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Comparison of Different Packaging Materials and Solutions on a Cost Basis for Volvo Logistic Corporation

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Abstract

The basic problem that this thesis addresses was to compare different packaging materials for Volvo Logistics Corporation (VLC) from a cost perspective. Since this thesis was conducted for VLC only, their main packaging solutions were defined and categorized by size. With this, various materials in each size category were studied, analyzed and compared from different aspects. These aspects ranged from volume efficiency to ergonomics and cleanliness. Some of these aspects were easy to quantify and calculate while others, such as ergonomics and cleanliness, had to be evaluated qualitatively. The outcome of this research was a financial/comparative model, which allows users to choose the packaging solution with the lowest possible cost or the packaging solution that best meets their requirements. The conclusion is that technically the best packaging solution is not necessarily the cheapest because of the indirect logistical costs in addition to the packaging price.

1. Introduction

1.1. Background

Twede and Parsons (1997) summarize the importance of packaging logistics as:

> *Logistical packaging affects the cost of every logistical activity, and has a significant impact on the productivity of logistical systems. Transport and storage costs are directly related to the size and density of packages. Handling cost depends on unit loading techniques. Inventory control depends on the accuracy of manual or automatic identification systems. Customer service depends on the protection afforded to products as well as the cost to unpack and discard packaging materials. Furthermore, the characteristics of logistics system determine the requirements and costs for packaging.*

Johansson et al. (1997) provided a closer view of the packaging effect on logistics costs by categorizing it into direct and indirect cost influences. Direct influences are costs for material or packaging, purchasing administration, storage, and internal handling of packaging, etc. Packaging design affects both the costs for the packaging as such and the costs for other activities in the cycle, which are considered indirect cost influences. An example could be the adaptation of packaging to a standard pallet in order to increase the volume utilization during transport, thus reducing transport costs. Additionally, packaging design affects the costs for packing, transport, storing, handling as well as collection and recycling.

1.2. Purpose and Objectives

The purpose of this thesis was first, to provide a general study of the pros and cons of different packaging materials and second, to compare different packaging solutions from a total cost perspective. The different packaging materials included wood, plastics, and corrugated cardboard.

1.3. Problem Definition

In order to achieve the purpose of this thesis, two major questions were developed which led us to the objectives of the thesis.

The first question was ”*which packaging-related logistical factors are important in Volvo Emballage packaging system and should be considered for the total cost analysis of different packaging solutions?”*

Answers to the first question were also used to answer the second question “*Which packaging solution serves the best in facilitating the logistics flow and costs the least from the total cost perspective?”*

1.4. Limitations and Demarcations

In general, wide varieties of solid and composite materials were used for the packaging. This research was limited only to common materials used for packaging within Volvo Emballage (VE), which were wood, plastic, cardboard, metal, and any combination of these materials. This limitation was mainly due to time constraints and a lack of resources.

1.4.1. Demands on Packaging

According to Jönson and Johansson (2001), a packaging system should fulfill various demands. These demands could be divided into three aspects: logistical, marketing and environmental. Figure 1 illustrates these aspects and their general commonality.

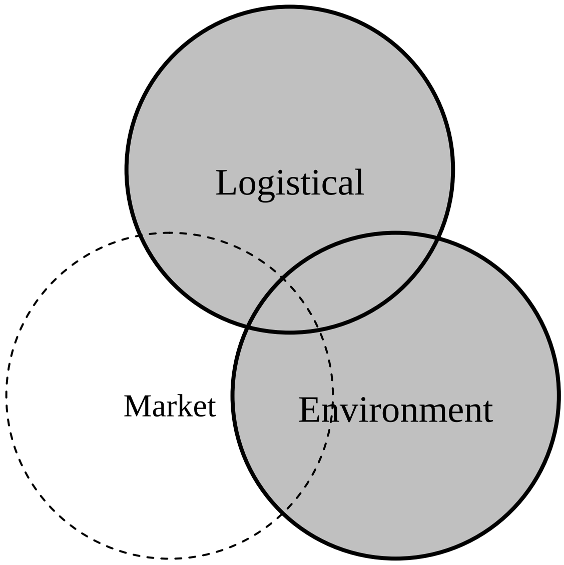

Figure 1. Three main aspects of packaging. Modified from Johansson et al (1997).

The focus of this thesis from a "demands on packaging" point of view is highlighted with gray color in the above figure. Usually the marketing aspect is a major concern for the retail industry, but VE packages did not serve this function, therefore, this aspect was completely disregarded. However, a general overview of this aspect was provided in the theoretical frame of reference.

Some subcategories from logistical and environmental aspects have also been removed. Within the environmental aspects, *toxicity* was not analyzed due to time limitations and the assumption that all available packaging solutions on the market have already passed this criterion according to national and international regulations and standards.

Within the logistical aspects, *package identification* was not researched in detail due to its lack of relevance pertaining to packaging characteristics, and more specifically towards packaging materials. A short description on *package* *identification* was provided in the analysis section, as well as reasons for its exclusion from this thesis.

Concerning other logistical demands on packaging, there were different actors in the VE packaging users' network who have set a variety of demands on packaging. Limitations from this perspective are discussed separately in the following section.

1.4.2. Demands on Packaging from Users' Perspective

Figure 2 illustrates the packaging production supply chain in a simplified manner, as well as the VE packaging users' network. The focus of this research is also demarcated in this figure, although, sometimes it went beyond this scope when addressing packaging environmental issues.

Within the VE packaging users' network, packages go through a number of stages in order to provide logistical utility, most of which is accompanied with some associated logistical cost. These stages, utilities and their associated costs are discussed later in the analysis section.

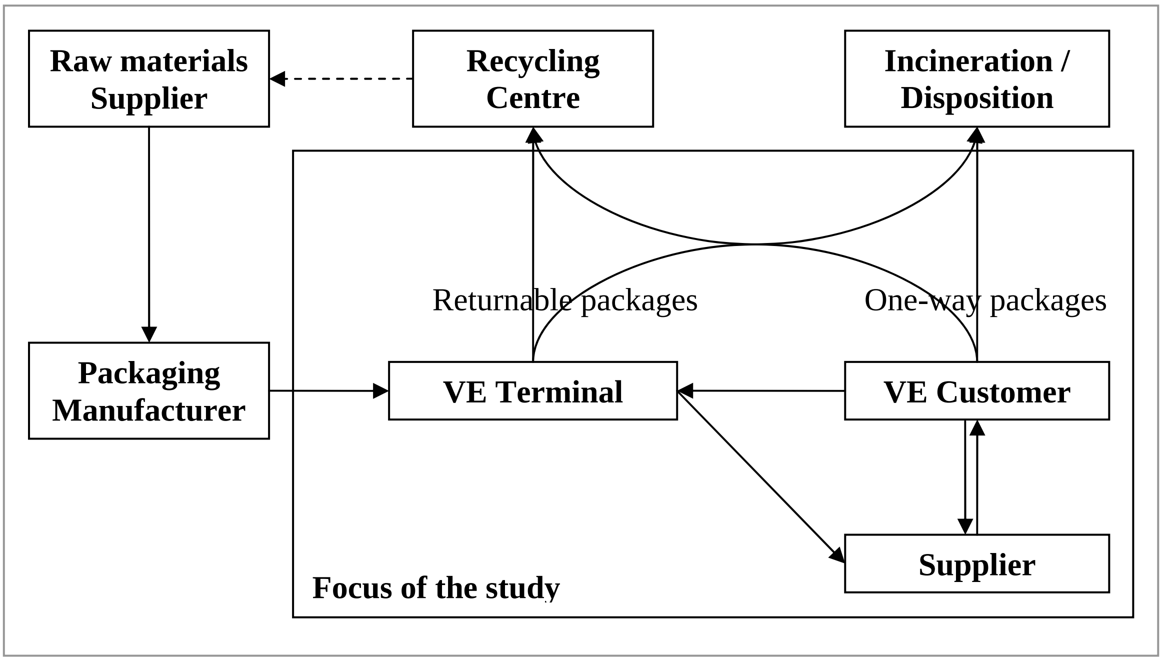

Figure 2. Simplified view of package production and usage cycle.

VE customers and their suppliers are different entities within the packaging users' network, and have differing packaging demands. As mentioned previously, this thesis consists of two different lines of investigation, though closely related to complement one another. The first discussion is a general study of the pros and cons that was conducted independent from each actor's packaging requirements.

However, the second discussion is to compare different packaging solutions from a total cost perspective. This was accomplished in relation to each entity's specific packaging demands. Since it was not always possible to express different packaging qualities and performances in terms of money, for some cases, general indices were introduced as a primary comparison for different packaging solutions.

These indices could be used by all entities when the exact costs are not available. However, exact monetary costs were calculated for VE.

In the comparison of various packaging alternatives, dimensional compatibility was not an issue. This flexibility was set by VE because they could order almost any appropriate size packaging that would well suit their company's material flow system. Therefore, issues such as design modularity were not discussed in this thesis.

1.5. Outline for the remainder of the Thesis

- *Chapter 2 - Theoretical frame of reference:* The scientific and organizational theories used in this thesis are presented in this chapter, with appropriate references to books, articles and Internet websites. The rational for the theoretical selections are also presented. To remain as consistent as possible with accepted terminologies and keywords, some definitions are provided that might differ from text to text. There were cases in which established theories were not appropriate for the focus of this research and had to be modified or tailored.

- *Chapter 3 - Methodology and methods:* In this chapter, different research methodologies and research sampling methods are described. The methods used for analysis are also presented in this chapter.

- *Chapter 4 – Packaging Materials:* This chapter provides a general study of the pros and cons of different packaging materials, such as wood, plastic, corrugated cardboard and metal.

- *Chapter 5 - Empirical results:* This chapter includes the presentation of the organization and results from the investigations, calculations and the methods used. Various packaging alternatives have been categorized regarding their size to facilitate the research process. Different aspects of packaging that this study has focused on are also presented here, along with a brief conclusion on the outcome of each of the associated aspects.

- *Chapter 6 - Analysis:* This chapter mainly contains a combination of the theories and the results. Using the theories presented from the theoretical frame of reference and the methods described in the methodology chapters, the research problem has been analyzed towards achieving the objectives. This chapter begins with a general description of the packaging materials of interest and then discusses their differing aspects. Later, different functions of packaging are identified and analyzed in detail from both a logistical and an environmental perspective. Additionally, there were some difficulties regarding this research, which also have been delineated here.

  Chapter 7 - Conclusion: The findings and the conclusions of this thesis project are discussed in this chapter. In addition, some recommendations for further research were suggested at the end of this section.

2. *Theoretical Frame o*f Reference

2.1. Definitions

Before proceeding further, some terms and phrases should be clarified to avoid misconceptions. In this section, only terms that might be misunderstood and require more clarification are defined. The definitions of other common terms within the logistics and packaging industry are disregarded.

2.1.1. Packaging

According to Paine (1981) packaging is defined as:

> *A coordinated system of preparing goods for transport, distribution, storage, retailing and end-use*

A better definition suited for this research is provided by EC Directive 94/EC of the European parliament and the council on packaging and packaging waste (Johansson et al., 1997).

> *Packaging shall mean all products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer.*

This definition focuses on four different, but important, matters related to packaging; packaging materials, functions of the packaging, type of products and materials that constitute a package and actors involved in the packaging process. The following is a short explanation concerning each of these matters as they pertain to the relevance of this research.

- *Packaging materials* considered in this case are limited to wood, plastic, cardboard and metal. The first objective of this thesis is to provide information about the pros and cons of different packaging solutions from a packaging materials perspective.

- *Functions of packaging*, which enhance the flow of the logistics, are the concern of the second objective of this research when performing a total cost analysis. A total cost analysis is calculated based on the quality of the services that a packaging solution offers within different packaging functions. The functions/aspects of the packaging that were in the scope of this research are presented in Figure 12.

- Concerning the *products*, most of the VE customers are from the automotive industry. Consequently, the packaging that was studied in this research was meant to support the transport of motor vehicle parts and components. These goods consist of a diverse assortment of products from small size nuts and bolt to large size dashboard modules. The type of goods affects the packaging requirements and expected functions. Thus, this issue was implicitly discussed when analyzing packaging functions.

- Finally, it is worth noting that there is a differentiation between different *types of users of packaging* in that there are packaging *users* and *packaging consumers*. In general, there are two major categories in business relations: business-to-business (B2B) and business-to-customer (B2C). To maintain clarity throughout this thesis, business customers will be referred to as packaging users and final customers will be referred to as packaging consumers. Hence, over this thesis the term *packaging users* refers to business entities and not the final customers. This classification is important from another perspective, that is, marketing function of the packaging has no importance in this analysis. On the other hand, logistical performance and environmental issues would be the main source of requirements on packaging.

2.1.2. Logistics and Packaging Logistics

Johansson et al. (1997) defined logistics as:

> *…. the process of planning, implementing and controlling the efficient, effective flow and storage of raw materials, in-process inventory, finished goods, services, and related information from point of origin to point of consumption for conforming to customer requirements. It considers the materials flow as a whole rather than the single activities and sub-flows separately, and has the focus on the total result of the flow.*

In the same way, Johansson et al. (1997) defined packaging logistics as:

> *[a field of study] aiming at developing (creating) packaging and packaging systems that support the objectives of logistics to plan, implement and control the efficient and effective materials flow.*

2.1.3. Packaging System

Johansson et al. (1997) states that:

> *Packaging system defines the frame for the life cycle of the packaging. Here the business potential of the packaging in the logistics chain is judged. Here also the system limitations are given in matters such as sizes, modules, one-way or reusable packaging, packing location, need for standardization, supply and so on.*

2.1.4. Packaging Solution

In this thesis, various packaging alternatives are referred to as packaging solutions. These solutions range from a simple base pallet to a combination of a pallet with frames and lid, as a packaging unit (containers). Small boxes were also considered as a packaging solution. In other words, every single or set of shaped materials that serves a purpose for packaging was considered as a packaging solution.

