acknowledge the role of packaging. This trend was later referred to as "packaging logistics" and triggered by Twede (1992), Johnsson (1998) and Jönson (2000). It focuses on the role of packaging in the supply chain. Since then, packing logistics has been advanced by other researchers such as Saghir (2004), Abukhader (2005), Olsson (2005), Hellström (2007), Viström (2008) and Dominic (2011). Packaging logistics research focuses on the interaction between the packaging system and the logistics system with the aim of reducing packaging-dependent costs and adding value to the whole (Kye et al., 2013).

1.1.1 Packaging influence

Packaging is an interface between the supply chain and its main customers (the end users); packaging enables the chain's primary task, which is to serve its customers (Klevås and Saghir, 2004; Hellström and Saghir, 2007). If packaging receives enough attention it can become an enabler and value-adding component by providing a wide range of opportunities in the whole supply chain, including cost reduction, enhancement of competitive advantage, marketing, sales and profit (Hellström, 2007).

From another point of view, packaging in relation to products and the logistics system is a fundamental component in the supply chain and has a significant impact on logistics' costs and performance (Twede, 1992; Bowersox et al., 2002). Hence, a perspective has been put forth by Bramklev et al. (2001) and Bramklev (2010), among others, that considers integrated product and packaging design and development. Research has also indicated the significance of product and packaging design and development in relation to logistics and the supply chain (e.g., Bramklev and Hansen, 2007; Olander-Roese and Nilsson, 2009).

Packed products are a major part of material flow as opposed to non-packed products or stand-alone packaging. Physical products are usually delivered to the consumers in the form of packed products. In other words, it is uncommon in modern societies to find a product that does not require some sort of packaging (Saghir, 2004). Thus, product and packaging can be viewed as a system in the supply chain. Such a view can contribute to improving supply chain efficiency and effectiveness by reducing costs and by increasing sales.

1.1.2 Efficiency and effectiveness

Packaging logistics research has pointed out the impact of packaging on supply chain efficiency and effectiveness (e.g., Saghir, 2004; Saghir et al., 2004; Azzi et al., 2012). Packaging logistics, according to Saghir (2002, p. 38), places emphasis on "*the potential of achieving improved supply chain efficiency and effectiveness, through the development of packaging in such a way that it improves packaging related activities*" by considering the interactions between the logistics system and the packaging system.

Efficiency is defined in accordance with Nilsson (2005) and Porter (1996) as doing things right. Supply chain efficiency in this dissertation is used primarily in relation to the physical function of the supply chain. The physical function embraces "*converting raw materials into parts, components, and eventually finished goods, and transporting all of them from one point in the supply chain to the next*" (Fisher, 1997). These efficiencies involve, for example, production and logistics processes (Rainbird, 2004; Nilsson, 2005). Saghir (2002) places manufacturing, distribution, handling and storage performance under efficiency in the supply chain. One way to measure supply chain efficiency is through product waste rates from manufacturing, distribution, handling and storage, and on the shelf (e.g., Van Hoek and Chapman, 2006). Packaging can contribute to reducing such waste.

Effectiveness is defined in accordance with Nilsson (2005) and Porter (1996) as doing the right thing. Supply chain effectiveness in this dissertation is considered to be the match between demand and supply, based on a less obvious but equally important function of the supply chain: market mediation (e.g., Heikkilä, 2002), which is related to the effectiveness in a given business (Rainbird, 2004; Nilsson, 2005). The purpose of the market mediation function "*is ensuring that the variety of products reaching the marketplace matches what consumers want to buy*" (Fisher, 1997). Saghir (2002) along with Olander-Rose and Nilsson (2009) place marketing related performance – service level, sales and consumer satisfaction – under effectiveness in the supply chain.

1.2 Problem description

The flow of product and packaging systems in the supply chain can encounter several problems in industrial practice. These hinder supply chain efficiency and effectiveness, leading to negative consequences at different places in the chain. Such consequences are essentially indications of the problems.

1.2.1 Efficiency and effectiveness problems in industrial practice

One problem regarding the flow of product and packaging systems in the supply chain is damage to the product and/or its packaging. This decreases efficiency in the chain. If secondary packaging does not perform its protective function of the contents (product and primary packaging), this can result in damage to the product and/or primary packaging. A consequence of damage is product loss in the supply chain. The World Food Program (WFP, 2013) also mentions the loss that occurs in the supply chain can be due to damage to the packed products. A damaged packaging cannot perform its marketing function. Frequently, liquid products with damaged primary packaging cannot be sold, even when no leakage has occurred. Among various factors that can cause damage to the packed products, the WFP (2013) mentions moisture and heat. Damages can also occur in storage and handling (Verghese et al., 2013). Stock and Lambert (2001) state that the longer the distances and the higher the number of times the product is handled, the greater the risk for damage and pilferage.

For liquid packed products, damage can result in leakage. Leakage from one package can impact many other primary packages inside one secondary packaging. Moreover, leakage can soften the corrugated board secondary packaging and make it collapse. The collapse of one can result in the surrounding secondary packaging collapsing and the total product loss can rapidly increase.

Another example of problems that the flow of product and packaging systems in the supply chain can encounter is low transport utilization. This results in inefficiency in the chain. The number of products that can fit inside a vehicle can vary depending on the product and its packaging characteristics (e.g., volume, weight and geometry). If the packaging is not performing its unitization function in accordance with the pallet used and/or the truck size, it reduces transport utilization. In other words, the higher the number of products that can fit inside a truck, the greater the transportation utilization. In addition, if packed products contain a high amount of unused space inside the packaging, transport utilization decreases. Packaging design initiatives to reduce the volume and weight in the supply chain are considered to be a de-carbonization potential by World Economic Forum (2009), equal to 132 megatons of CO_2 globally.

In industrial practice, such problem was identified by IKEA with its tea candle product (Gustafsson et al., 2005). In order to reduce the empty space inside packaging and in vehicles, the product and packaging developers together redesigned the tea candle product and its primary packaging considering the entire supply chain. This enabled space utilization on the pallets and in the truck. It resulted in a pallet reduction of 30% and 200 fewer trucks being used each year, as well as a 21% reduction in CO_2 emissions. This means that fewer trucks were used for the same number of products, resulting in higher transportation utilization. Inefficiencies like these add costs to the supply chain and are related to its physical function. These are referred to as "physical costs" and typically include production, distribution, and storage costs (e.g., Mason-Jones et al., 2000a).

Excess and shortage of packed products for sale in the supply chain are another set of problems in industrial practice. This is especially a problem for agricultural based products, where there is a production season and the demand for products varies throughout the year. The flow of product and packaging systems has to be managed according to the demand to avoid excesses and shortages. For products that have short product life cycles, an excess of them increases the risk of obsolescence (Fisher, 1997). In addition for food products, inadequate remaining shelf life is a reason for food loss and waste in the supply chain (Verghese et al., 2013). Lundqvist et al. (2008) report that inefficiencies in harvesting, transport, storage and packaging are dents in food availability. They claim that significant wastage occurs in food processing, at wholesalers, retailers and in households. One third of the total amount of food products that are produced for human consumption are lost or wasted in the world every year (Gustavsson et al., 2011). Other estimations claim that the wastage between the farm and the fork is 50% globally (Lundqvist et al., 2008). The direct economic cost of agricultural food product wastage is estimated to be 750 billion USD (FAO, 2013). Moreover, the environmental impact of uneaten food in terms of its carbon footprint is estimated to be equivalent to 3.3 gigatons of CO_2 (FAO, 2013). Packaging can contribute to reducing food wastage (Williams et al., 2008; Svanes et al., 2010), related environmental impacts, and to enable the efficient distribution of products (Verghese and Lewis, 2007).

On the other hand, not having the right product to supply the demand results in an opportunity cost (Qi et al., 2009). This cost means the customer loses sales in the market (Heikkilä, 2002). The cost of excesses and shortages of packed products is called the "market mediation cost" (e.g., Randall and Ulrich, 2001). Having a high number of excesses or shortages of packed products means that the supply chain is not able to supply the demand, which is its vital market mediation function. Consequently, these problems reduce the supply chain effectiveness. Packaging that enables longer shelf life for food products can reduce the risk of wastage and increase the ability to supply the demand. Designing and developing packaging in relation to the whole supply chain is vital to avoid problems in supply chain efficiency and effectiveness and thus prevent the consequences.

1.2.2 Cause of efficiency and effectiveness problems

Efficiency and effectiveness problems in the supply chain can be viewed as being caused by a gap. The gap can be represented by the extent to which an existing packaging solution satisfies the actors' needs placed on the product and packaging system along the supply chain. The gap between needs and satisfaction is illustrated in Figure 1-1. An example that describes this gap in practice is provided by Van Hoek and Chapman (2006). P&G measured product waste on the shelf to be between 2 to 10% (depending on country and category) in comparison to less than 0.1% defect rate in the factory. This was the consequence of warehouse procedures, transportation and store handling methods impacting the product and packaging system. The root cause identified was that the packaging was not suitable for the supply chain environment, which in itself was the result of the designers and developers not understanding the needs that the supply chain placed on the packaging.

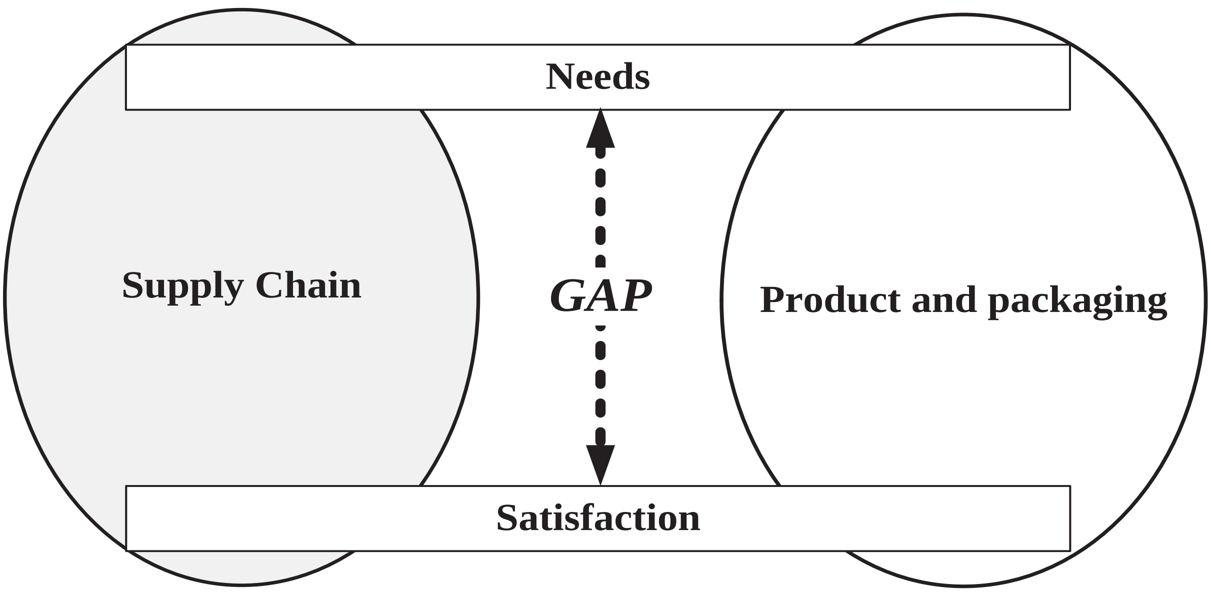

Figure 1-1 Illustration of the gap between needs and satisfaction.

The product and packaging system – as a part of the material flow of the supply chain – is exposed to various operations, production and logistics processes that take place in different settings from upstream to downstream of the supply chain (Rainbird, 2004). Accordingly, every actor has specific physical needs regarding the product and packaging system. Meeting or satisfying these needs by the product and packaging as one system can provide higher efficiency to the entire supply chain in line with its physical function. Thus, the design and development of the packaging from a holistic perspective for the intended product can eventually lead to overall supply chain efficiency (Azzi et al., 2012), reflected in terms of cost.

In addition to physical efficiency, the supply chain has to meet the demand at the final actor. Three main strategies for supplying the demand can be chosen based on the market mediation function of the supply chain: physically efficient or lean, market-responsive or agile, hybrid or leagile (Golicic and Sebastiao, 2011; Zhang and Huang, 2012). Comparing these strategies, the driver in a lean strategy is primarily cost, in an agile strategy primarily lead-time and availability, and in a leagile strategy primarily the service level (Naylor el al., 1999; Mason-Jones et al., 2000a; Christopher and Towill, 2001; Bruce et al., 2004; Agarwal et al., 2006; Hilletofth, 2009). Thus, not only the cost but also lead time, service and quality needs have to be met (Naylor et al., 1999) from the effectiveness point of view.

Based on the market mediation function of the supply chain, the difference between what needs to be provided to meet the demand and the extent to which the existing packaging solution satisfies the needs represents the gap. This gap can cause an excess or shortage of packed products for sales in the supply chain. Packaging can enable or hinder meeting the demand in the supply chain. Different supply chain strategies for responding to the demand can be chosen for the intended product (Qi et al., 2009). Various postponements of product or packaging can be chosen in relation to each supply chain strategy to supply the demand (e.g., Hilletofth, 2009; Stavrulaki and Davis, 2010) such as Design-To-Order (DTO), Make-To-Stock (MTS) and Pack-To-Order (PTO).

1.2.3 Research for satisfying the needs

Viewing the supply chain as a system (Huang et al., 2002), it interacts with the product and packaging system. However, the gap between needs and satisfaction has to be reduced to decrease the problems and eventually increase the supply chain efficiency and effectiveness. Research is thus required to contribute to reduce the gap.

The contribution of product and packaging together as a system to satisfy the needs and add value to the supply chain actors and end-customers, is regarded as a key factor in overall supply chain efficiency and effectiveness (Hellström, 2007). In spite of this, theoretical frameworks for supply chain management mainly address product related business processes and tend to neglect packaging. Cooper et al. (1997), Lambert et al., (1998) and Lambert and Cooper (2000) provide a well-known framework of supply chain management. In the framework, product development is a business processes that has to be considered in the supply chain management, but packaging related processes are neglected.

Taking into account the significant impact of packaging (Twede, 1992, Bowersox et al., 2002), industrial practice reveals that misalignments between needs and satisfaction impact supply chain efficiency and effectiveness (e.g., Van Hoek and Chapman, 2006; Twede et al., 2000). Previous research by Klevås and Saghir (2004) has pointed out the role of packaging and emphasized that there is a gap relating to the supply chain conditions and the product design that is to be bridged by packaging. According to the above descriptions, packaging solutions can satisfy the needs toward increasing supply chain efficiency and effectiveness.

Reducing the gap can be described based on supply chain functions (i.e., physical and market mediation [Selldin and Olhager, 2007]). Thus, both the supply chain and the product and packaging system have to comply with each other in order to be efficient in relation to supply chain operations (e.g., Johnsson, 1998) and effective in responding to the demand (e.g., Twede et al., 2000). In other words, packaging has to satisfy the supply chain's operational needs regarding material flow and the market mediating needs in supplying the demand. Taking into account these functions, the described gap can be studied.

1.3 Aim and research questions

The aim of this research is to contribute to the packaging logistics body of knowledge on reducing the gap between the supply chain needs and satisfying them, through packaging design and development directed toward increasing supply chain efficiency and effectiveness. Satisfying the actors' needs regarding operations along the supply chain has been studied in this dissertation based on the chain's physical function. Satisfying the needs in relation to supplying the demand has been studied based on the chain's market mediation function. These two main functions complement each other in efforts to achieve supply chain efficiency and effectiveness.

The dissertation contributes to the packaging logistics body of knowledge in four areas. These areas are explained in the four sub-sections and are as following:

- The lack of knowledge on supply chain needs on packaging.
- The lack of knowledge on supply chain focused packaging design and development methods.

- The lack of knowledge on the use of models and software for packaging design and development.
- The lack of knowledge on the role of packaging in relation to the supply chain strategy.

1.3.1 Lack of knowledge on supply chain needs on packaging

To provide packaging solutions that can satisfy the supply chain needs, the needs have to be identified first. Operations conducted by various actors from upstream to downstream create a range of needs that packaging has to comply with. The needs can be particular for individual supply chains, such as those in developing countries. Most previous packaging logistics and supply chain research, though, has been conducted in developed countries and little has been undertaken in developing countries (e.g., Lee and Lye, 2003). None of the research addresses the needs placed on packaging in supply chains in developing countries. The studies on developing countries are more focused in general terms on transportation, infrastructure, logistics and supply chain management (e.g., Jacobs and Greaves, 2003; Pucher et al., 2003; Dobberstein et al., 2005; Prater et al., 2009). Prater et al. (2009), for example, deal with operational issues in China and India; Dobberstein et al. (2005), with logistics in developing countries.

Industrial experts also report the lack of information and knowledge related to supply chain needs placed on packaging and its role in developing countries. They also report low supply chain efficiency, which is caused by problems in product and packaging systems. Each of the developing countries and their internal regions are in different stages of development. Thus, infrastructures that are necessary for supply chains (e.g., roads and truck) are at different levels of advancement (Prater et al., 2009). However, there are many generic needs on packaging in developing countries such as hand packing in production and manual handling.

To reduce the gap between needs and satisfaction, it is necessary to identify the supply chain needs. Then they can be used in design and development that results in packaging solutions for greater supply chain efficiency. To identify the needs, one has to understand the interactions between supply chains and packaging. To achieve such understanding, one needs to investigate the interactions between supply chains and packaging in developing countries. Accordingly, the following research question is put forward:

- **RQ1:** How do supply chains in developing countries interact with packaging?

1.3.2 Lack of knowledge on supply chain focused packaging design and development methods

Klevås and Saghir (2004) argue that a well-designed and suitable packaging by practitioners in product development is not necessarily the one that best satisfies the needs of the actors along the supply chain. Despite the devastating impact that packaging can have on supply chain costs and performance, it has been a tradition to consider packaging as serving a subordinate role in relation to product design (Azzi et al., 2012). Thus, most research in design and development focuses on the product itself and leaves out the packaging

There is not much research in the academic literature that has a supply chain perspective on packaging design and development (García-Arca and Prado-Prado, 2008). Whereas there is design and development research on concurrent development of products and their packaging (e.g., Bramklev et al., 2001; Bramklev and Hansen, 2007; Olander-Roese and Nilsson, 2009; Bramklev, 2010), there is still a lack in design and development methods considering product and packaging from a supply chain perspective. Klevås (2005b) sees the opportunity for savings by considering the product, the packaging and the supply chain characteristics early in the product development process. She considers the impact of packaging and product explicitly on logistics and benefits in terms of saving cost.

But as mentioned earlier, most design and development research tends to neglect packaging (Azzi et al., 2012) specifically in relation to the supply chain. One example is Design for X (DfX) research (e.g., Design for Supply Chain Management [Lee and Sasser, 1995], Design for Logistics [Dowlatshahi, 1996; Mather, 1992; Roozenburg and Eekels, 1995]). One of them is called Design for Packaging Logistics (Klevås and Saghir, 2004), which focuses on packaging in the supply chain and provides guidelines in terms of broad design roles. Yet a more detailed design and development method is necessary to identify, quantify and prioritize supply chain needs for packaging design and development.

Moreover, according to Klevås and Saghir (2004), methods that can provide packaging evaluations by having a holistic approach to the supply chain are necessary to avoid sub-optimizations. The authors point out the necessity of putting forward methods that connect the performance information from logistics back to the product design and development processes. Such methods are required that emphasize the role of packaging along the supply chain in contrast to the limited existing ones that are only suitable for certain supply chain stages.

In the product development literature, the operational lifecycle is used as an interface between product development and supply chain operations and it typically includes procurement, production, distribution and reverse logistics (e.g., Sarkis, 2003). The operational life cycle has not been explicitly used for packaging design and development in the scientific literature, however Sarkis (2003) states that packaging has a strong relationship to components of the operational life cycle (e.g., warehousing, transport).

In practice also, there is a lack of supply chain focused packaging design and development methods that provide packaging solution to satisfy supply chain needs for increased efficiency. In food and beverage supply chains, packaging plays an even more vital role compared to non-food products since it gets integrated with the product and hence it has to be taken into account. Basically, packaging is the component that makes it possible to protect and ship food products to various markets.

Thus the following question is put forward:

- **RQ2:** How can a design and development method be improved to satisfy the needs placed on packaging in the supply chain?

1.3.3 Lack of knowledge on the use of models and software for packaging design and development

Corrugated board box is a typical type of secondary packaging commonly used in supply chains, especially in developing countries. Its design can contribute to supply chain efficiency. In the academic literature, there is a widespread theoretical research on design and development of corrugated board and boxes (e.g., McKee et al., 1961; Koning, 1975; Dimitrov and Heydenrych, 2009). Moreover, industry has generated models and software (e.g., *CAPE PACK* and *TOPS* [Ge, 1996]) to provide estimations of the strength of the board and box. Yet, there is a lack of research on the use of these models and software for packaging design and development by different actors in the corrugated board packaging supply chain.

In practice, it is costly and time consuming to produce and test the performance of packaging solutions that are the outcome of design and development methods. These tests are conducted on a set of samples. Thus, models (i.e., predictive equations) have been generated instead to reliably estimate the performance (e.g., strength) of the box to reduce the necessity for the production and testing of every box (Urbanik and Frank, 2006). Basically, the models and software that are developed to make predictions contribute to the design and development of packaging by reducing the number of the tests required and the time spent on validating a packaging solution. These types of models and software can be used in corrugated board packaging design and development. However, in practice, there is a lack of knowledge about the models and software to be used. Moreover, the models and software are still not extensively used by industry. Such models and software serve packaging design and development for satisfying the needs in the supply chain.

The following research questions were put forward to provide propositions toward improving the use and development of models and software for corrugated board and box design:

- **RQ3:** What models and software are available for predicting corrugated board and box properties?
- **RQ4:** How do different supply chain actors in the corrugated industry use these models and software?

1.3.4 Lack of knowledge on the role of packaging in relation to the supply chain strategy

There is a lack of knowledge on supply chain effectiveness based on the market mediation function regarding the role of packaging. Addressing it complements the above mentioned areas of research for supply chain efficiency. Thus, it is necessary to explore the interrelations between various supply chain strategies and packaging.

According to the market mediation function of the supply chain, the product characteristics is used as a key driver for choosing the supply chain strategy (e.g., Huang et al., 2002; Christopher and Towill, 2006; Zhang and Huang, 2012) while packaging is most often neglected in their selection. As mentioned before in the supply chain management framework (e.g., Cooper et al., 1997), only the product structure is stated to be coordinated across supply chains in order to avoid inefficiencies.

Within supply chain strategies various postponements can be implemented for increased effectiveness, such as Engineer-To-Order (ETO) and MTS (Li and O'Brien, 2001; Burn and Castell, 2008; Stavrulaki and Davis, 2010). Hilletofth (2009) places ETO in relation to an agile supply chain strategy and MTS in relation to the lean while there is a range of other postponements between these two. In the design and development literature, design for supply chain management contributes to supply chain decision making in implementing postponement (e.g., Lee and Sasser, 1995; Chiu and Okudan, 2010). Design for supply chain management is also an example that focuses on product design in the supply chain and not packaging design.

Still, there is little research that addresses packaging in relation to the supply chain strategies and related postponements (e.g., Twede et al., 2000; Van der Vorst et al., 2001; Aitken et al., 2005; Hilletofth, 2009; Abukhader and Jönson, 2011). Abukhader and Jönson (2007) emphasize that there is an obvious lack of scientific literature on postponements for food, and thereby a lack of systematic attention to generate their application in the food industry. To increase effectiveness in industrial practice, specifically in food and beverage supply chains, it is necessary to have a deeper insight into the supply chain strategy in relation to both product and packaging as packaged consumer goods and the consequences on them.

The strategic impact of packaging solutions on supply chains is an area that requires research (Hellström, 2007) to improve supply chain effectiveness. Thus it is necessary to better understand and describe the current state of supply chain strategy research in relation to product and packaging in order to map the lack of consideration of packaging. Accordingly, the supply chain strategy interrelations with product and packaging have to be explored in the academic literature.

1.4 Research focus and demarcation

The focus of the research presented in this dissertation is on efficiency and effectiveness in the supply chain through packaging design and development. Such efficiency and effectiveness is based on actors' needs along the supply chain in supplying the demand. The needs in focus are the supply chain needs on packaging that have to be satisfied to increase the supply chain efficiency and effectiveness. This means aspects such as innovation in packaging design and sustainability (i.e., environmental, social and economic) are not the focal points for this dissertation.

The product and three levels of packaging (i.e., primary, secondary, and tertiary) are considered as a system in this dissertation. Among the components of the product and packaging system, the focus is mainly on the secondary packaging. One reason is that it is easier to change secondary packaging. Primary packaging machinery is often integrated in the main production line and considerable investment is needed to change it (Orth and Malkewitz, 2008). There is also less research on secondary packaging design and development in the academic literature. Azzi et al. (2012) report that from 1990 until 2011 only 19% of the publications – identified in Compendix, Inspec, OAIster, EBSCO and Web of Science – have addressed secondary packaging design and development in contrast to 54% on primary packaging.

The research presented has been conducted as collaborative research with packaging industry (i.e., Tetra Pak) which supplies the food and beverage producers (i.e., dairies). This means the research is also motivated by problems in industrial practice.

Therefore, the empirical context of this dissertation has been ambient milk supply chains which make up the major category of the Tetra Pak packaging portfolio. In this empirical context, ambient milk products were packed in carton packaging as the primary packaging. The packed milk products have a long shelf life at ambient temperature of about three to six months. This type of primary packaging requires fully-protecting secondary packaging, since it should not bear any load and is sensitive to physical impact. The secondary packaging focused on in this dissertation is corrugated board box, especially the Regular Slotted Container (RSC) type. This type of secondary packaging was used to provide full protection for the primary packaging and its content. Tertiary packaging (i.e., pallet) was not used by most actors in the investigated supply chain, except for dairies and distributors.

