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The fundamental role of the packaging system along the supply chain

Direttore della Scuola: Ch.mo Prof. ALESSANDRO PERSONA

Supervisore: Ch.mo Prof. ALBERTO REGATTIERI

Dottoranda: Giulia Santarelli

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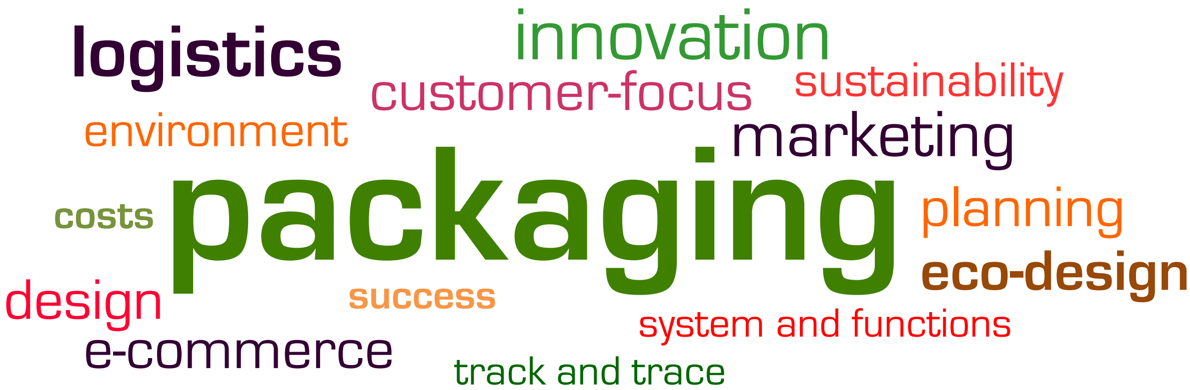
by

Giulia Santarelli



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Sommario

Il tema dell'imballaggio (i.e. *packaging*) ha assunto oggigiorno, e continuerà ad assumere in misura crescente nei prossimi decenni, un ruolo di fondamentale importanza lungo l'intera supply chain del prodotto. Se negli anni Cinquanta il *packaging* era in cerca di legittimazione, oggi è entrato in una fase matura e si trova al centro di fondamentali questioni distributive e comunicative. Parallelamente a ciò, il sistema *packaging* sta diventando considerevolmente rilevante anche nella questione della minimizzazione dell'inquinamento ambientale.

La presente tesi di dottorato si incentra su queste tematiche approfondendo strategie e metodi, e mostrando approcci innovativi per l'efficace progettazione, gestione e ottimizzazione del sistema *packaging*. L'elaborato inizia con una descrizione generale del sistema *packaging* analizzando le sue origini, le sue funzioni, e il suo ruolo lungo tutta la supply chain. A partire da questa analisi, è stato sviluppato un *framework* di riferimento per il sistema *packaging*, definito da cinque *packaging key drivers*, che sono: marketing, progettazione, logistica, costi ed ambiente. Ognuno di essi è stato approfondito e studiato usando diverse metodologie di analisi: dall'analisi empirica che ha permesso di definire un *benchmark* di riferimento, al caso studio che ha dato la possibilità di implementare nella realtà aziendale modelli e approcci sviluppati durante il percorso di dottorato, alla realizzazione di prototipi reali di *packaging*, e di vari prodotti a partire da imballaggi di cartone, legno e plastica al fine di soddisfare specifici bisogni.

I temi affrontati nella presente tesi di dottorato hanno portato interessanti risultati, sia dal punto di vista economico che ambientale, da un lato riducendo i costi dovuti al *packaging* e incrementando l'efficienza della gestione del sistema *packaging* per le aziende, dall'altro riducendo l'impatto ambientale dell'imballaggio grazie al riutilizzo degli stessi imballaggi per ricoprire funzioni similari o anche molto diverse dalla loro funzione primaria di protezione e contenimento del prodotto.

Abstract

Nowadays, packaging assumes a fundamental role along the entire supply chain and will continue to do so to an even greater extent in years to come. After establishing legitimacy in the 1950s, packaging today has entered a mature phase and it is at the centre of complex distributional and communicational issues. Packaging systems have also become considerably more important for the minimisation of environmental impact.

The present thesis focuses on the aforementioned issues, elaborating on current strategies and methods, as well as presenting new innovative approaches for effective design, management and optimisation of packaging systems. The work begins with a general description of packaging systems, with an analysis of their origin, functions and roles throughout the supply chain. Based on this study, a reference framework for packaging is then developed, defined by five key drivers: marketing, design, logistics, cost and environmental impact. Each driver is examined and studied using different methodologies. An empirical study allows definition of a reference benchmark on packaging, while a case study demonstrates the implementation of the developed approaches in a real industrial setting. Real packaging prototypes are developed, as well as various products that must meet specific needs, starting from cardboard, plastic and wooden packages.

Relevant results from both economic and environmental standpoints are presented with regard to the issues surrounding product packaging. Potential for cost reductions and increases in management efficiency of packaging companies are identified. It is shown that the environmental impact of packaging systems may be reduced through their re-use for both similar and very different functions to those for which packaging is traditionally employed: product protection and containment.

Acknowledgments

After my three years as a Ph.D. student, I firmly believe that the continuous support of a large group of excellent persons is essential to develop my research path, leading to the results discussed in the present dissertation. This is the time to express my gratitude to them.

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Giulia Santarelli

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1. Introduction

According to Saghir (2002a), packaging can be defined as

> [...] *a coordinated system of preparing products for safe, efficient and effective handling, transport, distribution, storage, retailing, consumption and recovery, re-use or disposal combined with maximising consumer value, sales and profit.*

Packaging, as it is known today, is the result of a long development process. It is the product of continuous research aimed at finding better methods of packing the various goods used everyday, in order to ensure the best protection for them.

The earliest forms of packaging, back in depth of the prehistory, were made from animal skins, large leaves and vegetables. Water was kept in containers made from coconut shells, animal skins or gourds – the hollowed-out dried skins of fruit and vegetables. Glass, which emerged in the Far East around 5,000 years B.C., was one invention destined to revolutionise men's capacity to conserve and transport goods. About 1,000 years later, the Egyptians used this material to create jars of all kinds.

In the Middle Ages, wooden barrels became the most frequently used way of preserving goods. They were used for storing all kinds of solids and liquids, protecting them from light, heat and dampness. Their considerable robustness allowed them to be transported on the dangerous roads of that age and to be carried by boat. It was during the Industrial Revolution in Europe that packaging really took off. The vast range of products made available to the consumer brought about a change in lifestyle, providing consumers with greater choice and allowing trade to flourish. The need for packaging grew up.

From then on, the rate of packaging innovation accelerated. The Frenchman Nicolas Appert invented the can in 1810. Although it was made from glass rather than metal, it represented the birth of a long-term preservation method for food. Canned food was first put to the test by the army during the Crimean wars and during the American Civil War before it became available to consumers. Indeed, many of the most prominent innovations in the packaging industry were developed first for military uses. Military packaging had to transport materials, supplies, foods, etc. under the most severe distribution and storage conditions. At the end of the 19th century, the American Robert Gair, had the bright idea of manufacturing in bulk a pre-cut cardboard panel, which, once folded, would form a box. This made the transportation of goods much easier and the box became the most widely used method of packaging from the beginning of the 20th century due to its low price and ease of use. In 1920, the invention of transparent cellophane marked the beginning of the plastic era and polyethylene, the first plastic used for packaging, was discovered in 1933. From then, a large number of technical innovations led to the continued improvement of packaging: for example, in the 1940s, packaging was developed for frozen food; in the 1950s, the aerosol came onto the market; cans, available from the 1960s, heralded the explosion of the soft drinks market.

Nowadays, packaging is much different from that developed thousands years ago. Packaging lies at the very heart of the modern industry, and efficient packaging is a necessity for almost every type of product whether it is mined, grown, hunted, extracted or manufactured. It represents an essential link between the product makers and their customers, and unless performed correctly, the reputation of the product will suffer and the goodwill of the customer will be lost. Properly designed packaging is the main way of ensuring safe delivery to the final user in good condition at an economic cost (Corner and Paine, 2002). Packaging enhances and protects goods, from processing and manufacturing through handling and storage to the final consumer. Moreover, packaging helps identify the products on the shelf, distinguishing itself from the competitors. Without packaging, materials handling would be a messy, inefficient and costly exercise and modern consumer marketing would be virtually impossible.

As it was from the beginning of the packaging history, the packaging issue has been and will continue to be always present in the everyday life. From the packaging of food that has to cover the main function of protecting and preserving the products from the environment, favouring the hygienic aspect, to the packaging of cosmetic products that has to be attractive for the final customer, to the packaging of luxury products that has to communicate the high value of the product with an elegant and valuable package, to the packaging of pharmaceutical products that has to inform the final customers about their active ingredients.

Used in a wide range of industries across food and drink, healthcare, cosmetics and other consumer goods as well as a range of industrial sectors, packaging has become an essential everyday item, with its usage growing broadly in line with the global economy. The global packaging market has recorded an annual growth rate of 2.6% between 2006 and 2012 and it is preparing to a further accelerate increase from 2013 to 2020 with an annual growth of 3.1%. The main sectors that represent over 90% of packaging volume all around the world (i.e. food, beverage and tobacco) assume different trends: a high growth for the food sector (more than 3%), a greater growth for the beverage sector (around 4%) and a flatter one for the tobacco (around 0.5%). Relevant growths are demonstrated also for the beauty/personal care and tissue/hygiene sectors with 3% and 4%, respectively (D'Annunzio, 2013).