2.1.5. Volvo Emballage (VE)

VE's business concept was to provide packaging logistics services, to manufacturing industries, such as car and truck manufactures. VE is a global supplier of packaging that can be re-used again and again. The packaging was used for shipping goods between customers. Any packaging not required was returned to VE terminals. Customers had access to a wide range of different packaging solutions, such as pallets, frames, lids, plastic boxes, spacers, etc. (User's Guide - Packaging Handling Published by VE)

2.1.6. Transaction cost

The emballage system is very similar to banking. Every customer signs a contract and was provided an account. Packaging movements between these accounts were registered and a transaction would then be generated. Fees for using the packaging were charged based on the transactions, which were called *transaction costs.* (User's Guide - Packaging Handling Published by VE)

2.1.7. Protection

Johansson et al. (1997) argues that product protection is one of the basic functions of a packaging. The basic premise is that packaging should provide protection for the product against the logistical environment and vice versa — meaning that packaging is supposed to protect the environment from hazardous products.

Most of the products that were transported by VE packaging were not concerned with the transport of hazardous materials. Because of this, only the protection of the product from logistical hazards was focused upon in this thesis.

2.1.8. Utility

Twede and Parsons (1997) discussed that packaging has to provide utility and explains it further as:

> *The economic definition of utility is equivalent to the value that a user places on a product. In the case of logistical packaging, the user is the logistical system, and the value is efficiency.*

2.1.9. Ergonomics

The following is the definition of ergonomics by Wilson (2000) in his article "Fundamentals of ergonomics in theory and practice".

> *Ergonomics is defined as a discipline in its own right, as the theoretical and fundamental understanding of human behavior and performance in purposeful interacting socio-technical systems, and the application of that understanding*

to design of interactions in the context of real settings. This definition is justified in the financial, technical, legal, organizational, social, political and professional contexts in which ergonomists work.

In this study, packaging was considered ergonomic when it was light in weight and did not require much energy or effort to handle. In other words, the criteria for ergonomic packaging was based on weight and handling ability.

2.1.10. Cleanliness

Cleanliness in this thesis refers to the impact of packaging solutions on the work environment. In other words, a package is considered clean when its impact on the work environment is as minimal as possible. The cleaner the package is, the cleaner the environment.

2.2. Packaging on Different Levels

In most packaging literature there are several lists of requirements that packaging has to fulfill (Jönson and Paine, 1998). Usually, not all these requirements can be met by just one packaging solution (Johnsson, 1998). Conventionally, products are packed in three levels: primary or consumer, secondary or multi-unit packaging, and tertiary or transport packaging (Johansson et al., 1997). This system works to fulfill the different requirements expected from packaging.

A three-level packaging system is most applicable for retail products. However, in an industrial packaging system, goods are primarily packaged in two levels. Here, the conventional view on the levels of packaging is summarized. Later they are used to define the classification and view of industrial packaging systems suitable for this research.

2.2.1. Conventional Classification of the Packaging System

a) Primary or Consumer Packaging

Primary packaging makes the product available as well as protecting and preserving its quality. It also helps the end-user identify the product and gives information about it. Additionally, their dimensions should be compatible with shop shelves. There are a number of other requirements that should be met such as attractiveness and being easy to open or close (Johansson et al., 1997).

b) Secondary or Multi-unit Packaging

Secondary packaging was designed to contain a number of primary packages. These packages should facilitate the handling activities inside the shop. Since they were used inside the shop, compatibility of their dimension to shop fittings is important. A tray made of cardboard is an example of secondary packaging (Johansson et al., 1997).

c) Tertiary or Distribution Packaging

Distribution packaging is used in different phases of distribution such as transportation, handling, storage, etc. The main contributions of distribution packaging is to functions of packaging are protection, unitization, handling ability and stack ability in larger scales. Examples of transport packaging are wooden pallets, plastic containers, crates of any material, etc.

d) Packaging Components or Packaging Aids

Due to vulnerable product characteristics and/or intense logistical hazards, requirements on packaging are sometimes so high and specific that despite many levels of packaging, they cannot be fulfilled. Therefore, packaging aids or additional components are required to ensure safe delivery of the products. In many cases, packaging solutions are used in combination with packaging aids referred to as packaging components. An example is shrink film that is used for increasing stability and strength of a packaging solution/system. Other examples are foam plastic cushioning, wooden or cardboard spacers, plastic bags, etc. Packaging aids are not classified as packaging; therefore, another level was not added to above categories.

2.2.2. Industrial Packaging System New Classification

a) Primary or User Packaging

Since there are no consumers in the industrial packaging system in its conventional sense, the word *user* was used to represent this level of packaging. The term *packaging user* implies many changes implicitly to one's view of primary packaging. One of these changes is that the marketing aspect of packaging, such as attractiveness, is not a viable issue. Instead, adaptation to the shop shelves, compatibility of the packaging dimensions to the shelves in the assembly line, packing facilities and distribution packaging are the issues and concerns that are of importance. Ergonomics would be more important if a user needs to pickup and lift products repeatedly throughout a day. User packaging should also provide adequate protection for the products.

Corrugated cardboard and small plastic boxes are examples of primary/user packaging. These packages are large enough to be able to put into distribution packaging systems directly without the need for multi-unit packaging. Another reason for this is that industrial products are consumed in large scales. Due to these reasons, the category of multi-unit packaging was omitted from this classification and secondary packaging was defined as distribution packaging in the new classification.

b) Secondary or Distribution Packaging

A number of primary packages were placed into distribution packaging mainly to achieve storage, handling and transportation efficiency. Examples of distribution packaging are wooden or plastic pallets, wooden containers (combination of base pallet, frames and a lid), large plastic containers and combitainers. Small boxes like corrugated cardboard or plastic boxes were first filled with smaller products and then loaded into distribution packaging.

In many cases though, distribution packages were used as both primary/user packaging and secondary/distribution packaging. This occurred when products were large enough to be placed directly into the distribution packaging. In such cases, packages served their fullest potential as a package. Such as the case is, packaging should serve its functional purposes for both the user and distribution packaging. It should provide protection, product information, ergonomic efficiency, etc., in addition to facilitating handling, storage and transportation. Using packaging aids/components were very common, in such cases, in order to fulfill all the required functionality of packaging, particularly protection.

2.3. Cost Analysis Techniques and Method

To acquire a proper perspective on how packaging affects the [logistical and environmental] costs, it must be placed in its proper context – as an integrated part of the logistics and supply chain management cycles from raw material to disposal of the used packaging (Johansson et al., 1997). This can result in a comprehensive cost analysis considering all the costs associated or related to a packaging solution. Packaging is meant to offer a variety of services and utilities in return for a cost. The basic premise for a total cost analysis would be to quantify all services and utilities associated with the packaging process in terms of money, and compare them against the packaging cost.

Cost-benefit analysis is another method that utilizes a quantitative approach for cost analysis. Services and utilities, that packaging provides, are calculated as benefits and are compared against those costs by either dividing them by the cost or subtracting the cost. Each criterion (subtraction or division) has its own economic implications. However, quantification of benefits and costs are highly sensitive to assumptions such as discount rates and residual value. It needs artificial and often arbitrary modifications to handle qualitative factors such as the value of improved occupational health or cleanliness of the factory environment. This method is appropriate for situations that involve hard costs and benefits, and that permit clear performance criteria (Keen, 1981). On the other hand, packaging is a very complicated process or system with many soft costs and benefits, in addition to hard ones, such that it is practically impossible to quantify all the effects on the process or system.

2.3.1. Decision support system

Managers seem to be more comfortable of thinking in terms of perceived value, then asking if the cost is reasonable. The dilemma that managers face in assessing *Decision Support System (DSS)* proposals is central to the issue of qualitative benefits. Basically, they require some way of deciding if the cost is justified. The main weakness of the cost-benefit approach is that it requires knowledge, accuracy, and confidence concerning the issues at hand. This for packaging is not always known. The benefit of a DSS is the incentive for going ahead. The decision to build a DSS seems to be based on value, rather than on cost (Keen, 1981).

What is needed is a systematic methodology that focuses on (Keen, 1981):

- Value first, cost second
- Simplicity and robustness: Decision makers cannot and should not have to provide precise estimates of uncertain qualitative future variables
- Reducing uncertainty and risk
- Innovation rather than routinization

In value analysis, the complex and demanding calculations of cost-benefit analysis are replaced by rather straightforward questions about its usefulness (Keen, 1981).

2.3.2. Value Analysis

Value analysis is a problem-solving system implemented by the use of a specific set of techniques, body of knowledge, and group of learned skills. It is an organized creative approach that has for its purpose the efficient (effective….seems like a better word) identification of unnecessary costs, i.e., costs that provide neither quality nor use, life, appearance, or customer features (MILES, 1989).

Regarding the packaging value analysis, Twede and Parsons (1997) say:

> *The functions of packaging are the basis for packaging value analysis. They outline what the package must do (for example, be able to survive an impact).*

Miles asserts that all costs are for function and defines value as the lowest cost that fully provides a required function. A product or service is generally considered to have good value if that product or service has appropriate performance and cost (MILES, 1989).

When applied to products, this approach assists in the orderly utilization of better approaches, alternative materials, newer processes, and abilities of specialized suppliers. It focuses engineering, manufacturing, and purchasing attention on one objective-equivalent performance for lower cost. The focus provides systematic procedures for accomplishing its objectives efficiently and with assurance (MILES, 1989).

2.3.3. Modifying Value Analysis for this research

Value analysis is normally used for product design and development. However, the product of interest in this study, standard packaging, already exists Thus, Value Analysis was used for identifying required functions and performance of a packaging solution. Those functions with minimal effects on the performance of the logistics system were not considered of interest, and were not evaluated. Each function corresponded with some logistical cost, some of which were easily quantifiable. However, some costs could not be quantified with available data and resources. Therefore, they were qualitatively broken down to their basic elements, in order to provide a better understanding of the possible costs associated from the lack of that particular function.

3. Methodology and Methods

The research approach decided upon was chosen according to the type of problem and purpose of the research. There were many considerations and variables that needed to be analyzed. It was found that no one method was ideal, but rather a collection of methods.

3.1. Research Methodologies

Confidence was obtained in this research project by knowing the facts; knowing the current situation; how to change this situation and how to change it to meet the desired requirements. There had not been a large body of research regarding packaging from the customer's perspective. Knowing the current situation was simply achieved by studying and analyzing the situation in various companies. Acquisition of such knowledge had to be systematic and based on an existing situation. There were various methods to gather and analyze information from existing systems. Literature study helped to create the frame of reference used to analyze the information, and a case study with a survey helped to gather the information required (Johnsson, 1998).

3.1.1. Literature Studies

The first step in the research process was to gain information about the subject matter. As discussed earlier, there were two objectives for this thesis. The first objective was a general study of the pros and cons of different packaging materials, which was accomplished theoretically and by conducting a literature review. The second objective was to compare different packaging solutions from a total cost perspective. This required both theoretical and empirical research. Therefore, theories, cost analysis techniques, evaluation methods, decision support systems, etc, were required and found in economic and logistics literature. These theories and methods formed the basis for the analysis machine, where empirical data were fed as inputs and empirical results were developed, which could be characterized as the outputs. This analytical relationship is shown in Figure 3, below.

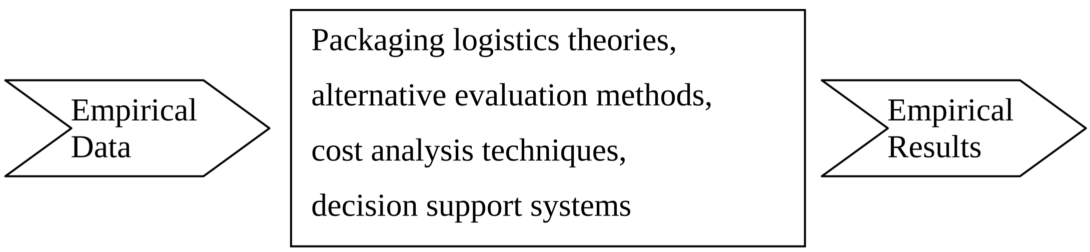

Figure 3. Analysis Procedure for the second objective of the thesis.

Regarding our background, the most relevant course that we studied in our two-year master program was the *Packaging and Cargo Carrier Technology* course. Although there were other courses within the logistics discipline that were indirectly related and required to have a proper perspective and understanding of packaging influence on logistical activities. We looked for materials related to packaging, but they were too general to use in our research. During our search, we came across a field of research within the packaging field, namely packaging logistics. Considerable amounts of research have been done in this discipline, mostly by Swedish research centers. This made the task a bit more difficult due to the language differences. However, the Packaging Logistics division at the department of Design Science in Lund University had many publications either in English or translated to English that proved to be the main resource for the literature study. In addition, Professor Diana Twede from the School of Packaging in Michigan State University had many publications in the field that helped in building the framework for the analysis. Regarding the general issues on packaging, the packaging logistics book published by Packforsk, was used periodically as a handbook.

Another major difficulty that we faced concerning resource materials was that most of the research conducted within the packaging logistics field, had thus far addressed only the consumer packaging aspects rather than distribution packaging. While our study had nothing to do with consumer packages, issues such as the marketing aspects of packaging had little to no effect within the industrial applications of packaging. This idea is also supported by Johnsson (1998) in his work called "Packaging Logistics: a value added approach".

3.1.2. Case Study

> *The case study is but one of several ways of doing social science research. Other ways include experiments, surveys, histories, and the analysis of archival information. Each strategy has peculiar advantages and disadvantages, depending on three conditions: (a) the type of research question, (b) the control an investigator has over actual behavioral events and (c) the focus on contemporary as opposed to historical phenomena (Yin, 2003).*
>
> *In general, case studies are the preferred strategy when "how" or "why" questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context. Such explanatory case studies can be complemented by two other types—exploratory and descriptive case studies (Yin, 2003).*

Considering the above, understanding the case study methodology and characteristics of this research, the choice of a case study seemed to be appropriate.