The empirical context is also limited to supply chains from the filling point at dairies to the point of sale at retail stores (see Figure 1-2). The point where product and primary packaging are integrated (i.e., the filling point at dairies) is chosen as the starting point. Thus, the flow of packaging material from packaging suppliers is not included. Since, the last point is the point of sale at retail stores, packaging design and development for consumers is not treated either.

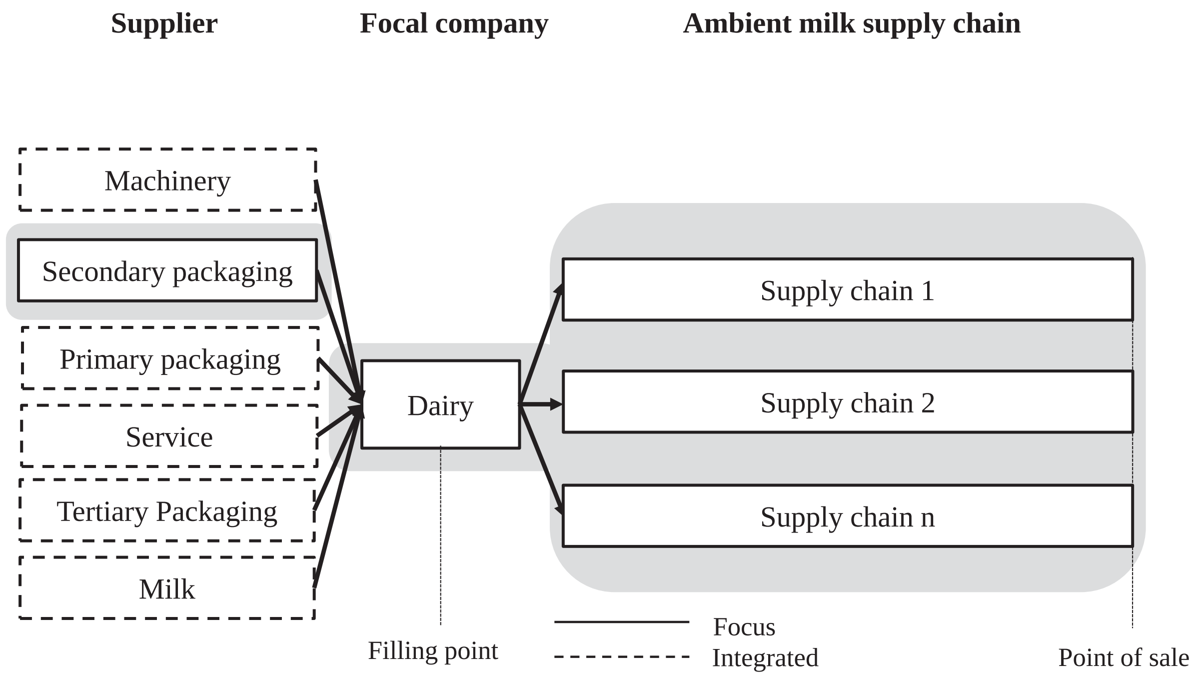

Figure 1-2 Research focus.

This research, when it comes to markets, is also limited to developing countries, while studies of the design and development methods have taken place at the headquarters in Sweden where R&D for developing countries mainly took place. The industry was located in Sweden and hence the research was conducted primarily in Sweden and partly in China. Thus, most of the data collection had Swedish sources but was not limited to them. The results can be used for analyzing packaging design and development in relation to supply chains in developing countries. It is also beneficial for providing packaging solutions that can increase supply chain efficiency and effectiveness.

Ambient milk packed products do not need to be chilled which makes them suitable for supply chains that lack cooling and freezing infrastructures in developing countries. It is estimated that food loss in distribution of developing countries is close to 50% (ECR Europe, 2009). In developing countries (i.e., low income), food wastage mainly occurs at the early and middle stages of the food supply chain (Gustavsson et al., 2011) such as on-farm, and in transport and processing (Nellemann et al., 2009). In low-income (i.e., developing) countries the reason for food losses and waste is reported by Gustavsson et al. (2011, p. V) to be mainly related to "*financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in difficult climatic conditions, infrastructure, packaging and marketing systems*". They also advise that investments in infrastructure, transportation, food industries and packaging industries are required to strengthen the food supply chains in developing countries. Thus, the food packaging supply chain is an interesting research area to be studied in developing countries.

1.5 Outline of the dissertation

This dissertation presents the research methodology, frame of reference, results from the appended papers, concluding discussion, contributions and further research, four appended papers and appendices. The chapters are as following:

Chapter 1 – Introduction

This chapter provides an overview of the main research area to establish a basic understanding and demonstrate its importance. It explains the relevance of the research. The background of the research is described; problems, gap, areas where knowledge is lacking and research questions are put forward. Then the research focus and demarcation, and outline of the dissertation are presented.

Chapter 2 – Methodology

The collaborative research process is described. Research design and scientific reasoning is presented. Data collection and analysis is explained. Research quality is also discussed.

Chapter 3 – Frame of reference

The framework of the research based on academic literature is presented. It consists mainly of an overlap between supply chain management and logistics, product design and development, and packaging design and development.

Chapter 4 – Results from appended papers

From the four appended papers, results are summarized and their connections to the research aim and research questions are clarified.

Chapter 5 – Concluding discussion

Results from appended papers are synthesized and further discussed in this chapter.

Chapter 6 – Conclusions and further research

The academic positioning of the research, academic contribution and contributions to industrial practice are described in this chapter. Suggestions for future research are also presented.

2. Methodology

2.1 Collaborative research

This research was conducted in a university-industry collaboration on problems in industrial practice and then matched to the academic literature in the field. Thus, the research questions were primarily based on industry problems. This is in line with Pushor (2008) who states that collaborative research can be on problems and challenges that the community finds puzzling, with the support of university academics. Collaborative research helps to bridge academic research and industrial practice, and strives to generate actionable scientific knowledge that meets practical demands and advances the causes of the scientific community (Lawler et al., 1985; Tenkasi and Hay, 2008; Börjesson, 2011).

Thus, a research steering group was established consisting of two academic researchers and four practitioners as co-researchers (Appendix A). Pushor (2008) states the involvement of co-researchers in all aspects of the research, such as shaping the research question, design and engagement in the inquiry process, as well as discussing field notes, making and communicating the meaning through research manuscripts, papers/articles and presentations. Thus, the steering group was involved in all these aspects by supervising while I conducted the entire research effort. The participation and contribution of each member varied based on their different roles, time they could spend, skills, background and interests in various aspects of the research as Pushor (2008) mentions.

The action to be taken based on the knowledge gained was entirely dependent on the industry's decisions for future implementation; I had no role in that. Whereas actionable knowledge is defined as knowledge that is meaningful for action or can be translated into it (Adler and Shani, 2001), it is not about the actual implementation.

2.1.1 Industrial Ph.D. at Tetra Pak and Lund University

This collaborative research was conducted through an industrial Ph.D. program, which is close to what Hart et al. (2004) call an "executive Ph.D." This setting was in line with Näslund's (2002, p. 328) advice that, "*logistics researchers have to gain* *extreme relevance by spending more time in the organizations.*" In addition, they have to gather information based on arguments about two basic methods in research namely, "asking questions" and "hanging out" (Dingwall, 1997). The industrial Ph.D. setting also provided opportunities for on-site visits for case studies in accordance with Ellram (1996, p. 105).

The industry partner was Tetra Pak's Package and Distribution Solutions Department. Its interest for the industrial Ph.D. program was to assist its customers (e.g., dairies) in developing countries with packaging solutions (e.g., secondary packaging design) to increase their supply chain efficiency (e.g., lowering product loss). Moreover, the Swedish government and educational authority also recommend that researchers at Swedish universities (e.g., Lund University) collaborate in research and development with companies, agencies, associations, and other organizations as a research model (Brulin, 1998). This model appears to be close to the concept of collaborative research (Ellström, 2008).

Tetra Pak designs and develops packaging solutions for various supply chains by applying a holistic approach to the product and packaging system to achieve higher efficiency. Tetra Pak is one of the leading liquid food-packaging suppliers in the world. These reasons made it a suitable collaborator for packaging logistics research. The Package and Distribution Solutions Department considers the product and all three levels of packaging and their interactions as a whole in milk supply chains rather than focusing on the parts in isolation.

Tetra Pak supplies 173 billion packages for liquid food and beverage products to 8,708 packaging machines in over 170 countries. This means that the company has extensive knowledge regarding packaging design and development, and the supply chains of its customers. Employees in the organization continuously conduct audits, field visits, measure product waste, and collect data from various supply chains around the globe. Accordingly, Tetra Pak's customers (i.e., dairies) in different countries have been provided with packaging and supply chain solutions that contribute to their supply chain efficiency. The Package and Distribution Solutions Department, where the research presented in this doctoral dissertation took place, is mainly located in Sweden and partly in China.

2.1.2 Collaboration process

Collaborative research is the basis of this dissertation. It has contributed to rethinking and transforming the packaging design and development methods, models and software as a part of the development processes to reduce the gap between supply chain needs and satisfying them. Mikaelsson (2002) carried out similar collaborative research with Volvo Car Corporation; Mikaelsson and Shani (2004) prescribed it for the rethinking and transformation of product development processes. From a methodological point of view, packaging development processes can be compared to product development processes.

Collaborative research can be used in multidisciplinary groups of researchers and practitioners to pursue a research question in more comprehensive, holistic, or integrated ways (Pushor, 2008). The research steering group fulfilled this condition of Pushor's (2008) (see Appendix A). In the collaboration between Lund University and Tetra Pak, nine quarterly meetings (approx. 2 hours each) were held by the steering group in the course of the empirical work. Figure 2-1 illustrates the meetings. There were five steering group members in the beginning and the sixth joined later in the process. In addition, I had separate weekly meetings with steering group members in industry and at the university. Further information on the steering group members is provided in Appendix A.

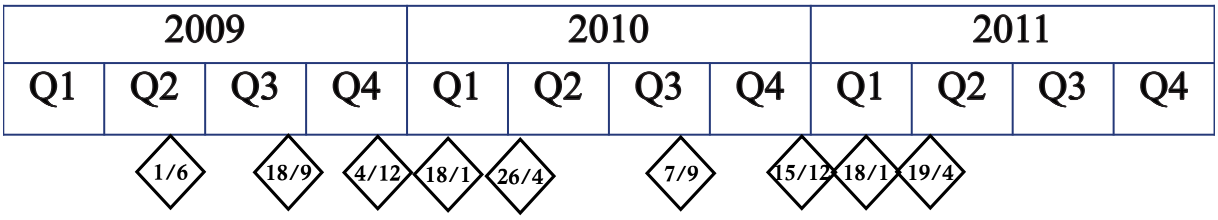

Figure 2-1 Quarterly meetings in collaboration between university and industry

Since, I was working full time at the company in the industry-university collaboration for 27 months during my Ph.D. research, I attended the group, department (i.e., Package and Distribution Solutions) and platform (i.e., Carton Economy) meetings for employees working with packaging design and development during that period. There was also an expert group at the company, the secondary packaging and distribution network, which held meetings every quarter that I attended (see Appendix B). In parallel to being involved in Tetra Pak, I was a member of TAPPI (Technical Association of the Pulp and Paper Industry) and CSCMP (Council of Supply Chain Management Professionals), which provided me with more industrial perspectives through their databases. They also provided access to research journals such as the *TAPPI Journal* and the *Journal of Business Logistics*.

2.1.3 Pre-investigation (initiation)

Four main questions based on the aim of the research were roughly formulated by the collaborating company. These questions took into account industry problems that were further explored and formulated as research questions through the process of a pre-investigation at Tetra Pak. This was a primary step in designing the investigations.

The pre-investigation based on pilot interviews, internal documents reviews and attendance at training sessions was conducted to understand the industry problems, match them to the academic literature and formulate the research questions. More information on data collection and analysis of the pre-investigation is provided in section 2.4. I formulated and proposed the research questions to the steering group. Members discussed the research questions and I reformulated them until I received their approval.

The pilot interviews not only contributed to understanding the problems, they also helped to identify the experts who could add to the data collection. Experts were suggested by the steering group because they had skills and expertise in the relevant areas. Through the interviewees, I was also able to identify other experts that could provide research data. In addition, steering group member number 6 was identified in the pilot interviews and joined the group because of his knowledge, skills and expertise on the reported problems for this collaborative research.

This pre-investigation was used to formulate the research questions and to design different investigations. The findings showed that there was a problem with the supply chain efficiency because of the packaging solutions that were used, which resulted in product loss. This problem was caused by a lack of knowledge in three areas: supply chain needs placed on secondary packaging in developing countries; consideration of those needs in design and development methods; and models and software that can be used to design corrugated board secondary packaging.

2.1.4 The researcher's role in collaborative research

The collaborative research setting gave me a dual role – referred to as a "knowledge worker" by Gummesson (2000) – as a researcher in academia and a consultant in industry. Using academic literature to contribute to industrial practice and using industrial practice to contribute to academic literature were two directions of the research according to Gummesson (2000). Such a role is also regarded as a scholar-practitioner who has one foot in the world of academia and another in practice while trying to contribute to both academic literature (e.g., theory) and practice (e.g., in industry)(Huff and Huff, 2001; Tenkasi and Hay, 2004 ; Tenkasi and Hay, 2008). This situation put my research in an iterative situation between academic literature and industrial practice in order to match them together. Thus, my choice of theories for describing and analyzing data was based on this iteration between empirical data collection and academic literature. The choice of theories was also discussed with researchers in the related fields and the results were reviewed by them in addition to the key informants and steering group reviews. For more information on the researchers chosen to discuss the theories relevant to industrial practice and who reviewed the papers, see Appendix F. Being an employee in two organizations provided a unique learning opportunity and colleague relationship between the researcher and the Tetra Pak employees. In this journey as an industrial Ph.D. student, I gained valuable experience and tacit knowledge regarding liquid food and beverage supply chains that can be used for further research.

2.1.5 Continuation of research at the university

My licentiate thesis was presented after the period of empirical investigations in collaboration with Tetra Pak, (Sohrabpour, 2012). The empirical findings were then further developed with the support of academic literature during my time at Lund University to strengthen the scientific contribution. This dissertation embraces both empirical investigations and related academic literature.

The impact of packaging design and development toward increasing the supply chain effectiveness in relation to the gap was not a focus of the industry during my empirical research at Tetra Pak. But data was available and discussions took place with experts about how packaging technology and materials enabled or disabled the dairies ability to meet the demands of the market. This was in line with research on design for supply chain management (Lee and Sasser, 1995) and postponement (Twede et al., 2000). I was also inspired by academic research (e.g., Hellström, 2007; Viström, 2008) and industrial reports from dairies at Tetra Pak, discussions with experts and presentations by top managers from the liquid food and beverage sectors (i.e., Tetra Pak customers) about the strategic role that packaging can have in supplying the demand in the market. An example was a report on a dairy that used the MTS postponement to utilize the production and reduce cost through the milk production season at farms with low prices. These types of dairies where interested in packaging with longer shelf life capabilities. In other seasons, they took advantage of flexible production and did not require long shelf life. There were top managers from the food and beverage industry who were interested in packaging technologies with low change-over time in production in order to catch up with the highly volatile demand for a range of products in various portions. There were those who wanted customized printing for a specific order. This inspired me to study how various supply chain strategies and packaging are interrelated, since there was a lack of research in this area and it was not the focus of Tetra Pak during the collaborative research. Thus, a literature review was conducted on supply chain strategy interrelations with product and packaging as a first step for more empirical investigations in future.

2.2 Research design

Four investigations were designed to contribute to reducing the gap between the needs and satisfying them, through packaging design and development toward increasing supply chain efficiency and effectiveness. The research design is "*the logic that links the data to be collected (and the conclusions to be drawn) to the initial questions of study*" (Yin, 2003, p. 19). Each investigation, though, had its specific purpose and/or research questions related to reducing the gap expressed in the overall research aim.

Figure 2-2 illustrates all four investigations based on the gap model. The supply chain makes up one system and product and packaging as a whole make up another. The two systems interact with each other. Figure 2-2 illustrates this interaction and the gap between needs and satisfaction in the supply chain. These needs are placed on the product and packaging system by various actors along the supply chain.

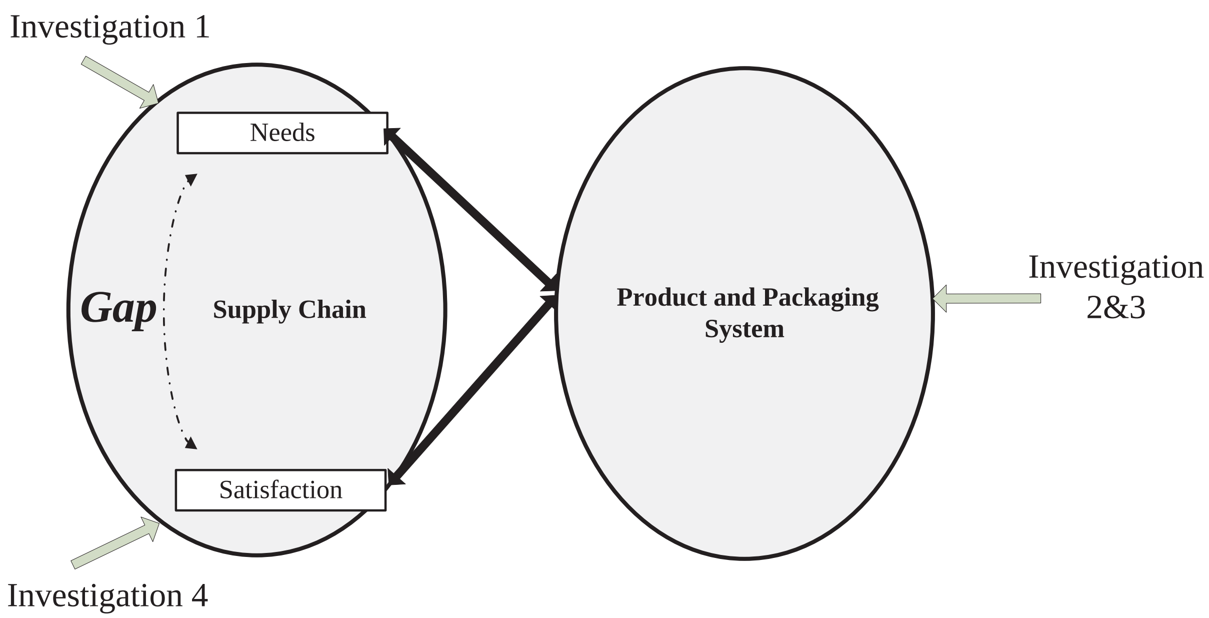

Figure 2-2 Gap model and four investigations

Three investigations were primarily related to the physical function of the supply chain toward increasing its efficiency. The first investigation was a case study that explored packaging in developing countries by identifying and describing supply chain needs on packaging. The outcomes were used in the second investigation, also a case study, to explore and analyze how an existing design and development method could be improved to satisfy the needs actors place on packaging along the supply chain. In the third investigation, models and software that could be used in the design and development method were identified, compared, and categorized. This was done to generate propositions on how to improve the use and development of models and software for corrugated board and box design.

In the fourth investigation, the market mediation function of supply chain (Fisher, 1997) was investigated to see how it could contribute to reducing the gap between the supply chain needs and satisfying them in order to increase the chain's effectiveness. A systematic review of the literature was conducted in the principal logistics and supply chain management journals to describe the current research trends in supply chain strategy interrelations with product and packaging.

Each of the four investigations resulted in a research paper following the same number ordering and attached to the dissertation. Each of the investigations is described in the following sub-sections.

2.2.1 Investigation 1 – case study A

To contribute to reducing the gap between the supply chain needs and satisfying them, through packaging design and development toward increasing its efficiency, RQ1 (How do supply chains in developing countries interact with packaging?) had to be answered. It was necessary to explore the interactions between the product and packaging system in order to identify and describe supply chain needs on packaging. Answering RQ1 made it possible to identify, describe and categorize supply chain needs placed on secondary packaging for ambient milk products in developing countries.

This investigation was designed as a case study because it was a suitable design for the first stages of the whole research process, including the exploration and categorizing of the supply chain needs placed on secondary packaging in developing countries, the development of propositions and the building of a knowledge base for the two following investigations. In other words, case studies are "useful in the preliminary stages of an investigation" (Abercrombie et al., 1984) and more suitable for the exploration, classification and hypothesis generation stages of the knowledge building process (Benbasat et al., 1987; Näslund, 2002).

This case study was based on three criteria: type of RQ1, control level over the research settings, and type of the events studied. The first criterion is motivated by Yin (2009) and Benbasat et al. (1987) who state that the case study method is suitable for answering "how" research questions (Näslund, 2002). The second criterion is motivated because no experimental control over events is required (Benbasat et al., 1987; Näslund, 2002; Yin, 2009). The third criterion is motivated because interactions between packaging and the supply chain are contemporary events and need to be explored in their natural setting according to Benbasat et al. (1987), Näslund (2002), Dul and Hak (2008), and Yin (2009).

Among different types of case studies, a single case study design was chosen to investigate what is considered to be a representative or typical case in order to "*capture the circumstances and conditions of an everyday…situation*" (Yin, 2009, p. 48) about interactions between the product and packaging system, and the supply chain. In addition, it had embedded, multiple units of analysis of ten countries in order to enhance the insights into the single case as described by Yin (2009, p. 52). This is illustrated in Figure 2-3. Thus, case study A is about ambient milk supply chain interactions with secondary packaging in the context of developing countries and involves several units of analysis. The ten developing countries were China, Egypt, India, Indonesia, Iran, Kenya, Russia, Thailand, Ukraine and Vietnam. They were chosen because they were widely spread geographically and were at different levels of development. With this case study design, the emphasis is on developing countries and not on each individual country. Yin (2009) emphasizes that a major difficulty in an embedded single case is focusing only on the subunit level (the individual countries) and failing to return to the larger unit of analysis (developing countries) and consequently comparing different countries (a traditional holistic multiple case study).

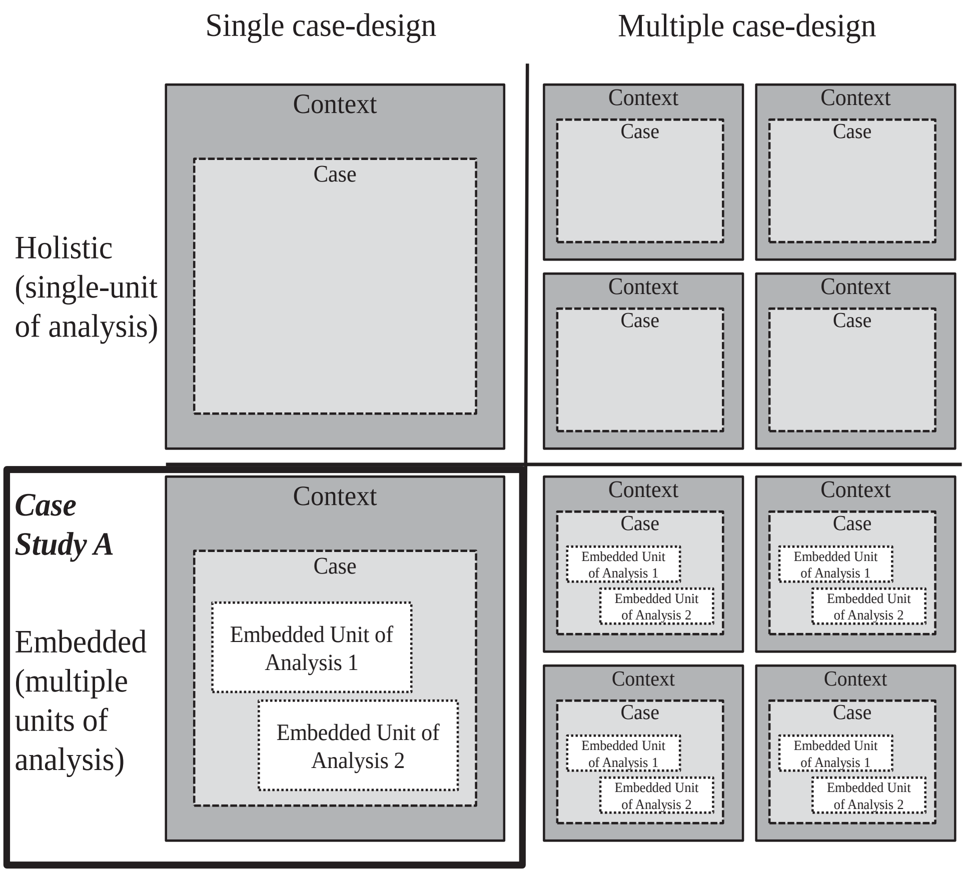

Figure 2-3. Case study design adapted from Yin (2009)

2.2.2 Investigation 2 – case study B

To design and develop packaging that can contribute to reducing the gap between the needs and satisfying them, toward increasing supply chain efficiency, RQ2 (How can a design and development method be improved to satisfy the needs placed on packaging in the supply chain?) had to be answered. Exploring and analyzing a packaging design and development method used by the collaborating company made it possible to suggest an improved method to reducing the gap.

A single case study was chosen and designed to examine Tetra Pak's packaging design and development method in industrial practice. It was chosen because according to Lyons (2005) case studies enable the detailed study of the design and development of the product, related processes and descriptions of a specific method from practice to illustrate a principle. Thus it can be used for packaging design and development method too. This case study included both the process of learning about packaging design and development methods and the results from the research/learning process inside the case company according to Näslund (2002). What made the case company suitable for this research was its holistic approach on packaging design and development for various supply chains aimed at higher efficiency. In addition to developing and providing the primary packaging for liquid food, Tetra Pak also offers its customers (i.e., dairies) recommendations on secondary packaging design. It was also a suitable case to study in order to match the results from investigation 1, which was carried out at the same company.

In relation to the three criteria used in investigation 1 for selecting a case study as the preferred method (based on Benbasat et al. [1987], Näslund [2002] and Yin, [2009]), this research was exploratory and had a "how" research question. It examined contemporary events that did not require control over the research setting (Yin, 2009), and offered the opportunity to observe and analyze a packaging design and development method in use, which was previously inaccessible for scientific investigation (Yin, 2009) in a company with extensive knowledge on it.