The present Ph.D. dissertation investigates the packaging topic from a quantitative and industrial perspective describing models, approaches and strategies for the effective design, management and optimisation of the packaging system.

The following paragraph concludes the introduction section providing the detailed outline of the present Ph.D. dissertation.

1.1 Dissertation outline

This preliminary chapter introduces the relevance of packaging issue for both companies and consumers, highlighting the improvements that a good-integrated management of the packaging system with the industrial functions can provide in order to increase company efficiency and improve people's daily life. A basic set of aggregated data quantitatively supports the description. In accordance with the introduced topics, the reminder of the present Ph.D. dissertation is organised as follows.

Chapter 2 firstly presents a general background on packaging, describing its levels, functions, and its fundamental role for all the parties along the supply chain and in web-operations. In accordance with an in-depth literature analysis on the topic, a general framework on packaging defining five different key drivers (i.e. marketing, design, logistics, cost, and environment) has been developed. Starting from the reference framework on packaging system, the following chapters describe each packaging key driver in details.

Chapter 3 focuses on the marketing aspect of packaging and wants to analyse how Italian customers perceive the quality attributes of primary packages during the use of a product.

Moreover, a comparison with the analogue Swedish study has been made in order to analyse the main similarities and differences between the two realities. This analysis has been allowed by an empirical study.

Chapter 4 presents an action research that allows the realisation of a packaging prototype for a dip sauce using a particular material mainly composed by paper. The study on the packaging prototype has led to a reduction on the transportation costs due mainly to the decrease of the packaging volume.

Chapter 5 deals the packaging logistics issue, discussing the importance that the packaging management can have within a company for logistics optimisation. The chapter aim is to describe the role of packaging in the traceability of material and product flows to improve their visibility, allowing reducing the distance travelled within indoor environment and in turn the transportation costs. The case study about the traceability of product packages is dealt with in *Chapter 8*.

Chapter 6 analyses how Italian companies perceive the packaging system through an empirical study conducted with several companies in Bologna district. The results of the study show that Italian companies do not know the amount of their packaging costs. In order to absolve this lack, a mathematical approach that considers all packaging cost parameters has been developed and presented in *Chapter 8.*

Chapter 7 focuses on the importance of the packaging system in the environmental issues, presenting the most common ways to reduce and minimise the environmental impact of packaging. A case study on the re-use of packages is presents in *Chapter 8*.

Chapter 8 discusses the application of the packaging framework to three key drivers: logistics, cost and environment. For the cost driver the mathematical approach and its application to a real case study are presented, underlining the importance to evaluate packaging costs for companies. After that, the chapter presents a case study on the traceability of material flows (i.e. packages and/or products) conducted within the assembly system of an Italian company by using the developed Radio Frequency IDentification-Ultra Wind Band (RFID-UWB). The use of RFID-UWB system allows knowing the position of materials in continuous and in real time, the consequent reduction of the distance travelled, and in turn the minimisation of transportation costs. Finally, the chapter describes a case study conducted in collaboration with a humanitarian logistics association, in order to analyse how it is possible to decrease the environmental impact of the packaging system in an emergency camp during disaster situations..

Chapter 9 introduces relevant packaging characteristics for e-commerce business, developing a reference framework, based on that described in *Chapter 2.* The framework has been shared with five companies selling online and has been applied to a case study with the intent to realise a new packaging system to be used in e-commerce business.

Chapter 10 concludes the present dissertation providing final remarks about the developed research activities and proposing suggestions for further improvements of models, approaches and prototypes.

Figure 1.1 illustrates the dissertation outline presenting the research questions (RQ), the methodologies (M) used and the main outlines (O) for each chapter.

Chapter 1	Introduction and research purposes
Chapter 2	RQ. Which are the packaging characteristics according to industrial functions?
	M. Packaging framework definition
	O. Starting point for the next chapters
Chapter 3	RQ1. How do Italian customers perceive primary packaging? RQ2. What is the difference between Italian and Swedish realities?
	M. Empirical study – Questionnaire to Italian customers
	O1. Definition of the most relevant packaging characteristics for Italian customers O2. Comparison between Italian and Swedish realities
Chapter 4	RQ. How is it possible to reduce transportation and warehousing costs operating on the design of packaging?
	M. Action research – Realisation of a packaging prototype
	O. Reduction of the transportation and warehousing costs due mainly to the reduction of the packaging volume
Chapter 5	RQ. How is it possible to trace material flows (i.e. Packages and products) within indoor environment?
	M. Case study – Application of an RFID-UWB system to an assembly plant
	O. Development of a flow traceability system that provides more transparent flows with the intent to reduce distance travelled and in turn transportation costs
Chapter 6	RQ. How do Italian companies perceive packaging?
	M. Empirical study – Questionnaire to Italian companies
	O. Definition of the most relevant packaging characteristics for Italian companies
Chapter 7	RQ. How is it possible to reduce the environmental impact of packaging?
	M. Case study – Re-using of packaging in an emergency camp
	O. Decrease of the environmental impact
Chapter 8	RQ. How is it possible to apply the packaging framework to the reality?
	M. Case study
	O. Application of the packaging key drivers to real case studies
Chapter 9	RQ. Which are the main packaging characteristics for e-commerce business?
	M. Case study – Framework application on an Italian retailer
	O. Definition of a packaging system for e-commerce business
Chapter 10	Conclusion and further developments

Figure 1.1. Research questions (RQ), methodologies (M) and outlines (O) of the Ph.D. dissertation

2. *The packaging system*

2.1 The concept of packaging

Packages have always been part of human life (Beckeman and Bramklev, 2007). Since the rise of civilisation in Mesopotamia, Egypt and China, the main and the most important functions of packaging have been to contain, preserve and protect goods and products (Saghir, 2004; Twede, 1992), giving great relevance to logistics aspects (i.e. storage, transport and product handling) (Beckeman and Bramklev, 2007). During the time, the marketing aspect has increased its importance: around 1000 B.C. many amphorae were stamped with information, such as the name of supplier and date of manufacturing (Beckeman and Bramklev, 2007).

Since the origins, packaging has evolved together with humankind and increased in complexity and importance (Saghir, 2004). In today modern society, it is hardly to find any product does not need to be packaged (Saghir, 2004) in order to fulfil both logistics and communication issues.

Since the 1980s many definitions of packaging have been provided. In 1983, Paine and Paine defined packaging as:

> *[...] a coordinated system of preparing goods for transport, distribution, storage, retailing and end use and a means of ensuring safe delivery to the ultimate consumer in sound condition at minimum cost.*

Some years later, Paine (1990) helped establish the functions performed by packaging, and continue to describe packaging as:

> *[...] a product with the initial purpose of protecting, collecting and providing information about the content.*

With reference to the functions outlined by Paine and Paine (1983) and Paine (1990), packaging is regarded as an extension of the product. It provides additional features to the product in order to fulfil the demands on product performance during the product life cycle – from the finalisation of the manufacturing or assembling of the product until the product is ready for being used (Bramklev et al., 2005).

After several years, Saghir (2002a) defined packaging as:

> *[...] a coordinated system of preparing products for safe, efficient and effective handling, transport, distribution, storage, retailing, consumption and recovery, re-use or disposal combined with maximising consumer value, sales and profit.*

According to the definitions mentioned above, packaging is an important competitive factor for companies to obtain an efficient supply chain. Packaging is an essential element and in many cases, without its use, product handling would be inefficient and impractical (Lockamy, 1995). Packaging contributes to the success of product supply chain, enabling efficient distribution of products, and reducing environmental impact of product spoilage and waste (Verghese and Lewis, 2007).

According to Paine (1990), better packaging can reduce cost, increase turnover, minimise damage complaints, and reduce waste. Hence, the packaging does not only preserve the quality of the main product, but also provides an opportunity to create added value to customers (Olander-Roese and Nilsson, 2009; Olsson and Györei, 2002) and to other actors in the packaging supply chain (Olsson and Györei, 2002). Moreover, packaging has the potential to influence the efficiency of the entire supply chain through optimum design (Olsson, 2001; Olsson and Györei, 2002) and furthermore, it could influence costs and effectiveness in the whole logistics process by considering it a prime element in that process (Johnsson, 1998).

Several authors dealt with the packaging issue, underlining its fundamental role of driver along the whole supply chain. Lockamy (1995) presented a conceptual framework for assessing strategic packaging decisions, examining the relationship between strategic packaging elements and the competitive edges on which firms can compete in the marketplace. Nilsson and Pålsson (2006) reviewed the literature in logistics and operation management and pointed out the lack of attention to packaging effects. Sohrabpour and Hellström (2010) identified, described and categorised supply chain needs on secondary packaging for ambient milk products in developing countries through an embedded case study. Löfgren et al. (2010) developed a method to measure the changes in the packaging area and applied it to several packages for everyday commodities in order to show how it is changed during the time.

2.2. The role of packaging along the supply chain

During last decades, the importance of packaging and its functions grew considerably due to new and diverse developments of packaging materials and methods (Domnica, 2010).