The case study method was one of the least understood and most often criticized research methods used today. Despite this, there appeared to be a growing interest in, and use of the case study methodology in business research (Ellram, 1996). Case study strategy focuses on understanding the current dynamics present (Yin, 1984 - cited Johnsson, 1998). They could involve a single or multiple companies and numerous levels of analysis. Case studies usually combine data collection methods such as archives, interviews, questionnaires and observations to gather and analyze the required data (Johnsson, 1998).

In this research, since the information gathered from the literature study were based on other experiences and events, rather than the company at hand, the optimal solutions defined were not entirely applicable for this situation. Therefore, a case study was arranged to help define the current situation and an optimal solution from the customer's viewpoint. To be able to conduct the case study, within the then current existing situation, the range of packages and customers were limited to a reasonable number. In other words, only the major customers and the most widely used packaging solutions within the VE system were chosen to be studied.

For the interviews, a few meetings were arranged with the major customers, at first. These first meetings were conducted with Volvo Cars marketing and packaging departments at Torslanda, in Gothenburg. During the first visit, a tour of the Volvo Cars Corporation production line was arranged to clarify the customer's exact treatment and handling of packages. Later, another meeting was arranged with the packaging department of the same company, which led to the second visit of the same production line. During the two visits to the Volvo Cars Corporation production line at Torslanda, a more detailed and comprehensive view of the exact packaging requirements was obtained.

Meanwhile, the same procedures were conducted with other meetings within both Volvo Trucks at Gothenburg and Volvo Powertrain in Skövde. These meetings were accompanied by visiting the production lines of each respective customer. These meetings showed that although the customer's may require various details from a packaging unit, in general though, they all had the same expectations (e.g. in ergonomics, handling, etc.).

After the customer's view concerning packaging requirements was documented, it became time to study the products within VE to see which would fit the customer's demand best. To do so, a visit was arranged to the VE terminal in Gothenburg. During this visit, all the handling machinery, storage spaces and packaging units used within VE were studied. This gave a clear picture of how a packing supply procedure was being conducted within VE. What packages were being used and how were they being used? What were the processes and procedures that were being used to process the packages, and so forth? For further details regarding the VE packages and their specifications, meetings were arranged with VE packaging engineers. Through these meetings, details of various packaging units, along with their advantages and disadvantages, were obtained.

At the same time, some other meetings were arranged with VE's environmental department and ergonomic consultant (ALVIVA) to gather data on different aspects of the existing packages. Some of these meetings were useful and some led to other solutions for data gathering. For example, the environmental department referred us to the various VE terminals and depots around the world to obtain the regional disposal cost for one-way packaging. This resulted in another step for gathering data on environmental aspects, by sending emails to all VE terminals and depots around the world.

3.1.3. Model Building

One of the main goals of this thesis was to build a financial model for the desired company to be able to evaluate the best packaging solution for its customers. This model was supposed to be a quantitative model that could calculate the least expensive solution for the customers. However, after the literature study, some of the defined aspects for analysis could not be quantified. Thus, based on the literature study and the information gathered by the case study, a mix model of quantitative and qualitative comparisons was developed. The quantifiable data (financial numbers) were inserted into the model along with the descriptions of the qualitative data. With this, customers could now define the best packaging solution based upon differing requirements. They could see the financial aspects as well as other packaging qualities that could help them make a better and more informed decision.

3.2. Research Sampling Methods

Logistics research is usually built on both quantitative and qualitative data. This research was not exempted from this fact. The data sampling in this thesis was through observations, interviews and a literature study. Observations and interviews were considered primary data while data gathered from literature was considered secondary data.

Visits to VE packaging terminals and VE customer plants were the major sources of inputs for the analysis. VE had several customers and arranging meetings with all of them was not practical. Therefore, meetings with a few of them were arranged such as Volvo Cars, Volvo Trucks and Volvo Powertrain. These customers were the major users of VE packages.

4. Packaging Materials

Regarding packaging materials, Johansson et al. (1997) states that various packaging materials have their own unique properties. Some are light in weight, some are hard and provide good protection, some are easily shaped, etc. These materials could be used either individually or in combination with each other for packaging. In the following sections, a brief introduction is provided on various packaging materials with which VE packages are made from.

4.1. Corrugated Cardboard

Corrugated fiberboard was invented around 1870 in the USA and then came via Germany to Sweden (notes from packaging course). It is mostly used as a material for one-way packaging mainly because of its fairly low price. 90-95% of all rigid one-way transport packages in Sweden are made from corrugated cardboard (Johansson et al., 1997).

Corrugated fiberboard consists of a corrugated layer called fluting, glued by a material usually made from maize starch to the liners (flat layers). This function provides the material strength, unity (plane layer) and protection against impacts (corrugated layer). Therefore, packages made of corrugated cardboard are becoming more popular these days. This is mainly due to the fact that these packages are not only very light in weight but also provide adequate protection for its customers.

There are four types of corrugated fiberboards:

- Single-faced
- Single wall
- Double wall
- Triple wall

Single-faced corrugated board only has one-liner and fluting, while the single wall has two liners on both sides of the fluting. As it is evident from its name, double wall has two layers of fluting and triple wall has three. The flutings within all these types have different heights, which thereby defines the thickness of the board.

Due to its material characteristics, packages made of corrugated cardboard have its highest strength when made in cuboid shapes. Mechanical strength characteristics of paperboard packaging materials are (Transport Information Service):

- *Bursting strength:* This occurs when the resistance exerted by a specimen of packaging material is sufficient against the bursting on exposure to pressure.
- *Puncture resistance:* The force that must be applied for a puncture tool of a specified shape and dimensions to pass completely through a test specimen. This force is expended to pierce; tear and bend open the test specimen.
- *Edge crush resistance:* Resistance to crushing of a perpendicularly arranged test specimen of paperboard (usually corrugated board) of a defined size.

Corrugated cardboard is the product of wood and therefore it is a hygroscopic material. When moisture is absorbed, corrugated cardboard drastically loses its mechanical strength and rigid characteristics. Another problem that arises from water absorption is the oxidation of corrosive package contents. This is also common with wood and is discussed in the next section under *humidity/moisture*.

Swedish Standard Institute (SIS) developed a standard, SIS 843009, which lists a number of qualities for the most common types of corrugated cardboard. These qualities include edge crush resistance, bursting strength, puncture resistance and water absorption.

4.2. Wood

As a packaging material, wood has many advantages. It provides high strength compared to its weight, high stiffness, good durability, and acceptable versatility for design in medium and large sizes. In comparison to other rigid materials like glass and steel, it is relatively light. Packaging made of wood has excellent rigidity, stacking strength and physical protection (Twede and Selke, 2005).

> *Wood is a low-cost commodity, easily available everywhere in Scandinavia, South America and North America. Trees are a natural resource, making wood universal, abundant and inexhaustible given proper forest management. Wood is an environmentally benign packaging material because it requires little energy to process, does not pollute, and bio degrades (Twede and Selke, 2005).*
>
> *Wood excels when it is made into packages that require great strength or are expected to convey a natural or furniture-like effect. Wooden packages are suited for small-scale production and can be manufactured with simple equipment in a variety of forms, including boxes, crates, pallets and barrels. For packages in which mass is an asset (like reusable pallets) wood can be lower cost than plastic or steel. Wood can be combined with metal to obtain benefits from both materials. Wood is used in pallets and crates for its strength and relatively low cost compared to other high-strength packaging materials (Twede and Selke, 2005).*
>
> *Since it is a natural material from a living tree, wood continues to undergo a natural lifecycle after harvesting. It is especially affected by water and is not a good moisture barrier. It is subject to sorption of water vapor and liquid and the presence of water can change its dimensions (Twede and Selke, 2005).*

Wood is predominately used for coarse transport packages and is still widely used around the world (Johansson et al., 1997). The most common wooden package is the wooden pallet, which is extremely popular within Western Europe. Wooden pallets have become quite popular with the increasing demand for transportation (Johansson et al., 1997). VE uses wooden packages as both primary and secondary packaging.

4.2.1. Properties of Wood

Humidity and Moisture Content

Hygroscopicity is one of the most important properties of wood as a packaging material. It means that depending upon the moisture content of the surrounding air; wood absorbs or releases water vapor, resulting in equilibrium moisture content. If the wood is in a relatively dry environment, it tends to release water vapor and conversely, it readily absorbs water vapor in a relatively moist environment.

The wood used for making packages should have 12-15% water content. These values approximately match the equilibrium moisture content at normal amounts of relative humidity within the atmosphere. Figure 4 shows the sorption isotherm for wood at 20°C.

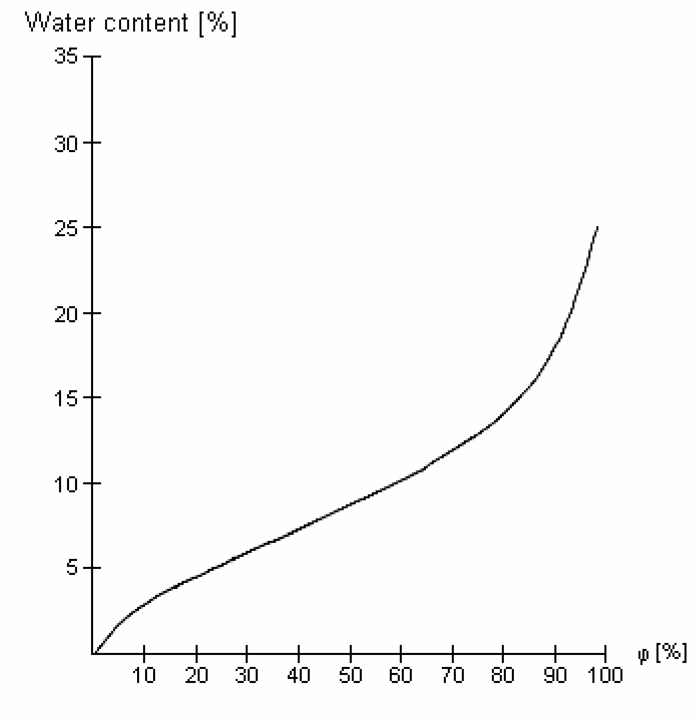

Figure 4. Sorption isotherm for wood at 20°C.

Excessively moist wood will eventually release a water vapor within the package (when it reaches a more dry environment) which may, for example, cause corrosion in package contents or other accompanying cargoes which could be at risk of corrosion.

Another issue that is specific to wooden packages (not the corrugated cardboard) is the fall of the extraction resistance of nails and screws as the wood water content rises. The number of required nails or screws increased if the water content of wood was high during package production. If the wood was processed at a water content of approximately 15%, the extraction resistance remains unchanged for several weeks after the process. However, if the wood is excessively moist during processing, extraction resistance falls as the wood dries out due to enlargement of the screw and nail holes get larger when shrinking. The wood *works,* i.e. swells, as it absorbs moisture and shrinks as it dries.

Dimensional Changes

Both excessively moist and excessively dry wooden packaging solutions may have a negative impact upon transport operations due to their dimensional changes.

Subsequent drying may have a negative impact because it sometimes reduces the dimensions of wood. Due to this shrinkage, screw and nail holes will enlarge and therefore extraction resistance and box stability will be reduced. On the other hand, gaps may suddenly appear between boards, which were initially fitted closely together, resulting in further degraded box stability. The greatest dimensional reduction usually occurs across the width and thickness of boards, while the length remains virtually unchanged.

If during processing, the wood is excessively dry, subsequent absorption of water and the resultant swelling in the future may cause boards to lever each other apart, so destabilizing screws and nail joints are often required to ensure the strength of the structure.

Density

Since the specific weight of wood was largely determined by the species of wood and lumber moisture content, it is highly variable. Often a distinction was drawn between softwoods (spruce, pine, fir, alder, lime, willow, poplar) and hardwoods (beech, oak, maple). The average density of hardwoods was assumed approximately to be 650 - 750 kg /m3, while softwoods are somewhat lighter in density, approximately 450 - 550 kg /m^3.

Strength

Moist wood has a lower strength than that of dry wood. For example, a wood with a moisture content of 20% has only half the compressive strength and only approximately two-thirds the flexural strength of a wood with a moisture content of 10%.

Heat treatment for Pest Control

> *When wood is used for export packages, there are special requirements for heat-treatment to destroy insects and other pests. Export shipments can expose a recipient country to pests that are not indigenous and pose special risk of spreading (Twede and Selke, 2005).*

To protect the forests around the world, the International Plant Protection Convention (IPPC) Secretariat, part of the Food and Agriculture Organization (FAO) of the United Nations, has issued ISPM 15 (International Standards for Phytosanitary Measures) "Guidelines for Regulating Wood Packaging Material in International Trade”. The mark shown Figure 5 is to certify that the wooden packaging material that bears the mark has been subjected to an approved measure.

All the VE packages that were used both locally and internationally were certified regarding this standard.

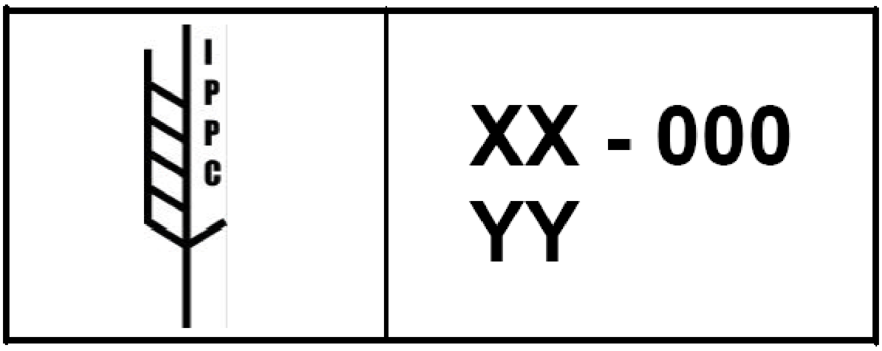

Figure 5. Marking for approved measures of IPPC standard.