Thus, a holistic single case design with a single unit of analysis was conducted (Figure 2-4). In the context of Tetra Pak, the case focused on investigating how design and development methods were used within the company, with an emphasis on how the methods contributed to meeting supply chain needs. The unit of analysis was the packaging design and development method and its use.

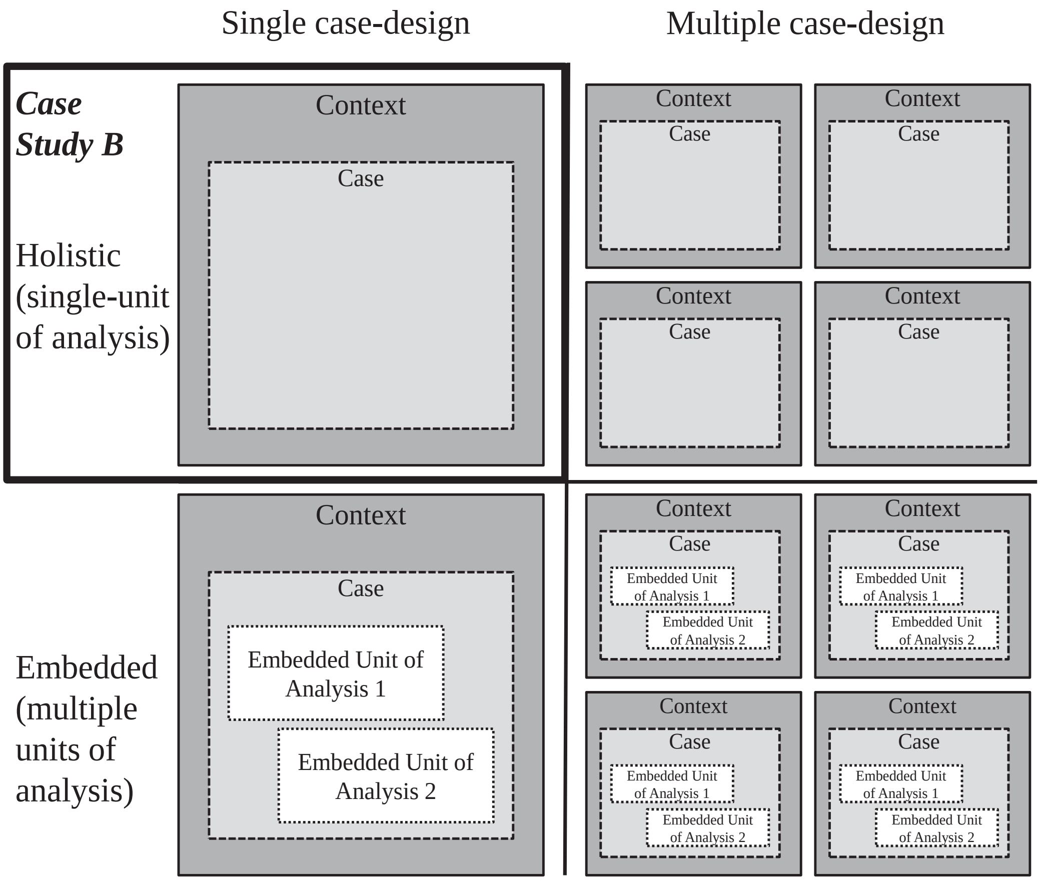

Figure 2-4. Case study design adapted from Yin (2009)

2.2.3 Investigation 3 – models and software mapping and analysis

In contrast to primary packaging, secondary packaging (e.g., corrugated board box as commonly used in ambient milk supply chains in developing countries) can be changed or modified relatively easily to reduce the gap between supply chain needs and satisfying them for supply chain efficiency. In the USA, a developed country, it is also estimated that 80% of the paper packaging volume used consists of various types of corrugated boxes (Twede and Selke, 2005). Corrugated boxes are recognized as providing products with temporary protection (Frank, 2014) along the supply chain.

In packaging design and development methods, models (e.g., in the form of mathematical formulas) and software are required. Models and software reduce the necessity of conducting physical tests in the design and development of packaging. The food and beverage industry as the customer of corrugated box secondary packaging can utilize some of these models and software based on their involvement in design and development and knowledge level.

Thus, RQ3 (What models and software are available for predicting corrugated board and box properties?) and RQ4 (How do different supply chain actors in the corrugated industry use these models and software?) had to be answered to improve the use and development of models and software for corrugated board and box design. The focus of investigation 3 was on regular slotted containers (RSCs) as secondary packaging for the ambient milk supply chains. Thus, it was necessary to identify various available models and software and explore the use of them for different actors in the corrugated board packaging supply chain. This investigation was designed as a combination of a literature review and empirical data. The literature review mainly answers RQ3 and the empirical data mainly answers RQ4. Models and software were identified, analyzed and compared for their use by different actors in the corrugated board packaging supply chain.

2.2.4 Investigation 4 – literature review

In accordance with the aim of this dissertation, the market mediation function of the supply chain (Fisher, 1997) also had to be investigated to contribute to reducing the gap between needs and satisfaction toward supply chain effectiveness. This is related to design for supply chain management (Lee and Sasser, 1995), which can contribute to supply chain effectiveness by implementing packaging postponement (Twede et al., 2000), but it was not a focus of the empirical work at the company. Thus, the three previous investigations were primarily related to the physical function of the supply chain towards increasing its efficiency.

A systematic literature review was conducted to better understand and describe the current state of supply chain strategy research in relation to product and packaging to contribute to reducing the gap between the needs and satisfying them toward increasing supply chain effectiveness. A systematic literature review was chosen since it is an efficient technique for summarizing the results of existing studies and assessing the consistency among previous ones (Petticrew, 2001). Systematic reviews help to locate, select, appraise, synthesize, and report the findings (Denyer and Tranfield, 2009). This systematic search was conducted using various methods (searching electronic databases of relevant journals, recommendations from experts and cross-referencing) to deal with the fragmented and interdisciplinary nature of the supply chain management field in relation to packaging. For more information, see Paper 4.

2.3 Scientific reasoning

Induction, deduction and abduction are three basic types of scientific reasoning. Inductive and abductive research starts out from empirical observations, while deductive research always starts out from a theoretical framework (i.e., hypotheses or propositions) (Kovács and Spens, 2005). Inductive and abductive research aim to develop hypotheses or propositions, while deductive research aims to test them (Kovács and Spens, 2005). In other words, the starting point of deductive research can be the conclusions from inductive or abductive research (Kovács and Spens, 2005). What makes abduction different from induction is partly related to the abductive reasoning's emphasis on the search for suitable theories for empirical observations, referred to as "theory matching", or "systematic combining" (Dubois and Gadde, 2002; Kovács and Spens, 2005). This implies a back and forth direction between theory and empirical study (Dubois and Gadde, 2002; Kovács and Spens, 2005).

The path of conscious scientific reasoning (Peirce, 1931; Kovács and Spens, 2005) for this dissertation as a whole is best described as abductive. The research questions and the theoretical framework emerged by matching evidence from industrial practice with theory; this continued throughout the entire research process. A characteristic of abductive research is the iterative matching of theory and evidence from the real world (Dubios and Gadde, 2002, p. 556) to find possible explanations and to extend previous theory (Kovács and Spens, 2005).

The reason for using an abductive approach was to understand the phenomena, as Alvesson and Sköldberg (2005) point out. The abductive approach was also used because it helps to derive propositions according to Andreewsky and Bourcier (2000) and Kovács and Spens (2005).

The abductive research carried out, provided new insights into packaging in developing countries, to packaging design and development methods from a supply chain perspective, to the use of models and software, and to strategies for supplying the demand. This was in the iteration between industrial practice and the academic literature. Kovács and Spens (2005, p. 138) note that, "*taking an abductive approach leads to new insight about existing phenomena … from a new perspective.*" This implies iteration between theory and empirical studies (Dubois and Gadde, 2002).

2.4 Data collection and analysis

Multiple sources of data for gaining a deeper understanding of the phenomena were used in various investigations. This represents what is called "data triangulation" by Denzin (1978), LeCompte and Goetz (1982), Shenton (2004) and Yin (2009). Table 2-1 presents the different sources for each investigation.

Table 2-1 Sources of data in investigations

	Pre-investigation	Investigation 1	Investigation 2	Investigation 3	Investigation 4 Literature review
Data collection					
Semi-structured interviews	X	X	X	X	
Internal documents	X	X	X	X	
Field observations/visits		X		X	
Training sessions	X		X		
Participant observation			X		
Group discussions				X	

In the pre-investigation, 26 pilot interviews were carried out with the Tetra Pak experts working in Sweden, Italy and China. These interviews were semi-structured. The value of using semi-structured interviews is being able to adapt to the specific communication characteristics of each interviewee in the beginning of an investigation according to Byrman and Bell (2007) and Trinczek (2009). The list of interviewees and the guiding questions are provided in Appendices C and D. It was necessary to learn about various processes, design and development methods for product and packaging design and development in order to design investigations for answering the research questions. Thus, I attended the relevant company training sessions as another means of gaining more knowledge. More information on the training sessions is provided in Appendix E, Nos. 1 and 4. Internal company documents (both written and visual) were also used. Data was collected by taking notes that were analyzed in terms of the main patterns provided by the industry as problems and areas in which knowledge was lacking. The research questions were then formulated.

In investigation 1, the data collection was based on Tetra Pak's internal documents both written and visual (reports and slide presentations, photos and video clips) from different countries, six semi-structured interviews with experts and field observations in China. The list of interviewees and guiding questions are provided in Appendices G and H. Data from observation in China were collected by means of field notes, photos and videos. Sensors and global positioning systems were also used to log temperature, humidity, vibration and acceleration in a freight transport between a dairy and a distribution warehouse. These various data collection methods contributed to identifying and gaining a rich description, and to categorizing supply chain needs.

The collected data were analyzed based on thematic analysis. Interviews were transcribed and analyzed until theoretical saturation was achieved (Corbin and Strauss, 2008). This happened at the third interview; the remaining three did not add a considerable amount of new data. After finishing the analysis, the findings were reviewed and commented on by experts and the key informants, and a consensus was reached about the findings.

In investigation 2, data was collected from Tetra Pak's internal documentation (manuals and previous project documents), by attending training sessions, through participant observations in projects using the investigated packaging design and development method, and semi-structured interviews with seven experts. Experts were interviewed because this is considered to be an efficient and concentrated data collection method by Bogner et al. (2009). The list of interviewees and the guiding questions are provided in Appendices I and J, respectively. The list of relevant training sessions is provided in Appendix E (Nos. 1, 2, 5 and 6). Participant observation was chosen because it helps reach significant and detailed findings that are difficult to get at with other methods according to Pålsson (2007). It also provides unique insight into the activities studied by the observer (Jones and Somekh, 2005) and opportunities to reveal tacit knowledge (Pålsson, 2007). Data from the interviews, training sessions, internal documents and participant observations was collected by taking field notes and follow-ups were conducted to clarify the data.

The collected data were described according to Olsson's (1976) conceptual design theories. They were further analyzed based on the design and development literature from an iterative search carried out during the investigation. Thus, the four domains of design (customer, functional, physical and process; see 3.3.2) (Chen 1999; Suh,

1990) and operational lifecycle (Sarkis, 2003) literature were used to analyze the data. The final results were reviewed by an expert who served as a key informant reviewer.

In investigation 3, a combination of a literature review and nine semi-structured interviews with academic and industry experts were conducted since data and research on such models and software were sparse and were not found in the pilot literature searches. The list of interviewees and guiding questions are presented in Appendices K and L, respectively. Most of the research in the area has been conducted by industrial experts. Thus, this combination (literature review with expert interviews) was used to identify different models and software in order to understand and learn how they worked. This helped in finding the related literature to review.

To learn about the corrugated board industry and investigate how the industry currently uses models and software to predict the properties of corrugated board and boxes, a review of Tetra Pak's internal documents, group discussions with experts and field visits were conducted (see Appendices M and N). The respondents were later contacted and asked about questions that had been overlooked or that had emerged during the analysis. Field visits to corrugated board and box producers were then conducted to observe how the models and software were used in industry practice. In addition, various test labs for testing paper, board and boxes were visited.

2.5 Research quality judgment

An in-depth understanding was necessary because the research questions were rather new and were defined based on collaborative research in packaging logistics. Therefore, the research was qualitative, which can serve as a basis for more quantitative research in the future. Qualitative research was chosen because it helps to get close to the meaning and perspectives that people bring the researcher from their everyday work; it also helps to gain rich descriptions that can be achieved through detailed interviewing, written documents and observations (Alvesson, 1996; Denzin and Lincoln, 1994; Patton, 2002). Qualitative research also provides the opportunity to evolve empirically-supported new ideas and propositions with relevance and interest for the practitioners (Näslund, 2002), which is in line with the collaborative research.

The criteria for judging the quality of qualitative research are different from those for quantitative research (Bryman and Bell, 2007). Various tactics are provided by Lincoln and Guba (1985) and Yin (2003) to judge the quality of research. Lincoln and Guba (1985) use trustworthiness that embraces four criteria: credibility, transferability, dependability and conformability. These criteria correspond to the parallel criteria in quantitative research: internal validity, external validity, reliability and objectivity (Bryman and Bell, 2007; Shenton, 2004).

LeCompte and Goetz (1982) use reliability and validity (external and internal) in judging qualitative research. Yin (2003) also uses construct validity, internal validity, external validity and reliability criteria for judgment. In this research, LeCompte and Goetz's (1982) criteria in combination with Yin's (2003) are used to judge the quality, since they apply to the qualitative research including case studies. These criteria are internal and external reliability and internal and external validity.

2.5.1 Reliability

Reducing the errors and biases in an investigation is the goal of reliability (Yin, 2003). "*Reliability refers to the extent to which studies can be replicated*" (LeCompte and Goetz, 1982, p. 32). LeCompte and Goetz also consider external reliability to be the degree to which an investigation can be replicated. Internal reliability deals with the question of observers or members of the research team agreeing on the sets of meaning, so that they describe the phenomena in the same way and arrive at the same conclusions about them (Bryman and Bell, 2007; LeCompte and Goetz, 1982). Internal and external reliability (LeCompte and Goetz, 1982) are discussed in following subsections.

External reliability

External reliability is a difficult criterion for qualitative research (Bryman and Bell, 2007), since it is impossible to freeze the settings and circumstances (LeCompte and Goetz, 1982). The replication of findings by other researchers is dependent on the extent to which the researcher was a member of the group studied and the position he or she held (LeCompte and Goetz, 1982). As mentioned before, I was an industrial Ph.D. student employed by the company and was a part of the everyday work as a colleague with other Tetra Pak employees. I was present at formal meetings (group, department and platform) and informal meetings (e.g., social events and breaks). To replicate this research, another researcher would have to replicate my role as an industrial Ph.D. student in the same company.

A clear description of those who provided data to the investigation is another approach to deal with external reliability threats related to informant bias (LeCompte and Goetz, 1982). Thus, lists of steering group members and interviewees are provided in the Appendices. The presentation of data collection methods and analysis is another approach to deal with replicability (LeCompte and Goetz, 1982), which has been addressed in this dissertation. Documentation of the procedures is one way to enable other researchers to repeat the investigations of others (Yin, 2003). Thus, in order to ensure reliability, a database was established that contained the processes of the investigations including the problem formulations in the quarterly meetings, data from the company's internal documents, interview transcriptions, field notes, photos, videos and the analysis. This enables other researchers to track the experts who provided input; the procedures applied and utilize the database in order to replicate this investigation.

Internal reliability

The optimum safeguard for ensuring internal reliability is the presence of multiple researchers according to LeCompte and Goetz (1982). The steering group members contributed to reducing threats to internal reliability by holding quarterly meeting and reviewing the papers. In addition, local key informants (LeCompte and Goetz, 1982; Magoon, 1977) reviewed the papers to confirm the interpretations of the meanings from investigations. Another approach is peer examination through confirmation of findings by researchers operating in similar settings through publication of results (LeCompte and Goetz, 1982). Thus, the appended papers were submitted, reviewed and/or published in conference proceedings or journals through a double-blind review process. The use of observational techniques, (i.e., video and audio recordings) to record and preserve as much of the raw data as possible (LeCompte and Goetz, 1982; Mehan, 1979), was another approach to enable other researchers to confirm the conclusions.

2.5.2 Validity

Validity requires that researchers demonstrate that the propositions generated or refined match the observations (Bryman and Bell, 2007; LeCompte and Goetz, 1982). Internal validity is related to the match between the researchers' observations and the conceptual categories they develop while understanding mutual meanings by the participants and the observer (Bryman and Bell, 2007; LeCompte and Goetz, 1982). External validity is concerned with the generalizability of findings (Bryman and Bell, 2007; LeCompte and Goetz, 1982; Yin, 2003).

Internal validity

One approach to strengthen the internal validity is to spend a long-term (6 month to 3 years) in the field (LeCompte and Goetz, 1982). As an industrial Ph.D. student, I spend 27 month in the industrial setting. Such a long period of collecting data provided me with the opportunity for continual data analysis to refine the results, discussions and propositions, and to ensure the match between them and participant reality in line with LeCompte and Goetz (1982). Moreover, spending time in the organization enabled me to learn the jargon, abbreviations and technical words that are a part of "going native" (Gray, 2009); not knowing what they meant would have affected my ability to interpret the data.

Another threat to internal validity is the "observer effect" that is related to data collection through participant observations and informal informant interviewing (LeCompte and Goetz, 1982). My role as an employee in the organization contributed to a higher validity of data. Being an employee at the company resulted in the creation of higher levels of trust from experts, which helped to improve the validity of the data. I also had the same access level to data as any other regular employee. The company provided access to its internal resources (e.g., labs, training sessions, internal documents and experts), customers in developing countries, and expertise in the research area. If I had not been employed by the company as a Ph.D. student, I would have had the lowest level of access, that of a visitor. And if my presence in the organization had been based on a contract between Lund University and Tetra Pak, my access to data would have been on the level of a consultant, which is very limited compared to the access of an employee.

On the other hand, problems of research exhaustion or saturation from being in a setting can occur in intensive, long-term investigations. This happens when the researcher is so familiar with the setting that new data are no longer observable (LeCompte and Goetz, 1982). This can be related to the side effects of going native in observing and analyzing objectively and it is considered as a sign for the termination of field residency (LeCompte and Goetz, 1982). Moreover, since I collected the data on my own and spent a long time in the organization, the corporate culture, national and personal values of the interviewees, my managers and the authors of the documents in the company could have started to bias my judgments and interpretation of data. These were indications that it was time to terminate my stay at the company after 27 month of working in the industry. In order to strengthen the empirical findings, they were further developed and analyzed by matching industrial practice and academic literature afterwards at Lund University.

External validity

Since small samples and case studies are used in qualitative research (Bryman and Bell, 2007; LeCompte and Goetz, 1982), statistical generalization is not an evaluation criterion (Bryman and Bell, 2007; Yin, 2003). Instead of statistical significance, qualitative findings are judged based on their substantive significance (Patton, 2002). Thus, Yin (2003) suggests using analytical generalizations. This is why theories were used for the analysis of the results from packaging logistics and design and development (e.g., the four domains of design) in the empirical investigations according to Yin (2003).

Construct validity comes under external validity according to LeCompte and Goetz, (1982). It is referred to as establishing correct operational measures for the concepts under investigation (Yin, 2003). Data triangulation (Denzin, 1978; LeCompte and Goetz, 1982) is one way to ensure construct validity. Thus, multiple sources of data according to Yin (2003) including observations, internal company documents and interviews were used. Discussions with key informants (LeCompte and Goetz, 1982) and having them reviewing the research finding in the form of papers (Yin, 2003) were also used. In addition, the steering group reviewed the findings at every meeting. Papers were reviewed in double-blind review processes for publication as well. In addition to all of the above, each of the papers appended to this doctoral dissertation were reviewed by an academic researcher in the relevant field, too.

3. Frame of reference

3.1 Point of departure

The scope of this research is in the overlap between supply chain management and logistics, product design and development, and packaging design and development. The overlap is illustrated in Figure 3-1. Using a supply chain perspective and benefiting from product and packaging design and development literature, the overlap is investigated.

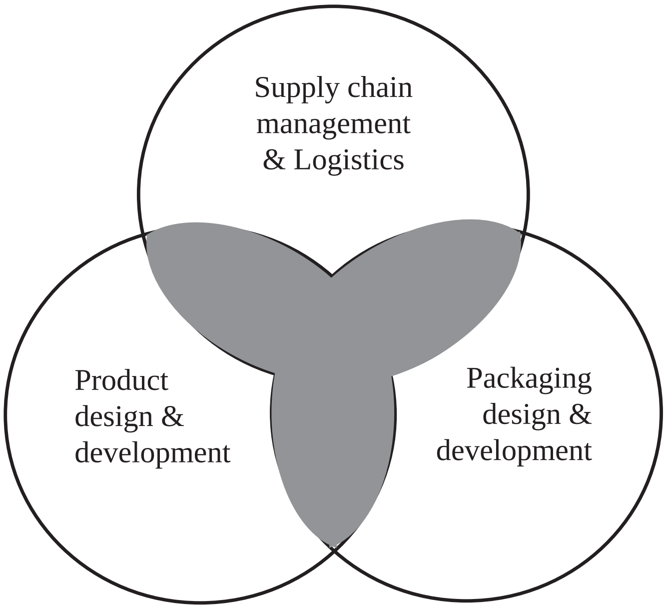

Figure 3-1 Scope of this research

This research proceeds from the packaging logistics field and tries to further contribute to it. Previous packaging logistics research has approached this overlap from three streams highlighted by Klevås (2005a). These three streams focus on the connection between:

1. packaging and logistics (e.g., Bowersox et al., 2002; Johnsson, 1998; Hellström, 2007; Saghir, 2002; Twede, 1992; Twede et al., 2000);
2. product development and logistics (e.g., Bowersox et al., 1999; Dowlatshahi 1996; Foo et al., 1990);
3. product development and packaging (e.g., Bramklev et al., 2001; Bramklev, 2004; Paine, 1990; Shina, 1991; Bramklev and Hansen, 2007; Olander-Roese and Nilsson, 2009; Bramklev, 2010).

The research presented embraces the intersection of the three research streams. The research combines management (e.g., supply chain management) and engineering (e.g., product and packaging design and development) based on packaging logistics research. However, others have investigated supply chain and logistics problems from other angles and academic backgrounds (e.g., business management, organization and transport (Arlbjorn and Halldorsson [2002])).

The remainder of chapter 3 describes each of the overlapping areas illustrated in Figure 3-1. They encompass the scope of the research.

3.2 Supply chain management and logistics

Of the four perspectives on supply chain management and logistics illustrated in Figure 3.2, the unionist one has been selected for this research. A unionist perspective considers logistics to be a part of supply chain management (Larson and Halldorsson, 2004). The CSCMP definition (2013) takes logistics management activities into account as a part of supply chain management. Accordingly, supply chain management also encompasses "*manufacturing operations and it drives coordination of processes and activities with and across marketing, sales, product design, finance and information technology*" (CSCMP, 2013, p. 187).

Therefore, the supply chain management definition that is put forward by CSCMP (2013, p. 187) is used as a basis in this research. This definition integrates a broad range of activities under supply chain management such as the "*planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities*" (ibid). According to the definition, the essence of supply chain management is the integration of supply and demand management. The CSCMP definition (ibid) further states that "*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*".

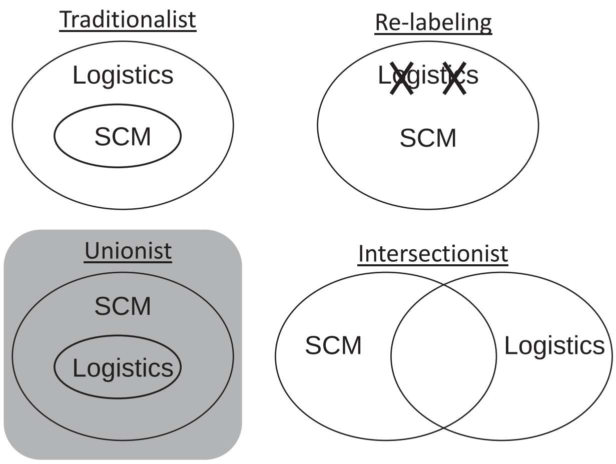

Figure 3-2 My perspective of SCM in relation to logistics (adapted from Larson and Halldorsson, 2004).

Most importantly, packaging is considered part of the logistics function in the CSCMP (2013) definition of logistics management. Accordingly, logistics management "*plans, implements, and controls the efficient, effective forward and reverse 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*" (CSCMP, 2013, p. 117).

3.2.1 Supply chain business processes

Theoretical frameworks for supply chain management address product related business processes (e.g., Cooper et al., 1997; Lambert et al., 1998; Lambert and Cooper, 2000), see Figure 3-3. In the literature review by Cooper et al. (1997), product structure is considered as one supply chain management component. They mention the impact of product complexity on the supply chain in terms of the number of suppliers for different components. They include the coordination of new product development across the supply chain and the product portfolio as a part of product structure issues and highlight that lack of such coordination can result in production inefficiencies. Sanders (2007, p. 183) states that supply chain management also "…. *takes a systems view regarding all activities and functions that are needed to bring a product or service to market*". Stock and Lambert (2001, p.4) also state that "*logistics is, in itself, a system; it is a network of related activities with the purpose of managing the orderly flow of material and personnel within the logistics channel*". Coyle et al. (2003) consider a systems relationship between activities in the supply chain, such as transportation, warehousing, packaging and materials handling. However, these literatures mainly neglect packaging among the business processes.