Packaging is built up as a system usually consisting of a primary, secondary, and tertiary level (Chapman et al., 2003; Davis and Song, 2006; Jönson, 2000; Saghir, 2002b, Saphire, 1994). The primary package concerns the structural nature of the package; it is usually the smallest unit of distribution or use and it is usually the package in direct contact with the contents (sometimes, especially when the package has to contain food, a plastic bag or film can be put between the package and the contents). The secondary package relates to the issues of visual communication and it is used to group primary packages together. The main purpose of the secondary package is to protect the products during the transportation to the final destination and provide information for the user. Finally, the tertiary package is used for storing and transporting products. The various levels and their interactions should be regarded as a packaging system (Olsson et al., 2004; Saghir, 2004). The performance of the packaging system is affected by the performance of each level and that of the interactions between them (Hellström and Saghir, 2007). Figure 2.1 shows the three levels of the packaging system (Hellström and Saghir, 2007).

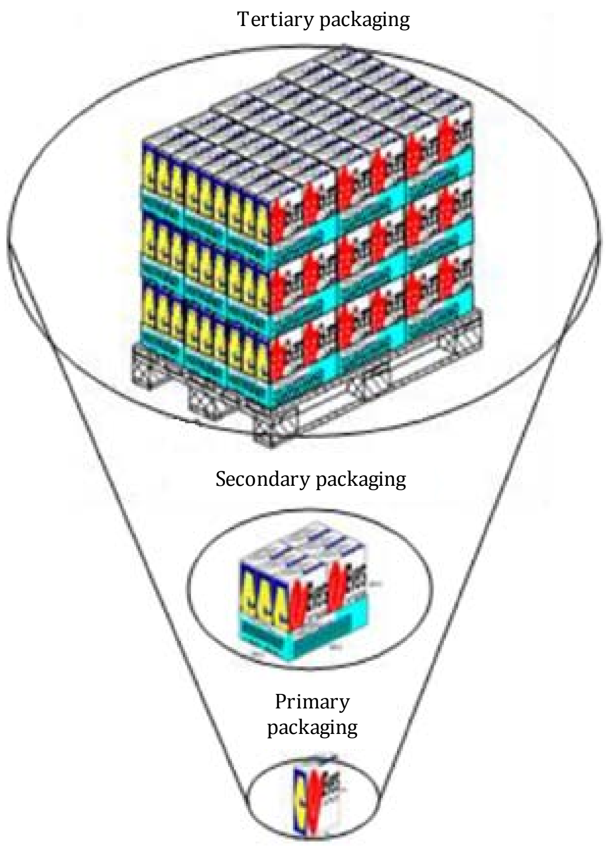


Figure 2.1. The packaging system (Hellström and Saghir, 2007)

During the years, several authors reviewed the basic functions of packaging (e.g. Bramklev et al., 2004; Chan et al., 2006; Domnica, 2010; Gordon, 1990; Johansson and Weström, 2000; Lockamy, 1995; Prendergast and Pitt, 1996; Robertson, 1990; Williams et al., 2008) and recognised them as: logistics, marketing and environment.

Traditionally, packaging is viewed as a means affecting every logistics activity (Bowersox and Closs, 1996; Saghir, 2004). Throughout history, packages are used to contain, store and transport goods and products (Beckeman and Bramklev, 2007; Hellström and Saghir, 2007). The fundamental logistics function of packaging is mainly to protect products during movements through distribution channels (Dominic, 2005; Dowlatshahi, 1996; Hellström and Saghir, 2007; Hermansson, 1999; Jönson, 2001; Klevås, 2005; Lockamy, 1995; Olander-Roese and Nilsson, 2009; Prendergast and Pitt, 1996), and, from the other hand, to protect the environment from products (Hellström and Saghir, 2007; Klevås, 2006). Packaging is also considered a critical/versatile marketing tool for sales promotion, customer attention and brand communication (Ampuero and Vila, 2006; Domnica, 2010; Kotler, 2006; Lee and Lye, 2003; Nancarrow et al., 1998; Nickels and Jolson, 1976; Rundh, 2005; Schoormans and Robben, 1997; Underwood and Ozanne, 1998; Underwood, 2003). Packaging is considered as a vehicle to provide customers with product information and promote the product through its visual appeal, to attract customer attention and create a positive impression (Gray and Guthrie, 1990; McDaniel and Baker, 1977; Olander-Roese and Nilsson, 2009; Prendergast and Pitt, 1996; Rod, 1990; Simms and Trott, 2010; Wells et al., 2007). Furthermore, the role of packaging in terms of accounting for less waste of resources and less damaged goods, has been increased in importance since the 1990s (Livingstone and Sparks, 1994).

According to its functions, the package is an extension of the product (Bramklev et al., 2004; Domnica, 2010) because it is a fundamental element for the containment and preservation of the product itself and it is essential for its end life (i.e. the use). Moreover, packaging is a fundamental interface between the product and the whole supply chain, because it interacts with all the industrial functions as logistics, manufacturing, marketing, information systems, and environmental performance (Hellström and Saghir, 2007; Pålsson et al., 2012).

Considering the simplified supply chain of a manufacturing company (Figure 2.2), it is possible to analyse the relevant role that packaging assumes for all the parties along the supply chain.

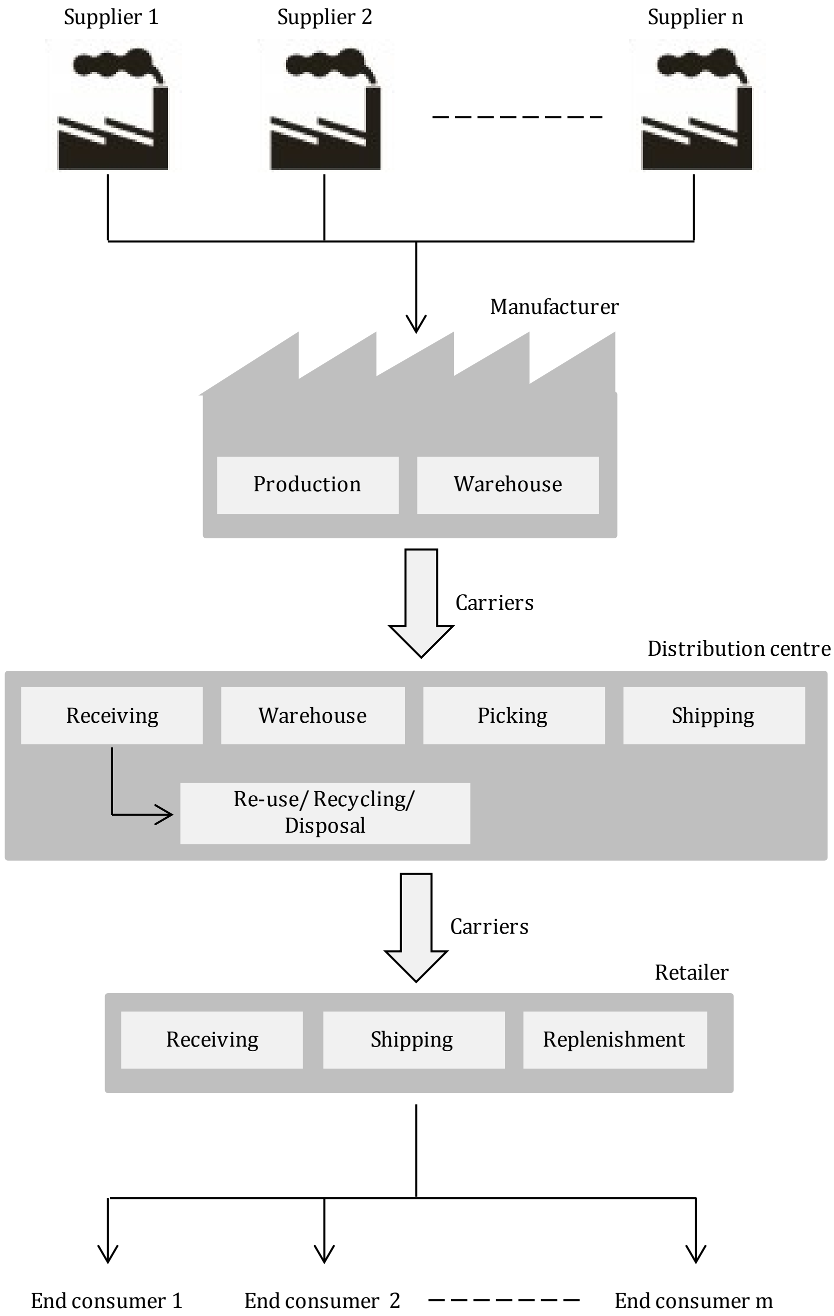


Figure 2.2. Typical supply chain of a manufacturing company

Each party in the supply chain has different interests and requirements regarding packaging. They are shown in summary in Table 2.1.