4.3. Plastic

Plastic or polymer consists of a very wide range of materials with different properties. These materials also have a wide price range. The cheapest of these materials, polyethylene (PE) and polypropylene (PP), were used for packaging. These packages range from simple plastic bags and warping to plastic boxes and containers (Johansson et al., 1997).

PE was classified by density into PE-LD and PE-HD. PE-LD is a low-density polyethylene which has a density of approximately 0.92 - 0.94 g/ cm3. It was produced by a high-pressure process while PE-HD is a high-density polyethylene with a density of approximately 0.94 - 0.96 g/cm3. It is produced by a low pressure process (Transport Information Service). Most of the packages used within the VE packaging system were made of High Density PolyEthylene (PE-HD).

Both PE-LD and PE-HD are insensitive to water and exhibit a milky haze when uncolored (nearly crystal clear only when converted into thin films). The usual temperature range for PE usage was approximately -50 to +60°C for PE-LD, while the upper limit for PE-HD was approximately 90°C (Transport Information Service).

PE films were in particular, characterized by their good water vapor barrier properties. However, their permeability to gases and aroma substances is disadvantageous. Thanks to its higher density, PE-HD has better barrier properties towards oxygen, carbon dioxide, water vapor and aroma substances compared to PE-LD (Transport Information Service).

PE is not only converted into films (PE films, composite films, shrink films), but it was also used to produce bottles, bottle crates, drums, boxes, bowls etc (Transport Information Service).

4.4. Metal

First steel and then later aluminum, became the most common metals used in packaging. The advantage of aluminum to steel is its lighter weight and its higher resistance to corrosion (Johansson et al., 1997). Aluminum is one the most common elements after oxygen and silicon. To produce new aluminum, significant energy is required while recycling the old aluminum (by melting) only requires around 5% of that energy. Pure aluminum tends to be soft and plastic, both in warm and cold conditions. Therefore, for packaging, alloys of aluminum, which were strengthened, were mostly used.

Steel is an alloy of iron, which had less than 2% carbon content. Due to its high strength, steel could be used as a support for parts in large packages. Steel was also considered stronger than aluminum but it was also heavier (notes from packaging course)

VE only used metals, partially in its combitainers, which are described further within this thesis.

5. Empirical Studies and Results

5.1. Volvo Emballage Packaging System

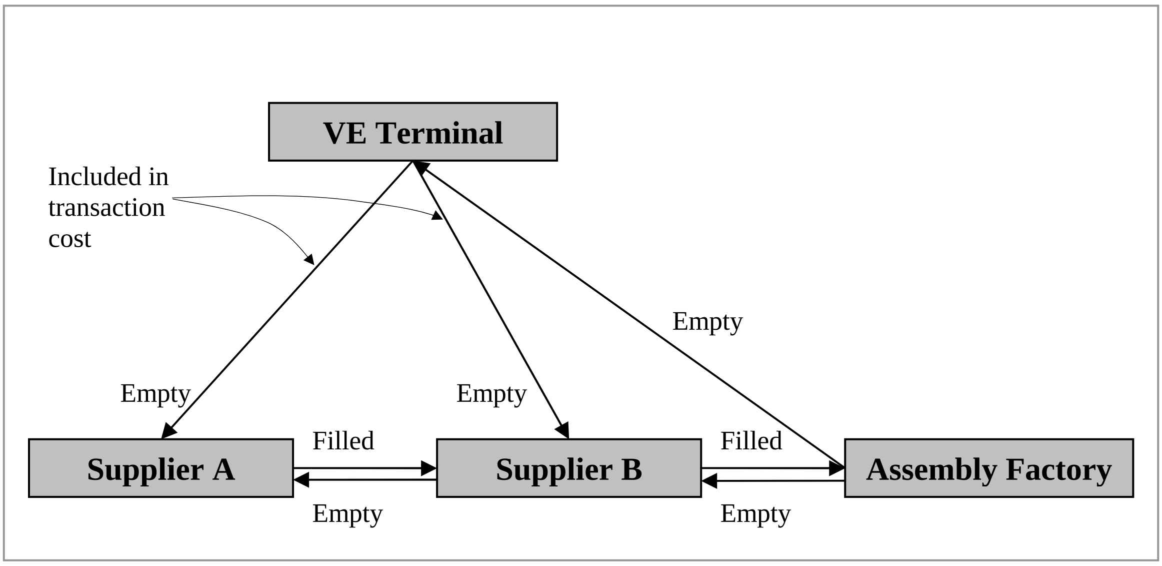

Figure 6. Volvo Emballage packaging system.

Figure 6 shows VE packaging users' network in a simplified manner. Here, this network was referred to as the Volvo Emballage (VE) packaging system. As shown in the above figure, these packages were only used for industrial applications.

5.1.1. Actors involved in Volvo Emballage Packaging System

Volvo Emballage, VE customers, Suppliers for VE customers and transport service providers were actors involved in the VE packaging system. Each of these actors had different requirements. These requirements were studied to gain a better understanding of the packaging costs and their implications on the logistics system. Major customers of VE were Volvo Cars, Land Rover, Aston Martin and Volvo Group, including Mack Trucks, Renault Trucks, Volvo Trucks, Buses, Construction Equipment, and Volvo Penta.

5.1.2. Packaging in the Flow

By applying the Value Analysis technique to packaging, it would suggest that the value of packaging was related to its cost and performance. The cost of packaging material was clearly known and was equal to its purchasing price. However, the packaging performance was of a complex nature and required a great deal of analysis. To measure the performance of a packaging solution, the system and processes, in which the packaging was used, should first be understood. To do this, the package would have to be followed from the point it enters the VE packaging system. In this system, packages go through a number of stages in order to provide logistical utility, most of which was accompanied with logistical costs. Table 1 shows these stages, costs, utilities and locations of these stages. In practice, some costs are indifferent to the quality and type of package, which was not listed below. Table 1 is the basis for the break down and identification of the packaging functions and costs.

Table 1. Stages of packaging and their associated costs, utilities and the locations.

#	Stage/Process	Cost	Utility	Location
1	Purchasing packages from packaging manufacturer	-Administration -Purchasing -Capital tied-up		Packaging manufacturer
2	Shipping the purchased packages to VE terminal	-Transportation	- Volume and Weight efficiency	In transit between package manufacturer and VE terminal
3	Delivery of packages to VE terminal	-Handling/unloading -Storage	-Volume and Weight efficiency	VE terminal
4	On demand, **empty** packages are shipped to the supplier*	-Handling/loading -Transportation -Administration	-Volume and Weight efficiency	In transit between VE terminal and supplier
5	Delivery of the empty packages to the supplier	-Handling/unloading -Storage	-Handle-ability -Volume and Weight efficiency	Supplier's storage facility
6	Moving empty packages from storage to the product packing area	-Handling	-Handle-ability	In transit between different units inside the factory
7	Package consumption/ Packing the products into the package	-Assembly of the package	-Protection -Package assembly time -Package design for convenient packing	Supplier's packing facility
8	**Filled** packages are shipped to the customer**	-Handling/loading -Transportation	-Protection -Handle-ability -Volume and Weight efficiency	In transit between supplier and customer
9	Delivery of the filled packages to the customer	-Handling/unloading -Storage	-Protection -Handle-ability -Volume and Weight efficiency	Customer's storage facility
10	Moving filled packages from storage to the product consumption area	-Handling	-Protection -Handle-ability	In transit between different units inside the factory
11	Product consumption/ Picking the products from the package	-Ergonomics -Disassembly of the package after emptying	-Ergonomic convenience -Package disassembly time	Product consumption area such as assembly line

#	Stage/Process	Cost	Utility	Location
Packages were used as long as they were needed and useable. Customer shipped the empty packages to the supplier and the supplier shipped them back to the customer, filled with the demanded products. Packages that were no longer needed were shipped back to the VE terminals as well as packages that required washing or repairing. Packages that could not function were also returned to the VE terminal and then shipped to waste handlers.				
12	Returning packages to the VE terminal	-Handling/loading -Transportation	-Volume and Weight efficiency	In transit between customer and VE terminal
13	Washing/ repairing/ disassembly/storage	-Washing -Repairing -Automated disassembly -Storage	-Durability -Volume and Weight efficiency	VE terminal

*** Supplier is the supplier of VE customer — **customer is the VE customer**

5.2. Studied Packaging Solutions

Various types of data were gathered within VE. These include data on different packaging types and materials currently being used by VE. To be able to analyze and compare these packages better, they were classified concerning their sizes into three different categories: large, medium and small. For simplification, out of many alternatives, only four were considered for detailed cost analysis. These alternatives were from medium and small size packages, which contained more variety of materials for packaging in comparison, to the large packaging.

5.2.1. Large Size Packages

The large packages consisted of two different types, EMB 400 and EMB 419, which were both widely used by VE customers. These packages were a combination of different materials such as steel, plastic and wood. Because of this, they were called combitainers (short for combination-containers) and came in various standard sizes. These packages were mostly used for large size components in a one-layer packaging style. The medium and small sizes of combitainers were not widely used by VE's major customers and therefore, they were neglected in this research.

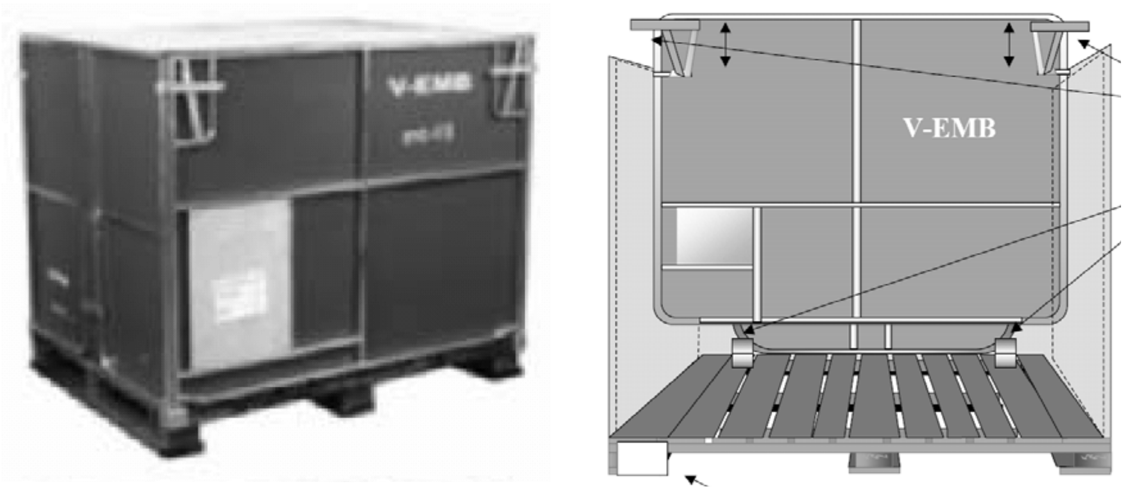

Figure 7. EMB 419, Combitainer.

The EMB 419 was an older version, which consisted of a wooden base pallet with steel framed sides covered with corrugated plastic, as shown in Figure 7. To disassemble the EMB 419, the sides were removed and stored next to each other on a base pallet, with succeeding disassembled base pallets stacked one upon another. EMB 400, a more recent large packaging solution, consisted of sides made from corrugated plastic attached to a steel frame that collapsed inward and folded onto the plastic base pallet. When storing EMB 400, each packaging unit could also be stacked one on top of another.

5.2.2. Medium Size Packaging

On the other hand, medium size packages were the more common packaging type. The reason was that these packages were not only used as primary packages, but also used as transport packaging for small size packages to ease their handling processes. This packaging size had various dimensions to meet various requirements. The materials widely used by VE, were wood (L, K, F, etc.) and plastic (292, 291, etc.).

Wooden Package

Wooden packages consisted of a wooden base pallet where rows of foldable wooden frames could be built upon it, with a lid on top to form a box shape, see Figure 8, top row pictures. Although this system is not airtight, it did provide good protection against mechanical impact for the contents inside and provided some basic protection against rain, snow, dust and sun light. Sometimes wooden base pallets were used alone without frames and lids, especially when transporting empty packages; see Figure 8, bottom row pictures. This figure also shows the alignment and arrangement of these components to prepare them for storage or shipment to users’ facilities.

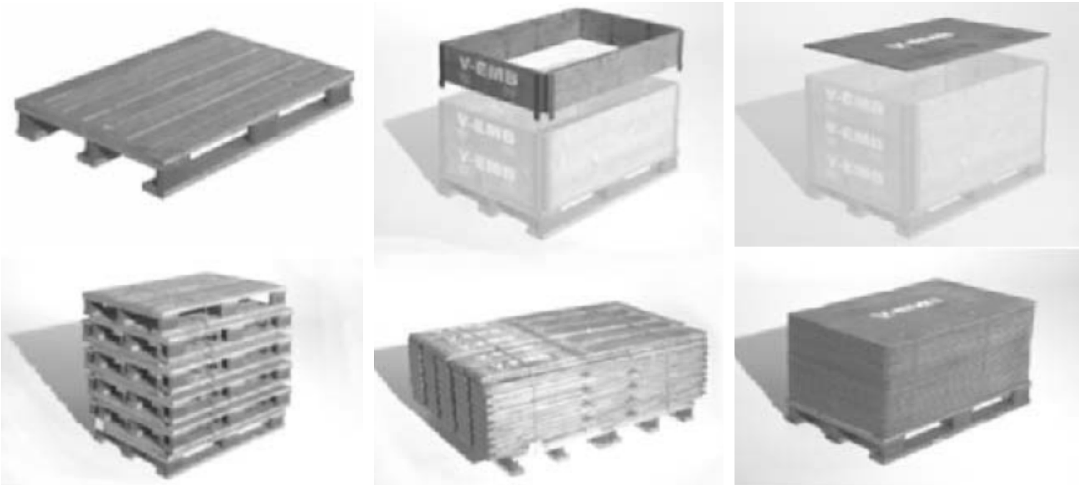

Figure 8. Wooden pallet, EMB 1 – Wooden frames, EMB 21 – Plywood Lid, EMB 71 [type L].