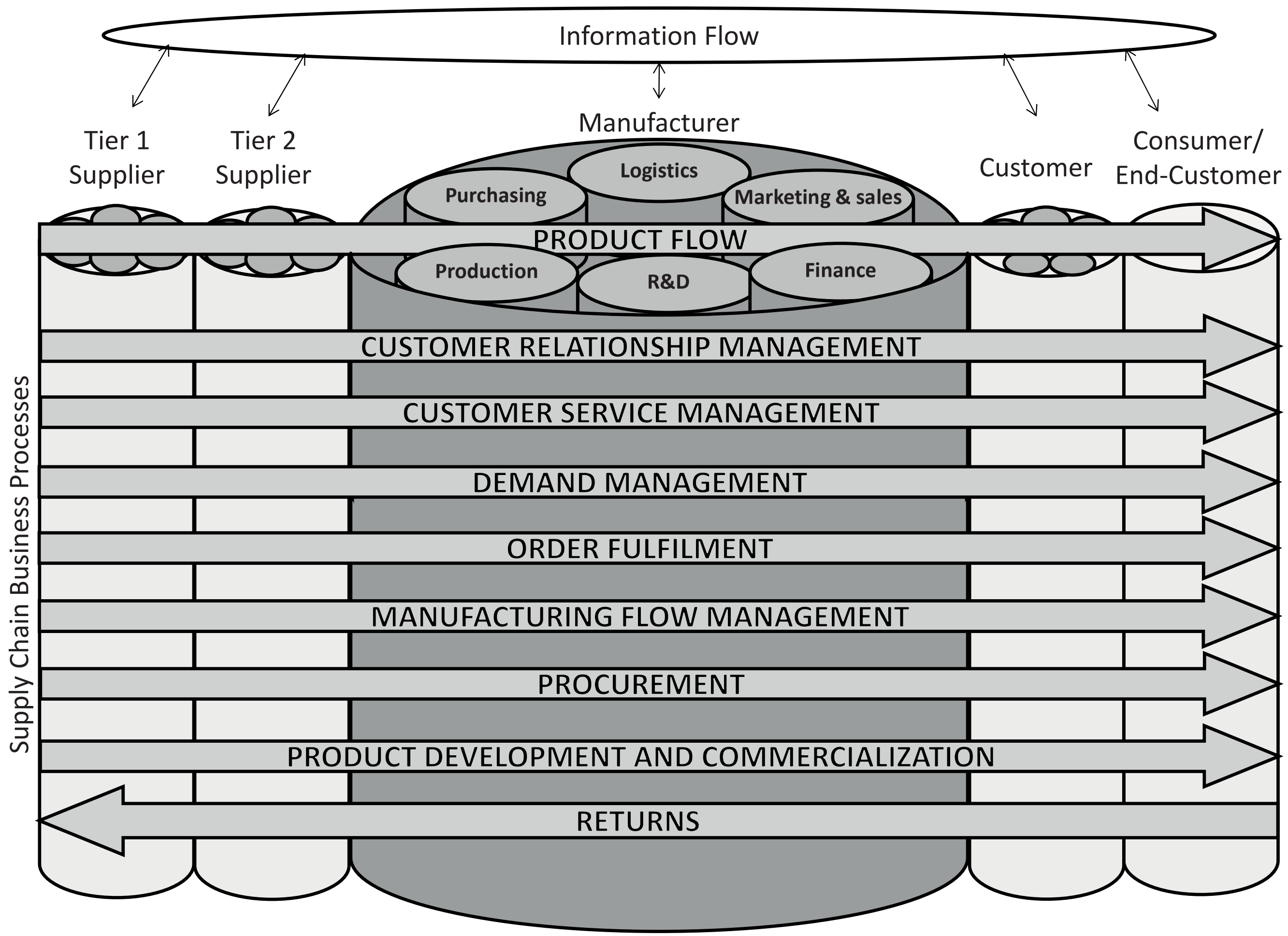

Figure 3-3 Supply chain management: integrating and managing business processes across the supply chain. (Lambert and Cooper, 2000; Cooper et al., 1997).

Neglecting the coordination of product and packaging as one system in the supply chain can result in sub-optimizations of its physical flows. Fugate et al. (2006) states that sub-optimization of a system often leads to inefficient allocation of limited resources, higher system costs, compromised customer service, and a weakened strategic position. Saghir (2002), for example, reveals that packaging suppliers offer packaging solutions to satisfy the food producers' most important needs. These include smooth and flexible processing, but other needs along the supply chain have to be satisfied as well. For example, distributers put needs regarding efficient distribution and retailers need efficient handling and sales. Saghir (2002) thus concludes that sub-optimizations are most likely to occur since different actors have different needs.

Cooper et al. (1997) define supply chain management as the integration of the business processes, the management components, and the structure of the chain. Key business processes across the supply chain are product development and commercialization, demand management, order fulfillment, customer relationship management, customer service management, manufacturing flow management, procurement and returns (Cooper et al., 1997)

Each firm in the supply chain has its functional silos (i.e., logistics, production, marketing and sales, R&D, purchasing and finance [Lambert et al. 1998; Lambert and Cooper, 2000]) that must be related to each key supply chain business processes (Cooper et al., 1997). These researchers also call for the integration of business processes beyond logistics in the supply chain, such as new product development.

Packaging in the business processes

Packaging has to be considered as a part of product development and the commercialization business process since in addition to the product, packaging is a part of the physical flow in the supply chain. Packaging's significant impact on logistics cost and performance, marketing and sales, production, product development and the environment has frequently been pointed out in previous research (e.g., Paine, 1981; Ebeling, 1990; Twede, 1992; Prendergast, 1995; Bowersox et al., 2002; Klevås, 2005a; Verghese and Lewis, 2007; Wells et al., 2007; Gustafsson et al., 2009; Rundh, 2009; Azzi et al., 2012; Rundh, 2013; García-Arca et al. 2014), but is still in its infancy compared to the research on products in the supply chain management literature.

Therefore, some research has considered logistics with the support of concurrent product and packaging development (e.g., Bramklev et al., 2005; Bramklev and Hansen, 2007; Motte et al., 2007; Bramklev, 2010). This type of research usually falls between product development business processes and silos such as R&D, marketing and sales, logistics, and production. Other research has focused on demand management business processes in relation to marketing and sales, production and logistics (e.g., Twede et al., 2000; Dominic, 2005; Abukhader and Jönson, 2007; Viström, 2008; Abukhader and Jönson, 2011; Dominic, 2013). Nevertheless, their research takes into account product and packaging together in the supply chain. Thus, this dissertation continues both research by considering product development and demand management business processes.

3.2.2 Supplying the demand

Strategies for supplying the demand can be set within demand management business processes. The strategies are reported to be physically efficient and market-responsive (Fisher, 1997; Li and O'Brien, 2001; Wong et al., 2006; Selldin and Olhager, 2007). Other researchers frequently refer to physically efficient strategies as lean, and market-responsive ones as agile (e.g., Sanderson and Cox, 2008). In addition to "lean" and "agile" strategies, a third one called "hybrid" or "leagile" has been repeatedly used in the literature (e.g., Mason-Jones et al., 2000b; Childerhouse and Towill, 2000; Christopher and Towill, 2000; Van der Vorst et al., 2001; Childerhouse et al., 2002; Christopher and Towill, 2002; Huang et al., 2002; Aitken et al., 2005; Hilletofth, 2009; Stavrulaki and Davis, 2010; Zhang and Huang, 2012).

The three main decision factors in setting supply chain strategy are product, market and the supply chain itself as the market mediator (Fisher, 1997; Huang et al., 2002). The nature of the product is a key driver in choosing the supply chain strategy (Fisher, 1997; Huang et al., 2002), not packaging. Two major product types are often discussed in the literature: functional and innovative (e.g., Fisher, 1997; Lamming et al., 2000; Childerhouse and Towill, 2000; Li and O'Brien, 2001; Van der Vorst et al., 2001; Childerhouse et al., 2002; Lee, 2002; Catalan and Kotzab, 2003; Wong et al., 2006; Selldin and Olhager, 2007; Sanderson and Cox, 2008; Qi et al., 2009; Stavrulaki and Davis; 2010; Golicic and Sebastiao, 2011; Wagner et al., 2012). Other researchers call these two product types "commodities" and "fashion goods" (e.g., Christopher, and Towill, 2000; Christopher and Towill, 2001; Mason-Jones et al., 2000a; Mason-Jones et al., 2000b). Christopher and Towill (2002; 2006) instead refer to them as "standard" and "special".

Functional or standard products compared to innovative or special ones are defined based on the following characteristics: having a stable demand pattern, a longer life cycle, lower product variety, lower contribution margins, and longer lead times for make-to-order (Fisher, 1997). Innovative or special products, compared to functional or standard ones, have shorter product life cycles, higher product variety, higher contribution margins, and shorter lead times for make-to-order (Fisher, 1997). These two product types are compared in Table 3-1.

Table 3-1 Functional versus innovative products: differences in demand (Fisher, 1997).

	Functional (predictable demand)	Innovative (unpredictable demand)
Aspect of demand		
Product life cycle	More than 2 years	3 months to 1 year
Contribution margin	5% to 20%	20% to 60%
Product variety	Low (10 to 20 variants per category)	High (often millions of variants per category)
Average margin of error in the forecast at the time production is committed	10%	40% to 100%
Average stockout rate	1% to 2%	10% to 40%
Average forced end-of-season markdown as percentage of full price	0%	10 to 25%
Lead time required for made-to-order products	6 months to 1 year	1 day to 2 weeks

The supply chain strategy and the product types should be matched according to Fisher (1997). He provides a model to do so. The model is widely used in the supply chain management literature (e.g., Qi et al., 2009; Stavrulaki and Davis, 2010; Golicic and Sebastiao, 2011; Wagner et al., 2012). Much research has also tried to empirically study this model, such as Selldin and Olhager (2007) and Wagner et al. (2012). The model is illustrated in Figure 3-4.

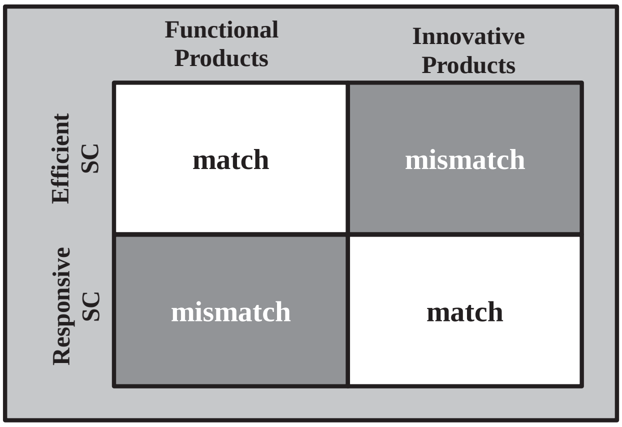

Figure 3-4 Matching supply chains with products (Fisher, 1997).

Product types based on the product life cycle phase and complexity are used by Cigolini et al. (2004) for setting the supply chain strategy. They use product types according to product life cycle phases are: introduction (innovative), growth, mature/functional (simple and complex). Product life cycle as used in the supply chain management literature includes introduction, growth, maturity, and decline (e.g., Cigolini et al., 2004), which is different from what is used in the design and development literature. Each of the above mentioned phases requires different strategies to meet the demand. Cigolini et al. (2004), use the product life cycle in relation to supply chain strategy in line with its market mediation function. In other words, from a supply chain effectiveness point of view, product lifecycle phases and their duration are the bases for setting the supply chain strategy.

3.2.3 Packaging in the supply chain

Packaging logistics takes into account the multifunctional and multidisciplinary nature of packaging (Saghir 2004). It also emphasizes the understanding of the role of packaging in relation to the supply chain effectiveness and efficiency while considering product development, logistics, marketing and environment (Saghir 2004; Saghir et al., 2004). From a packaging logistics focus, there is not only a close relation between packaging and product, but there are also synergies between packaging and logistics, with the potential to increase supply chain efficiency and effectiveness (Saghir, 2004; Saghir et al., 2004). Synergies between packaging and logistics (Hellström and Saghir, 2007; Kye et al., 2013) are stated by Azzi, et al. (2012) as being one of the drivers for packaging design and development to achieve higher effectiveness and efficiency in the supply chain. Furthermore, packaging logistics aims to design and develop packaging systems that satisfy the supply chain needs (e.g., logistics processes and supplying the demand [Dominic, 2009]). These needs could be related to the physical functions in the supply chain or its market mediation function. In packaging logistics research, few researchers (e.g., Abukhader and Jönson, 2007; Wiström, 2008; Abukhader and Jönson 2011) consider packaging in relation to postponement in the supply chain, which is in line with the market mediation function of the supply chain. Their research considers the postponement of packaging and labeling based on the demand. Thus, packaging can contribute to the supply chain effectiveness.

Packaging logistics considers various stages that are related to an operational life cycle such as handling, transport, distribution, storage, retailing, consumption and recovery, reuse or disposal stages (e.g., Saghir, 2002; García-Arca et al., 2014). Using the operational life cycle (e.g., Sarkis, 2003) is in line with the physical function of the supply chain and it can be used to increase supply chain efficiency. The operational lifecycle in design and development is different from the product life cycle mentioned in section 3.2.2.

3.3 Product design and development

The design and development of products and their packaging aim to satisfy needs throughout their operational lifecycle as it is used in Olsson (1976). These needs vary depending on the target market (the final customer) and the actors in the supply chain of products and packaging. The design and development process is iterative, as Chen (1999) explains, going from marketing to design to manufacturing to marketing to design, etc., and it does not necessarily begin from the societal and human needs: it can begin anywhere in the chain.

In this research, design and development are used as general terms relating to satisfying the needs of actors in the supply chain. "Design" in the literature is either considered as a part of "development" or "design" and "development" are used as synonyms (see Motte et al., 2011, pp. 89-90).

3.3.1 Three dimensional concurrent engineering (3-DCE)

Three-dimensional concurrent engineering (3-DCE) extends concurrent engineering and takes into account product, process and the supply chain design (Fine, 2000). Aligning product, process and supply chain is mentioned as a way to increase efficiency and competitive advantage, and 3-DCE aims to match them together (Ellram and Stanley, 2008; Ellram et al., 2007; Fine, 2000; Fine et al., 2005). In 3-DCE, product design and development consider product specifications; process design considers manufacturing methods, facilities, equipment and output; while supply chain design deals with logistical channels, customers and suppliers, relationships among members of a supply chain, insourcing and outsourcing (Ellram et al., 2007). An example is a large consumer products firm that improved its processes, its supply chain operations, and its product and packaging system as a whole (Ellram et al., 2007). This was accomplished through improved performance and lowered costs by end-to-end supply chain analysis (e.g., auditing logistics and manufacturing), and by engaging all inside and outside functional areas of the firm that interacted with a given product resulting in enhanced performance and lowered costs.

3.3.2 Four domains of design

Four domains of design are used in this dissertation to describe and analyze packaging design and development that can satisfy the supply chain needs toward increasing its efficiency. All designs are involved in a continuous processing of information between and within the four domains: customer, functional, physical and process (Chen, 1999; Suh, 1990). These design domains can be used to describe different fields such as products, organizations, systems, materials and software (Suh, 1998). Accordingly, design is regarded as "*an interplay between 'what we want to achieve' and 'how we choose to satisfy the need (i.e., the what)'*" which is illustrated in Figure 3-5 starting from the left with what we want to achieve and progressing to the right, which embodies the design solution based on the needs identified (Suh, 1998, 204).

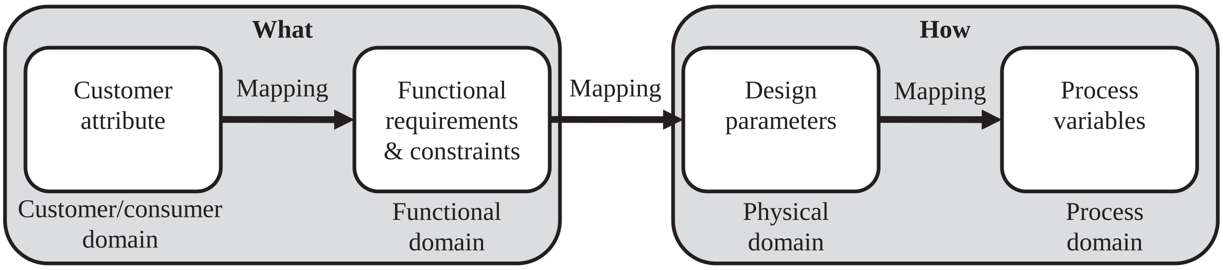

Figure 3-5 Four domains of design (adapted from Chen, 1999 and Suh, 1990).

Each domain describes needs, requirement, parameters or variables that have to be translated and mapped to the characteristics in the next domain (Aungst et al., 2003; Chen, 1999; Suh, 1998). The first domain includes the needs of customers (attributes) for products, systems or materials (Suh, 1998). Taking a supply chain perspective, customers can be different actors along the supply chain putting needs on the product and packaging systems that can be satisfied through packaging design and development.

The second domain embraces functional requirements and constraints. A functional requirement is a "*minimum set of independent requirements that completely characterizes the functional needs of the product*". "*Constraints are limitations and bound on acceptable solution*" (Suh, 1998, p. 205). Constraints can be imposed as a part of the design characteristics or come from the system in which the design solution must function; the product, system or material under design and development must meet the constraints (Suh, 1998).

To characterize a design that satisfies the specified functional requirements within the constraints, design parameters are used that set the key physical variables in the third domain (Suh, 1998). Finally, the forth domain is about producing products based on the assigned design parameters, which are specified by process variables (Aungst et al., 2003; Chen, 1999; Suh, 1998). The process that can produce the specified design parameters is characterized by key variables in the process domain (Suh, 1998).

3.3.3 Design for X

Design for supply chain and design for logistics, which are known as a part of "design for X thinking" (Hoek and Chapman, 2006), are regarded as designs for efficiency by Chiu and Okudan (2010). Thus, supply chain operations are to be considered in design for supply chain as a part of "design for X thinking" (Van Hoek and Chapman, 2006). From another point of view, the X in "design for X" symbolizes any operational life cycle phase concern to be evaluated (Watson and Radcliffe, 1998; Klevås and Saghir, 2004; Klevås, 2005a) and it is related to the main design requirements that the product must satisfy. Some examples of Design for X are: Design for Logistics (Dowlatshahi, 1996; Mather, 1992; Roozenburg and Eekels, 1995), Design for Storage and Distribution (Gopalakrishnan et al., 1996), Design for Material Logistics (Foo et al., 1990) and Design for Manual Packaging (Lee and Lye, 2003).

Design for supply chain management aims to design products and processes that contribute to managing costs (i.e., manufacturing and logistics) and performance in the supply chain (Lee and Sasser, 1995). Design for supply chain management contributes to increased supply chain effectiveness through the delayed product differentiation (postponement) (Lee, 1993). Such an approach provides opportunities for decreasing the inventory, improving supply chain flexibility in meeting customer demands and higher customer service performance (Klevås, 2005a). The dilemma mentioned by Lee (1993) is that the cost of material and labor are the main drivers in cost estimation in physical supply chains, but the benefits of decreased inventory, quicker response times to customers and increased availability are difficult to measure. This is in line with Fisher's (1997) less obvious supply chain function: market mediation.

Most of these design methods are provided to map specific functional requirements (functional domain) to their design solutions (physical domain) (Chen, 1999). But it is also necessary to have methods that consider the customer/consumer domain and the needs identification from a supply chain perspective. Most of these design methods tend to focus only on one part of the operations (Van Hoek and Chapman, 2006) or operational lifecycle (Klevås and Saghir, 2004; Klevås, 2005a) instead of considering the product and its packaging in the entire supply chain.

3.3.4 Conceptual design

Some product design and development methods are classified as being matrix-based by Malmqvist (2002). Such a method *"represents some view of the product structure (product elements and their relationships)"* and it is illustrated in the form of a matrix (Malmqvist, 2002, p. 203). "Conceptual design" (Olsson, 1976) is a matrix-based method that has been sparsely used in research. Some researchers refer to it such as: Andersson (1996), Johannesson and Claesson (2005), Hansen and Andreasen (2007), Motte (2008) and Bramklev and Ström (2011).

Conceptual design (Olsson, 1976) is a method that considers different parts of the operational life cycle and uses an analysis tool – matrix – to evaluate design trade-offs, something that Klevås and Saghir (2004) called for. Conceptual design aims at design and development of draft solutions that satisfy specific needs and hence requirements. These needs are set at the beginning of the development process. There are several steps in conceptual design (Olsson, 1976):

- Product definition – the main task, parts and possible interactions of the product are clarified.
- Product investigation and criteria search – the purpose of the product investigation is to search for information and previous experiences that can be useful in the development of the product. The criteria search elaborates on the needs and requirements of the product and clarifies their correlations and priorities.
- Development of product propositions – aims to show possible product design concepts and their feasibility to meet the requirements and needs put forward.
- Evaluation of product propositions – the developed product propositions are evaluated in relation to the requirements and needs.
- Presentation of chosen product proposition – the chosen product proposition is described according to its advantages, disadvantages and criteria fulfillment.

In the criteria search, the needs that the product has to satisfy are translated to tangible requirements. These requirements are the basis of design solutions and they serve as a foundation for evaluating them. A matrix including the operational life cycle and the evaluation criteria of the product is utilized to cover the needs and requirements of the product. The operational life cycle has five stages according to (Olsson, 1976) that are: development, production, distribution, use, and recycle/reuse.

In order to understand and analyze needs and requirements four evaluation criteria (i.e., process, environs, humans, and economy) are employed. They are also used to evaluate and prioritize the needs, requirements and technical attributes in product design and development. The process criterion is related to processes and operations. The environs criterion is related to the product's relation to its surroundings (e.g., durability in harsh environments). The human criterion embraces such aspects as ergonomic and esthetical considerations to meet the purpose of the product. Lastly, the economy criterion considers costs and economical aspects of the product and is considered as a boundary for the solution (see Figure 3-6).

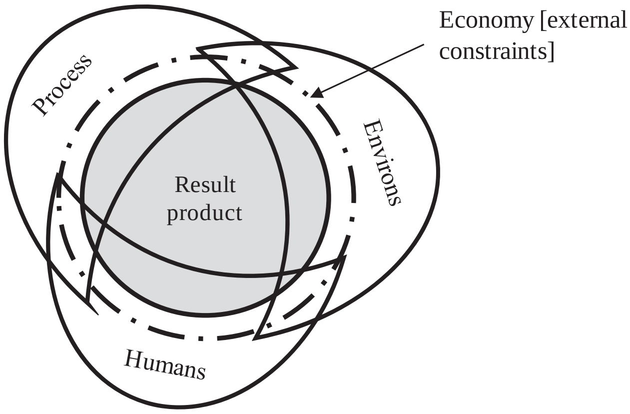

Figure 3-6 Evaluation criteria and external constraints of a product (adapted from Sveriges Mekanförbund, 1971).

Together, the operational life cycle and evaluation criteria are analyzed in a matrix called the Criteria Search Matrix (CSM) to provide a tool to cover and collect requirements for the product matching the needs and requirements (see Table 3-2). Basically, CSM maps the needs from the customer/consumer domain to the requirements and constraints in the physical domain. The matrix is structured as a checklist including the five operational life cycle stages in the rows and the four product-related evaluation criteria in the columns (Johannesson and Claesson, 2005).

Table 3-2 Criteria search matrix (CSM) (adapted from Olsson, 1976).

	Analysis tool for product design and development		**Evaluation criteria**			
			Process	**Environs**	**Humans**	**Economy**
		Weight				
Operational life cycle	Development					
	Production					
	Distribution					
	Use					
	Recycle/reuse					

3.4 Packaging design and development

Packaging has a variety of functions in the supply chain. In design and development, it can be considered a product with distinct functions such as communication, containment, convenience, information, preservation, promotion, protection, unitization, waste reduction and recycling (ECR Europe, 2009; Livingstone and Sparks, 1994; Robertson, 1990).

3.4.1 Product and packaging system

The three levels of packaging – primary, secondary, and tertiary (Dominic et al., 2000; Jönson, 2000) – that contain the product are regarded as a system, see Figure 3-7. All of the components in such a system are interrelated. A systems approach also emphasizes the interactions between the three packaging components and the product and highlights the interdependence of the components in the product and packaging system. In other words, the performance of the product and packaging system depends not only on the performance of each component, but on the interactions between them (Hellström and Saghir, 2007). These interactions are crucial to the overall performance of the system and along the entire supply chain.

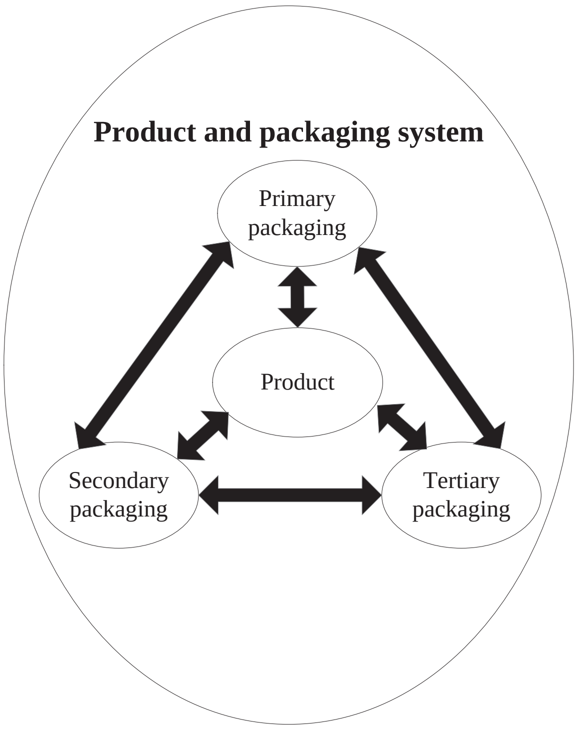

Figure 3-7 Product and packaging system and the interactions among its different components.

Moreover, packaging is defined as *"a coordinated system of preparing goods for safe, secure, efficient and effective handling, transport, distribution, storage, retailing, consumption and recovery, reuse or disposal combined with maximising consumer value, sales and hence profit"* (Saghir, 2002, p. 51). Thus various needs regarding various operations are placed on the packaging itself as a part of a system that contains the product too. Based on functions and the definition of packaging, the needs put on product and packaging system are related to multiple disciplines including logistics, marketing, production, product development, and the environment (Jönson, 2000; Klevås, 2005a; Prendergast, 1995; Saghir, 2004).