Party	Role of packaging
***n* Suppliers**	Suppliers are more interested in the logistics aspect of packaging than in marketing. They have to send products to the manufacturer and their purpose is the minimisation of the logistics costs (i.e. transportation, distribution, warehousing), so they prefer a package that is easy to handle and transport. Moreover, suppliers select the package from a filling viewpoint, such as the ease to fill package with the product.
Manufacturer	The manufacturer produces finished products to sell to the distribution centre and, indirectly, to end consumers. It is important for the manufacturer to take into account all the aspects: product protection and safety, logistics, marketing and the environment. – Product protection and safety: packages have to protect and contain the product, withstanding mechanical shocks and vibrations; – Logistics: the manufacturer has to handle, store, pick and transport the product to the distribution centre. It has to make primary, secondary and tertiary packaging that are easy to transport, minimise logistics costs and improve the efficiency of the company; – Marketing: the manufacturer has to sell its products to the distribution centre that sells to the retailer and in turn to end consumers. The manufacturer is indirectly in contact with end consumers and has to make primary packaging (the package that users see on the shelf) that attracts consumers to buy that product instead of another one. As Pilditch (1973) said, the package is a "silent salesman", the first thing that the consumer sees when buying a product; – Environment: people are more and more careful about protecting the environment. The manufacturer has to study a package that minimises materials used and can be re-usable or recyclable. The manufacturer has to balance the aspects described above with the ease to fill the package with the product, in order to obtain an efficient supply chain.
Wholesaler	The wholesaler purchases products from the manufacturer and transports them to the distribution centre. It is mainly interested in the logistics aspect of packages because the most important functions are warehousing, picking and shipping the products. The wholesaler needs a package that is easy to handle and transport rather than one with an attractive shape and design.
Retailer	The retailer has to sell products to end consumers and for this reason, he needs to consider on what end consumers are interested. Marketing and environmental aspects are important: marketing because the package is a "shop window" for the product; environment since people are careful about minimising pollution preferring to buy products contained in recyclable or re-usable packages.
***m* End consumers**	End consumers are interested in marketing (indeed primary and secondary packages are effective tools for marketing in traditional shops (Pilditch, 1973)) and environmental aspects.

Table 2.1. The role of packaging for the parties of the supply chain

Although the relevant role of packaging is recognised by all the parties along the supply chain, there are inefficiencies moving from the packaging supplier, to the packer/filler, to the point of sale and consumer (Dominic, 2005). There is not enough coordination between parties in the study and development of packaging: the packaging supplier is not involved in the activities on the market place (Dominic, 2005); the important upstream information from the market place about the consumer is not always released on time to the supplier to produce packages that are suitable for the consumer (Dominic, 2005). Dominic (2005) created a knowledge base that will be usable for the packaging industry, identified the network integrators and analysed the development for packaging suppliers.

Since few decades the online shopping has increased in accordance with the great utilise of the Internet and packaging has assumed a fundamental role in the e-commerce supply chain. Next paragraph describes the relevant role of packaging for e-commerce supply chain.

2.2.1 The fundamental role of packaging for e-commerce supply chain

E-commerce is an emerging business that encompasses the process of trading goods, information, or services via computer networks 24 hours a day, seven days a week without any limitation (Barwise et al., 2000; Collier and Bienstock, 2006; Da Silveira, 2003; Fraser et al., 2000; Turban et al., 2000). It can be distinguished from the broader concept of e-business that refers to any business operation conducted through information networks, such as customer services, Enterprise Research Planning, and knowledge sharing (Da Silveira, 2003).

Currently, there is no internationally accepted definition for e-commerce. However, the British Department of Trade and Industry (2003) defined e-commerce as:

> *[...] any exchange of information across electronic networks, at any stage in supply chain, whether within an organisation, between business, between business and consumers, or between the public and private sectors, whether paid or unpaid, using an electronic network to simplify and speed up all stages of the business process, from design and making to buying, selling and delivery.*

E-commerce has changed manufacturing systems from mass production to demand-driven, possibly customised, Just In Time[1] manufacturing system, and supports functional activities in organisations such as marketing, purchasing, design, production, sales and distribution, human resource management, warehousing and supplier development (Gunasekaran et al., 2002). The advent and increase of e-commerce has had a significant impact on packaging system that should

1 Just In Tim (JIT) is a manufacturing program with the primary goal of continuously reducing, and ultimately eliminating all forms of waste (Sugimori et al., 1977).

be reconsidered. Visser (2002) analysed the changing role of packaging for e-commerce, underlining the difficulty to translate the existing packaging design used for the traditional shopping in a real shop and marketing tactics into online retailing.

Although e-commerce is an emerging business and packaging is increasing its relevance along the supply chain, there is not a wide number of articles dealing with packaging for e-commerce. E-commerce requires a new paradigm for the entire product packaging system.

Three are the main issues to discuss about packaging system for e-commerce: logistics, marketing and the environment.

Some authors underlined the fundamental logistics role of packaging for e-commerce (INCPEN, 2012; Korzeniowski and Jasiczak, 2005; Sarkis et al., 2004) and Olsson (2001) focused on the effects of the sale channel of the Internet on packaging logistics. Packaging fulfils a complex set of logistics functions. The primary role of packaging in e-commerce is to protect, preserve and contain goods (Hyde, 2012; INCPEN, 2012). Adequate protection of goods can be ensured by selecting proper packaging materials and accessories, and packaging design, taking into account the possibility that goods do not meet customer expectations and need to be re-packed and returned (Korzeniowski and Jasiczak, 2005). Other functions, as ease of processing and handling, as well as transport, storage, convenience, and re-use are all affected by packaging system. Moreover, several electronic tools, like Electronic Data Interchange (i.e. the structured transmission of data between organisations by electronic means, EDI) can help the management of online packaging from the logistics point of view. EDI enables minimal stocks to be held with the consequent saving in storage, insurance, warehousing and labour costs (Gunasekaran et al., 2002).

One of the biggest challenges of e-commerce business is the so called *last mile* that is the home delivery service for the customer. Frequent and numerous home deliveries may create incentives for manufacturers to take back their packaging, to use refillable or recyclable packaging materials, or to study new and cheaper home deliveries solutions, in order to become increasingly cost-effective (Sarkis et al., 2004). Punakivi et al. (2001) defined two different home delivery solutions in order to reduce the company costs and the time the customer has to stay at home waiting for the delivery: reception box and delivery box solutions. The first system involves the possession of a fixed box at the customer, equipped with a safety system, and in which goods may be left. The second system provides that the good delivery is left at the customer within a safety box which will then be withdrawn at a later time or at a subsequent delivery. These two delivery solutions could allow reducing the delivery time and eliminating the need to deliver the goods again, increasing customer satisfaction. In addition, Kämäräinen (2001) examined how different solutions for good receipt affect home-delivery efficiency, analysing the service levels provided by the alternatives and the costs for e-grocer.

The marketing of products has changed through the Internet and e-commerce. The function of packaging the product in an attractive manner becomes less important (Holdway et al., 2002; Korzeniowski and Jasiczak, 2005; Sarkis et al., 2004). The more customers shop online, the less important shelf presentation will become (Visser, 2002). In an online shop, users cannot directly see the package nor touch the product, but other characteristics such as protection and re-usability for an efficient take-back of products take on great importance (Huang et al., 2009). The changing role of packaging for e-commerce in the purchase of a product makes it desirable and possible to give more attention to the consumer perception of a brand while the user is using it, and less attention to its shelf presentation (Visser, 2002).

From the environmental point of view, companies should follow some simple practical approaches to select the packaging for e-commerce (INCPEN, 2012; Korzeniowski and Jasiczak, 2005): the minimisation of weight, size and materials used to produce packages, use of recycled materials and the re-use of product packages. These could produce benefits in terms of costs and environmental impact (due for example to less energy used to produce packages from recycled materials if compared with virgin raw materials). According to Kowal (2010), re-using something like paper or cardboard for packaging is always preferable to recycling, and of course, much better than throwing those items away. Furthermore, Holdway et al. (2002) pointed out the possibility to extend the packaging life through re-use in new and different applications. The Industry Council for Packaging and the Environment (INCPEN, 2012) stated that companies that monitor their packaging system in online shopping may achieve savings, make supply chains more sustainable and reduce the environmental impact.

According to the main purposes fulfilled by packaging (Robertson, 1990), the main packaging requirements that a company should consider before starting e-commerce business are as follows:

- Protection: the protection of products is the most relevant packaging function because products have to arrive in good condition at consumers. Products have to be protected from mechanical, chemical and biological damage (Korzeniowski and Jasiczak, 2005), thanks also to the use of accessories (e.g. pluriball, air pillows, polystyrene chips, etc.);
- Handleability: the ergonomic aspect, that is everything relating to adaptations to the human physique and behaviour when using the product, has to be considered. To confirm this, the empirical study conducted on the packaging perception by end consumers (*Chapter 3*), stated that the main requirement that a packaging should guarantee is the handleability (e.g. easy of handling, easy of opening, user-friendly, etc.);
- Security: packages must ensure secure shipping. It could be necessary to install identification technologies, like Radio Frequency IDentification tags or barcodes, on packages in order to reduce thefts, increase security, and minimise time spent on the traceability of products;

- Respect for the environment: e-commerce produces more material waste than the traditional commerce, because of more frequent orders in smaller quantities. In order to have the minimum environmental impact, it could be necessary that companies recycle packages, and minimise dangerous substances in emission when packaging waste is disposed;
- Re-use: more and more companies have started to re-use packages to ship products to end consumers minimising both the environmental impact and costs. The re-use of packages could also increase customer satisfaction thanks to the low environmental pollution produced.