The base pallet (Figure 8, left column) is the most important component of this wooden package, since it must withstand the forces applied to the box from both above (stack pressure) and below (by forklift trucks, ropes, etc.). For forklift trucks and other handling equipment usage, appropriate lifting points are provided under the base pallet.

Frames came under strain from stack pressure forces during storage and from dynamic forces during handling. Due to this, in most cases, a maximum of five frames could be used for one packaging unit.

The box lid, which lies directly on the top frame, generally consisted of a single layer of board made of plywood. It had to absorb the stack pressure forces, which arose when several boxes or the like were stored on top of one another.

Plastic Container

Plastic pallets (not containers such as EMB 292, EMB 291) were becoming more interesting for some customers. The reason for this is that plastic pallets were lighter in weight (an advantage in handling and transportation), and considered cleaner in comparison to the wooden pallets (they do not produce residues and fibers on the factory floor). Plastic pallets also had a longer life span compared to wooden pallets.

However, since VE does not have any such pallets, it was hard to define the increase in demand for them. Therefore, in this thesis only an existing plastic container, EMB 292 (as shown in Figure 9, to the left), was researched as an alternative for wooden packages among medium-sized packages.

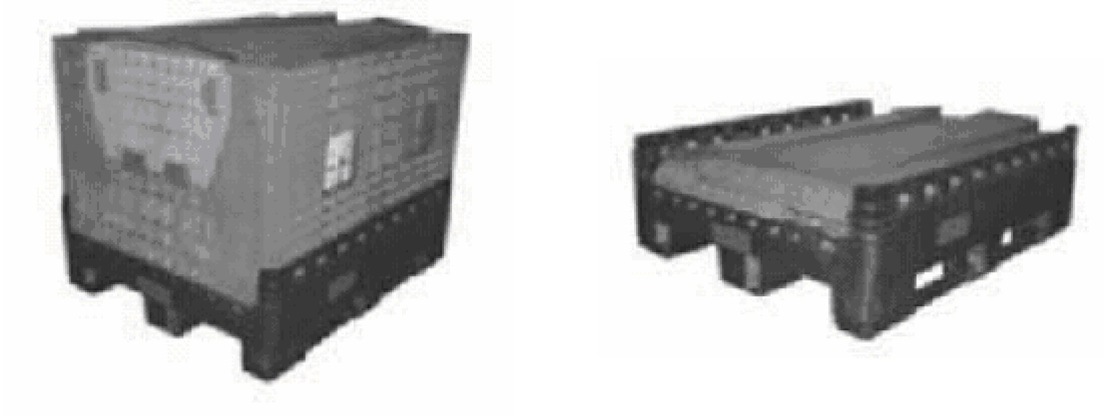

Figure 9. Erected and collapsed plastic Container FLC, EMB 292.

Another type of the plastic packaging solution that was researched was the plastic container. The plastic container that VE offered to its customers was made of High Density Polyethylene (PE-HD). One of the advantages of this plastic container was that it did not absorb moisture resulting in higher packaging characteristic stability. Therefore, it was less vulnerable to different environmental stresses, which was good for both the package itself and the products inside.

A noteworthy point concerning this plastic container was that it was shaped like a collapsible box with a plastic lid. For ergonomic purposes, two doors were provided on two sidewalls, next to each other, to provide easy access to the contents located in the bottom of the container. Another point with this plastic container was that it was similar in disassembly to the combitainer, EMB 400. In other words, it was collapsible and had no separable parts except its lid (as shown in Figure 9, to the right).

However, this collapsible design limits the height of the sidewalls to the width of the base pallet. This was because when the sidewalls collapse on the base pallet, they should fit directly on it and should not exceed its boundaries. Considering this limitation, to achieve the highest level of efficiency, most plastic containers must possess a square base pallet.

There were also some cardboard (one-way packages) medium size packages but due to their high costs (transaction) and low protection, they were not selected for use within the VE group. Only some external suppliers used them to send materials longer distances (since returnable packaging were not profitable at those distances). The customer's suppliers located in markets where VE products were not available used these types of packages.

5.2.3. Small Size Packaging

The small size packages that VE used were made of plastic and cardboard. Wood was not a suitable material for small size packages because it was considered heavy and difficult to shape appropriately in that size. One of the main aspects of small size packaging was its efficient nest-ability. In other words, plastic boxes could be designed with a nest-ability into one another and cardboard boxes could be folded when they were empty, while wooden boxes could not be easily designed to have such characteristics. Thus, cardboard (one way) and plastic (returnable) were materials used most often for packages in this size.

Plastic Boxes

Plastic boxes were made in various dimensions as they were in medium packages. They were capable of being designed with sloped sides so that they would be efficient to store (nest them into each other as shown in Figure 10). VE uses these boxes as primary packaging solutions for its customers.

Figure 10. Small size plastic box, EMB 750 & 751.

Cardboard Boxes

As for cardboard boxes, they could be made into boxes from layers of folded cardboard sheets, which provide better storage (as shown in Figure 11). VE uses these boxes as secondary packaging solutions for its customers.

Figure 11. Box of Corrugated Board, Type B, EMB 151.

5.3. Financial Model

To achieve the second objective of the thesis, a financial model was developed to serve as a decision support system for VE managers. This model was built using Microsoft office Excel. A static table showing this model is shown in Table 2, below.

The transaction cost used to be the most common factor in selecting a packaging method among VE customers. However, this model considers several factors in order to provide a comprehensive view of packaging performances and costs. The second section in the analysis chapter explains how these factors have been identified. Each package method was given a score based on the findings of this research. The methods and reasons by which these scores were calculated have been elaborated on in the third section of the analysis chapter. In the original model, the reasons for selecting each score were commented on beside its value. This made the model transparent and flexible such that managers could change the packaging scores if they discover that the packaging method was to be used for special purposes or the environment, which may differ from the assumptions that were made throughout this research.

In addition to the packaging scores, a column was designed for a Customer Weighting Factor (CWF) to consider the importance of each factor, regardless of the packaging performance with respect to that factor. For example, a package method may not score very high in cleanliness but that factor itself might not be as important and it may not affect the overall score of the packaging. This column was left empty because the importance of the packaging parameters and their associated costs differs from one customer to another due to the variability of each organization’s cost structure and managerial excellence. The Customer Weighting Factor could also be expressed in any scale. The ideal situation would be the monetary scale such that the total score would be more tangible for the decision maker, though it could simply be expressed in a one-to-hundred scale.

Table 2. The Financial Model based on different logistical and environmental factors for the selected packaging solutions.

Factor	Condition	Situation/ location	CWF*	Medium		CWF*	Small	
				Wood	*Plastic*		*Card-board*	*Plastic*
Transaction				5	3		5	4
Protection		Climatologic		2	5		1	5
		Mechanical		4	4		2	4
Load Capacity		Handling		5	3		1	5
		Transport		5	3		1	5
		Storage		5	3		1	5
Volume Efficiency	Full	Transport		4	3		5	2
	Empty	Transport		4	3		5	1
	Full	Storage		4	3		5	2
	Empty	Storage		4	3		5	1
	Full	Handling		4	3		5	2
	Empty	Handling		4	3		5	1
Weight Efficiency		Transport		3	4		5	2
		Storage		3	4		5	2
		Handling		3	4		5	2
Design		Assemling		1	5		3	5
		Disassemb.		1	5		4	5
Handleability		Handling		3	3		3	3
Compensation	(price)			4	2		5	2
Cleanliness				2	5		2	5
Ergonomics				4	3		3	4
Environment.				4	5		2	5
Dimensions Flexibility				4	2		3	3
Total Score								

*** CWF: Customer Weighting Factor**

Eventually, the total score was calculated by the summation of the multiplication of each CWF by the packaging score within each corresponding category. This could be formulated as follows:

*Total packaging Score = ∑ (Customer weighting factor for each packaging factor * corresponding to the packaging score)*

The final point to mention was that the model was based on a positive view, which means the packaging solution with a higher total score would better suit the customer's requirements.

6. Analysis

First, different packaging aspects were discussed in further details - see Figure 1. Addressing the second objective of this research begins by identifying logistical packaging functions and continues by analyzing the identified functions. Environmental issues related to packaging, makes up the final part of the analysis. However, there were some difficulties in the analysis process that were presented at the end of this section.

6.1. *The Packaging Aspects and Functions*

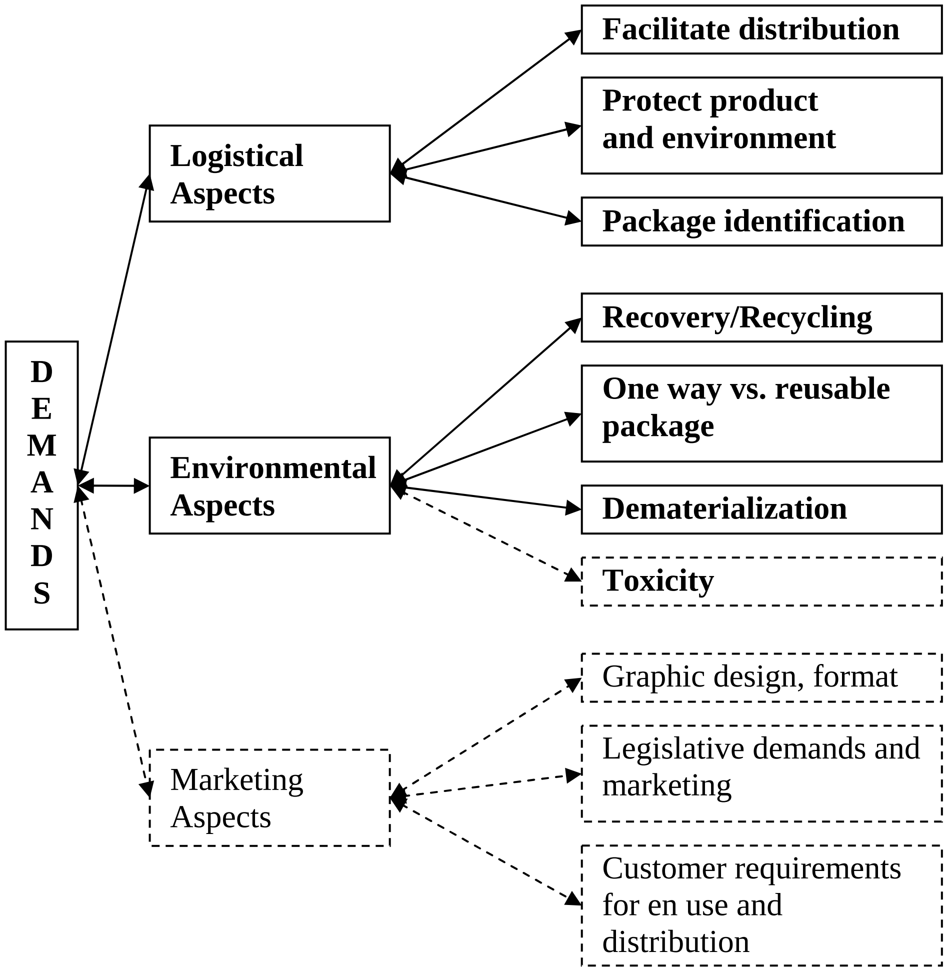

Figure 12. Overview of packaging aspects and functions. Modified from Jönson and Johansson (2001).

As shown in Figure 12, packaging serves three main functions, which are logistical, environment, and market functions. Johansson et al. (1997) assert that these functions have important interest in common, see Figure 1. In some cases, they co-operate in the border areas while in other cases the demands are conflicting. They express this issue as:

No other component in the distribution chain is exposed to so many, heavy and often conflicting demands as the packaging.

6.1.1. Logistical Aspect

Johansson et al. (1997), said that the logistical function includes the integral functions of the packaging and contributes to making handling more efficient in the distribution channel. Packing and unpacking activities, internal materials flow, and return handling are all part of this function.

Twede and Parsons (1997) explained the logistical view of packaging as:

There is an increasing trend to view logistical packaging in terms of the value that it provides in logistics, rather than in terms of traditional materials. Packaging is part of a total logistics system. The goal is to minimize the cost of packaging materials as well as to reduce the cost of damage, waste and the cost of performing logistics operations. Logistical packaging adds value by providing protection, utility and communication.

This view of packaging was the platform for the analysis of logistical functions concerning packaging.

6.1.2. Environment Aspect

Johansson et al. (1997) defined the environmental function to focus at improving resource economy, to reduce environmental stresses and to facilitate the reuse of packaging. The systems approach was very important when deciding on how a packaging method meets the environmental demands. The reduction of the amount of packaging material and the facilitation of the separation of a packaging method into its different component materials, are some examples of the environmental function.

6.1.3. Market Aspect

Regarding the market function, Johansson et al. (1997) said that packaging fulfills the market function in different ways by contributing to making the product more attractive. Through an appealing design or layout, the packaging method attracts more customers.

According to this definition, this function was the concern of retail industry, which deals with final customers. However, VE packages were only used by their business customers. As mentioned earlier, this packaging function was not the subject of this study.

6.2. Identifying logistical Packaging Functions

In order to identify the logistical packaging functions, the value analysis technique was used. Value analysis based a packaging value on its performance/utility and the cost for it. In Table 1, these utilities and costs were identified. However, some utilities such as cleanliness were not easy to characterize during the first analysis and were added later.