3.4.2 Packaging design considering logistics and the supply chain

Design for Packaging Logistics (DFPL) (Klevås and Saghir, 2004) provides design guidelines that are broad design rules according to Watson and Radcliffe (1998). Supply chain needs are inputs to DFPL and it considers packaging, logistical and product requirements. DFPL takes into account marketing, environment, transport, inventory, warehousing, and order processing requirements (Klevås and Saghir, 2004). Without a holistic approach that takes into account the operations in the whole supply chain, there is a risk for sub-optimization (Klevås and Saghir, 2004).

In addition to these design guidelines, design tools must be used to evaluate the design trade-offs (Klevås and Saghir, 2004), such as the Criteria Search Matrix (CSM) (Olsson, 1976) and packaging scorecard (Olsmats and Dominic, 2003). It is not enough to use DFPL; other operational life cycle considerations such as manufacturing are also required (Klevås and Saghir, 2004). Since a packaging solution provided by technicians does not necessarily satisfy the needs of the customers along the supply chain, it is crucial to create methods and tools that connect packaging and logistics interactions in the supply chain to the product design and development (ibid).

Inspired by 3-DCE, Dominic (2011) suggests a method called "holistic packaging development". It considers the alignment of the supply chain, logistics processes and packaging system together as three cornerstones. Dominic (2011) reports the potential of his packaging design and development method for increasing supply chain efficiency. Supply chain actors work together accordingly to satisfy needs that come from customers and consumers. Dominic points out the issue of sub-optimization regarding packed products. Each actor, such as the packaging supplier, is interested in making its processes efficient. Consequently, when it comes to packed products as a system made up of product and packaging, there is no control over them and the logistics processes. Holistic packaging development uses packaging scorecard (Olsmats and Dominic, 2003) to gather the supply chain actors' needs and to assess them. The holistic packaging development method can serve as a basis for gathering and prioritizing supply chain needs but it does not provide a method for translating the needs into requirement all the way to packaging solutions.

4.Results from appended papers

According to the aim of this dissertation, four papers were written based on the four investigations presented in the methodology chapter. The results from papers 1, 2 and 3 contribute to the packaging logistics body of knowledge about increasing supply chain efficiency, while the results from paper 4 contribute to knowledge about increasing supply chain effectiveness. The main results from each appended paper in relation to the aim, RQs and areas where knowledge is lacking are summarized in this chapter. Figure 4-1 illustrates the four papers and the research questions in relation to the gap. It should be noted that detailed answers to the RQs are in the appended papers.

Paper 1 answers RQ1. The paper explored the interactions between packaging and supply chains in developing countries and suggested propositions. Supply chain needs on packaging were identified and categorized that can be used in packaging design and development to enhance supply chain efficiency.

In paper 2, an existing packaging design and development method for supply chain efficiency in the case company was explored and improved in order to answer RQ2. The supply chain needs on packaging that were identified in paper 1, in combination with the operational life cycle, were then used as input to suggest an improved packaging design and development method for supply chain efficiency. Various steps were suggested for the proposed method. One step included the modeling and simulation of packaging, which was further investigated in paper 3.

Paper 3 extended the modeling and simulation step from paper 2 in order to answer RQ3 and RQ4. Models and software that could be used in the design and development method reported in paper 2 were identified with a focus on secondary packaging. A list of the models and software identified for corrugated board and box and their use was also presented in paper 3. Propositions toward improving the use and development of models and software for corrugated board and box design and development were put forward.

The results from papers 1, 2 and 3 were complemented by those from paper 4. Paper 4 contributes to the packaging logistics body of knowledge on reducing the gap between the needs and satisfying them by linking product and packaging with supply chain strategy toward increasing supply chain effectiveness. This is in line with market mediation function of the supply chain. Product and packaging postponements (e.g., PTO, LTO) in relation to supply chain strategies were also presented.

The results from the appended papers are summarized in the next four sections.

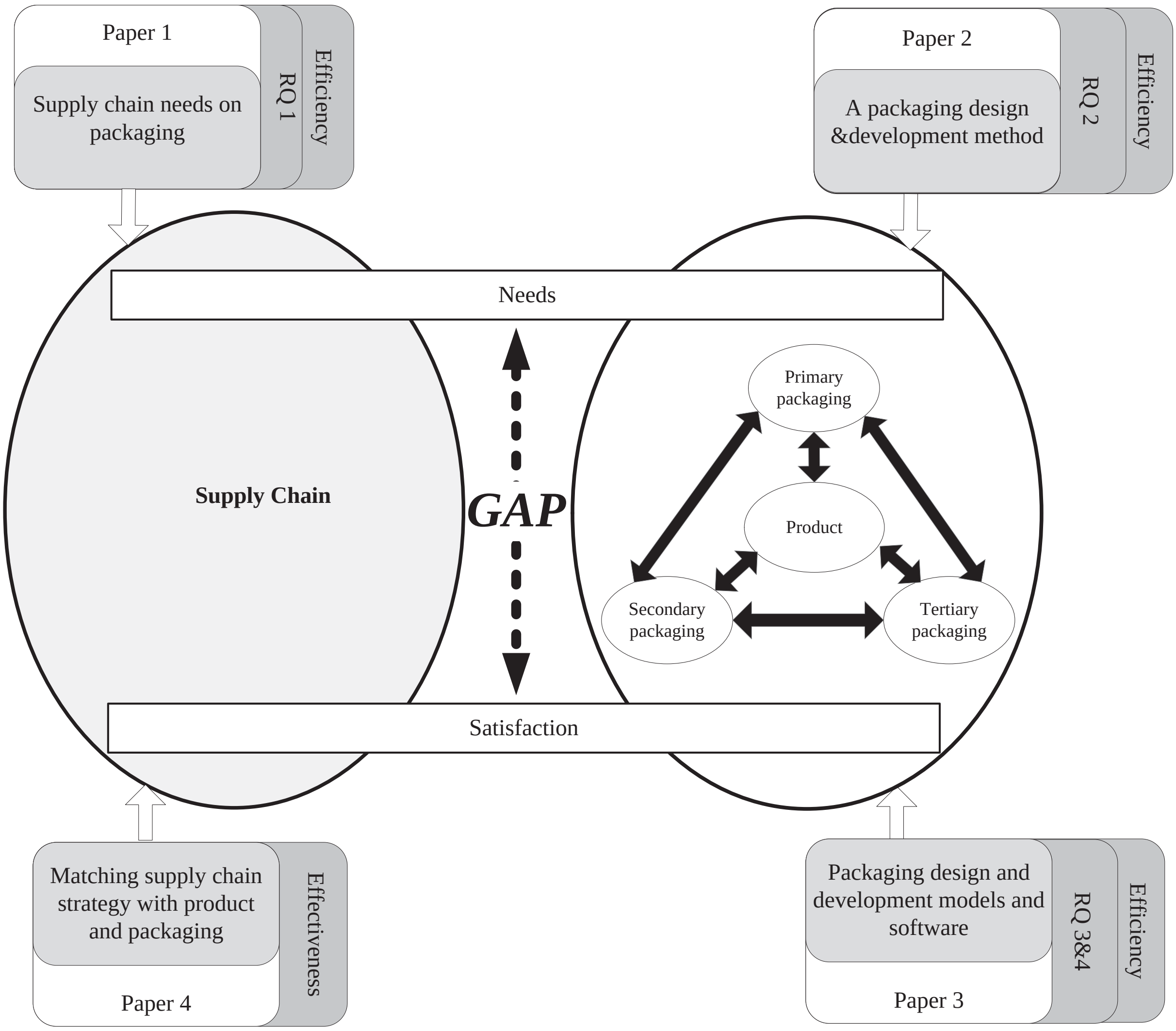

Figure 4-1 The papers and the research questions in relation to the gap.

4.1 Supply chain needs on packaging

4.1.1 Interactions and propositions

The results of paper 1 show that there are extensive interactions between packaging and the supply chain in developing countries. Secondary packaging serves a significant role in compensating for the impact of weak infrastructures. This has to be taken into account in the design and development of packaging in order to provide solutions that can reduce the gap between the supply chain needs and satisfying them toward increasing supply chain efficiency. By recognizing the multi-functional role of packaging in the supply chain, packaging provides an opportunity to decrease the total cost of the supply chain and improve its performance in developing countries. Thus, packaging trade-offs regarding the various supply chain needs must be carefully considered in order to design and develop product and packaging systems that can improve supply chain efficiency.

Although each supply chain is context specific (Lapide, 2006; Godsell et al., 2011) and changes over time, three generic types of milk supply chains were identified: traditional trade, modern trade, and the school milk program (see Figure 4-2). The traditional trade supply chain is the most dominant one in developing countries. It has many actors including a chain of distributors and various wholesalers. The modern trade supply chain often includes a large retailer with a chain of stores. School milk programs that are often subsidized by the government make direct shipments from the dairy to the schools or through distributors.

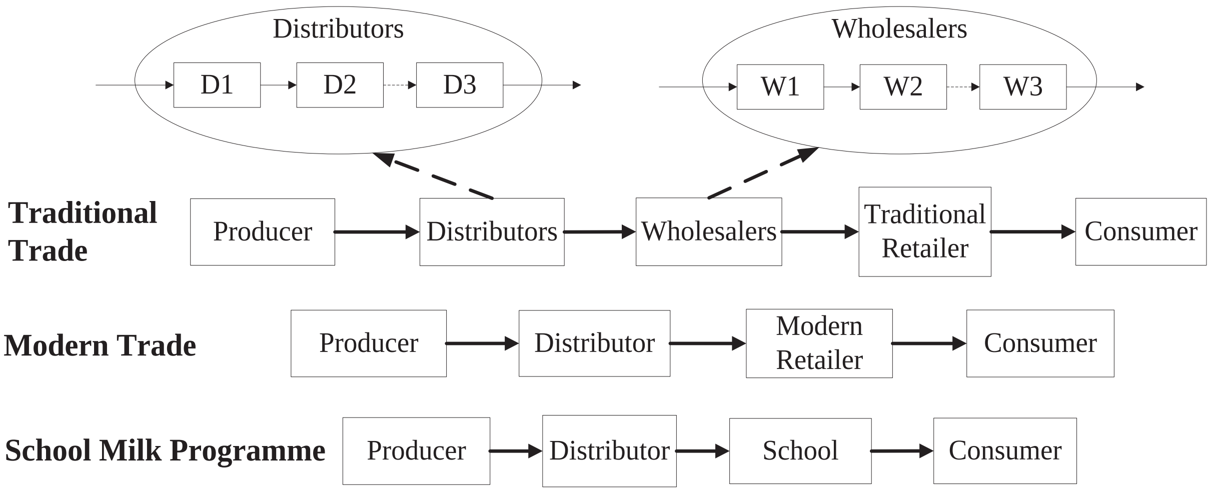

Figure 4-2 Milk supply chains in developing countries (paper 1)

In such supply chains in developing countries, lack of infrastructures (i.e., chilled or frozen distribution) makes ambient food and beverages more viable. Weak infrastructures, including roads, handling equipment and vast numbers of supply chain actors, intensify the supply chain interactions with product and packaging systems. It is vital to consider this for packaging in relation to its functions, one of which is protection.

Actors in these supply chains are focused on decreasing their own costs rather than those of the entire supply chain, which results in sub-optimizations. Such sub-optimizations can be reduced by sharing data and information throughout the supply chain. Sharing can also contribute to communicating the supply chain needs with the dairies and in determining what needs are essential to be satisfied for increasing supply chain efficiency through packaging design and development.

Just as in developed countries, a holistic packaging perspective is needed when designing and developing product and packaging systems for increased supply chain efficiency in developing countries. This means taking into account the supply chain needs regarding packaging and the packaging needs regarding supply chains as a complex whole (Hellström and Nilsson, 2011). They state that this type of interaction is dynamic and changes over time, which is in contrast to treating a supply chain as being composed of separate, independent parts that are assessed in the moment on their own. According to results of paper 1, the following propositions are presented in Table 4-1 based on the supply chain needs and challenges of packaging in developing countries.

Table 4-1 Propositions based on interactions between supply chain and packaging.

	Propositions from paper 1
1. Role of packaging	Packaging needs to be viewed as a vital and central supply chain component in developing countries since it can compensate for the impact of weak infrastructures and has a considerable impact on supply chain cost and performance.
2. Extensive interaction	A shift of focus, from viewing packaging as a cost driver to a multi-functional supply chain component, provides an opportunity to decrease the total cost of supply chains and to improve their performance in developing countries.
3. Supply chain sub-optimizations	Data and information sharing between supply chain actors is needed in developing countries in order to enable involved decision and policy makers to collaborate and take actions towards decreasing supply chain sub-optimization.
4. Conflicting supply chain needs	Packaging trade-offs between sourcing and purchasing, production, warehousing and handling, transport, marketing and climate conditions need to be carefully considered in order to develop and design effective packaging systems for supply chains in developing countries.
5. Lack of holistic perspective	A holistic packaging perspective is needed in order to develop and design effective packaging systems for supply chains in developing countries.

4.1.2 Supply chain needs

The list of supply chain needs on secondary packaging in developing countries presented in paper 1 serves as input to design and development. These supply chain needs are categorized in six categories: sourcing and purchasing, production, warehousing and handling, transport, marketing, and climate conditions. These needs are often different and mismatching as can be seen in Table 4-2. Therefore it is vital to consider trade-offs (e.g., Jahre and Hatteland, 2004) and come up with packaging solutions that can increase the supply chain efficiency.

Table 4-2 Supply chain needs on secondary packaging in developing countries.

Category	Need on packaging	Reason for the need	Actor
Sourcing and Purchasing	Nearby supplier	*Transport costs*	Producer
	Cheap packages	*Material costs*	Producer
Production	Easy to hand pack Large packages	*Filling efficiency* *Material costs*	Producer
Warehousing and Handling	High stacking capability in storage	*Storage space utilization*	Distributor Wholesaler Retailer School
	Enduring rough manual handling	*Lack of training* *Lack of handling equipment* *Working situation*	Producer Distributor Wholesaler Retailer
	Enabling manual handling	*Lack of handling equipment* *Low labor costs* *Vast number of supply chain actors*	Producer Distributor Wholesaler Retailer

Transport	Enduring rough transport conditions	*Poor road quality* *Old trucks* *Transport mode* *Distance*	Producer Distributor Wholesaler
	High stacking capability in vehicles	*Transport cost* *Space utilizations on the truck*	Producer Distributor Wholesaler
Marketing	Compatibility with retail shelf	*Shelf size*	Producer Retailer
	Attractiveness to consumers	*Different brands with various quality images* *Multipack or a sales unit*	Producer Retailer
	Ease of being carried	*Multipack or a sales unit* *Consumer adaptation*	Producer Retailer School
Climate Conditions	Protect against climate conditions	*Humidity* *Temperature*	Producer Distributor Wholesaler Retailer School

4.2 A packaging design and development method

The packaging design and development method used by the collaborative partner company was explored, analyzed and improved in paper 2. The gap between what is needed and how the needs are satisfied is a motivation for developing or redesigning packaging. This gap is mainly based on the interaction of product and packaging systems with the supply chain. The needs can be related to supply chain design, operations and production processes.

4.2.1 Package Requirement Cascading (PRC) method

The method used by the industrial partner in collaborative research for packaging design and development was called Packaging Requirement Cascading (PRC), and was developed based on Olsson's conceptual design (1976). Conceptual design is originally a product development method that was adapted by the industrial partner for primary and secondary packaging design and development.

Various customer/consumer needs on packaging in PRC are categorized into five categories based on an operational life cycle: development, production, distribution, use, and recycle/reuse. PRC is used not only to identify supply chain needs placed on product and packaging system, but also to prioritize important functional requirements and design attributes. Five steps of development have to be taken in PRC: collection and structuring the needs, weighting the needs, breaking down the needs into requirements, adding technical attributes, and correlating requirements with technical attributes.

Outcome of PRC is draft specifications for the packaging solution. These specifications can be further developed into a finished packaging solution (primary and secondary), where characteristics such as dimensions (size), strength, and choice of material are set. PRC is illustrated in Appendix O.

4.2.2 Propositions and supply chain adapted packaging design and development method

In order to improve the packaging design and development method to reduce the gap between supply chain needs and satisfaction three propositions are put forward. These propositions are based on an expanded operational life cycle, 3-DCE (Ellram et al., 2007; Fine, 2000; Fine et al., 2005) and the four domains of design (Chen, 1999; Suh, 1990). According to results of paper 2, the following propositions are presented in Table 4-3.

Table 4-3 Propositions for improving the packaging design and development method.

	Propositions from paper 2
1. Use the four domains of design	Use the four domains of design to improve the packaging design and development method. It is necessary to follow clearly defined steps to reduce the gap between supply chain needs and satisfying them. The four domains of design (Chen, 1999; Suh, 1990) offer an opportunity to better define such steps (e.g., needs, requirements and constraints) in relation to the entire supply chain.
2. Use an expanded operational life cycle	Improve the packaging design and development method by using an expanded operational life cycle. It recognizes the supply chain needs and categorizes them to reducing the gap between needs and satisfaction.
3. Integrate the product and packaging system, supply chain and processes	Integrate the product and packaging system, the supply chain, and the processes in design and development. By considering the concurrent development of product and packaging (Olander-Roese and Nilsson, 2009; Bramklev et al. 2005) as a system in relation to logistics and supply chain design, the competitive advantage of the firm and the whole supply chain will be enhanced.

According to above propositions, PRC was further improved to become a new, supply chain focused packaging design and development method in paper 2. The new method contributes to reducing the gap between the needs and satisfying them by providing a base for better integrating the needs and for mapping them along the entire supply chain. It does this by applying an expanded operational lifecycle to include eight categories: design and development, sourcing and purchasing, production, warehousing and handling, transport, marketing, use, and recycle/reuse. The expanded version is based on the supply chain needs identified and reported in paper 1 and related literature (e.g., Olsson, 1976; Sarkis, 2003; Rundh, 2009). By recognizing the product and packaging system from a supply chain perspective, the expanded operational lifecycle complements the previous research, which primarily addresses products with a limited life cycle.

Improved evaluation criteria including requirements and external constraints are also suggested that contribute to the evaluation and prioritization of the needs to be satisfied. The identified needs have to be evaluated and prioritized because not all of them can be satisfied. Thus, the four domains of design based on Chen (1999) and Suh (1990) were used to improve the evaluation criteria (i.e., requirements and constraints). The requirements in the evaluation criteria were also further developed by using 3-DCE (e.g., Ellram et al., 2007; Fine, 2000; Fine et al., 2005). The requirements are divided to process, supply chain, and product and packaging system. External constraints include economic, legal and environmental constraints. Thus, the Criterial Search Matrix (CSM) (Olsson, 1976) was further developed and is presented in Table 4-4.

Table 4-4 Improved supply chain focused CSM with expanded operational life cycle adapted from Olsson (1976)

	Supply chain focused CSM		**Evaluation criteria**			
			Requirements			**External constraints**
			Process	Supply chain	Product and packaging system	Economic, legal, environmental
		Weight				
Expanded operational life cycle	Design and development					
	Sourcing and purchasing					
	Production					
	Warehousing and handling					
	Transport					
	Marketing					
	Use					
	Recycle/reuse					

The steps that have to be taken to map supply chain needs to provide the draft specifications of a suitable packaging solution for the intended supply chain are suggested based on the four domains of design (Chen, 1999; Suh, 1990) in addition to PRC itself. Moreover, the improvement of the method helps to enhance the alignment of product and packaging development, processes and the supply chain by recognizing the supply chain needs from an expanded operational life cycle. The extended operational life cycle and the steps to be taken are illustrated in Figure 4-3.

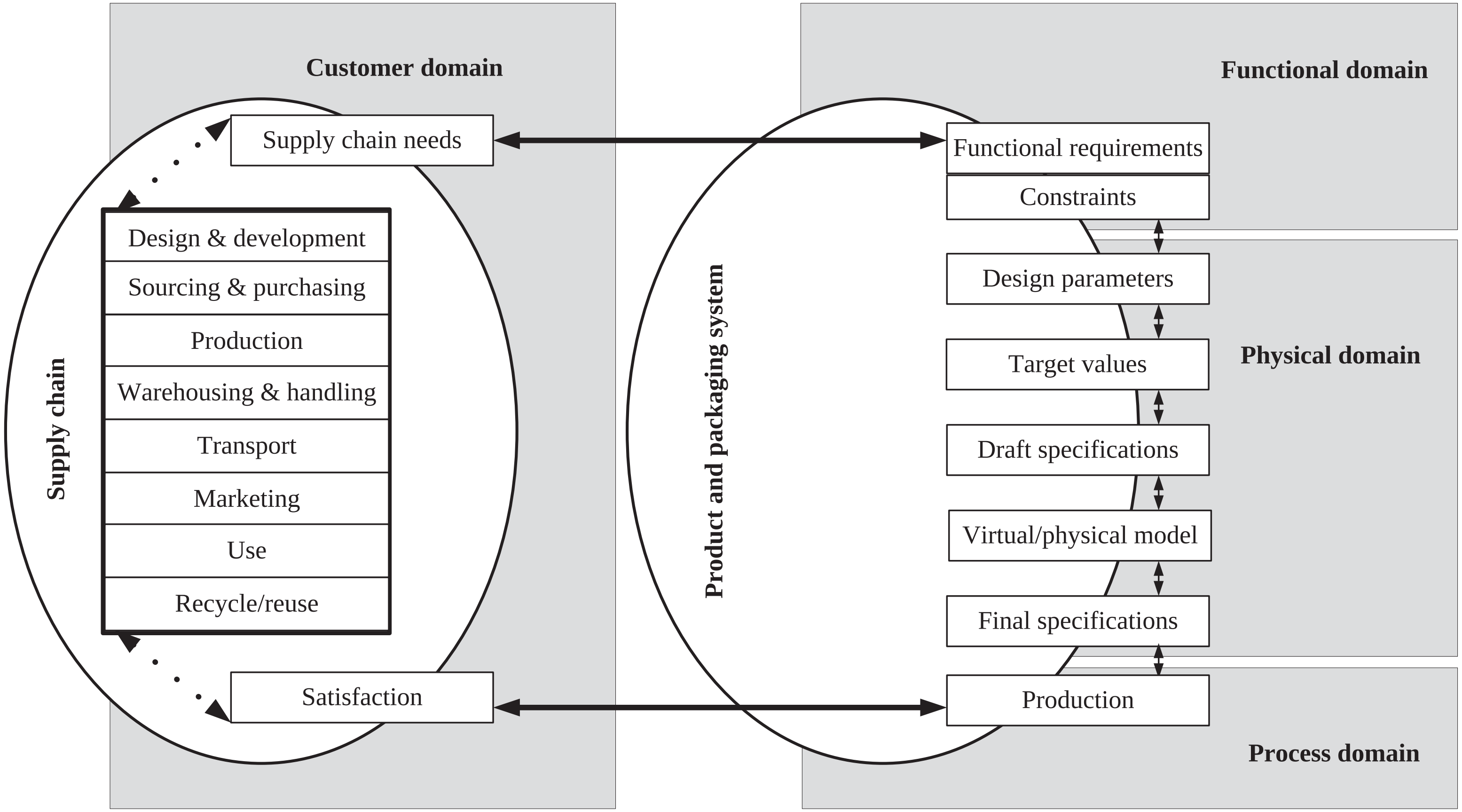

Figure 4-3 Supply chain focused packaging design and development method. Expanded operational life cycle (left side) and steps between needs and satisfaction (right side).

4.3 Packaging design and development models and software

Models and software are used in packaging design and development methods. The models contribute to setting the final specifications of the packaging solution as illustrated in Figure 4-4 (i.e., virtual/physical model), specifically for corrugated boxes. Corrugated box (mainly Regular Slotted Container) is widely used in the supply chains in developing countries as reported in paper 1.

For the design and development of corrugated board and boxes, eighteen models and four software programs were identified and then compared and categorized in relation to the different supply chain actors' usability in the corrugated board and box supply chain. The models and software identified were developed based on either a numerical or an analytical/empirical approach. The timeline in Figure 4-5 illustrates the progress of the identified models and software. Further details on these models and software programs are included in paper 3.

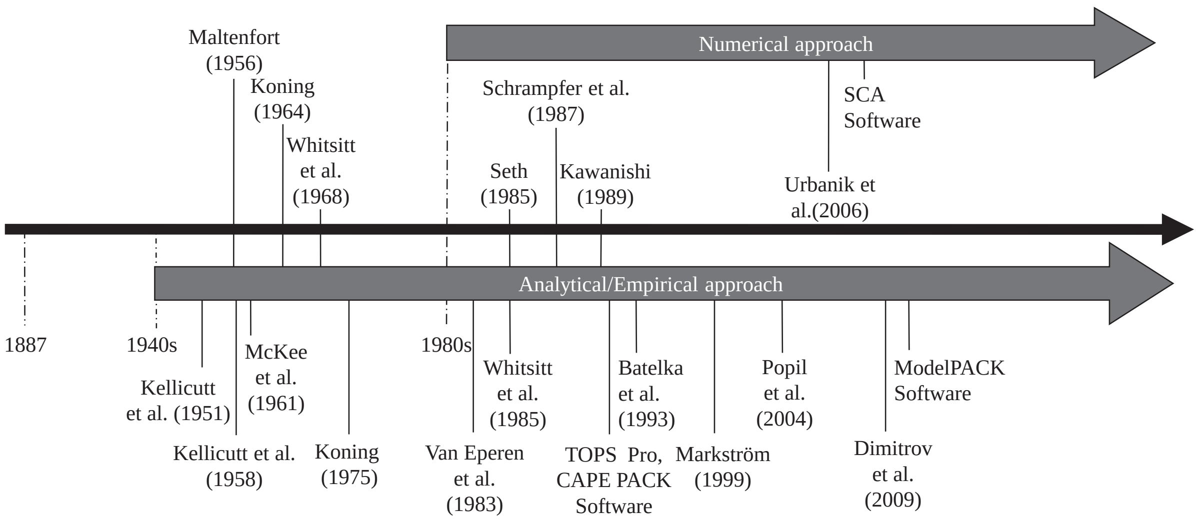

Figure 4-5 Progress of models and software identified. Further information and references are included in the Paper 3.