2.3 A holistic view of packaging

Today, providing *the right package for the right product for the right market* is of fundamental importance for the global enterprise activities (Beckeman and Bramklev, 2007). The activities are managed in a network of functions and/or divisions (e.g. product development, assembly and production) often separated geographically around the world (Beckeman and Bramklev, 2007). The main drivers of these trends are: globalisation and distance between point of production and point of consumption (Jahre and Hatteland, 2004), increase number of disposable products, changes in demographics and lifestyle (Jahre and Hatteland, 2004; Lofthouse et al., 2009), improvements in hygiene standards (Olsmats, 2000), development of self-service distribution (Jahre and Hatteland, 2004), increase of e-commerce and home-delivery services (Holdway et al., 2002). One consequence of this is an increased demand for transportation, handling and storage of parts, sub-assemblies and final products between enterprise divisions in a way that ensures error-free deliveries, protection of parts and products, and compliance with respect to environmental standards and regulations for the packaging system (Beckeman and Bramklev, 2007). In order to manage these problems and make the best decisions for a given situation in an effective and efficient way, it is important to understand the interactions between packaging functions along the supply chain.

According to Dominic (2005), many authors stressed the importance to have a holistic view of packaging in order to understand consumer demands and improve the efficiencies and in pursuit of value creation (Vernuccio et al., 2010). A holistic view of packaging could lead to higher consumer satisfaction, increase the efficiency of the process and reduce operational and usage costs (Dominic, 2005; Dowlatshahi, 1999; Olsson et al., 2008). When contemplating packaging as a whole, the natural interaction among different levels would become manifest, depicting the important dependence among them (García and Prado, 2008).

Packaging is cross-functional and plays a fundamental role along the supply chain, fulfilling requirements placed on it from logistics, marketing and the environment (Johansson et al., 1997; Johnsson, 1998; Prendergast, 1995; Stock and Lambert, 2001; Twede, 1988). It is important to detect a trade-off between packaging functions and industrial divisions in order to save resources and reduce the environmental load (Olsmats and Dominic, 2003; Prendergast and Pitt, 1996; Saghir, 2002b). The main purpose of packaging producers is to standardise packages to benefit in terms of scale economies, while retailers are challenging this standardisation through increased demands for differentiation and special promotions (Olsson and Györei, 2002). Even within the company, the different departments have their special requirements. Marketing asks for a package that looks nice and has a proper size. Production wants the package is as easy as possible to handle through all processes. The purchasing department focuses on secure supply at lowest possible cost. The logistics section asks for standardised packages for facilitating the transport. The environmental perspective wants a package built with biodegradable materials and focused on the energy efficiency in production, use and disposal. According to the many different packaging requirements, there is an increasing tendency to see packaging as part of a larger integrated system involving actors throughout the whole supply chain. Figure 2.3 shows the main packaging interactions (modified version of Saghir, 2002b).

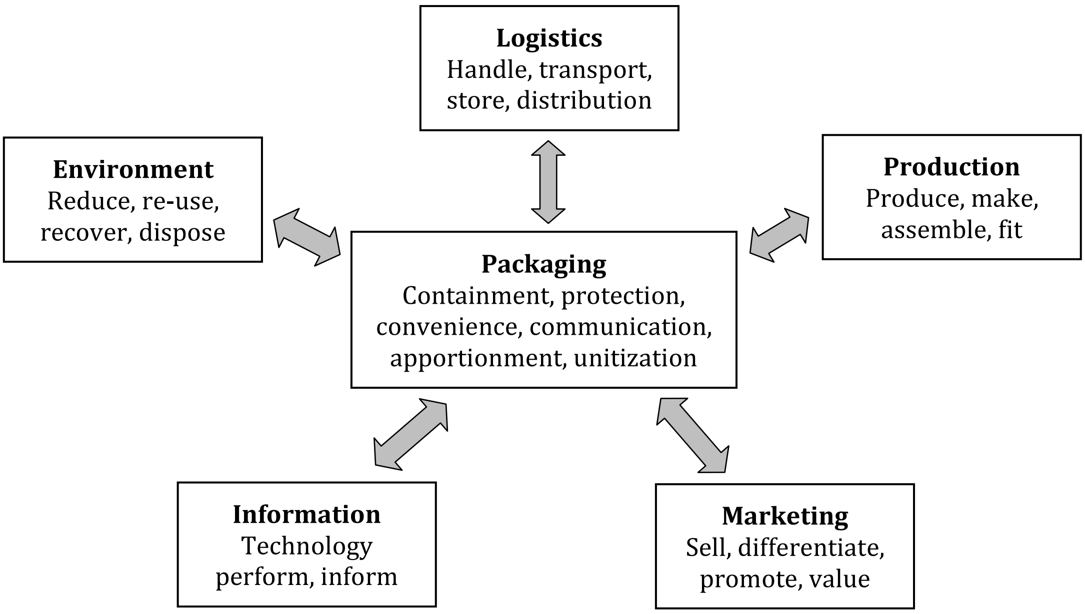


Figure 2.3. Packaging interactions (modified version of Saghir, 2002b)

Many studies have focused on the holistic view of packaging and some aspects of interfaces between packages and the industrial divisions have been investigated (Bowersox and Closs, 1996;

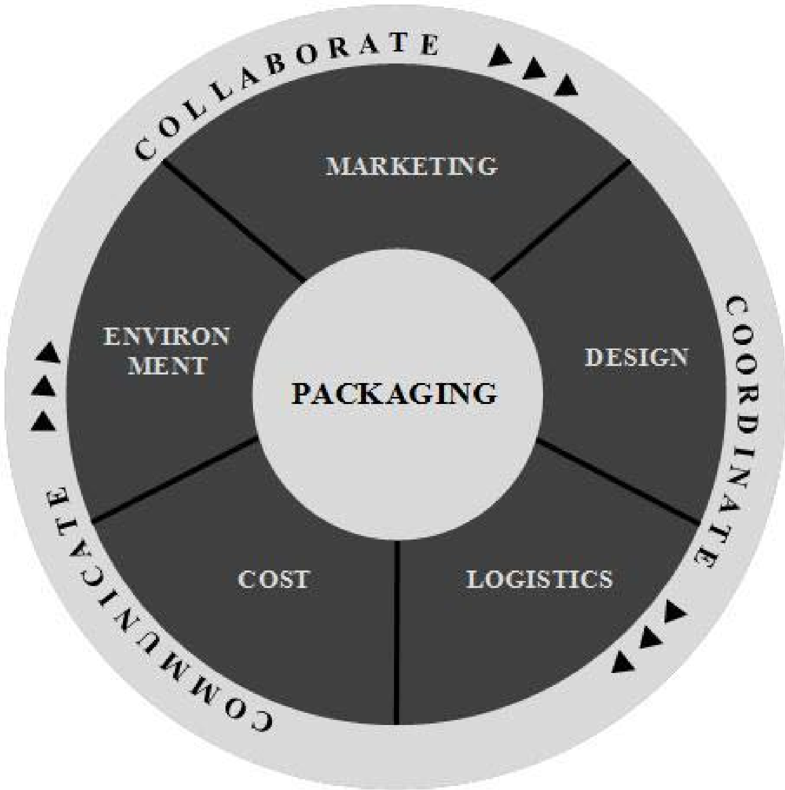
Lancioni and Chandran, 1990; Prendergast and Pitt, 1996). Mather (1992) recognised the packaging potential of reducing costs by planning a logistically effective design; indeed the package has a great impact on the efficiency of logistics activities, such as transportation, storage and handling, and on the logistics system as a whole. Johnsson (1998) argued for a more dynamic integration between packaging and logistics to increase advantages, since the package and the logistics system should support each other to operate in the best manner. A packaging decision taken for example in the production division, affects not only the packaging system, but also the interacting logistics processes. The same logic implies that a logistics decision affects not only logistics processes but also the interacting packaging system in those processes (Twede, 1992; Twede and Parsons, 1997). Dowlatshahi (1999) suggested some logistics requirements for packaging to be incorporated with marketing and manufacturing at the design stage. Olsson and Györei (2002) illustrated the packaging impact from two previous studies (i.e. Györei, 1995; Györei, 1998) in terms of the four Cs (i.e. Customer value, Convenience, Communication and Cost) and discussed the trade-off in the packaging value chain, raised by the aim of creating packaging solutions that serve different value chain actor requirements. Jahre and Hatteland (2004) provided an understanding of trade-off in supply chain. By taking a starting point in the logistics role of packaging and the potential trade-off within marketing and environmental roles, it was illustrated the difficulties and the necessity to face with integrated systems. In 2007, Beckeman and Bramklev created a conceptual model on the interfaces between packaging and logistics activities. Some years later, Vernuccio et al. (2010) proposed an original multidisciplinary analytical framework, focusing on marketing, logistics and ethics disciplines, which are considered some of the most relevant components of a strategic packaging planning.

2.4 A reference framework on packaging system: the definition of packaging key drivers

Previous works on packaging framework (e.g. Azzi et al., 2012; Lockamy, 1995; Olsmats and Dominic, 2003; Rundh, 2005; Simms and Trott, 2010; Svanes et al., 2010) are available in literature, but none deals with the role of packaging as a fundamental driver in the integrating management of the industrial functions along the whole supply chain.

According to Saghir (2004), a framework for evaluating packaging concepts with emphasis on a wider systems view is needed.