6.2.1. Protection Function

Twede and Parsons (1997) highlights the importance of the protection function for packaging as:

> *Packaging is responsible for maintaining a product's condition throughout a logistical system. Protection is a valuable packaging function because in-transit damage can destroy all of the value that has been added to a product. Damage wastes production and logistics resources; replacement orders add further costs, and delays can result in lost customers.*

6.2.2. Identification Function

The Identification function of a package helps to indicate the materials inside the package along with the package's origin and destination. This process could be conducted through either RFID transmitters or scanning barcodes. Since the transferring materials differ for each transaction to the other, the identification tags need to be replaced for each transaction. Hence, VE performed this process by scanning the barcodes on the packages, which was more efficient in their system. In other words, barcodes were placed on each package on a temporary basis, scanned at every required point of the transaction and removed as soon as the transaction was complete and the package was cleared.

The identification barcodes consisted of a piece of paper with all necessary data printed on them. This paper was attached to the package when it was transported from one point to another. Since the identification could be attached to any type of material, it did not matter what type of packaging material was used, because the identification process outcome was the same for all. Due to this and since this thesis focused on the advantages and disadvantages of different packaging materials, the identification function was not researched further.

6.2.3. Utility Function

The utility function for packaging was about how packaging affects the productivity, efficiency and cost of logistical operations. All the logistical operations were affected by packaging utility—from truck loading and warehouse picking productivity, to customer productivity and packaging waste reduction. Ergonomics is also a utility issue because healthy workers are more productive while personal injury lawsuits only incur cost to the system (Twede and Parsons, 1997). It could be concluded that the entire cost for all logistical operations was affected by the utility function for packaging.

The following categories were used to characterize the logistical packaging utilities as they pertain to Volvo Emballage:

- Volume and weight efficiency
- Handle-ability
- Assembly and disassembly time

- Dimensions compatibility
- Ergonomics
- Cleanliness
- Other value adding properties

Each of these categories was analyzed in the following section.

6.3. Analyzing the Logistical Packaging Functions

6.3.1. Protection

Regarding protection, there were many issues to consider as part of the analysis, to include measurement of the distribution hazards and environmental conditions, damage analysis and carrier liability, characterizing products and their fragilities, and packaging performance and laboratory testing (Twede and Parsons, 1997).

The amount of protection that a package is expected to provide depends on the value of the product, as well as the package's physical characteristics and the expected hazards in the logistical system. An important goal of packaging is to provide the required protection by using cost-effective materials (Twede and Parsons, 1997). Consequently, the relationship can be conceptualized as (Twede and Parsons, 1997):

Product value + product characteristics + logistical hazards
= package protection needed

Here, the purpose is to calculate the costs associated with packaging protection. Protection is associated with a damage rate of the products and in turn, with their damage costs. Good protection results in lower product losses and damage costs. However, many other variables exist that contribute to the damage rate of the products. The relationship between damage rate and other variables was formulated as:

Damage rate of products = f (product characteristics, logistical hazards, packaging protective capability)

It is practically impossible to calculate all the possibilities for the damage rate by changing each variable for every single packaging type. Therefore, the focus is directed towards parameters that depend only on packaging such as packaging strength and load capacities. Packaging protection is in direct relation with the packaging strength. As a rule of thumb, it could be said that stronger packages provide better protection. There are varieties of laboratory tests that specify packaging strength against different types of environmental stresses. However, common stresses should first be identified in order to provide appropriate test results. Common stresses that can damage a product and packaging are listed below:

- *Mechanical stresses:* stacking, pressure, side compression, vibration, impact, forces of inertia, abrasion, puncture

- *Climatologic stresses:* temperature, damp, sunlight, air pressure, precipitation, wind
- *Chemical Stresses:* chemicals, air pollution such as salt spray and water
- *Biological Stresses:* mould, bacteria, insects, rodents, birds
- *Other stresses:* dust, sand, electric fields such as magnetic fields and radioactivity, fire, sound pressure, theft

A Swedish study found that mechanical and climatologic stresses account for most product damages during transport (Twede and Parsons, 1997). Another study at Gothenburg harbor illustrated the importance of compression strength and board stiffness for corrugated fiberboard boxes (Twede and Parsons, 1997). These studies agreed with authors' observation of VE packaging system. Most of the *standard packages* that were used in VE were primarily used to provide protection against mechanical stresses. If special protection against other environmental stresses were needed, packaging aids were used additionally. For example, if protection against precipitation and dampness were needed, plastic films were used to provide insulation. However, it is worthy to be reminded that packages made of plastic materials are by far better than packages made of wood or corrugated cardboard against climatologic stresses. Among chosen alternatives for a comparative study, plastic container EMB 292 and the plastic blue box were superior compared to the wooden L-type box and corrugated cardboard box EMB 151, respectively.

Concerning mechanical stresses, packages normally came with some technical specifications such as shear, bending or pressure resistance, which were measured by laboratory tests. The type of test depended on the environmental stresses that a package was exposed to in the logistical chain. For example, wooden pallets were usually handled with forklift trucks, which inserted bending and shear force to the deck and runner of the pallet— see Figure 13. Consequently, laboratory tests measured the bending and shear strength of these pallets at different points. Figure 13 shows how the test to measure a deck board's bending strength was performed for wooden L type pallets.

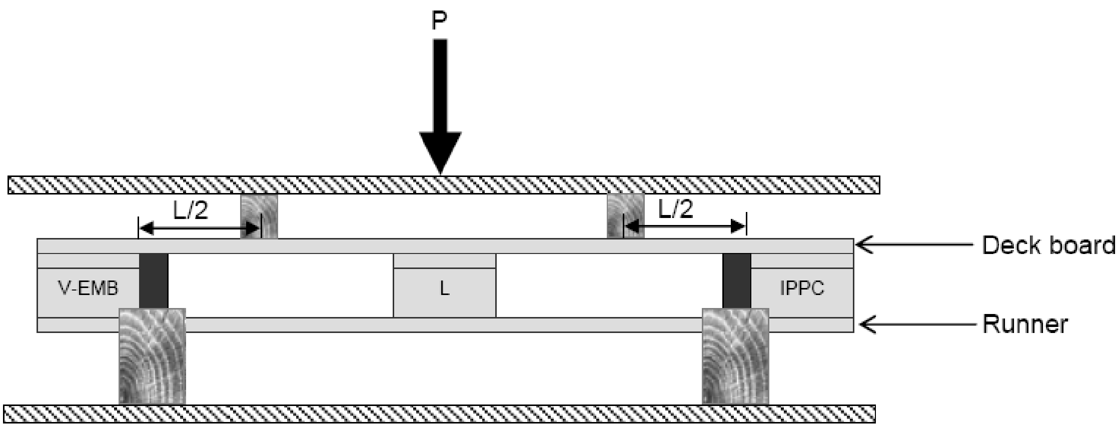

Figure 13. Static bend test of the deck board

Load Capacity

Results from laboratory tests were used to determine the weight limits of a package in different logistical activities. These activities were mainly handling, transportation and storage. The corresponding technical expressions were static load capacity, maximum dynamic stacking load and maximum static stacking load, respectively.

The strength of the packaging material increased the stack-ability of the packages. Stack-ability helps for better space utilization in both transport and storage. If the packages were not stackable, racks and structural aids were required to be able to utilize the available space. This incurs more cost to the system.

Stack-ability had a direct relation with load capacity. As a rule of thumb, the stack-ability limit in transport was double the unit load capacity in handling, and the stack-ability limit in storage was double the stack-ability limit in transport.

In Table 3, different load capacities were provided for each of the selected packages.

Table 3. Weight limits (taken from packaging Handling User's guide issued by VE in 3-06)

Medium size packaging	**Wooden L-pallet + 4 Frames + Lid (EMB 1, 21, 71)**	**Plastic Container – EMB 292**
Unit load	1000 kgs	500 kgs
Transport load capacity	2000 kgs	1000 kgs
Storage load capacity	4000 kgs	2000 kgs
Small size packaging	**Plastic Box - EMB 750 & EMB 751**	**Corrugated board - EMB 151**
Unit load	40 kgs	Variable
Transport load capacity	500 kgs	500 kgs
Storage Load Capacity	500 kgs	500 kgs

As shown in the above table, between the medium-size packaging solutions, the wooden L-type packaging unit offered double the load capacity than the plastic container EMB 292. In the small-size packaging category, the load capacity of plastic blue boxes was by far higher than corrugated cardboard boxes EMB 151.

6.3.2. Volume and Weight Efficiency

There was a general demand that a package solution should weigh as little as possible. A load carrier was limited by volume and weight, thus the packaged goods amount is a significant consideration. Heavy and volume consuming packaging reduce the actual goods quantity per load carrier. To withstand the stresses from several trips, reusable packaging usually had a more robust design than the corresponding one-way packaging. This though reduced the relative volume and weight efficiency (Johansson et al., 1997).

Packages that were often handled manually should have been weight adapted. What was considered as a “manageable weight” depended on the handling frequency and how the package was lifted (Johansson et al., 1997). This was discussed in more detail in the handling and ergonomics sections.

Johansson and Weström (2000) said that the consequence of a deficiency in volume/weight efficiency was poor utilization of a distribution chain. They listed the possible economic impacts in the form of:

- Increased transportation costs
- Increased storage and warehouse costs
- Increased handling costs
- Environmental costs

a) Effect of Weight Efficiency on Transportation Cost

The higher the weight of a package, the higher the fuel consumption of the transportation means. This incurred a cost to the system in two ways: first, one of the factors in the transportation cost of a consignment was its weight, and second, the pollutant emissions, which were discussed in the environmental, cost category.

When transporting filled packages, usually, the major source of weight for shipping was goods packed inside the packages; therefore, the weight effect on the vehicle’s fuel consumption was neglected. This effect is more crucial when transporting empty packages.

Table 4 shows the weight versus inner volume for each packaging solution. Smaller numbers indicate better performance of the packaging method, in terms of their weight efficiency.

Table 4. Weights versus Efficient Volume

Medium size packaging	**Wooden L-pallet + 4 Frames + Lid (EMB 1, 21, 71)**	**Plastic Container – EMB 292**
Weight/ Inner Volume	71 / 0.700 = 101 kgs/m3	57 / 0.617 = 92 kgs/m3
Small size packaging	**Plastic Box - EMB 750 & EMB 751**	**Corrugated board - EMB 151**
Weight/ Inner Volume	1,67 / 0.015 = 111 kgs/m3	0.24 / 0.020 = 12 kgs/m3

b) Effect of Volume Efficiency on Transportation Cost

Volume affected transportation cost in two ways: when transporting empty and when transporting filled packages. In either case, packaging could have considerable influence on the cost of transportation. Good design of the packaging reduced the transportation of air by providing volume efficiency, e.g. nest-able plastic boxes were nested into each other when transported empty and utilized the space more efficiently compared to non-nest-able plastic boxes.

The Volume Reduction Index (VRI) was a good indicator to measure the volume efficiency of empty packaging. VRI was defined as the ratio of the utility to the cost; the useable volume that packaging provides (inner volume) divided by the volume it occupied when transporting empty. This index was not the cost of anything, but rather an indicator for a rough comparison of different packaging alternatives to estimate the effects of the volume efficiency for the transport of empty packages.

As shown in Figure 6, the number of times that packages were shipped empty was more than the occurrences than they were shipped full (Number of arrows that were labeled *empty* was more than those that were labeled *filled*). This meant that the cost for shipping in the empty mode should have been seriously considered and the efficiency of packages in empty mode should not be neglected.

The transportation cost from the VE terminal to the supplier was considered in the *transaction cost*. VE customers returned the emptied packages to their suppliers or to VE terminals when the empty packages were no longer required. These costs were not considered in the *transaction cost* and should be calculated by VE customers. Calculations for VRI are provided for the below selected packages in Table 5.

Table 5. Calculations for Volume Reduction Index

Medium size packaging	**Wooden L-pallet + 4 Frames + Lid (EMB 1, 21, 71)**	**Plastic Container – EMB 292**
Volume Reduction Index	2.4	1.6
Small size packaging	**Plastic Box - EMB 750 & EMB 751**	**Corrugated board - EMB 151**
Volume Reduction Index	1.25	8.3

On the other hand, volume efficiency affected the transportation cost in another way, that being when packages were transported full. This effect was measured by the Volume Efficiency Index (VEI), which was the ratio of the inner dimension (useful volume) to the outer dimension (outer dimension is the cubic space that a packaging occupied) of the packaging. Calculations were given for the selected packages in Table 6, below.

Table 6. Calculations for Volume Efficiency Index

Medium size packaging	**Wooden L-pallet + 4 Frames + Lid (EMB 1, 21, 71)**	**Plastic Container – EMB 292**
Volume Efficiency Index	0,700 / 0,940 = 74%	0,617 / 0,912 = 68%

Small size packaging	**Plastic Box - EMB 750 & EMB 751**	**Corrugated board - EMB 151**
Volume Efficiency Index	0,015 / 0,026 = 59%	0.018 / 0.020 = 90%

The effect of volume Efficiency Index was not considered in the *transaction cost* and should be considered by VE customers when analyzing the cost of transportation from their suppliers to their plants.

In addition to the volume efficiency, weight limits or load capacity affected the transportation cost. Table 3 showed the weight limits during transportation for different packaging solutions. Stack-ability during transport was not an issue for these packaging solutions except for corrugated cardboard.

c) Storage cost

The same went for the storage cost as the transportation cost, in terms of the effect of the volume efficiency. Nevertheless, this cost was more visible for automatic warehousing systems than a conventional warehouse since the volume was more precious there. Storage costs for packaging in VE terminals were considered in the *transaction cost*. Packaging storage costs for different customers differ according to their own facilities and should be considered in the calculations according to their methods.

6.3.3. Handle-ability and Handling

In short, handling could be considered as the interface between places/space like storage area, transportation vehicle, or usage area of the products such as assembly line. Handling was usually a short and temporary process that a package went through to connect three processes: storage, usage, and transport vehicle. Handling was conducted manually, with the aid of tools or handling equipment such as lift trucks, or automatically such as an automated robotic warehouse and conveyor systems.