4.3.1 Supply chain use of models and software

Models and software characteristics were compared depending on whether they used paper, board or box properties, and on whether they included environmental factors (e.g., moisture and temperature). The supply chain actors – a paper producer (paper mill), a corrugated board producer (corrugating factory), a box producer, and the customer (e.g., dairies) – use of models and software is discussed in paper 3.

According to the comparison, models and software that use paper properties to predict box properties are applicable for paper mills, corrugating factories, and board and box producers. This is because these actors have access to the paper properties, which can enable more accurate predictions in the design and development of packaging.

Customers (e.g., dairies) in corrugated box supply chains usually do not have access to paper properties; but they can measure some of the board properties. Thus, only models that use board properties are applicable for them (e.g., McKee et al., 1961; Schrampfer et al., 1987; Kawanishi, 1989; Batelka and Smith, 1993). Moreover, their lack of knowledge about paper and the inability to measure paper properties represent a major problem in using models that can predict box properties based on paper properties for higher accuracy.

Software such as *CAPE PACK*, *ModelPACK* and *Tops Pro* (See Appendix P) include the climate conditions in their predictions and can be used by customers (e.g., dairies). Whereas, there is no model that covers the entire scope from paper properties to environmental factors while considering the impact of the logistics processes (e.g., handling, load frequency) for the final customer.

4.3.2 Propositions toward improving the use and development of models and software

New insights, in the form of propositions toward improving the use and development of models and software, are suggested by considering the literature and practice. These propositions are presented in Table 4-5. They are explained more in detail in paper 3.

Table 4-5 Propositions on models and software

	Propositions from paper 3
1. Knowledge and data sharing	Knowledge, information- and data sharing regarding corrugated board and boxes between different actors in the supply chain from paper mill down to customer is needed in order to improve prediction accuracy. This would enable effectiveness and efficiency of the box design by considering material and process uniqueness, such as production processes and material composition.
2. Selling the knowledge	There is a potential business case for companies which have a massive amount of knowledge and advanced software for simulating corrugated board by selling knowledge or renting out their software. Such a win-win situation helps customers or producers of corrugated board to optimize their package designs while companies owning models and software can rationalize the cost of developing models and software.
3. Manufacturing noise	To make more accurate predictions of corrugated board and box properties it is vital to measure and consider manufacturing noise in prediction models and software.
4. Integration of aspects and disciplines	Integration of different influential aspects and disciplines like quality, manufacturing, fiber mechanics, packaging, and logistics are needed in order to improve the effectiveness, efficiency, and consistency in the production and prediction of corrugated board and box properties.
5. Robust design	Using robust design simulation of boxes contributes to an industrial strategy to deal with modeling, simulation, and quality of corrugated board and box as a long-standing problem.

4.3.3 A holistic modeling perspective

A holistic perspective considering both noise and control factors for modeling corrugated board and box is proposed in paper 3. This perspective enables practitioners and researchers to identify causes of variations in the predictions of models and software. Hence, they can use the suggested holistic modeling perspective to increase the accuracy of their predictions.

Using a P-diagram (Taguchi, 1987; Suh, 1990) from robust design provides such a holistic modeling perspective for considering both noise and control factors that impact the model precision. This means taking into account the full box in the supply chain (e.g., dairy supply chain) with both control and noise factors. This holistic view in addition to traditional ways of generating models in restricted lab conditions can provide the foundation for providing more accurate and more practical models and software. The holistic perspective is illustrated in Figure 4-6.

According to the P-diagram (Taguchi, 1987; Suh, 1990), noise factors are of three types: manufacturing, environmental and inherent. Manufacturing noise which occurs in production has a significant impact on the Edge Crush Test (ECT) and Box Compression Test (BCT) of corrugated board and the box (for further information see Batelka and Smith, 1993 and Weigel, 2001) and consequently on prediction models and software. Environmental noise (e.g., pallet pattern, overhang, stacking height, transportation mode, and handling) occurs downstream in the corrugated box supply chains. Environmental noise factors are mainly considered by software rather than theoretical models. Inherent noise factors come from the material itself (e.g. variation in fiber strength and fiber-fiber bond strength).

Thus, both control and noise factors have to be taken into account to increase the quality of boxes in production and use, and for increasing the prediction accuracy of models and software. Control factors are usually used in the absence of most noise factors in order to predict the response of the box (e.g., BCT, stacking strength or time to failure) in various models. Models are mainly focused more on control factors in the absence of environmental and manufacturing noise (see Paper 3). On the other hand, software programs try to provide pragmatic estimations that consider environmental noises.

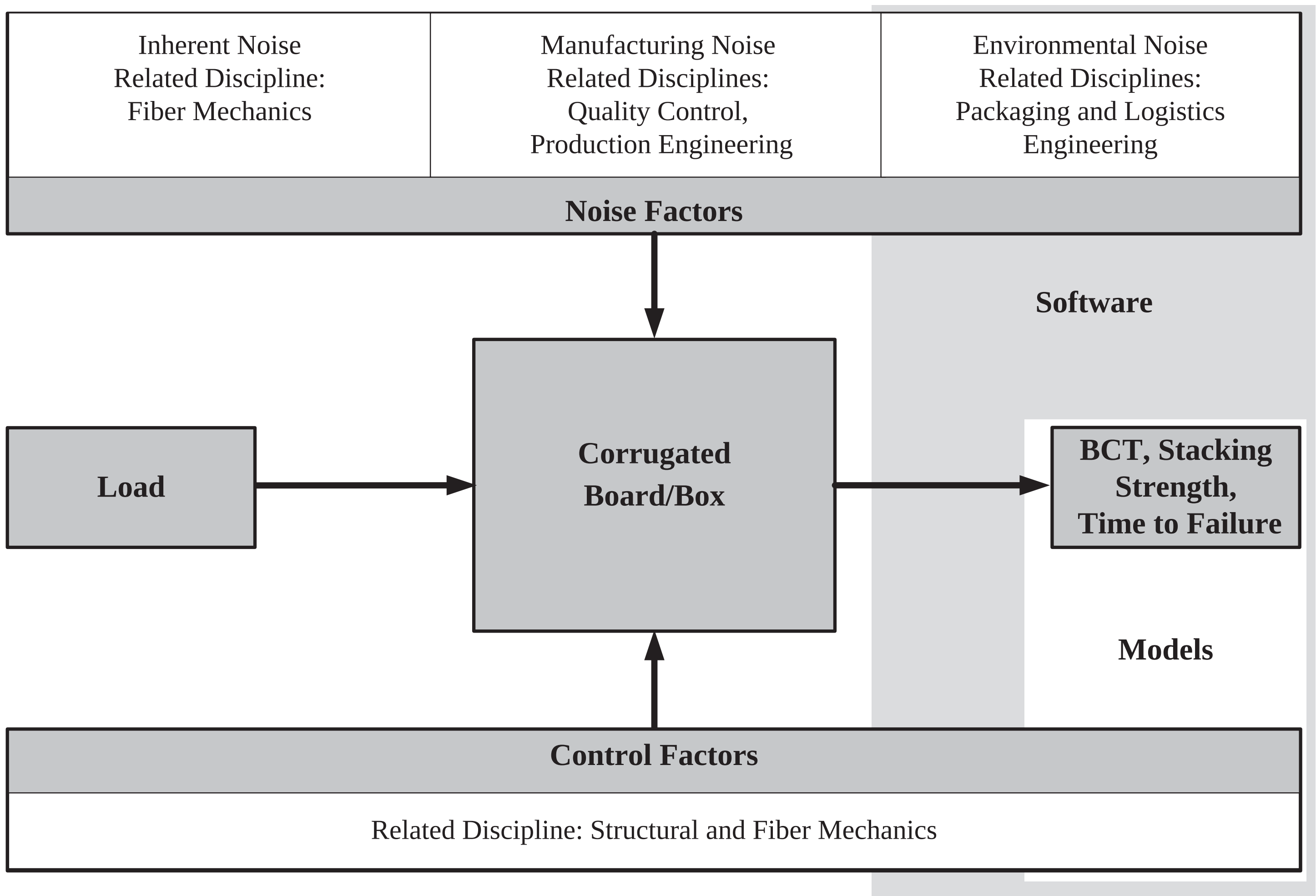

Figure 4-6 Holistic perspective for modeling corrugated board and box

4.4 Matching supply chain strategy with product and packaging

The supply chain strategy interrelations with product and packaging and how they can be matched were explored in the literature and described in paper 4. In the interrelation between supply chain strategy and product, much research has been conducted since Fisher (1997), but still there is a lack of research regarding packaging, which was indicated in the articles reviewed. In addition, the Fisher (1997) model is not adapted for food and beverage packaging supply chains.

4.4.1 Supply chain strategy and product

Huang et al. (2002) have advanced Fisher's model (1997) and put forth the most integrative conceptual model that can be used for describing and matching supply chain strategy with product type. This model divides supply chain strategies into three types – agile, hybrid and lean – in relation to the three product types, namely innovative, hybrid and standard (see Figure 4-7). Huang et al. (2002) introduced the hybrid or mix product type and it is used by other researchers such as Brun and Castelli (2008), Lo and Power (2010), Zhang and Huang (2012). Hybrid products are defined by Huang et al. (2002) as the ones including different combinations of standard components or being a combination of standard and special components. The product type is the single most important factor for supply chain selection according to Huang et al. (2002)

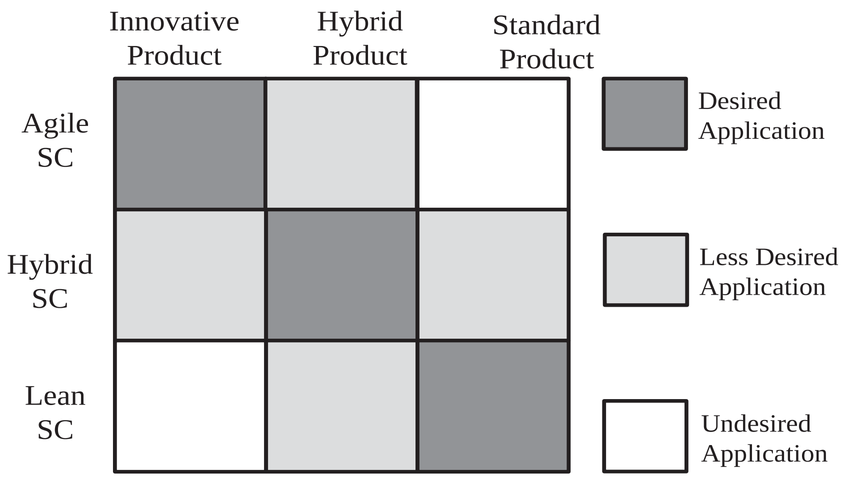

Figure 4-7 Matching product with the supply chain (Huang et al., 2002).

Converting the four mutually exclusive quadrants of the Fisher model to nine with interrelations that are more flexible can be used to describe and match the supply chain strategy and product type. The quadrants categorize the interrelations between supply chain strategy and product as "desired application", "less desired application", and "undesired application". Matching the supply chain and the product can influence the effectiveness of the supply chain in responding to the demand through various postponements. Examples of postponements for each supply chain strategy are provided by Hilletofth (2009) and Stavrulaki and Davis (2010):

- agile: ETO, DTO;
- leagile: PTO, Label-To-Order (LTO);
- lean: MTS.

4.4.2 Supply chain strategy and packaging

The literature reviewed indicated that packaging has not been explored in depth in previous supply chain strategy research. The primary focus has been on product types, even though some research can be regarded as focusing on food packaging such as FMCG (Fast-Moving Consumer Goods) , which includes canned drinks (Lamming et al., 2000) and food and beverages (Wagner et al., 2012). For food products, packaging is often integrated with the product. This means that food products and their primary packaging together resemble a unit with specific physical characteristics. Thus, packaging has to be taken into account in setting the supply chain strategy. Moreover, packaging can enable various postponements through printing technologies (e.g., Twede et al., 2000).

Packaging in the literature is mainly considered in the leagile or hybrid strategy (e.g., Hilletofth, 2009). Packaging in the leagile strategy provides the opportunity for postponement, which is mostly reported for non-food products (e.g., Christopher et al., 2006; Hilletofth, 2009) and some for food products (e.g., Twede et al., 2000; Van Wezel et al., 2006). In this strategy, lean processes can be adapted upstream of the decoupling point and agility can be adapted downstream (e.g., Twede et al., 2000; Hilletofth, 2009). A balance between cost and quick response can be achieved in the leagile strategy (Lo and Power 2010; Mason-Jones et al., 2000b; Childerhouse and Towill, 2000; Stratton and Warburton, 2003; Christopher and Towill, 2002). The challenge of balancing between efficient production and flexible performance in the food processing industries is mentioned by Van Wezel et al. (2006). Thus, adapting postponement in the food and beverage industry is challenging, and according to Van Wezel et al. (2006), the food processing industry's flexibility is restrained by hard-wired production process characteristics and organizational procedures in the planning process.

5. Concluding discussion

This chapter provides concluding discussion on the role of packaging in relation to supply chain efficiency and effectiveness based on the overall aim of the dissertation. The three main conclusions are presented in the following three sections based on the four investigations. These conclusions contribute to the packaging logistics body of knowledge in the four areas where knowledge is lacking as described in section 1.3. The conclusions are:

- The supply chain strategy and its product and packaging characteristics have to be matched from a supply chain effectiveness point of view. This conclusion, presented in section 5.1, is based on the results of investigation 4 and motivated by investigation 1. It relates to one of the four areas where knowledge is lacking: the role of packaging in relation to the supply chain strategy.
- Packaging design and development have to comply with the physical supply chain needs of various actors along the chain to increase supply chain efficiency. This conclusion, presented in section 5.2, is based on the results of investigations 1, 2 and 3. The sub-sections relate to three of the four areas where knowledge is lacking: supply chain needs on packaging, supply chain focused packaging design and development methods, and the use of models and software for packaging design and development.
- Packaging can contribute to supply chain efficiency and effectiveness by reducing the gap between needs and satisfaction if the packaging is matched to the supply chain strategy and if it is designed and developed to satisfy physical supply chain needs. This final and overall conclusion, presented in section 5.3, is based on the results of all four investigations. It relates to all four areas where knowledge is lacking.

5.1 Matching product and packaging with the supply chain strategy

The supply chain strategy and its product and packaging characteristics have to be matched from a supply chain effectiveness point of view. This is because the product and packaging together as one system has specific characteristics that are vital to consider in choosing the supply chain strategy. This is particularly so for food and beverages. Shelf life, for example, is a characteristic that is dependent upon product and packaging together. In addition to the product, packaging plays a key role in setting the supply chain strategy. Thus, in setting the supply chain strategy, packaging characteristics need to be considered, particularly for food packaging; this is lacking in Fisher's (1997) decision factors.

Matching the supply chain strategy and its product and packaging characteristics is based on the market mediation function of the supply chain and influences its effectiveness. The supply chain strategy has to be chosen prior to setting the efficiency metrics related to the supply chain's physical function. The three supply chain strategies to choose from are those that are physically efficient or lean, market-responsive or agile, and hybrid or leagile (Sanderson and Cox, 2008; Stavrulaki and Davis 2010; Golicic and Sebastiao 2011; Zhang and Huang, 2012). Efficiency metrics are, for example, related to production, distribution and handling (Saghir, 2002). A reason for choosing the supply chain strategy prior to setting the efficiency metrics is that market related metrics (e.g., service level, image performance, sale performance and consumer satisfactory performance) are "*often negatively related to cost efficiency*" as Saghir (2002) states. Therefore, focusing primarily on supply chain efficiency increases the risk of sub-optimizing the supply chain for cost issues and hinders its effectiveness. In the following sub-sections (5.1.1-5.1.3), packaging postponement, shelf life and packaging characteristics in relation to supply chain strategy are discussed and three propositions are put forward.

5.1.1 Packaging postponement in relation to supply chain strategy

A considerable amount of research has been conducted on supply chain strategy related to the product, but little related to packaging. Investigation 4 indicated a lack of research on the influence that packaging per se can have in setting supply chain strategy in addition to the product itself. The little research that has considered packaging, has mainly addressed postponements such as PTO or LTO (e.g., Hilletofth, 2009; Abukhader and Jonsson, 2007). In relation to the three types of supply chain strategies, only three types of products (i.e., standard, special and hybrid) are mainly taken into account and not any sort of packaging.

Recognizing and taking into account the influential role of packaging characteristics when setting the supply chain strategy provides opportunities to enable supply chain effectiveness. Postponement is one opportunity that packaging can provide. Viström (2008), for example, argues that the increasing demand for differentiated product offers (higher variety) implies shorter series for each variant, which packaging has to cope with. He has presented the case of using inline digital printing in the food industry for agility in the supply chain. This printing technology can enable PTO since it has a shorter changeover time. Another example is Twede et al.'s (2000) study of a canned food supply chain. Such packaging technology makes it possible to pack a product in cans and postpone the labeling (LTO). Postponement of labeling helps to decrease the excess or lack of packed food products for various customers. Such packaging technologies can enable supply chain effectiveness by coping with demand variation and product differentiations as measures for setting the supply chain strategy.

From another point of view, packaging can provide opportunities to deal with variations and seasonality in the supply of the raw material (e.g., agricultural based products). This was not addressed in the literature reviewed in investigation 4 either. Instead, variations and seasonality of market demand in relation to supply chain strategy was the focus and was frequently examined. Moreover, variation in supply has not been considered to be among the main decision factors for supply chain strategies in the Fisher (1997) model. In contrast, food production is usually dependent on agricultural products (Twede et al. 2000) that can be seasonal. Through postponement opportunities (e.g., LTO, PTO, MTS), packaging can enable dealing with variations and seasonality in the supply of the raw material.

The indications of the role that packaging can play to deal with variations and seasonality in the supply of raw material, was identified in investigation 1 also. According to internal company documents, packaging with long shelf life (e.g., up to one year) and high storage utilization capability was used to implement MTS. There were reports on dairies that had implemented MTS by using carton packages. This type of packaging in integration with the milk products provided long shelf life to be used during the agricultural milk production season, enabling the dairies to deal with the variation in milk supply. As a result, the dairy could sell the packed products the rest of the year when demand arose. Thus, the packaging characteristics enabled the MTS to deal with supply.

5.1.2 Shelf life and supply chain strategy

In food and beverage supply chains, shelf life periods play a vital role and have to be considered as a product and packaging characteristic in setting the supply chain strategy for responding to the demand. Shelf life is defined as *"the time between* *harvesting or processing and packaging of the product, and the point in time at which it becomes unacceptable for consumption"* (Aramyan et al., 2007, p. 306). Essentially, the limited shelf life, in combination with demand uncertainty and fluctuations can lead to the shortage or excess of packed products (Doganis et al., 2006).

Supply chain management research on matching the supply chain strategy with products, from Fisher (1997) to Wagner et al. (2012), uses a typical measure: product life cycle. From the Fisher model's perspective, food and beverages are considered to be commodities. Wagner et al. (2012) followed the same path, but when the data was analyzed, it revealed a major misfit with the Fisher (1997) model. Wagner et al. (2012) showed that what were considered to be commodities (food and beverages) were matched, on the contrary, to the agile supply chain, which is in a mismatch area of the Fisher model. This inconstancy questions the assumptions of these researchers regarding food and beverage.

In contrast, Van der Vorst et al. (2001) state that poultry as a food supply chain, has high demand uncertainty in an inflexible production environment. They mention the challenge of volatile and unpredictable demand, frequent deliveries and rigid production flexibility in this industry. Arguably, Wagner et al. (2012) claim that it is easier to predict demand in the food and beverages supply chain. Even though this statement was made in comparison to the textile and apparel industry, it shows an accepted generalization about the food and beverage packaging industry. Thus, expecting an easy-to-predict demand for all food supply chains and as a consequence, assigning the lean strategy to them in general (Wagner et al., 2012), is in contrast to Van der Vorst et al. (2001) and it is not a sound conclusion.

This is a tension in theory that comes from generalizations, such as food and beverages having longer life cycles and lower variety while stock-outs are lower, and the supply chain response has to match the needs of the more predictable functional products according to Wagner et al. (2012). They also claim that the competitive priority of the supply chain is improvements in terms of lower costs and inventories. This depends on the type of product and its packaging even though cost can be a constraint. A misconception here is that the Fisher (1997) model is used for food and beverage packaging supply chains without being adapted for such use. In this model, food and beverage packed products as a whole are neglected. This misunderstanding comes also from Fisher's Campbell soup example, which is used as a functional product example. The soup is packed in a can (i.e., ambient packaging) with long shelf life, which does not represent the entire range of packed food products including fresh or frozen. Each of these packed products has specific characteristics to be considered. Thus, a more descriptive measure of characteristics of packed food and beverage products is required in the Fisher (1997) model.

One measure that can be used to explain this tension is the shelf life of the packed products: the shorter the shelf life, the greater the pressure on the supply chain to be agile. For long shelf life there is no pressure from packed products characteristics to be agile. Therefore, a lean strategy can be chosen, which also fits the Fisher model. Based on the above discussion, the following propositions are put forward to improve the Fisher (1997) model:

- ***Proposition 1.*** *Long shelf life is positively related to a lean supply chain strategy.*
- ***Proposition 2.*** *Short shelf life is positively related to an agile supply chain strategy.*

Moreover, packed food products with a long shelf life and flexible packaging and printing technology (e.g., Twede et al., 2000; Viström, 2008) can provide postponement opportunities (e.g., LTO, PTO, MTS) in a leagile supply chain strategy. Short setup times enable the implementation of Make-To-Order (MTO) (e.g., juice, bread and tea, Abukhader and Jonsson, [2007]) in an agile supply chain strategy. Thus, various supply chain strategies can be implemented by matching them to a suitable product and packaging (i.e., types and technologies) as a whole. Accordingly, the following proposition is put forward:

- ***Proposition 3.*** *Packed food products with long shelf life and flexible packaging and printing technologies provide opportunities for implementing leagile strategies in the supply chain.*

5.1.3 Packaging characteristic and supply chain strategy

In matching the supply chain strategy and packaging for the food and beverage products, the demand characteristics and packaging characteristics also have to be matched. It means that packaging characteristics have to be considered in relation to the demand in the intended supply chain. Field observations in China (investigation 1) indicated that there was a demand pattern connected to the milk production date within the shelf life of the packed products. The pattern was a high demand for newly packed milk based on its production date and low demand for older packed milk, even though the shelf life provided by its ambient carton packaging was long (i.e., three to six month). However the latter products were acceptable for consumption, having several month of shelf life left, consumers were not interested in buying them. This surprisingly led to mark downs on milk boxes. Mark downs are often reported on special products such as textile and fashion apparel (e.g., Cigolini et al., 2004; Christopher and Towill, 2006; Brun and Castelli, 2008) in relation to the supply chain strategy. A few weeks after the production date, markdowns occurred in the retail stores on milk packages (see Figure 5-1).

Figure 5-1 Mark down of milk products.

This demand pattern also led to extra pressure on the supply chain to be agile while packaging characteristics were not matched with the intended supply chain. Keeping long shelf life characteristics was an over-packing example in the supply chain and had to be avoided by modifying the packaging solutions. Thus, packaging in use could be changed to provide shorter shelf life to match the supply chain needs. Based on the above discussion, it is proposed that shelf life to be added to the Fisher (1997) measures as an additional characteristic for packed food products that needs to be matched with the supply chain strategy. The length of shelf life (i.e., short and long) can be defined by further empirical investigations. See Table 5-1.

When implementing various strategies, it is also necessary to consider supply chain operations based on the product and packaging characteristics in use for food and beverages. This is because packed food characteristics impact the operations in the supply chain. Food and beverages can be processed and packed as fresh products with limited shelf life (e.g., less than a week for fresh milk according to Doganis et al., 2006) that requires chilled distribution. Food products can also be processed and packed in the frozen form with a long shelf life. They then require frozen warehousing and distribution in the entire physical supply chain. They can also be processed and packed as ambient products with long shelf life (e.g., ambient milk with 3 to 6 month based on investigation 1). This type does not need extra infrastructure in the supply chain as is required for fresh and frozen packed products.

Table 5-1 Standard vs. special (adapted from Fisher, 1997).

	Standard	Special
Aspect of demand		
Shelf life	***Long***	***Short***
Product life cycle	More than 2 years	3 months to 1 year
Contribution margin	5% to 20%	20% to 60%
Product variety	Low (10 to 20 variants per category)	High (often millions of variants per category)
Average margin of error in the forecast at the time production is committed	10%	40% to 100%
Average stock-out rate	1% to 2%	10% to 40%
Average forced end-of-season markdown as percentage of full price	0%	10 to 25%
Lead time required for made-to-order products	6 months to 1 year	1 day to 2 weeks

The packed food and beverage characteristics also influence other levels of packaging (i.e., secondary and tertiary packaging). For example, in ambient milk supply chains, corrugated board boxe is used as secondary packaging in many developing countries (investigation 1). For chilled packed products (i.e., fresh milk) in Sweden and Norway, metal rolling racks (see Jahre and Hatteland, 2004) that function both as secondary and tertiary packaging are used. In addition to packed food and beverage characteristics, supply chain needs such as warehousing and handling influence the choice of other levels of packaging and they have to be considered in implementing supply chain strategies.

Thus, transportation and warehousing for ambient food and beverage products can be similar to non-food products but chilled and frozen ones have to have cooling or freezing capability in transportation and warehousing. Moreover, chilled and frozen food supply chains have different characteristics regarding responsiveness or cost efficiency that cannot be analyzed using the Fisher (1997) model or further developments of it so far (e.g., Huang et al., 2002). New dimensions are required to be added to the model to enable it to analyze various food and beverage supply chains accordingly.