Five packaging key drivers have been defined in order to develop an innovative reference framework: marketing, design, logistics, cost and environment, each one of fundamental importance for the final resolution of the product package at minimum cost. In order to increase efficiency and effectiveness and reduce costs, it is necessary that the packaging key drivers act in a coordinate and collaborative way and communicate the necessary information with each other. The reference framework on packaging is presented in Figure 2.4.



Marketing	Design	Logistics
Attraction Communication Promotion Customisation Customer satisfaction	Dimensions Volume Weight Materials Protection and preservation Resistance Convenience	Containment Unitisation Standardisation Storage and distribution Traceability Reverse logistics

Cost	Environment
Efficiency Cost parameters	Waste reduction Pollution minimisation Recycling Re-use Sustainability

Figure 2.4. A graphical representation for the packaging framework

First, the ***marketing*** function of packaging is analysed. Through its aesthetic function, packaging contributes to make the product more *attractive* and affects consumers during their purchase decision. The packaging attractiveness could be realised by using several ways such as colour, shape, size, that attract the consumer and bring him to buy that product.

Another fundamental aspect of marketing function of packaging is the *communication* that allows consumers to recognise instantly products through distinctive branding and labelling. According to Olsson and Larsson (2009), the communication function of packaging is threefold: communication of necessary information, communication of promotion, and communication to consumers. Packaging must communicate all necessary information (e.g. content, expiration date, materials, etc.) about the product and the package to stakeholders and consumers. The second communication aspect concerns the *promotion* of the product. Promotion is the incentive that makes known and appreciated a product, and its main objective is to affect the consumers. Packaging has to communicate the product benefits, attracts consumers, and holds the attention against the visual clamour of competitive products. This means that packaging should be a differentiating element during the purchase process. It is demonstrated that the product and the package are often perceived as closely integrated and the consumer initial impression of the quality and value of a product is sometimes determined by their packaging perception (Olsson and Larsson, 2009; Silayoi and Speece, 2004). If packaging communicates high quality, consumers assume that the product is of high quality and, viceversa, if packaging communicates low quality, consumers think about a low quality product.

Another interesting characteristic of packaging relating to the marketing function is the *customisation*. Marketing prefers the variation, specialities and different packaging sizes in order to be adaptable to each single customer need. Packaging customisation could be a fundamental issue to increase *customer satisfaction* that is crucial for the success of companies (Matzler et al., 1996). Achieving customer satisfaction means understanding and anticipating what users want, but do not expect, from the product in the future. The most important aspect is to delight customers and surprise them. A crucial element is to recognise which product qualities are decisive for satisfying the costumer and which features may prevent dissatisfaction.

Packaging ***design*** is the second key driver for the definition of a reference framework on packaging, and it is necessary to take into account both the physical and mechanical characteristics.

From the physical point of view, the shape of a package (in terms of *dimension*, *volume* and *weight*) is considered relevant. If the volume and weight are not designed in an efficient way, there is poor utilisation of the distribution chain, increasing costs. For both environmental and economic aspects, there is a general demand that the package should be reduced in terms of dimension, volume and weight as possible. *Materials* used for realising package constitute another important aspect affecting the design process. Packaging design should call for the reduction of materials used per unit of product. This is not only a cost saving measure, but also facilitates manufacturing operations, handling, transportation, and packaging disposal. Packaging should be mono-material to ease the recycling of products, and biodegradable to reduce the pollutant emissions.

From a mechanical point of view, a package should cover the traditional functions of *protection* and *preservation* of the product in the right conditions during both the exposition in the shelf and the transport, and high *resistance* to vibrations and shocks during the handling and distribution. The protection of the product is a fundamental function that package should cover and it concerns the protection of the product from the environment and the protection of the environment from the product. The choice of the protection degree of products depends on the value and fragility of the products themselves.

Another fundamental characteristic affecting packaging system is the *convenience*. It simplifies the use of products by the consumer, making handling as convenient and user-friendly as possible. Packaging should be as easy as possible to open, re-close (if necessary) and grip.

A framework on packaging must consider the ***logistics*** aspect too. The first important characteristic is relatively to the *containment* of products. It is primarily responsible for restraining the contents of packaging (Lockamy, 1995). Another interesting aspect is the *unitisation* function of packaging that permits primary packages to be unitised into secondary packages, and for secondary packages to be unitised into tertiary packages for the efficient movement of packed products. Unitisation facilities the optimisation of material handling activities by reducing the number of discrete packages or loads which require handling. In order to optimise the unitisation process, it could be necessary that the packages are standardised. Packaging *standardisation* (i.e. the use of a limited number of different sizes of packages for the transportation and handling of products) is considered optimal from the logistics point of view, since it allows better results in the transportation and warehousing efficiency. The strength of standardised packaging is that it makes it easier to develop efficient logistics systems because it places similar demands on transport and material handling equipment (Sonnevold, 2000a; Starkey, 1994; Stock and Lambert, 2001; Torstensson, 1999). However, standardisation may also lead to less adaptability with regard to change (Jahre and Hatteland, 2004). Thus, when setting standard specifications for packaging, it is important to anticipate future changes of the packaging context as well as the permanence of these specifications (Koehorst et al., 1999).

From the logistics point of view, it is indispensable to consider the *storage* and *distribution* of products, optimising the number of vehicles and routes, and reducing waste trips. From recent years, the *traceability* of packages, and thus of products, during the distribution is assuming fundamental importance. Packaging traceability technologies (for example Radio Frequency IDentification (RFID)) allow the identification of packages position in real time and in continuous, increase of packaging information, reduction of shipment delays and tracking of lost shipments. The packaging identification shall also protect against theft and product manipulation during distribution. From a theoretical point of view, the application of the RFID technology to product packages could lead to a more detailed knowledge of the impact of the real time data, i.e. the identification of products in real time, the evaluation of the travelled time and distance travelled, in a logistics system.

Last relevant aspect to consider about packaging logistics is the *reverse logistics*. Reverse logistics is the term used to describe the back flows of packaging and shipping materials from the retailer to the manufacturer. These flows are no added value and it could be necessary to optimise them, for example by using the outbound trip for taking back unwanted and/or empty products.

The fourth fundamental packaging key driver concerns the ***cost*** evaluation. First, it should be operated for reducing costs as much as possible, increasing the *efficiency*. The right use of the packaging system (in terms of materials, shape, transportation, stocking, etc.) can create important savings and benefits to companies that consider and analyse it. Packaging involves several industrial areas and several packaging *cost parameters* should be taken into account. They are related to cost of engineering, purchasing cost, transportation cost, warehousing cost, cost due to the reverse logistics, and cost of disposal. In order to minimise the total packaging cost, it could be necessary to integrate all the industrial parties involved in the process of packaging realisation, making a trade-off between them.

Since the 1990s, the ***environment*** has assumed increasingly importance in the packaging system. Packages should be developed by using as little material as possible in order to *reduce waste* and *minimise pollutant* emissions when packaging waste is incinerated or landfilled. The reduction of waste and consequently of the environmental impact of packaging could be possible by selecting *recyclable* materials and designing packaging that could be *re-usable*. In this way, the disposable of packaging could decrease the negative environmental effects produced by pollutant emissions and reduce waste volume. The *re-use* of packaging concerns its repeated use for a similar or for a different function (for example a cardboard packaging could become a box, a bag or a shelf). This aspect could become of fundamental importance in humanitarian logistics field where it is important to save everything in order to save money for helping more people as possible.

Another relevant characteristic to consider relating to the environmental aspect is the *sustainability*. The environmental sustainability is the rates of renewable resource harvest, pollution creation, and non-renewable resource depletion that can be continued indefinitely. Environmental sustainability is an interesting field since it operates in order to protect the environment and preserve scarce resources, for both present people and future generations, improving efficiency and optimising continuously environmental performance of the packaging system.

Next chapters will discuss each packaging key driver in details, analysing their main characteristics and requirements, and presenting each one through empirical studies (i.e. marketing and cost key drivers), case studies (i.e. logistics and environment key drivers) and action research (i.e. design key driver). After that, a case study on packaging for e-commerce supply chain is presented with the intent to underline the main similarities and differences between the packaging system for traditional shopping and that for e-commerce business.

3. *The first packaging key driver: Marketing*

3.1 Customer expectations and packaging communication

Marketing function determines the proper product mix for a given market segment, establishes pricing strategies, promotes the product mix for customer awareness, and identifies the strategic locations of product stores for a given market area (Lockamy, 1995). These market driven decisions have a direct impact on packaging apportionment, unitisation, and communication.

Product package is recognised as a vital tool in the marketing mix (Dowlatshahi, 1996; Hawkes, 2010; Hellström and Nilsson, 2011; Mensonen, 2012; Olander-Roese and Nilsson, 2009; Olsson and Györei, 2002; Rod, 1990; Rundh, 2009; Simms and Trott, 2010). By its marketing capabilities and properties, packaging plays a decisive role in facilitating meeting consumer needs and expectation (Saghir, 2004), attracting consumer interest, reinforcing the product image and visibility, persuading customers, and selling the product (Domnica, 2010; Olsson and Larsson, 2009; Prendergast and Pitt, 1996; Rundh, 2009; Silayoi and Speece, 2007; Underwood and Ozanne, 1998; Vernuccio et al., 2010).