Manual handling, finally, depends upon the abilities of each single human. It could therefore be difficult to distinguish the packaging parameters from the abilities of an individual human. In this respect handle-ability, “machine-ability” was also included, meant how the package performed together with packaging machines, automatic warehousing and handling equipment (Johansson and Weström, 2000).

Johansson and Weström (2000) pointed out that the deficiency in handle-ability affected both manual and automatic handling and would have an economic impact regarding;

- Work-load disorders
- Product damage due to incorrect handling
- Increased machinery costs
- Customer or consumer rejection of a product(market aspect)

Handling costs were also affected by weight limits for each packaging solution. The unit load weight limits in Table 3 were the limits that each packaging solution could tolerate during the handling process. The higher these limits were, the more unit loads could be handled in a handling activity, especially for automated handlings.

The cost of handling operations performed in VE facilities was considered in *transaction cost*. The cost of handling operations was conducted by the customers and suppliers in their facilities and should be estimated by them due to the differences in handling machines, equipment, and procedures.

6.3.4. Transaction Cost

VE transaction cost = *Administration cost (fixed costs + variable costs) + handling cost + storage cost + transportation cost + capital tied-up cost + repair and maintenance/wash cost + purchasing cost*

Administration costs (fixed costs + variable costs) were independent from packaging types. Therefore, they were not analyzed in this research. Table 7 showed the transaction cost for medium and small size packages, respectively. Each of these costs was calculated per transaction.

Table 7. Transaction cost and its constituents for medium-sized packaging

Medium size packaging	**Wooden L-pallet + 4 Frames + Lid (EMB 1, 21, 71)**	**Plastic Container – EMB 292**
Transaction cost	57.90 SEK	90.00 SEK
Small size packaging	**Plastic Box - EMB 750 & EMB 751**	**Corrugated board - EMB 151**
Transaction cost	6.40 SEK	3.00 SEK

***Profit margin was set to zero in the calculation of transaction cost.**

6.3.5. Assembly and Disassembly Time

The assembly time was the time it took to erect the collapsed packaging. The packaging disassembly time was the opposite action, meaning to collapse and disassemble the emptied packaging solution. This time had more importance in lean production. To measure the cost of this parameter, a simple calculation could be made.

> *Assembly & disassembly cost = (assembly + disassembly time) * man-hour cost*

In Table 8 these *times* are shown for researched packaging alternatives.

Table 8. Assembly / disassembly time

Medium size packaging	**Wooden L-pallet + 4 Frames + Lid**	**Plastic Container – EMB 292**
Assembly / Disassembly time	120 / 120 seconds	10 / 10 seconds
Small size packaging	**Plastic Box - EMB 750 & 751**	**Corrugated board - EMB 151**
Assembly / Disassembly time	Zero	30 / 5 seconds

As shown in Figure 14, plastic boxes have no need for assembly or disassembly. In other words, they were ready to be used without any extra effort.

Figure 14. Plastic Box

6.3.6. Dimensions Compatibility

As discussed in the limitations and demarcations section, the dimensions compatibility of a packaging solution was not an issue and was not researched in detail. However, some noteworthy points regarding dimensions compatibility are as follows:

- Unit load utilization like container or pallet space utilization which were solved by modularity of package sizes
- Compatibility of dimensions with automated handling machines like conveyors
- Compatibility of dimensions with warehouse infrastructure
- Small size packages mean more calls to handle, more administration, more units to pack, etc.

Most of the current equipment and facilities within the customers and suppliers' factories, as well as Volvo Logistics terminals, were compatible with wooden pallets (e.g. the automated disassembly machinery for wooden packaging solutions in the VE terminals).

6.3.7. Ergonomics

It was only via weight that the packaging material influenced the ergonomic factor directly. In other words, the lighter the material was, the more ergonomic the package would be. This does not incorporate all ergonomic aspects for the packaging material though. In many cases, the material influenced the ergonomics indirectly via design and other aspects. For example, a package designed with a handle was much easier to lift than a plain package. For small sizes, plastic could be designed and molded into nearly any shape while this was not true for wood. This gave plastic an ergonomic advantage.

To clarify some of the ergonomic aspects, it should be mentioned that VE followed a set of rules announced by its consultant, Alviva, in ergonomic matters. This meant that Volvo followed a checklist to see whether its packages were ergonomically designed or not. There were no calculations pertaining to any level of ergonomics. For the comparison of the different packaging materials, on an ergonomic aspect, a “Pros and Cons” analysis had to be performed. Later a formula had been recommended to calculate a weight limit for packages as prescribed by NIOSH (The National Institute for Occupational Safety and Health). (This formula would make it considerable easier to calculate whether a package is ergonomic or not.)

a) Medium Size Packages

- Wood (wooden pallets with frames)
  - Pros
    - ✓ Wooden packaging solutions have flexible height because of their ability to lower their height, by removing a frame from this packaging system. This will allow easy access to the materials deep in the package unit while also enables the unit to be placed alongside the production line in any direction (due to the lean production system requirements). These frames, could easily be removed, folded and stored on the side (of the pallet or the production line depending on the production line design) until the package is empty and the whole packaging unit is taken away from the location. In other words, they have an adjustable height. An illustration of this is shown in Figure 8.
  - Cons
    - ✓ Manual disassembling of the wooden frames from the pallets requires more time and energy compared to the plastic packages. Although currently this action is done automatically by VE in two of their terminals in Gothenburg and Skövde for customers in near proximity in a very efficient way (more proficient than the plastic packages), but in general plastic packages are more efficient to disassemble compared to wooden packages.

        - ✓ Wood is heavier than plastic, thus handling wooden pallets is more challenging than handling plastic pallets.

        - ✓ Wood absorbs water. Thus when it is placed in a wet environment (e.g. under the rain) its weight will be increased as a result. Since this increases the handling problems for the wooden packages, it is considered an ergonomic issue.

        - ✓ Wood has fibers, which will not only litter the working environment but it could also injure the operators hand if it comes into direct contact with it. Since all the operators are required to wear gloves, this is not an issue, but still is considered one of wooden packages ergonomic drawbacks.

- Plastic containers

    - Pros

        - ✓ Plastic containers are much easier for manual disassembly. Therefore, significant time and resources can be saved by the customers to disassemble the packaging unit manually.

        - ✓ When disassembled, there is no need for separate storage of the packaging unit parts since everything is attached to the base pallet. This means less transportation and handling and thus, more ergonomic advantage for the handlers. An illustration of this is shown in Figure 9.

        - ✓ Plastics containers are much lighter in weight compared to wooden pallets with frames.

        - ✓ Plastic does not absorb water, thus when placed in an open area, it does not change weight in moist conditions.

    - Cons

        - ✓ Plastic containers have an access door located on their sides for easy access to the materials placed deep in the packaging unit. For plastic containers with the same size as the wooden L pallets, the access door on the narrow side of the packaging unit has to be eliminated, since it gets too narrow for the worker to access the materials easily. Widening the access door in such condition is also impossible, since that narrows the width of the sidewalls on each side, which eventually reduces the strength of the sidewalls.

b) Small Size Packages

- Plastic (boxes)

- Pros
    - ✓ As shown in Figure 14, plastic boxes have no need for assembly or disassembly. In other words, they are ready to be used without any extra effort.
    - ✓ The smallest plastic package within VE (EMB 500) is 2.5 times larger than the cardboard package used in the system (EMB 100). This means less handling and thus, more ergonomic advantages. (Their transaction costs are nearly the same, hence the EMB 500 is much more efficient to use compared to EMB 100.)
- Cons
    - ✓ The plastic boxes are much stronger than the cardboard boxes, thus they can contain more material. Due to this and in regard to their own material weight, these boxes tend to become heavier compared to cardboard boxes. Therefore, they would face more handling issues and limitations, and this is an ergonomic disadvantage. In other words, the manual handling weight limit is 12 kg and since investing in handling equipment is expensive, it is considered that the packaging unit in addition to the items inside it does not exceed this limit. Hence, with plastic packages, their capacity will not be completely utilized. On the other hand, lean production system requires smallest packages to include and handle at least 2 hours of material. Therefore, the plastic packages do have a small ergonomic disadvantage here, but this issue can be solved by using multiple boxes on the line.

- Cardboard (boxes)
    - Pros
        - ✓ They are extremely light on their material weight aspect. Therefore, are much easier to handle and their capacity could be more efficiently utilized compared to plastic boxes. Thus, the convenience of manual handling is considered an ergonomic advantage.
    - Cons
        - ✓ They have a low weight limit for the materials they handle. Thus, their sizes have to be kept smaller than a fixed limit. This means that their largest size will never exceed this limit, which means less material handled, which means more packaging unit handling requirements.

- ✓ Assembling and disposal of these packages increases the amount of required handling in total perspective.

NIOSH (National Institute of Safety and Health) and The University of Michigan have presented the following formula to calculate the Recommended Weight Limit of a package as a guideline for manual lifting (Twede, 2000) :

*RWL = 23.13 Kg * HF * VF *DF * FF * AF *CF*

Where:

RWL = Recommended Weight Limit
HF = horizontal factor, distance of hand/arm extension
VF = vertical factor, starting point
DF = distance lifted
FF = frequency, lifts/minute
AF = asymmetry, twisting
CF = coupling factor, adequacy of grip

6.3.8. Cleanliness

"Maintaining a clean facility ultimately saves money." (Marinucci, 2005) According to this, and also as evident in many companies these days, cleanliness has become more of an important issue since it affects the employees' health, the production rate and also the employee's mood (i.e. an employee with a better mood is always more efficient). (Marinucci, 2005) However, unfortunately this factor had a long way to go to gain significant importance in a company's decision-making. Currently most of the companies were concentrating on other general aspects and neglecting this issue. In other words, these companies were concentrating on hours and dollars instead of pennies and seconds. While these pennies and seconds will add up to become dollars and hours later on, cleanliness would become an issue for all the companies and it would be better to be prepared for it when it comes.

On the other hand, companies who have dealt with special items such as electronics, have to keep their environment clean. Therefore, when using unclean packages, these companies have had to pack their items twice, once inside the factory site and the second time outside to load it into the unclean packages for shipment. If they were packed and loaded into clean packages from start, such double packing would not have been necessary. This would save time and effort.

The un-cleanliness of a packaging material was not only due to the packaging material's quality but it was also due to its nature, such as the one-way cardboard boxes. For example, concerning medium size packages, wooden pallets were considered an unclean packaging solution. In small size packages, cardboard boxes were considered unclean packages. The major issue with wooden pallets was their fiber residues, which would scatter around the factory floor and create an untidy environment. These residues normally appeared due to careless handling of packages by the employees. The solution to this problem was either better handling of the packages or the use of plastic packages (which have no fibers and thus no residues). On the other hand, small size packages did not have these residues, but had a much larger issue.

Their problem was that one way packaging had to be disposed of. During this disposal, at the production site, these packages were discarded in or around the waste bin. This created a muddled appearance. This appearance might not directly interfere with the employee's health or production rate, but it would surely influence it indirectly. In other words, the muddled appearance would dampen the employee's mood, thus decreasing their productivity.

Cleanliness was just one of the aspects considered while choosing the packaging type. In other words, the customer had to decide how to keep his or her factory environment clean. Some companies preferred to clean their production site regularly, while others see this as an extra cost and preferred to avoid it as much as possible.

6.3.9. Other Value Adding Properties

Some other value adding properties are discussed here. The following parameters were either indirectly considered or neglected due to their insignificance as they pertain to the cost analysis.

a) Durability

The durability of packaging was considered in the purchasing cost indirectly. This was because the number of the packaging usages was considered in the transaction cost.

b) Dimensions Flexibility

Packages with flexible dimensions were better for space utilization. This was more visible in lean production because the available space was limited along the assembly line. For example, wooden pallets with frames had a flexible height, which allowed users to adjust the frames according to a desired quantity while plastic containers had a fixed height and were not adjustable.

One-way packages, such as corrugated cardboard, were more adaptable to both products and facilities. In most cases, usage of multi-trip packages like plastic boxes was economically feasible in the standardized forms.

6.4. Environmental issues

There were no direct environmental costs and all indirect costs were related to the disposal of the wastes due to the regulations. From an environmental perspective, there were two ways to increase efficiency, by either prevention (source reduction) or repair (recycling or other means). The choice was closely dependent on the customer, in that their choice was based on financial aspects, regulations and/or policy.

Although, the environmental perspective still had a hierarchy, which consisted of reduction, reuse and recycling (PE2) steps. The reduction step was meant to reduce the raw materials used to build a package. The reuse and the recycling step's meanings were as their names implied. Due to this hierarchy, reuse was considered better than recycling since it did not require the energy used for the recycling procedures. On the other hand, reuse itself consumed energy and chemicals for the cleaning and returning procedures. Both actions had administration costs, but the reuse administration cost was much higher than the recycling in most cases. With all that in mind, still a sufficient return system along with a sufficient life cycle made reuse more profitable, in the long run compared to recycling. When the package life cycle ended, it could be either recycled or remanufactured for further use. This comparison helped to clarify the pros and cons of the returnable and one-way packaging systems.

Another environmental treatment concerning packaging materials was to use compost or reconstitute them. During these procedures, these materials would help to produce other materials, such as the use of plastics in extracting iron from ore or incinerating them and generating energy, then using their remains as fertilizer.

Packages were categorized into returnable and one-way packages. Returnable packages were those that were reused after their primary objective was completed. In other words, when a customer received an item, he or she returned the package to the supplier or to another customer, either full or empty. The package, though, remained functional (it was used for further applications). On the other hand, a one-way package lost its functionality after it was used once and it had to exit the application cycle. This procedure normally included the recycling of the packaging materials, where they were used (the recycled materials) as new packaging materials.