5.2 Packaging design and development for supply chain efficiency

For increasing supply chain efficiency, packaging design and development has to comply with the physical supply chain needs of various actors along the chain. To increase supply chain efficiency, it is vital to take into account the supply chain needs on packaging (investigation 1) and design and develop packaging based on them (investigations 2 and 3). Thus, packaging can contribute to reducing the gap between needs and satisfaction based on the physical function of the supply chain (investigations 1, 2 and 3). Among such needs that have to be satisfied, a categorized list is presented in Table 4.2 of the ones identified in ambient milk supply.

Sub-section 5.2.1 discusses supply chain needs and packaging in design and development. Sub-section 5.2.2 discusses damage reduction by use of corrugated board packaging and its design using models and software. The life cycle for packaging design and development is contrasted to the life cycle used in setting the supply chain strategy in 5.2.3.

5.2.1 Supply chain needs and packaging design and development

It is vital to consider needs on packaging from the entire supply chain in design and development in order to increase supply chain efficiency. This is because mismatching needs are often placed on packaging from different actors. Considering these needs provides opportunities, for example, to design and develop solutions that utilize the truck and the warehouse space for all the actors in the chain rather than just one. Identifying supply chain needs along the supply chain is in line with the its physical function and is related to the physical costs (e.g., Fisher, 1997; Mason-Jones et al., 2000a).

Primary and secondary packaging in relation to tertiary packaging can be designed and developed to increase supply chain efficiency. But changing primary packaging in the food supply chains studied required a change of packaging machinery as a part of the main production line; this necessitated high capital investment as Orth and Malkewitz (2008) also report. To increase efficiency in the supply chain, it is usually easier to change or design and develop new secondary packaging rather than primary ones.

Secondary packaging provides an opportunity to improve supply chain efficiency by using specific logistics metrics. Examples of the metrics used in industrial practice that were found in the investigation 1 were pallet and truck utilization rates. These were calculated by using *CAPE PACK* software. The logistical metrics were used to satisfy some of the supply chain needs on primary and secondary packaging (corrugated boxes) containing milk products. Ge et al. (1996) used a similar software called *COPS* in their investigation on packaging logistics cost reduction possibilities for increasing efficiency.

Thus, secondary packaging has to be considered as a part of the whole product and packaging system while taking in the supply chain actors' needs to design and develop solutions that can provide higher efficiency for the entire supply chain. Moreover, the secondary packaging for ambient food and beverage products can be similar to other non-food products since they do not need chilled or frozen supply chains. This means that the results of design and development of such packaging can be used for other ambient and non-food supply chains.

5.2.2 Reducing damage through corrugated board packaging

Corrugated board box as secondary packaging can contribute to supply chain efficiency by reducing the damage to the products and their primary packaging. This reduction decreases the risk of leakage and eventually leads to less food waste. Moreover, by providing protection, corrugated board as secondary packaging reduces the risk for damage to the primary packaging, which can result in unsold packed products.

A central constraint in providing corrugated board secondary packaging solutions is cost. All of the interviewees in investigation 1 (Appendix G) mentioned cost as the most important factor in design and development of packaging (i.e., primary, secondary and tertiary) for ambient milk supply chains in developing countries. This was also confirmed by managers in the meetings that were attended (Appendix B). One reason was that the focus of the collaborating company was mainly on a physically efficient milk supply chain for developing countries. Wang (2014) also reveals that the biggest challenge for packaging designers in a corrugated board industry is to make creative designs by considering both production and cost.

One potential example to improve supply chain efficiency in the studied supply chains was to replace the RSC boxes with bliss case. Ge et al. (2008) compared three types of corrugated boxes: RSC, wrap-around and bliss case boxes. Through experimental comparison, they found that bliss case boxes are stronger – on average 6.2% in comparison with RSC and 34.2% in compare to wrap-around – for taking load (i.e., compression strength). But bliss case boxes require a more complicated production and assembling process (Ge et al., 2008). Therefore the managers at the collaborating company primarily did not support the use of bliss case boxes to decrease the damage and increase the supply chain efficiency. The extra strength provided by bliss case in comparison to RSC was not considered significant enough by the managers.

To contribute to efficiency of supply chain, a holistic view of the corrugated board packaging is required in packaging design and development to protect the product along the supply chain against damages (investigation 3). The holistic view in this dissertation is based on the p-diagram (Taguchi, 1987; Suh, 1990), which means considering control and noise factors on the whole corrugated box along the supply chain from its production to the final customer, rather than focusing just on control factors or few noise factors in the laboratory conditions. This is explained in section 4.3.3. The inherent noise factors from material, noise from production and from the environment (e.g., climate, logistics, warehousing and handling) can be considered by using a p-diagram to analyze and model them.

To increase the accuracy of models and software used in corrugated packaging design and development, it is also necessary to include noise factors that are more influential regarding the performance of the box. It is necessary to develop models and software that cover these three noise factors to increase the supply chain efficiency. More accurate models and software can enable design and development that avoids under packing or over packaging (Johnsson, 1998) and help to decrease the cost of packaging (Urbanik and Frank, 2006) by providing efficient corrugated board packaging.

The investigation on models and software for corrugated board and box design and development (investigation 3) indicated that there are packaging suppliers that have a tremendous amount of knowledge and experience built up over decades of research and production. They have developed advanced software strictly for internal use (e.g., *SCA*). This software as intellectual property has not been accessible for other actors in the supply chain. The competitive advantage and the vast resources put into developing such software are the main reasons for restricting access. There is a major business opportunity to sell this knowledge to companies that use corrugated board and boxes. However, emerging technologies such as cloud computing can provide remote access without infringing on the intellectual property rights of the software developer. Cloud computing can also be used to charge for the service on a consumption basis (Sharif, 2010).

This is an opportunity for companies and organizations that have a massive amount of knowledge or advanced software for simulating corrugated board to offer it as a service. This could be a win-win situation where customers or producers of corrugated board will improve their box designs while companies owning software can rationalize its development costs. This can be further developed to advance the corrugated board and box industry from being primarily a commodity seller to becoming a knowledge seller to various actors in the supply chain. Use of these models and software can contribute to corrugated board packaging design and development towards increasing supply chain efficiency.

5.2.3 Life cycle for packaging design and development vs. setting the supply chain strategy

The operational life cycle provides a basis for collecting needs along the supply chain as a part of a packaging design and development method for supply chain efficiency (investigation 2). But the term "life cycle" for products has been used differently in the supply chain management and design and development literature. This presents challenges in interdisciplinary research and industrial practice. For example, an interviewee or reader with a background in any of these disciplines understands terms in different ways. Thus different perceptions and interpretations influence the research.

In the design and development literature, a "product life cycle" is considered to be the operational life cycle that includes stages such as procurement, production, distribution and reverse logistics (e.g., Olsson, 1976; Sarkis, 2003, Klevås, 2005). It is often referred to as life cycle. On the other hand, in the supply chain management and marketing literature, "product life cycle" is mainly used with four phases: introduction, growth, maturity, and decline (e.g., Day, 1981; Aitken et al., 2003; Cigolini et al., 2004). This is driven by a marketing perspective (Kaminski and Rink, 1984; Gmelin and Seuring, 2014). In the data collection for this dissertation, engineers working with design and development related to "operational life cycle" as if it were "product life cycle" and "packaging life cycle".

It can be argued that the life cycle and functions of the supply chain are correlated. Thus, analyzing a product based on the physical function of the supply chain is different from analyzing it based on the market mediation function. The operational life cycle takes into account the physical interactions and operations that can be used for supply chain efficiency. Using an operational lifecycle can contribute to the design and development of packaging to increase supply chain efficiency. Consequently, the expanded operational life cycle based on the supply chain needs identified in investigation 1 and the academic literature (e.g., Sarkis, 2003) is suggested in investigation 2. The expanded operational life cycle includes design & development, sourcing & purchasing, production, warehousing & handling, transport, marketing, use and recycle/reuse.

Basically, "product life cycle duration" in the supply chain management literature is used as a measure of supply chain effectiveness (e.g., Childerhouse et al., 2002; Aitken et al., 2005) and is related to the market mediation function of supply chains. A new product starts from the introduction stage and goes through various phases (e.g., Aitken et al., 2003; Cigolini et al., 2004). The length of this life cycle (i.e., 3 month to a year and more than 2 years) is explicitly an aspect of the Fisher (1997) model and used by other researchers such as Selldin and Olhager (2007) and Lo and Power (2010). The term "product life cycle" from the supply chain management literature was unfamiliar to design and development engineers and was not of interest to them since they were for the most part only focused on the physical function of the supply chain. This was one indication of a one-sided understanding of the supply chain that can compromise its effectiveness.

5.3 Matching packaging with the intended supply chain

Packaging can contribute to both supply chain effectiveness and efficiency by reducing the gap between needs and satisfaction if it is matched to the supply chain strategy (investigation 4) and if it is designed and developed to satisfy physical supply chain needs (investigations 1, 2 and 3). One way to increase the effectiveness of supply chains (i.e., in response to the demand) and the efficiency of the physical supply chain (i.e., in operations) is through the postponement of packaging while packaging design and development is being considered in relation to the supply chain's physical needs. In the ambient milk supply chains explored in investigation 1, it was not possible to implement most postponements, even though such implementations have been frequently reported in the literature. This was because there was no semi-finished product in the milk supply chain. The milk also had to be processed and packed in primary packaging quickly. In addition, the carton packaging in use did not enable the postponement of printing and labeling because the packaging was already printed before going to the packaging line at dairies. Van der Vorst et al. (2001) suggested the use of leagility and postponing the packaging and labeling as long as possible. But packaging postponement proved to be unfeasible in the food supply chain that Van der Vorst et al. (2001) studied, due to constraints on the perishability of the semi-finished products and the need for traceability of products in the production process.

But for other food and beverage supply chains, postponement is possible. For example, with liquid food (i.e., juice), the concentrate is shipped in bulk from another continent to Europe and packed as 100% natural juice in carton packages instead of being packed before shipping (Abukhader, 2007). Postponements such as MTO are suitable for responding to demands in the market in line with supply chain effectiveness, and therefore achieving higher filling rate in transport in line with supply chain efficiency. Abukhader and Jönson (2007) provide another packaging postponement case in the tea supply chain (Tetley Tea). The tea was shipped from an

Asian country, then packed according to Scandinavian market needs in primary and secondary packaging, and then put on the pallet as a PTO postponement.

The levels of packaging (primary, secondary and tertiary) do not play the same role in relation to supply chain effectiveness and efficiency. The product and its primary packaging have greater influential strategic value compared to secondary and tertiary packaging, specifically for food and beverage supply chains. For example, primary packaging has a more influential marketing function (Azzi et al., 2012; Orth and Malkewitz, 2008) and is integrated with the product until it is consumed. Thus as Saghir (2002, p. 45-46) states *"marketing metrics are mainly related to primary packaging (typically consumer packaging) and perhaps also display packaging"*. Secondary and tertiary packaging in comparison to primary packaging have a greater influential operational value in the physical supply chain and can influence the supply chain efficiency (e.g., pallet utilization and transport utilization). This point of view is taken into account in investigation 1 and is considered in packaging design and development in investigation 2. Saghir (2002, p. 45-46) also reveals that in contrast to primary packaging, *"logistical metrics are related to secondary packaging (box) and unit load (pallet). Cost-related metrics are relatively easy to measure, but should here be measured along the whole supply chain"*.

The difference in the role of primary and secondary packaging can result in some efficiency and effectiveness issues. Primary packaging can reduce supply chain efficiency by having shapes that reduce the secondary packaging space utilization. In investigation 1, primary packaging could have a tetrahedron shape (i.e., *Tetra Classic Aseptic*) due to its marketing value, but this decreased space utilization inside secondary packaging and hence the supply chain efficiency. On the other hand, the secondary packaging design can utilize the material by using large boxes. This can negatively impact sales, though, because having a high number of milk products in one box goes against consumers' needs. This is further explained in following two examples:

- Example 1. In the field observation of ambient milk supply chains in China (investigation 1), it was found that secondary packaging was used as a sales unit with a notable marketing function. Secondary packaging in such situations can be considered from both the physical and market mediation functions of the supply chain. This can happen in food and non-food supply chains. Having a number of primary packed ambient milk products in each box according to the final customers' (consumers') needs strengthens the role of secondary packaging in relation to supply chain effectiveness. In the traditional trade supply chains (investigation 1), some wholesalers changed the secondary packaging by re-packing them in smaller ones before selling them to the traditional retailers. This was because the milk production lines were producing one flavor of a product at a time. Thus, each sales unit coming from the dairy contained 8, 12 or 24 identically packed milk products. Wholesalers were re-packing the secondary packaging containing 24 primary packages of milk. Three sales units containing 8 packed milk products were made out of each of the large ones. In this way consumers were provided with fewer milk packages and high flavor variety. Thus, a mix of different milk flavors was offered in each box based on the orders. In Figure 5-2 large boxes of milk are shown with the small sales unit for re-packing. In Figure 5-3 the re-packed ones in the smaller sales units are shown which contain four milk flavors. This can be considered as an implementation of PTO for secondary packaging sales units to comply with the demand in the supply chain.

Figure 5-2 Re-packing the large boxes of packed milk (red) to smaller sales units (green)

Figure 5-3 Re-packed in sales units containing four flavors.

- Example 2. A similar postponement of secondary packaging is reported in the academic literature by Abukhader and Jonsön (2007). They describe cases of secondary packaging (e.g., variety pack) postponement for food products (e.g., candy, canned fruits and margarine) in European countries. For margarine Abukhader and Jonsön (2007) report the need for 12 or 24 units in secondary packaging based on the market. Instead of having a third party conduct the re-packing process or expanding the packaging lines to include both sizes, the brand owner postponed the secondary packaging to be done at the target market. Another similar example is reported by Abukhader and Jönson (2011). They explain a scenario of packing one type of candy in each secondary packaging and then mixing them based on the orders at the distribution center of the wholesaler through a re-packing process.

6. Contributions and further research

This dissertation contributes to academic literature and to industrial practice. The contributions from a theoretical research-focused point of view are mainly in the packaging logistics field in an overlap of product and packaging design and development with supply chain management and logistics. Contributions to industrial practice are mainly related to packaging design and development for supply chain efficiency. According to the research conducted, the academic positioning of this dissertation along with contributions and suggestions for further research in the packaging logistics field are provided.

6.1 Academic positioning

From a supply chain management literature point of view, this research positions the coordination of both product and packaging design and development under supply chain management business processes. According to Cooper et al., (1997), Lambert et al., (1998), Lambert and Cooper (2000), product development is a key business process in supply chain management that this dissertation expands to include the entire product and packaging system. One reason is that product and packaging together as one system flow in the supply chain rather than being stand-alone products. From a design and development literature point of view, this research positions product and packaging design and development in relation to the four domains of design (i.e., customer, functional, physical, process) according to Chen (1999) and Suh (1990). Models and software for corrugated packaging design and development are positioned in the physical domain.

In addition, the product and packaging system is considered, in relation to demand management, as another supply chain management key business process based on Cooper et al., (1997), Lambert et al., (1998), Lambert and Cooper (2000). In demand management, the Fisher (1997) model for matching the supply chain strategy and product is used and extended to include packaging. The same reason as above is valid here: Product and packaging as a system flow in the supply chain.

Moreover, packaging can enable or hinder the effectiveness and efficiency in the supply chain. That is why it has to be considered in the supply chain management business processes, both product development and demand management. On the other hand, using a supply chain perspective in relation to product and packaging systems provides an interdisciplinary approach toward higher effectiveness and efficiency in the supply chain. This is possible when both the market mediation and physical functions of supply chain are considered rather than just focusing on one of them.

6.2 Academic contribution

The following four contributions are made to the packaging logistics body of knowledge on reducing the gap between the supply chain needs and satisfying them, through packaging design and development directed toward increasing supply chain efficiency and effectiveness. These four contributions are based on the four areas where knowledge is lacking as described in section 1.3. In these contributions, a limited number of models and methods are provided rather than the grand and middle range theories that are mentioned by Arlbjorn and Halldorsson (2002) and Halldorsson et al. (2007). Models from various disciplines, such as packaging design and development, and supply chain management and logistics, are used in this research that has to be understood from their contexts. These models demonstrate correlations between different factors based on the discipline they come from. For example, in corrugated box design and development, correlations between influential factors in relation to the strength of packaging are put forward as models (e.g., McKee et al., 1961). In supply chain management and logistics, interrelations for matching between the supply chain strategy and the product are put forward as models (e.g., Fisher, 1997).

The first academic contribution is an expanded operational life cycle which is primarily based on the list of identified supply chain needs on packaging, the packaging life cycle from industrial practice and academic literature. This is used as a method for identifying, collecting and analyzing the supply chain needs on product and packaging system, in order to provide packaging solutions based on existing trade-offs in the supply chain for higher efficiency. Considering the extended operational life cycle enhances the collection of the needs along the entire supply chain. The expanded operational life cycle embraces the following steps: design & development, sourcing & purchasing, production, warehousing & handling, transport, marketing, use, and recycle/reuse. The expanded operational life cycle in total contributes to the packaging design and development literature to set the starting point which identifies the needs as a part of a systematic method.

Secondly, this dissertation provides an improved packaging design and development method. It can be used as a basis for packaging design and development for supply chains by further developing previous research in the packaging logistics field on packaging design and development in terms of supply chain needs. The previous research has mainly provided broad guidelines (e.g., DFPL) or assessment methods (e.g., packaging scorecard) for packaging along the supply chain. The method is proposed to better integrate the needs of supply chain actors. Thus, an existing product design and development method was adapted for packaging with a new supply chain focused perspective. Instead of starting out from a limited operational life cycle, the expanded operational life cycle was used to take into account the supply chain needs in the method. The design and development method also provides necessary steps for mapping and translating supply chain needs to packaging specifications in order to design and develop packaging solutions toward increasing supply chain efficiency. In order to satisfy the needs on product and packaging systems the following steps are suggested: collect the needs, translate them into functional requirements and constraints, clarify the design parameters, set the target values, provide draft specifications, carry out virtual/physical modelling of the solution, set the final specifications, produce the packaging.

Thirdly, as a result of comparing models and software this dissertation suggests using a p-diagram (Taguchi, 1987; Suh, 1990) as a method to provide a holistic perspective for modeling corrugated board packaging. It can be used as the basis for creating more accurate models and software. Such a perspective allows considering noise (i.e., inherent, manufacturing and environment) in addition to control factors in modeling and simulation of corrugated board packaging. More accurate models and simulations can be provided while considering the entire supply chain in which the product and packaging flows.

Finally, this dissertation suggests improvements to a model for matching supply chain strategy and product while denoting the role of packaging. In order to match product and packaging characteristics and supply chain strategy from a supply chain effectiveness point of view, the shelf life period has to be considered and added to the Fisher (1997) model. Packaging is considered in relation to the market mediation function of the supply chain. The shelf life period is a product and packaging characteristics that can play a key role in setting the supply chain strategy in response to the demand. Thus, the addition of shelf life as a measure for packed food products is proposed in matching supply chain strategy with product and packaging. Basically, the shorter the shelf life, the greater the pressure on the supply chain to be agile. The consideration of other food supply chains characteristics (i.e., chilled and frozen) is also proposed regarding the responsiveness or cost efficiency of the Fisher (1997) model. Thus, new dimensions have to be added to the model as well.

6.3 Contribution to industrial practice

This dissertation contributes to industrial practice as well. The contribution is particularly to the food and beverage industry (e.g., packaging companies and dairies) to increase their supply chain effectiveness and efficiency through packaging design and development.

This research helps managers and engineers who make decisions regarding supply chains, logistics, product and packaging design and development by providing suggestions for industrial practice. Considering the product and packaging together as one system is the basis for contributions to the engineers and managers' decisions in industrial practice. The following three contributions to industrial practice are made.

The first contribution to packaging design and development engineers and supply chain managers is a list of supply chains needs on packaging in developing countries. This list provides an understanding of supply chain interactions with packaging in developing countries and can serve as a basis for the design and development of packaging solutions that can increase supply chain efficiency. The detailed description of the supply chain needs and the reasons behind each of them provides the packaging design and development engineers and supply chain managers with a deeper understanding for increasing supply chain efficiency. This list can also be used to provide packaging development engineers and supply chain and logistics managers with a common overview of the product and packaging to enable increased supply chain efficiency and avoid sub-optimizing decisions. It should be noted that this list does not cover the entire supply chain needs but just presents the identified needs.

The second contribution that packaging development engineers can benefit from is the packaging design and development method that is explored, analyzed and improved. Packaging engineers can use this method to enhance their packaging design and development methods in industrial practice to increase supply chain efficiency. The method also contributes to enhancing development engineers' communication with supply chain and logistics managers in matching the product and its packaging solution with the supply chain environment. This method further assists the decision makers in aligning product and packaging development, processes and the supply chain in the industry. For product and packaging engineers specifically, the list of supply chain needs and the proposed method can serve as input to their design and development processes, product and packaging design and development methods and analysis tools. In other words, it contributes to reducing the gap between needs and satisfaction in their supply chains toward increasing its efficiency.

The last contribution is providing choices for the packaging industry (e.g., collaborating company and dairies) in the use of models and software for corrugated board packaging design and development. This is achieved through the identification, categorization and comparison of models and software for corrugated board and box design. A list of models and software and their use for various actors in the supply chain is provided. Insights on corrugated board supply chain actors' (i.e., paper producer, corrugated producer, box producer, and customer) use of these models and software are also put forward. The following choices are presented:

- There are more accurate models available that industry can use instead of the traditional ones (such as the simplified McKee model) to design more efficient packaging solutions. For example, packaging design and development engineers can use Batelka and Smith (1993) instead, which covers RSC, Wrap-Around and Bliss Case corrugated boxes and does not have the limitations of the simplified McKee model.
- Software like ModelPACK is also available that covers a wide range of paper and board materials produced in European countries. It does not, however, support packaging design and development for paper and boards that are produced in other parts of the world (e.g., developing countries).
- The packaging industry (e.g., collaborating company and dairies) can develop their internal software as well. But providing models and software that are more accurate and include various noise factors is time consuming and hence costly. For example, SCA spent over 20 years developing its internal software.
- There is a business opportunity for companies like SCA. They can sell their knowledge or rent their software to companies that use corrugated board and box. It can be done by using emerging technologies such as cloud computing to protect their intellectual property rights. This can be a new choice for packaging design and development in the future.

6.4 Further research

This dissertation is a starting point for more research on packaging design and development in the supply chain. Further research is required, since what is presented here was conducted to answer a few limited research questions. Other ways to answer the research questions can also be explored. This research did not embrace product design and development or consumer packaging design and development, but rather on secondary packaging and from production to retail. It would be of interest to use this research to add to those areas. Exploring packaging design and development in the supply chain led me to identify other research opportunities for the future beyond the borders of this dissertation. Six of the most notable ones are put forward.

First, the list of needs on packaging can be further developed by investigating other food (e.g., frozen and chilled) and non-food supply chains. They can be explored by investigating countries other than the ones chosen here. It should be mentioned that the list of needs on packaging was only the result of exploring ambient milk supply chains in developing counties. The propositions for dealing with challenges in developing countries can also be tested in further research.

Secondly, through additional research, the packaging design and development method proposed for supply chain efficiency has to be validated. There is a lack of studies on packaging design and development methods for supply chain efficiency and more are required to complement the packaging logistics body of knowledge. Even though there are many industries dealing with design and development of packaging, there is little academic research on their design and development methods in relation to supply chain efficiency. These types of methods have to be adapted to stage-gate processes, used in industry in order to be implemented for industrial applications. An in-depth consideration of the product, process and supply chain together, rather than focusing on them separately, has the potential to improve supply chain efficiency and effectiveness. In this way, more design and development methods can be provided.

Thirdly, models and software for corrugated board packaging have to be tested and compared against each other and their validity checked in further research. Such tests also provide a basis for comparing their accuracy and capabilities. Comparison can make an important contribution to both academic literature and industrial practice by using the same data set as the basis. Models and software are currently based on different experiments and data sets that are too different for comparisons. Propositions that are provided regarding corrugated packaging design and development also have to be validated by further research.

The fourth opportunity is testing propositions suggested in the concluding discussion chapter to improve the Fisher model and adapt it to the food and beverage supply chains. This can be done by means of empirical studies. Thus, as discussed, the shelf life of food and beverage products can play a major role in relation to supply chain strategy. This measure is neglected in the supply chain strategy stream of research coined by Fisher (1997). The focus of most of the previous research on the role of the product in relation to the supply chain strategy has frequently resulted in neglecting the role of packaging. Even though, as mentioned, packaging characteristics also have to be considered in selecting a supply chain strategy, especially for food and beverage products. Shelf life is just one identified measure; other measures regarding packaging can be explored and added to the model.

The fifth opportunity is that research beyond the Fisher model should include variation in supply when setting the supply chain strategy, even though supply variation is an inherent specification of agriculture-based food and beverage products and is mentioned in the food packaging related literature (e.g., Twede et al., 2000). Such research would mainly be focused on demand variation and demand seasonality, and not on supply variation and seasonality. Thus, supply variation and seasonality can also be integrated in the demand-focused research in the future. Huang et al. (2002) provided another model that tries to improve the Fisher (1997) model. This model suggests three supply chain strategies in relation to three product types. But it is not further explored empirically as Fisher (1997) did. Thus it is a good subject to be tested in future research.

Finally, the influence of various packaging technologies and materials and their interrelations to supply chain strategy can also be investigated. Such research is expected to make a substantial contribution to academic research and to decision making in industry. The packaging technology and material in use can be a major enabler or disabler in implementing various supply chain strategies. Packaging innovation for supply chain efficiency and effectiveness, as stated, is not treated in this research. However, there are examples that can be explored in academic research such as the 2013 Supply Chain Innovation from CSCMP award, which presents increasing efficiency and effectiveness through corrugated board packaging (see Clyne and Wilkinson, 2013). By postponement (i.e., DTO) of corrugated board packaging until the orders are received from the consumers, Staples could design a box for the numbers of products that are ordered. In this way, corrugated boards are not converted to boxes until the orders are received.