In the long run, the returnable packaging cost could supersede the one-way packaging cost by eliminating the purchase and disposal costs. There was still the high administration cost for controlling the return cycle, which had to be limited, or it would undermine the whole profitability of the returnable packaging system. This administration cost was influenced by many factors but the two main factors were short cycles and short traveling distances. Short cycle times could lead to a smaller amount of required packages. This in turn could eventually lead to both lower required investments and tied up capitals. Short traveling distances made controlling the return cycle much easier since there were fewer aspects that had to be considered. Little demand variation, comparable inbound-outbound payloads and standard products also contributed to easing the process control. For example, the Kanban system worked perfectly with a returnable packaging system. Radio Frequency Identification (RFID) also facilitated the administration of the returnable packaging system.

Aside from the administration cost, the returnable packaging system had other costs related directly to the packaging materials, designs and types. These costs were related to the amount of washing required, the container's life cycle and the dimensions of the package (specially the inner dimensions).

When comparing JIT and Supply Chain Management (SCM) regarding returnable packaging, JIT worked perfectly. Since there were lower stock tied-up, shorter transportation distances (lower transportation costs), steadier demands and an increased control on the system, these all provided for an efficient returnable packaging system. Thus, this method worked very well with returnable packaging. On the other hand, in a SCM system, a well organized and goal oriented supply chain was also a great case for returnable packaging systems. However, such systems require highly efficient administration and a high level of cooperation between the actors in the supply chain (Twede, 2000).

The following is a discussion of different packaging materials from a recycling perspective. In the end, one can decide which packaging material suits their needs best regarding this aspect.

- Wood was the most common material used in medium size packages by VE. Wooden packages were cheap to produce and easy to handle and work with. They were efficiently reusable and when they reached the end of their life cycle, they would be sent for incineration and energy production.

- Plastics could be treated in various ways when it comes to their waste handling. Incineration should be the final option since some plastics produce extremely toxic and harmful residues. Therefore recycling was usually preferred for plastic materials, although the cross contamination from the resins was a problem within this procedure. In other words, if different types of plastic were recycled together, the product would be degraded due to cross contamination of the plastic. The easiest solution to this problem was to separate the different plastic wastes at the start of the waste handling procedure.

In some cases, when plastics could no longer be recycled and reused, they were utilized for extracting iron from ore in iron-ore furnaces. For this procedure, they were fed to the furnace and would react with the oxygen and allow the iron to separate. Other materials produced like this included synthesis gas, methanol, paraffin, sulphur free oils and slag for road construction. All of these materials could be drawn from the feed stock recycling process (Denison and Ren, 2001).

Thus, although handling plastic waste was harder than steel, it still was extremely efficient. After the plastic had reached its end of life cycle, it could be used to produce new materials, thus it still could be considered an efficient and safe packaging material from an environmental aspect, if treated correctly.

- Paper and cardboard were used for one-way packages (mostly small size packages). Recycling paper and cardboard was perhaps the easiest attained and longest standing recycling system. The only problem with recycling papers was that after a while, the fiber lengths tend to shorten and the paper looses its quality. A solution to this problem was to mix new paper materials with the recycled product. This would help the recycling but still was a temporary solution. Paper cannot be recycled forever. Still, a 100% recycled paper could be used as a secondary packaging material or as bumpers and buffers in packaging.

It should be noted that whenever a new material is used by VE for packaging, an Environmental Impact Assessment (EIA) was required to check whether it had a negative impact on the environment or not. In other words, an EIA would evaluate if the new material used was environmentally acceptable or not. (It should be noted that EIA was carried out for new packaging materials and not for new packaging units.) Since this was a one-time cost for the material, and many different packaging units consisted of this same material, the EIA cost per packaging unit as an environmental cost could be neglected.

Regarding the environmental disposal costs, environmental regulations vary around the world and are highly dependent on the period during which one is calculating the cost. Therefore, the disposal cost changes by time frame and region. In some countries, the disposal companies pay to dispose of the waste while in others, the packaging waste could be sold. A decade ago, the disposal regulations were not as strict as they are today, thus it was much easier and cheaper to get rid of the waste. Table 9 shows the disposal costs for cardboard (since the only one-way packaging unit that was analyzed in this paper was cardboard boxes) in VE terminal sites around the world.

As evident in Table 9, cardboard could be sold in Korea or China, but in Australia, they have to be disposed with a cost. According to this table, environmentally, customers in different countries paid varying amounts for the disposal of cardboard packaging. The negative sum reflects that in the named countries, one could earn money by selling the produced wastes.

As for recycling, there were usually two types of costs, one was the cost for transporting the waste to the recycling center and the other was for sorting the waste in accordance with designated recycling procedures in the center. In many regions, most of the sorting was conducted at the collection point. This meant that much of the sorting cost was reduced, i.e. well-sorted waste could help reduce the recycling cost in general.

Table 9. Cardboard Disposal Costs

Country	per ton (in original currency)	per ton (converted to Swedish Krona)
Belgium	-60 €	-548.4 SEK
Australia	-166 AUD	-964.46 SEK
Korea	35,000 KRW	350 SEK
China	600 RMB	492 SEK
Sweden	20 SEK	20 SEK
UK	0 £	0 SEK
France	-1425 €	-13024.5 SEK

Note: In Sweden, there is also an annual standard fee of 7,000 SEK

Note: This table has been prepared using regional information as of April 2007. The currency exchange rates were calculated as of November 6, 2007 by Forex.se.

Finally, when considering the environmental aspect, the size and weight of the package should also be considered. This is because these factors all affect the weight/volume efficiency and thus will effect the required transportation. Poor weight/volume efficiency will lead to more transportation work, more traffic, more fuel consumption and emissions that are more toxic. This will in turn have a negative impact on the environment.

Scientists, today, have concluded that the current levels of consumption and environmental burdens imposed by transportation will more than surpass what is tolerable (Whitelegg, 1993). This development will significantly affect the environment unless transportation becomes more efficient at the same time that new technology is being developed (Swedish Waste Research Council 1993). Package weight, as either a part of a consignment (transporting filled packages) or as a consignment itself (transporting empty packages), affects the fuel consumption of the transport vehicle, which has lead to higher amounts of pollutant emissions. On the other hand, inefficient packages, in terms of volume (as a part of consignment when shipped full and consignment itself when shipped empty), increased the total transportation volume, which again means more pollutant emissions. Quantifying these effects would be out of the scope of this research, but weight and volume efficiency of the packages could be used for rough estimates. See Table 5 and Table 6 for relative comparisons. It was recommended, even from environmental aspect, to have chosen a package with high weight/volume efficiency.

Due to the discussions above, it was concluded that plastic boxes were ecological to use within the factory (where the transportation distances were considerably short) compared to cardboard boxes. Still in some special circumstances, this statement was not true, such as when materials traveled long distances from the suppliers to the customer. These materials were usually packed in one-way packaging, to eliminate the repacking procedure. They were then sent directly to the production line with their initial packaging. Hence, although in general it was ecological to use plastic boxes within the production line, one-way packaging would have been a better choice since it traveled a long distance (one-way flow of materials) and would have eliminated a redundant packaging procedure.

In general, one-way packaging was recommended for long traveling distances since the returnable packaging’s material and administration cost for these routes exceeded the one-way packaging’s purchasing and waste disposal costs. On the other hand, there was also the return process for returnable packages. In some cases where materials travel both ways, returnable packages would have been more efficient to use. In such cases and in the long run, the cost of returnable packaging could supersede the one-way packaging by eliminating the purchase and disposal costs (Twede, 2000).

Still, the cost for suitable one-way packaging in some markets was so high that sending empty returnable packages was much cheaper. Thus, VE had various depots and terminals around the world, using returnable packages to transport items globally and profitably.

From an environmental perspective, the returnable packages were always preferred. Thus, plastic boxes were preferred for small size packages while in medium size packages this did not matter since both packages were returnable. Although plastic had some environmental impact, meaning it had to go through a cleaning process, it still was considered better than cardboard (one-way packaging).

In some cases, a special packaging type was required. Therefore, customers usually would acquire their own packages directly. VE was not involved in such procedures. The reason was that, the customer company required its own customized packages, which could not be shared with others. Thus, it was not cost efficient for them to rent these packages from a third party logistic company. Such packages could have included customized steel racks, customized packages for the paint shop, etc.

Some ideas in environmental issues section have been taken from Denison and Ren (2001).

6.5. Difficulties in measurements

In addition to the limitations and complexity discussed throughout this report, several other difficulties existed when measuring the performance of the packaging logistics functions. These difficulties were mentioned by Johansson and Weström (2000) in the article “Measurements of Packaging Logistics Parameters”. The following is an excerpt taken from that article.

- It can sometimes be hard to distinguish the role of the packaging from other activities. Product losses can naturally occur because of careless handling. Tied-up capital can be a result of bad planning etc.

- To get a complete picture of the consequences, many data has to be gathered, data which is not always easy to find. For example, to get a complete picture of the volume efficiency, data has to be gathered in several points along the distribution chain. Since the packaging system is built up/broken down along the supply chain, it could also be difficult to compare the volume efficiency between different packaging levels. Sometimes the complete pallet load is handled; sometimes the secondary packaging is handled. It gets even more difficult when mixed loads are handled.

- For the parameter handleability, the packaging performance is linked to the person handling the packaging. Different personal abilities as regards muscular power, co-ordination of movement, understanding of written information etc, mean that the influence from packaging parameters are hard to distinguish.

- The link to logistics cost are not always easy to establish.

7. Conclusions

The cost analysis of different packaging materials depended on their parameters, if they were soft or hard. A hard parameter was a quantifiable parameter while a soft parameter was not. Therefore, the existing cost analyses models within VE, and with its customers, were more or less all with regards to hard parameters. The basic challenge of this study was to define, grade and quantify (as much as possible) the soft parameters involved with various packaging solutions. These parameters were then supposed to be added to the existing hard parameters to form a comprehensive cost analysis model.

The soft parameters defined in this study were ergonomics, environment, cleanliness, handling etc. Most of these parameters were easy to quantify (e.g. handling was expressed in terms of the time required to assemble or disassemble a package, which could be multiplied by the labor cost to estimate the handling cost). Some were difficult to quantify (e.g. to quantify the cleanliness cost, the amount of personnel and materials required to clean the factory per a specific amount of time had to be calculated, which access to such data was extremely hard and out of the scope of this study). Hence, the easy soft parameters were quantified as much as reasonable possible. Since gathering and analyzing the difficult soft materials required contact with the customers to inquire about their other suppliers and personnel, this procedure was considered to be next to impossible. Therefore, after some discussions with the supervisors at both the University College and Volvo Logistics, it was decided that these aspects should be provided in a qualitative manner along with the quantifiable aspects to help the customer make the best available choice on an individualized packaging solution.

The final conclusion, derived from this research, was that there is no general optimal packaging solution. Customers have their own specific requirements, which will lead to their own unique optimal packaging solution. Therefore, various aspects (pros and cons) of different packaging solutions, available at the time of this research, were described to help customers make an optimal decision. In other words, this study could be considered as a decision support system for managers to decide the best available packaging solution.

7.1. Suggestions for further research

During the interviews, some ideas and recommendations were provided for new packaging types regarding the medium size packages. The first idea was to use reinforced plastic packaging units. These packages would not only possess almost all of the plastic packaging unit's positive aspects, but they would also have some of the wooden packaging unit's positive aspects as well. On the other hand, these packaging units have other problems such as a substantial initial investment to purchase a fleet of them. Another problem is that reinforced plastic would weight more. This would damage plastic's weight advantage compared to wood.

Then a more feasible and efficient idea was developed. That idea was to use plastic base pallets with wooden frames as a system. This would help in benefiting from most of both packaging units positive aspects. For example, if wooden frames were efficiently removed, stored and transported within VE terminals, they could contain more weight and thus make stack-ability a possible solution to the storage problem. On the other hand, the plastic base pallet not only solves the cleaning issue but it also has a longer life span, a lighter weight, does not absorb water and is much more efficient compared to a wooden base pallet, in terms of repair. This was an idea for a new packaging system for the medium size packages, which was developed after the conclusion of this research.

As explained earlier in the theoretical frame of reference, value analysis was used for the evaluation of different alternatives relative to simplicity and flexibility. Another method for detailed evaluation of different packaging solutions was the use of a packaging scorecard. This though requires more time and resources. We recommend that VE use this method in the next phase of their packaging selection and consider this study as a base and start for a comprehensive packaging selection study.

As the retail supply chain is the largest user of packaging, it is also here that one finds most of the studies on packaging influences on logistics activities(Johnsson, 1998). As mentioned earlier in the literature studies section, there was not much work conducted specifically on industrial packaging applications— without any consideration of marketing aspects. Although emergence of packaging logistics has helped with addressing packaging as an integrated part of logistics, although there is much room for more specialization. Most of the cases dealing with packaging logistics had, thus far, been dealing with views on the marketing aspects of packaging as a major packaging requirement. In the area of industrial or business customer applications, the packaging focus had little to nothing to do with the marketing issues of a package. This new field of study could change the basic definitions of packaging.

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Appendix: Symbols and Acronyms Reference:

- *VE:* Volvo Emballage

- *VLC:* Volvo Logistics Corporation

- *Emballage*: is the Swedish word for packaging, which is widely used in the Volvo group and in Sweden, even in an English context.

- *EMB*: each Emballage or packaging has a unique identification number in VE Emballage pool. Customers place their orders using this number. E.g. EMB 1 refers to wooden L-type pallet.

- *Hard and soft parameters:* If the current level of human capability in calculation and feasibility of performing a certain calculation were considered, quantifiablity of the parameters falls into two categories; parameters that were quantifiable were referred to as “hard” parameters and the otherwise were referred to as “soft” parameters. A parameter could be a cost or function or any other parameter subject to calculation.

- *Decision support system:*

  Decision Support Systems (DSS) are designed to help improve the effectiveness and productivity of managers and professionals. They are interactive systems frequently used by individuals with little experience in computers and analytic methods. They support, rather than replace, judgment in that they do not automate the decision process nor impose a sequence of analysis on the user. A DSS is in effect a staff assistant to whom the manager delegates activities involving retrieval, computation, and reporting. The manager evaluates the results and selects the next step in the process (Keen, 1981) .