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Appendices

Appendix A: Research Steering Group

Steering group	Title/name	Background	Gender
University	Professor Annika Olsson	Ph.D. in Packaging Logistics	Female
	Associate Professor Daniel Hellström	Ph.D. in Packaging Logistics	Male
Industry	Director	Executive MBA	Male
	Manager	Licentiate in Chemical Engineering	Female
	Development Engineer	Licentiate in Packaging Logistics	Male
	Development Engineer	Post Doc in Structural Mechanics	Male

Appendix B: Meetings Attended

Department meetings:

- Every Monday, about half an hour for the employees in Sweden.
- Every month, 2 hours for employees in Sweden and China.
- Platform meeting once a year, a whole day.

Group meetings

- Every Friday, about one hour for the packaging design group in Sweden.

Secondary Packaging & Distribution Network Meetings

- Quarterly, about half a day.
- 35 members: experts working with secondary packaging in Tetra Pak mainly from Sweden, Italy, Germany and France.

Appendix C: Interviewees in Pre-investigation

- Introduction meeting and pilot data collection on practical problems, identification of the experts and the basis for designing interview questions for investigations.
- Interview duration: 45 minutes on average.
- Data collection by taking notes.

No.	Title	Gender	Education	Experience and responsibilities	Focus	Country
1.	Package Design Manager	Female	Licentiate Chemical Engineering	Food packaging, product development, packaging material, product life cycle and market support, university collaboration	Primary and secondary	Sweden
2.	Package Specification Manager	Female	MSc. Chemical Engineering	Food packaging, packaging material and production process, package quality	Primary	Sweden
3.	Support Engineer	Male	B.Sc. Chemistry	Pharmaceuticals, food packaging, product life cycle, package test, distribution, product development process, modeling	Primary and secondary	Sweden
4.	Project Leader	Male		Food packaging, design test method for packaging design, physical simulation of the damages, work flow improvement	Primary and secondary	Sweden

5.	Project Manager	Male	High school	Technical service, package and distribution solutions, package performance data collection,	Primary and secondary	Sweden
6.	Development Engineer, Associate Project Manager	Female	MSc. Mechanical Engineering, Product Development and Design	Package design, Merchandizing portfolio, efficient replenishment, distribution solution, product life cycle, usability, graphical design	Primary and secondary	Sweden
7.	Director Package Design and Distribution Solutions	Male	MBA	Technical service	Primary and secondary	Sweden
8.	Development Engineer	Male	PhD Mechanical Engineering	System engineering, system design,	Primary and secondary packaging machine and distribution system	Sweden
9.	Development Engineer	Male	MSc. Mechanical Engineering	System engineering, System design, Simulation in forming and finite element process	Primary and secondary packaging machine and distribution system	Sweden
10.	Development Engineer	Male		Packaging material	Primary and secondary	Sweden
11.	Pack Spec Manager	Female	MSc. Material Technology	Food packaging	Primary	Sweden

12.	System Engineer	Male	PhD Mechanical Engineering, Machine Design	Engineering design process, Improvement of test methods, engineering trainings, sub-project manager, package design, product requirements	Primary and secondary packages and machineries	Sweden
13.	Package Engineer	Male	MSc. Biomedical Engineering	Packaging material	Primary and secondary packages	Sweden
14.	Vice President	Female	MSc. Engineering	Project management, marketing	Primary and secondary packages and machineries	Sweden
15.	Development Engineer	Male	Post Doc. Structural Mechanics	Packaging technology	Primary and secondary	Sweden
16.	Development Engineer	Male		Paper material and manufacturing	Primary and secondary	Sweden
17.	Equipment Verification & Validation Manager	Male	High School	Development and engineering, technical support, technical service, package validation, machine material interaction	Primary packaging machinery	Sweden
18.	Packaging Engineer	Female	MSc. Chemical Engineering	Packaging test, package design	Primary	Sweden
19.	Packaging Engineer	Female	MSc. Mechanical Engineering	Packaging test, package design	Primary and secondary	Sweden

20.	Development Engineer	Male	Licentiate packaging logistics	Package design	Primary and secondary	Sweden
21.	Package Engineer	Male	MSc. Mechanical Engineering	Sub-project manager, planning, risk management and setting budget for package related activities in technical development projects, technical support at customer sites, competitor benchmarking, test methods development, machine installations, market support, purchasing	Primary and secondary	Sweden
22.	Packaging development engineer	Female	MSc. Chemical Engineering	Packaging test and design	Primary and secondary packaging development	Sweden
23.	Package Design Manager	Male	BSc. Mechanical Engineering	Primary, secondary packaging specifications, package and packaging material (performance and quality improvements) Test methods development	Primary and secondary packaging	Italy

24.	Portfolio Strategy Manager	Male	Licentiate Electrical Engineering	Product management method, portfolio management, process design and implementation, portfolio analysis, product strategy, product development needs, robust design, market studies	Primary packaging	Italy
25.	Development Engineer	Male	MSc. Physics	Simulations, requirements management, systems engineering	Primary, secondary, tertiary packaging simulations and machinery	Italy
26.	Package and Distribution Solution Manager, China	Male	MSc. Mechanical Engineering Diploma Marketing and Finance	Food packaging, development, project management, product life cycle activities, distribution chain analysis, consumer research projects, cost reduction, university collaboration, package data collection project	Primary packaging	China

Appendix D: Guiding Questions for Pre-investigation

1- Please introduce yourself.
   - Name
   - Title
   - Scope of responsibility
   - Experience at Tetra Pak
   - Experience before joining Tetra Pak
   - Educational background

2- What are your current projects?

3- What's your perspective about Tetra Pak?

4- What challenges do you have regarding packaging in developing countries? Please explain.

5- What are the issues on primary packaging? Please explain.

6- What are the issues on secondary packaging? Please explain.

7- How do you capture the needs in the milk supply chain?

8- What are your design and development processes?

9- How do they work?

10- How are these issues considered in your design and development methods and processes?

11- What methods and models do you use in your development processes?

12- How do they work?

13- What methods and models do you used to design corrugated secondary packaging?

14- Are there any other methods and model that are used in Tetra Pak?

15- How do you calculate the cost of the corrugated board packaging?

16- Do you know any other experts who have the knowledge about your challenges?

Appendix E: Company Training Sessions

No.	**Training sessions at the company**	**Duration**
1.	Introduction to Tetra Pak, web based training	0.5 day
2.	World Class Engineering, web based training	2.5 days
3.	MACS Model on Calculating Cost	1 day
4.	Information Security	0.5 days
5.	Introduction to Robust Design	0.5 day
6.	Requirements Management Cascading Proficiency	2 days
7.	Basic Statistics	1.5 days
8.	Project Management, Leadership and Communication	5 days
9.	MS Project, Advanced	2 days
10.	Filling Machine Training	3 days

Appendix F: Theory Discussants and/or Paper Reviewers

No.	Title	Field	University
1.	Professor	Engineering design	Lund, Sweden
2.	Associate Professor	Engineering design	AgroParisTech, France
3.	Professor	Engineering design	Ecole Centrale Paris, France
4.	Researcher	Engineering design	Lund, Sweden
5.	Associate Professor	Innovation engineering	Lund, Sweden
6.	Researcher, Ph.D.	Paper physics	Georgia Tech, USA
7.	Emeritus Professor	Supply chain management	Canfield, UK

Appendix G: Interviewees for Investigation 1

[Respondent number according to interview sequence] Title	Countries of experience	Total years of experience	Experience in developing	Gender	Age	Previous experience
[1] Senior packaging development engineer	Brazil, China, Kenya, India Indonesia, Mexico Vietnam	4	4	F	29	Primary and secondary packaging development
[2] Senior packaging development engineer	Iran, Kenya	6	6	M	36	Packaging specialist
[3] Senior packaging development engineer/manager	Brazil, China Egypt, India, Indonesia, Thailand, Peru, Philippines, South Africa	11	6	M	36	SCM & logistics, secondary packaging development
[4] Senior packaging development engineer/manager	China, Egypt, India, Kenya, Thailand, Ukraine	20	2.5	F	48	Packaging material
[5] Senior project manager in packaging performance	China, Egypt, Indonesia, Kenya, Russia, Ukraine, Vietnam	28	2	M	58	Filling line technical service
[6] Senior packaging development engineer	China, Egypt, Kenya, Russia, Thailand, Ukraine Vietnam	4	3	M	30	Medical substance analysis

Appendix H: Guiding Questions for Investigation 1

The following questions are for the semi-structured interview and were sent to the interviewees beforehand. The reason for having these questions is to understand supply chain needs on secondary packages and to develop packaging solutions to increase supply chain efficiency. The focus of this interview was on corrugated board packages.

Introduction

1. Name?
2. Age?
3. Gender?
4. What are your responsibilities? /What do you do in your everyday job?
5. What is your background? /Can you explain how you ended up here?
6. How long have you been working in this position?

Reflection on packages

7. What secondary packages do you consider to be good ones?
8. What secondary packages do you consider to be bad ones?
9. Have you noticed different needs for different actors in the supply chain? (Question for experts)
10. How are the packages perceived by your customers? (Question for experts.)

Success experience

11. Have you ever felt that a particular secondary package was perfectly satisfying the needs?
12. In what way?
13. What is the benefit of the package? Can you be more specific?
14. When did the incident happen? Where?
15. What specific circumstances led up to this situation?
16. Exactly what was said and done?
17. What happened that made you feel the interaction was satisfying?

Failure Experience

18. Have you ever felt that a particular secondary package was very dissatisfying?

19. In what way?
20. What was the consequence? Can you be more specific?
21. When did the incident happen? Where?
22. What specific circumstances led up to this situation?
23. Exactly what was said and done? How did you solve it?
24. Did you use any external help?
25. What happened that made you feel the interaction was dissatisfying?

Dream Packages

26. If you wanted to decide/design secondary packages for your needs what would you take into consideration? How would it be if cost didn't matter?

Open Questions

27. Is there anything that you would like to add to the interview?
28. Do you want to receive a copy of the paper?

Appendix I: Interviewees for Investigation 2

No.	Interviewee	Gender	Experience	Education
1.	Senior project manager	F	Primary packaging material development	M.Sc. Chemical Engineering
2.	Project manager	M	Packaging machinery development	B.Sc. Electrical Engineering, M.Sc. Organizational Change Management
3.	Packaging development engineer	F	Primary and secondary packaging development	M.Sc. Risk Management and Safety Engineering
4.	Senior packaging development engineer	M	SCM & logistics, secondary packaging development	Licentiate in Engineering Packaging Logistics
5.	System engineer	M	Systems engineering	Ph.D. Mechanical Engineering-Machine Design
6.	Manager packaging design	F	Primary and secondary packaging	Licentiate in Chemical Engineering
7.	Packaging development engineer	F	Primary and secondary packaging development	M.Sc. Chemical Engineering

Appendix J: Guiding Questions for Investigation 2

These questions are designed as a guideline for semi-structured interviews.

1- Please introduce yourself.
   - Name
   - Title
   - Scope of responsibility
   - Experience in Tetra Pak
   - Educational background

2- Have you used PRC?
3- How long have you been using this method?
4- In which part of your development process do you use PRC?
5- In what project you have used it?
6- Please explain the way you use it.
7- What are the difficulties in using PRC?
8- What are the advantages of using this method?
9- How do you cascade the requirements?
10- Are there other methods with a similar purpose in Tetra Pak?
11- Have you used those methods?
12- Do you know anybody else who uses PRC?
13- Do you want to add anything?

Appendix K: Interviewees for Investigation 3

No.	Occupation/title	Background	Organization
1.	Senior R&D Specialist	Ph.D. Paper Technology	SCA
2.	Specialist	Ph.D. Material Mechanics	
3.	Researcher	M.Sc./Ph.D. student in engineering and mathematics	
4.	Researcher	M.Sc./Ph.D. student in engineering and mathematics	
5.	Senior Manager, Technical Operations and Resources	Ph.D. Physics	Packaging corporation of America
6.	Manager, Paper/Board/Box Analysis Testing Laboratory	Ph.D. Plasma Physics	Georgia Tech
7.	Structural Mechanics	Professor	Lund University
8.	Development Engineer	M.Sc. Mechanical Engineering	A-Dev
9.	Post Doc Structural Mechanics	Post Doc	Tetra Pak

Appendix L: Guiding Questions for Investigation 3

These questions are designed as a guideline for semi-structured interviews to gather data the capabilities of your model for other industries that use corrugated board boxes (e.g., dairies like Tetra Pak customers) and academia . These questions were also used as the basis for group discussions.

Questions for models:

1- What models and software do you use to predict the strength of corrugated board and box?
2- How do they work?
3- If you wanted to use a simple model for industrial use, which one would you use?
4- How does your model work?
5- What are the advantages and disadvantages of your model?
6- How does your model work in comparison to the McKee model?
7- Does your model need a specific measurement instrument?
8- What are the input factors to the model?
9- What are the outputs of the model?
10- Are there any factors that this model is missing in order to make a more accurate prediction?
11- How accurate are the predictions?
12- Do you have any references for them?
13- Have you tested the models and software?
14- Do you have any test data on them? How can I gain access to them?
15- Do you know any other models or software?
16- Do you have any references to them?
17- Do you want to add anything?

Questions for software:

1- What are the capabilities of your program?
2- What advantages does your program have?
3- What disadvantages does the model have?
4- Does it need paper properties to predict box properties?

a. Which paper properties are the inputs for the model?
b. Are these paper properties standard for the industry?
c. Which standard test methods do you use for measuring the properties?

5- What is the accuracy of the predictions in comparison to the physical test results?

6- Does this model have the capability to have board properties as input and box specifications as output?
a. If yes, what are those board properties?
b. What is the accuracy of the predictions in comparison to the physical test results?

7- Do you consider the impact of humidity in your model?

8- Do you consider the impact of creep in your model?

9- What are the outputs of the model?

10- Have you made any regression models in your FEM program?
a. If yes, what are the capabilities of your FEM program?
b. What advantages does your program have?
c. Does it need paper properties to predict box properties? What paper properties are the inputs for the model?
d. What is the accuracy of the predictions in comparison to the test results?
e. Does this model have the capability to have board properties as input and box specifications as output?
i. If yes, what are those board properties? What is the accuracy of the predictions in comparison to the test results?
ii. Which standard test methods do you use to measure the properties?
f. Do you consider the impact of humidity in your model?
g. Do you consider the impact of creep in your model?
h. What are the outputs of the model?
i. What advantages does the model have?
j. What disadvantages does the model have?

11- How do you see the future?
a. Are you interested in adding more capabilities to your model?
b. What are those capabilities?

12- Do you want to add anything?

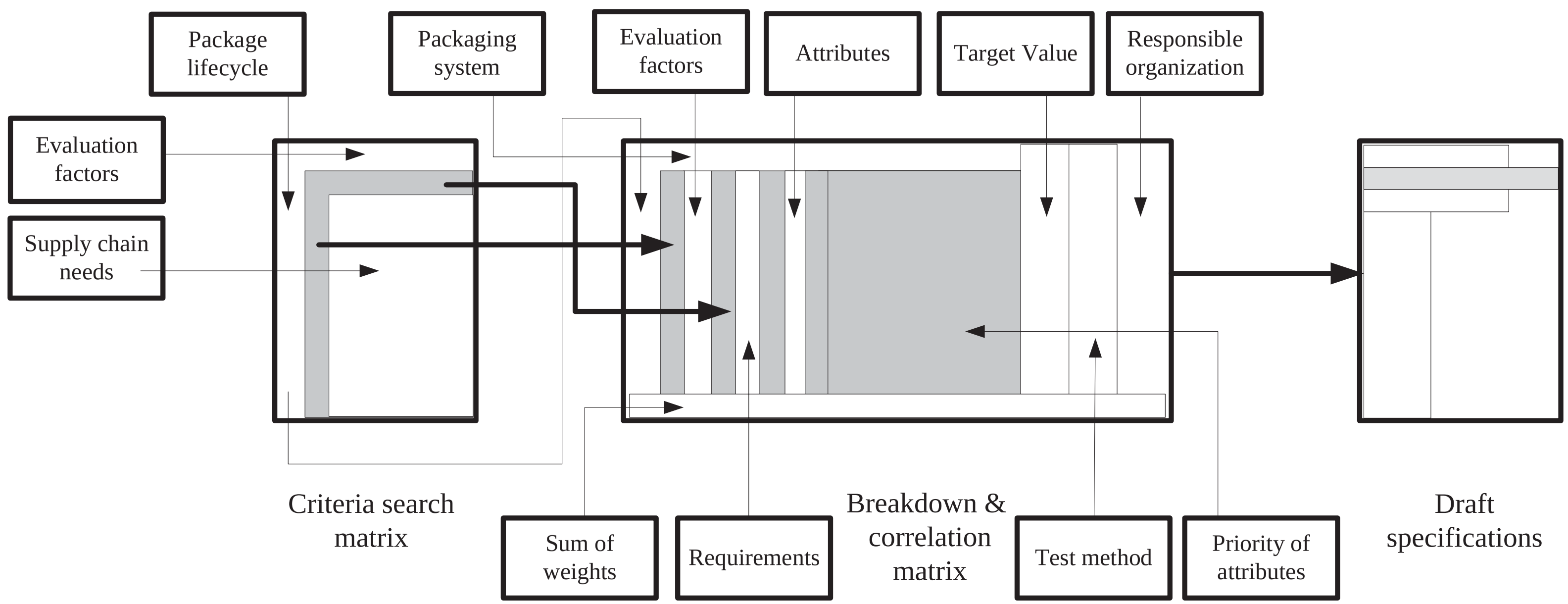
Appendix M: Experts for Investigation 3

No.	Occupation/title	Background	Organization	Group discussions
1.	Senior research associate	Licentiate in Engineering Process Solutions	Innventia	1.5 hours
2.	Senior research associate	M.Sc. Measurement Systems and IT		
3.	Senior research associate	M.Sc. Mechanical Engineering		
4.	Packaging R&D manager	M.Sc. Material Science	Billerud	1.5 hour
5.	Development engineer	Licentiate in Engineering Material Science		
6.	Development engineer	Development engineer	Tetra Pak	

Appendix N: Field Visits for Investigation 3

No.	Field visit	Organization	Country
1.	Test laboratory	Billerud	Sweden
2.	Test laboratory	Tetra Pak	Sweden
3.	Test laboratory	SCA-Mid university	Sweden
4.	Test laboratory and production	NEFAB	China
5.	Production	Smurfit-Kappa	Sweden

Appendix O: Packaging Requirements Cascading (PRC)



Appendix P: Software for Corrugated Board and Box Design

				CAPE PACK	TOPS Pro	Model PACK
		FCT				2
Input	Paper	RCT	Liner		1	
			Medium		1	
		Thickness				1
		Basis Weight				1
		CCT				1
		SCT				1
		CMT				1
		Burst				1
		Tensile Stiffness				1
		Stretch at Break				1
	Board	ECT		2	2	2
		Basis Weight				2
		Bending Stiffness				2
		Thickness /Caliper		2	2	2
		Bursting Strength				2
		Puncture Resistance				2
		Perimeter		2	2	
		Height of Fluting				1,2
		Single/Double Wall				1,2
		Flute Constant (take up)			1,2	1,2
		Shape Factor			2	

		Length-to-Width Ratio Factor	2	2	
		Direction of Fluting	2	2	
	Box	Types	2		1,2
		Dimension	2		1,2
		Dimensional Weight to Load			1,2
	Environ mental Factors	Internal Support	2	2	
		Printing	2	2	
		Divider Type	2		
		Flap Gap Factor		2	
		Relative Humidity	2	2	1,2
		Storage Time	2	2	1,2
		Creep (paper)			1
	Pile of boxes	Pallet Surface Factor	3	3	
		Interlock	3	3	
		Overhang	3	3	
Output	Board	Thickness			X
		Basis Weight			X
		Bending Stiffness			X
		ECT			X
		FCT			X
		Bursting Strength			X
	Box	BCT, McKee	X	X	X
		BCT, Analytical			X
		BCT, Time Affected			X
		24 Hour Static Stacking			X
		Bottom deflection			X
	Pile of boxes	Stacking Strength	X	X	

Knowledge Needed for Use	Packaging Engineering	X	X	X
	Logistics Engineering	X	X	
	Structural and Fiber Mechanics			X
Models Used	Simplified McKee Mckee et al. (1961)	X	X	X
	Kellicutt and Landt (1958)		X	
Board Type	Single Wall	X	X	X
	Double Wall	X	X	X

1- Predicts box performance from paper properties
2- Predicts box performance from board properties
3- Predicts pile of boxes performance from box properties

Appended papers

DIVISION OF PACKAGING LOGISTICS, LUND UNIVERSITY
Doctoral dissertations and Licentiate theses

Hahn K, 1991, A study of the compressive behaviour of corrugated board panels. Licentiate thesis.

Renman M, 1994, A mechanical characterization of creased zones of corrugated board. Licentiate thesis.

Borglin J, 1995, Development of a decision support system for the selection process of corrugated packaging. Licentiate thesis.

Patel P, 1996, Biaxial failure of corrugated board. Licentiate thesis.

Aquilon M, 1997, Cultural factors in logistics management. Licentiate thesis.

Henriksson L, 1998, Packaging requirements in the Swedish retail trade. Licentiate thesis.

Johnsson, M, 1998, Packaging logistics – a value added approach. Ph.D. dissertation.

Patel P, 1999, Nonlinear creep model of paper and corrugated board materials. Ph.D. dissertation.

Persson E, 1999, Creating a competitive advantage in the corrugated board industry. Licentiate thesis.

Berglund A, 1999, Incorporating environmental aspects in transport purchasing. Licentiate thesis.

Bergström P, 2000, A strategic view on relationship in the grocery supply chain – the case of a low complex product. Licentiate thesis.

Saghir M, 2002, Packaging logistics evaluation in the Swedish retail supply chain. Licentiate thesis.

Olsson A, 2002, The integration of customer needs in e-business systems. Licentiate thesis.

Wallin C, 2003, Contract packaging and its implications for the supply chain – a case study of a contract packager. Licentiate thesis.

Nilsson F, 2003, A complex adaptive systems approach on logistics – implications from adopting a complexity perspective. Licentiate thesis.

Abukhader SM, 2003, The environmental implications of electronic commerce – the assessment approach problem. Licentiate thesis.

Orremo F, 2003, E-business in an established customer vendor relationship. Licentiate thesis.

Hellström D, 2004, Exploring the potential of using radio frequency identification technology in retail supply chains. Licentiate thesis.

Bramklev C, 2007, *Towards Integrated Product and Package Development*, Ph.D. dissertation, Lund University, Swede.

Bramklev C, 2004, Concurrent development of product and packaging – towards an integrated development procedure. Licentiate thesis.

Saghir M, 2004, A platform for packaging logistics development: a systems approach. Ph.D. dissertation.

Klevås J, 2005, On opportunities of integrated packaging, logistics and product development – experiences from a case study at IKEA. Licentiate thesis.

Gustafsson K, 2005, The process of creating a nation-wide pool system for transport packaging – from vision to decision. Licentiate thesis.

Abukhader SM, 2005, Towards horizontal environmental assessment for supply chain and logistics management. Ph.D. dissertation.

Nilsson F, 2005, Adaptive logistics – using complexity theory to facilitate increased effectiveness. Ph.D. dissertation.

Olsson A, 2006, The change from feature focus to customer focus in packaging development. Ph.D. dissertation.

Johansson O, 2006, Towards a model for managing uncertainty in logistics operations – a simulation modeling perspective. Licentiate thesis.

Dominic C, 2006, Packaging Networks - a framework for integrating packaging suppliers in the Demand Chain. Licentiate thesis.

Beckeman M, 2006, The rise of the Swedish food sector after WW II. What, why, how and who? Licentiate thesis.

Svanberg J, 2006, A constructive approach to the interaction between risk and logistics. Ph.D. dissertation.

Pålsson H, 2006, Interorganizational collaboration in the context of introducing new technology. Licentiate thesis.

Hellström D, 2007, On interactions between Packaging and Logistics – Exploring implications of technological developments. Ph.D. dissertation.

Lareke A, 2007, Tyrannical consumers – initiate value creation in the food value chain. Licentiate thesis.

Bramklev C, 2007, Towards Integrated Product and Package Development. Ph.D. dissertation.

Viström M, 2008, Aspects of the impact of Technology Integration on Agility and Supply Chain Management – the Potential of Digital Packaging Printing. Ph.D. dissertation.

Bjöörn, U, 2008, Integrating Packaging and Logistics in Industrial Development. Licentiate thesis.

Olander, M, 2008, Towards a new business paradigm – A study of the paper packaging industry. Licentiate thesis.

Johansson O. 2009, On the value of intelligent packaging – a packaging logistics perspectives. Ph.D. dissertation.

Pålsson H. 2009, Logistics value of using tracking data from uniquely labeled goods. Ph.D. dissertation.

Lindh H. 2009, Traceability in food supply chains – Beyond food safety. Licentiate thesis.

Ringsberg H. 2011, Traceability in food supply chains - Exploring governmental authority and industrial effects. Licentiate thesis.

Dominic C. 2011, Packaging logistics performance. Ph.D. dissertation.

Beckeman M. 2011, The Potential for Innovation in the Swedish Food Sector. Ph.D. dissertation.

Silgård Casell S. 2011, Support for the industrial packaging development process. Buyer and supplier perspectives. Licentiate thesis.

Grönvall K. 2011, Exploring influences on information sharing in supply chains – A scenario planning study. Licentiate thesis.

Sohrabpour V. 2012, Towards satisfying supply chain needs through packaging design and development. Licentiate thesis.

Abbasi M. 2012, Themes and challenges in developing sustainable supply chains. Towards a complexity perspective. Licentiate thesis.

Ringsberg H. 2013, Food traceability in regulated fresh food supply chains with an emphasis on the Swedish fishing industry. Ph.D. dissertation.

Olander-Roese, M. 2014, From powerpoints to reality-managing strategic change in the paper packaging industry, PhD dissertation.

Abbasi M. 2014, Exploring themes and challenges in developing sustainable supply chain s– a complexity theory perspective, PhD dissertation.