Through its aesthetic function, packaging seduces the consumer (Domnica, 2010), communicates to him (Silayoi and Speece, 2004), and affects his purchase decisions at the point of sale (Prendergast and Pitt, 1996; Rod, 1990), when packaging becomes an essential part of the selling process (Rettie and Brewer, 2000), and the seller last chance for influencing customers to buy the product (Domnica, 2010).

Consumers evaluate a product during both the purchase and the consume/use (Kupiec and Revell, 2001; Löfgren and Witell, 2005; Zeithaml, 1988). Löfgren (2005) referred to this concept as the *first and second moment of truth*. The *first moment of truth* is about obtaining customer attention and communicating the benefits of an offer, i.e. the purchasing situation. A fundamental marketing function of the package in the store is to attract rapidly customer attention and differentiate the product from competitive products and brands (Mensonen, 2012; Rod, 1990; Underwood et al., 2001). In a supermarket with 1,500-1,700 articles in display, the consumer passes by 300 articles/minute and 53% of all purchases are done under the driving force of the moment (Domnica, 2010). Within those few seconds, the package needs to be a "silent salesman" that sells the product, attracts the customers, and holds the attention against the visual clamour of competitive products (Judd et al., 1989; Löfgren, 2005; Pildtich, 1973). Silayoi and Speece (2004) analysed the main packaging elements that potentially affect consumer purchase decisions, separating them into two categories: visual and informational elements. The visual elements consist of graphic and size/shape of packaging, and relate more to the affective role of decision-making. Informational elements relate to information provided and technologies used in the product package, and are more likely to address the cognitive side of decisions (Silayoi and Speece, 2004). The *second moment of truth* is about providing the tools the customer needs to experience the benefits when using the product, i.e. the usage of the product at the point of consumption and recycling (Löfgren, 2005).

In the business to consumer domain, the product and its package are often perceived as closely integrated and the consumer initial impression of the quality and value of a product is sometimes determined by his perception of the package (Olsson and Larsson, 2009; Silayoi and Speece, 2004). If it communicates high quality, consumers assume that the product is of high quality; from the other hand, if the package symbolises low quality, consumers transfer this low quality perception to the product (Silayoi and Speece, 2004). The integrated product and packaging system needs to maintain and communicate the value perception, since package gives a promise of what the enclosed product has to fulfil (Downes, 1989). In this interface between the product and the consumer, communication cover a fundamental role (Olsson and Larsson, 2009), and package represents one of the most important vehicles for communicating the brand message directly to the target consumer (Wells et al., 2007). In agreement with Matzler et al. (1996), customer satisfaction is crucial for future business success. Achieving customer satisfaction means understanding and anticipating what users want, but do not expect, from the product in the future. Matzler et al. (1996) also stated that the most significant point is to delight the customer with products and services, generating a positive response in the customer and surprising him. A crucial element is to recognise which product qualities are decisive for satisfying the customer and which features may prevent dissatisfaction.

Many studies were conducted on the marketing function of packaging. Rod (1990) described the packaging as a marketing tool and a good means to attract consumers during the purchasing process. Löfgren and Witell (2005) focused on an empirical investigation of how customers experience packaging in everyday commodities in order to increase the knowledge of the role of packaging in the perception of quality. Simms and Trott (2010) developed a theoretical framework on packaging to examine how it contributes to marketing function.

3.2 The marketing perspective: the questionnaire on customer perception of primary packaging

3.2.1 The concept of packaging quality

In order to understand the customer perception on packaging attributes, it is necessary to analyse the concept of quality. Kano et al. (1984) developed the theory of attractive quality, inspired to Herzberg's Motivator-Hygiene Theory (M-H Theory), a two-factor theory of job satisfaction (Herzberg et al., 1959). Herzberg et al. (1959) firstly introduced a distinction between satisfaction and dissatisfaction, stating that factors causing satisfaction are different from those generating dissatisfaction. Ishikawa and Lu (1985) considered quality as a two-dimensional concept: backward-looking quality (attributes that underline defects and flaws in quality) and forward-looking quality (attributes that can become a product sale point).

Quality was often considered a multidimensional concept. Garvin (1987) identified eight dimensions for describing the basic attributes of product quality (i.e. performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality) and Juran et al. (1988) defined quality as the extent to which a product successfully serves the purpose of the user. In 1991, Feigenbaum recognised that the quality concept could be described by using a spectrum of quality attributes, such as reliability, serviceability, maintainability and attractability.

One criticism concerning quality was that people often consider all quality attributes to be equally important. Consequently Kano et al. (1984) defined a perspective of quality in which quality attributes were divided in different categories, based on the relationship between the physical fulfilment of a quality attribute and the perceived satisfaction of that attribute. During the years, the theory of attractive quality was applied in strategic thinking, business planning and product development, in order to demonstrate lessons learned in innovation, competitiveness and product compliance (Watson, 2003).

Löfgren and Witell (2008) defined different approaches for classifying quality attributes. Many studies concerning quality attributes used the original five-level Kano questionnaire (Lee and Newcomb, 1997; Löfgren and Witell, 2005; Matzler et al., 1996). In 2001, Kano introduced a three-level questionnaire in order to improve the classification process. Two other approaches were introduced for classifying quality attributes: the classification through direct questions and via importance.

According to Kano (2001), the theory of attractive quality was originated because of the explanatory power of a one-dimensional recognition of quality. Kano et al. (1984) classified the quality attributes in five categories:

- Attractive quality: it is a surprise and delight attribute that provides satisfaction when fully achieved, but does not cause dissatisfaction when not fulfilled. Such attributes are not normally expected and they are often unspoken, since they unexpectedly delight customers (Kano, 2001);
- One-dimensional quality: it provides satisfaction when achieved and results in dissatisfaction when not fulfilled. According to Gustafsson (1998), one-dimensional attributes are those with which companies can compete;
- Must-be quality: it is taken for granted when achieved, but results in dissatisfaction when not fulfilled since customers expect these attributes and view them as basic;
- Indifferent quality: it is neither good nor bad and consequently it does not result in either customer satisfaction or dissatisfaction;
- Reverse quality: it refers to a high degree of achievement resulting in dissatisfaction and to a low degree of achievement resulting in satisfaction.

All quality attributes can be satisfied or dissatisfied independently and they can change from a status to another in accordance with the changes in customer perspective. Kano (2001) stated that quality attributes follow a life cycle in which they start with being "indifferent" and finally end as "must-be" attributes.

3.2.2 The methodology

A five-level questionnaire of Kano's theory of attractive quality (Kano et al., 1984) was used by Löfgren and Witell (2005) to analyse the perception of Swedish customers with regard to packaging quality attributes during the purchase and the use of a product. Based on Löfgren and Witell's work (2005), it has been reproduced the same empirical investigation on Italian users to compare the results with the corresponding situation in Sweden.

The study has been based on an empirical investigation on how Italian customers perceive packaging quality attributes during the use of a product. The analysis has been conducted by submitting a questionnaire to 845 Italian users, randomly chosen and directly interviewed. The sample is comparable with that of Sweden (708 responses). The Italian respondents have comprised 377 women (44.6%) and 468 men (55.4%), from several parts of Italy and having an average age of 33.1 years. The main level of education has been high school (41.1%), followed by bachelor (22.3%) and master's degree (22%) (Figure 3.1).

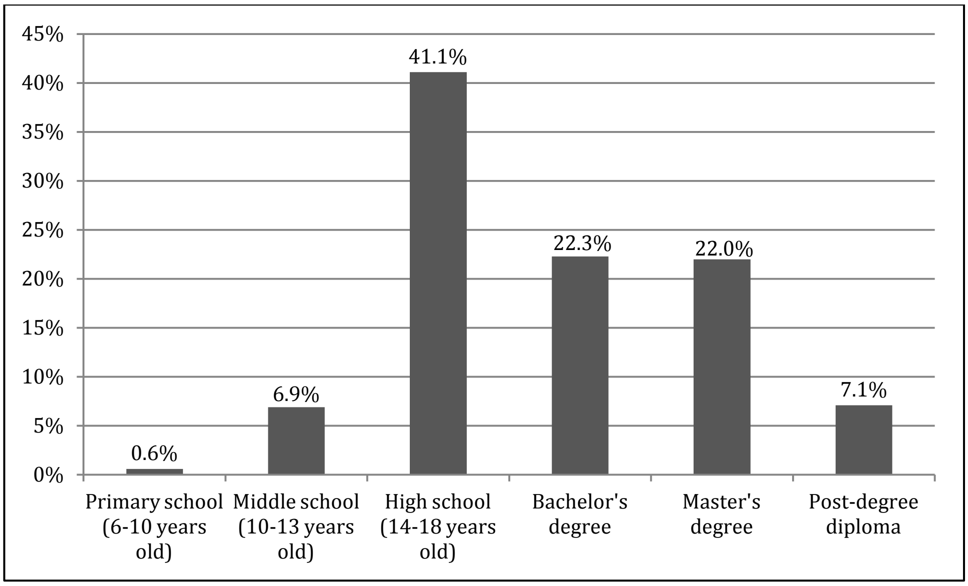


Figure 3.1. The classification of the Italian sample by education level

The questionnaire (shown in Appendix A) has asked Italian customers how they perceive packaging quality attributes during the use of a product. It has been divided in three sections:

1. General information about the customers (e.g. age, gender, level of education);
2. Packaging features: several pairs of questions, relative to the user packaging perception if packaging presents a specific characteristic (functional question) and if it does not present that attribute (dysfunctional question). Customers have had to choose among five alternatives (*I like it that way*, *It must be that way*, *I am neutral*, *I can live with it that way* and *I dislike it that way*) (Figure 3.2);

1.1 What is your perception of a package that protects the product? *(Functional question)*	1. I like it that way	1. Penso sia positivo quando è così
	2. It must be that way	2. Mi aspetto sia così
	3.I am neutral	3.Non mi interessa/Neutrale
	4.I can live with it that way	4.Posso accettare che sia così
	5.I dislike it that way	5.Non mi piace quando è così
1.2 What is your perception of a package that does not protect the product? *(Dysfunctional question)*	1. I like it that way	1. Penso sia positivo quando è così
	2. It must be that way	2. Mi aspetto sia così
	3.I am neutral	3.Non mi interessa/Neutrale
	4.I can live with it that way	4.Posso accettare che sia così
	5.I dislike it that way	5.Non mi piace quando è così

Figure 3.2. An example of a double question (functional and dysfunctional)

Responses to both functional and dysfunctional questions have been required in order to categorise customer needs. The classification into *attractive* (A), *one-dimensional* (O), *must-be* (M), *indifferent* (I), *reverse* (R) and *questionable* (Q) (Q responses include sceptical answers (Kano et al., 1984)) has been made by using an evaluation table (Figure 3.3), adapted by Löfgren and Witell (2005) from Berger et al. (1993).

Quality attribute → ↓		Dysfunctional				
		Like	Expect	Neutral	Accept	Dislike
Functional	Like	Q	A	A	A	O
	Expect	R	I	I	I	M
	Neutral	R	I	I	I	M
	Accept	R	I	I	I	M
	Dislike	R	R	R	R	Q

Quality attributes
A = Attractive
O = One-dimensional
M = Must-be
I = Indifferent
R = Reverse
Q = Questionable

Figure 3.3. Evaluation of Kano's questions adapted by Löfgren and Witell (2005) from Berger et al. (1993)

For each pair of questions (functional and dysfunctional), a relative value has been calculated in order to define the packaging quality attribute dimension. Figure 3.4 shows an example of the application of the procedure of response analysis inspired to Löfgren and Witell (2005).

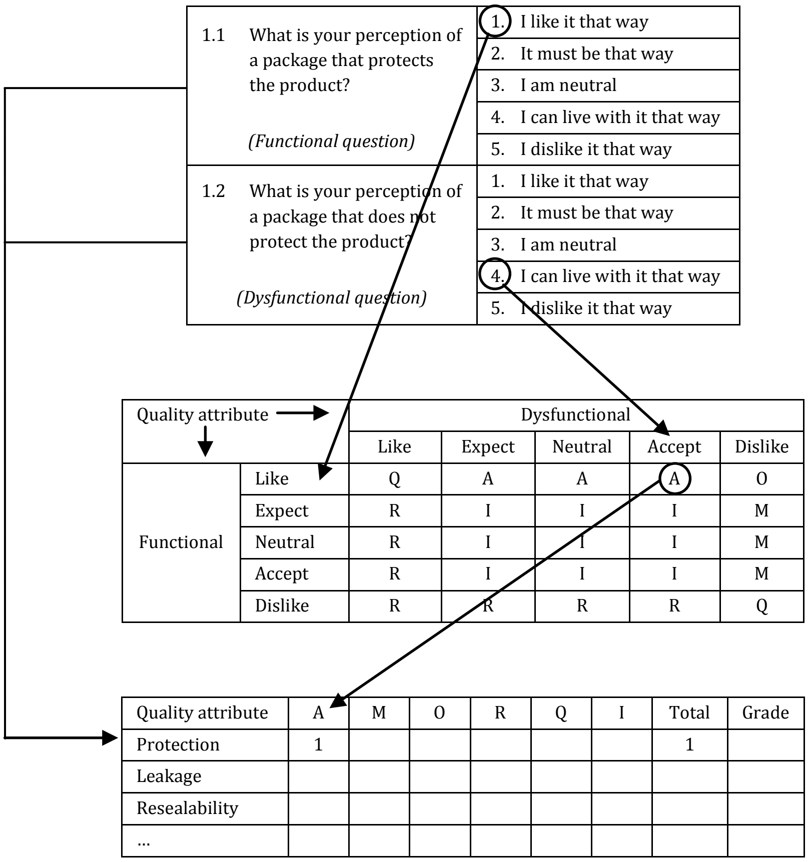


Figure 3.4. A schematic example of the procedure used for classifying packaging quality attributes (Löfgren and Witell, 2005)

The analysed packaging quality attributes have been classified into three entities:

a. Technical: packaging technical functions (e.g. protection of the product, use of recyclable materials, additional characteristics);
b. Ergonomic: everything relating to the adaptation to the human physique and behaviour when using the product (e.g. ease of grip, ease of opening, ease of dosing, user-friendly);
c. Communicative: packaging ability to communicate information to customers (e.g. use of symbols, declaration of contents, instructions for using packaging, communication of the brand).

3. Importance of packaging characteristics: customers have had to assign a level of importance between 1 (not important) and 10 (very important) to packaging quality attributes, discussed in the second part of the questionnaire.

3.2.3 Results and discussion

In order to evaluate the statistical significance of the study, the category strength (CS), the total strength (TS) and the number of questionable answers (Q) have been analysed with a statistic test: 15 packaging quality attributes have presented a p-value < 0.05 (11 of them have had a p-value < 0.01). Moreover, the number of questionable answers has been very low (about 0.5% for each question): the data have demonstrated that the analysis has been statistically relevant.

The results of the empirical study are presented in Table 3.1.

Quality attribute	Classification	Classification agreement	CS [%]	TS [%]	Q answers [%]	Better [0÷1]	Worse [0÷1]	Level of importance [1÷10]
Technical entity								
Protection	Must-be	38.7%	10.1	78.5	0.9	0.41	0.69	9.59
Leakage	Combination	I (26.8%) O (25.4%)	1.4	68	1.1	0.52	0.46	7.30
Resealability	Combination	A (33.7%) O (33.1%)	0.6	79.1	0.9	0.68	0.46	8.33
Recyclable material	One-dimensional	43.9%	13.8	87.2	0.5	0.75	0.58	8.72
Additional functions	Indifferent	50.1%	14.7	43.6	0.8	0.44	0.09	5.80
Attractive and nice looking print	Indifferent	64.8%	44	28.1	0.9	0.28	0.08	4.52
Hygienic	One-dimensional	51.3%	12.7	94.5	0.4	0.56	0.90	9.52
Ergonomic entity								
Easy to grip	One-dimensional	39.7%	17.1	80.9	0.1	0.59	0.63	8.40
User-friendly	One-dimensional	41.6%	11.2	86.6	0.1	0.56	0.72	8.50
Easy to open	Combination	M (32.1%) O (34.6%)	2.5	80.3	0.6	0.51	0.70	8.60
Easy to empty completely	One-dimensional	33.1%	3.7	72.8	0.8	0.45	0.62	8.06
Easy to dose	Attractive	38%	7.1	79.7	0.6	0.70	0.42	7.90
Fit in storage spaces	One-dimensional	32.3%	5	75.7	0.1	0.60	0.49	7.45
Contain just the right quantity	Indifferent	31.4%	5.6	63.3	1.5	0.53	0.41	7.39
Easy to throw in the household waste	One-dimensional	46.2%	21.1	87.1	0.1	0.62	0.72	8.32

Communicative entity								
Declaration of contents	Indifferent	46%	27.7	52.1	0.6	0.36	0.36	7.04
Instructions	One-dimensional	29.7%	6.1	75	0.7	0.53	0.55	7.97
Symbols	One-dimensional	35.3%	9.2	78	1.1	0.53	0.63	8.03
Open-dating	Must-be	51.7%	12.4	93.8	0.6	0.43	0.92	9.47
Aesthetically appealing	Indifferent	61.3%	37.9	36.4	0.2	0.34	0.13	5.00
Communicates product family category	Indifferent	43.9%	20.3	54.3	0.4	0.45	0.31	6.38
Communicates a certain brand	Indifferent	40.3%	15.1	58.3	0.4	0.34	0.46	7.01
Appearance = content	One-dimensional	32.1%	6	73.2	0.1	0.48	0.59	8.24

Table 3.1. An overview on packaging quality attributes

Each packaging quality attribute has been classified as attractive (A), one-dimensional (O), must-be (M), indifferent (I), reverse (R) or questionable (Q). The greatest number of quality characteristics of packaging (10 out of 23) have been one-dimensional, such as the use of recyclable materials, hygiene, ease of grip, user-friendly, use of instructions and symbols; the absence of these attributes leads the customers to be dissatisfied. 7 out of 23 packaging quality attributes have been considered indifferent by Italian customers (e.g. aesthetically appearance, declaration of contents, communication of the brand). Only two packaging quality attributes have been defined must-be features: protection and expiration date. Customers take the expiration date and the protection of the product for granted and they are dissatisfied if these attributes are not fulfilled. The ease of dosing has been the only attractive quality attribute, according to Italian customers' responses. This characteristic may be interesting to be further explored, as it may be a factor of surprise and delight for customers. Moreover, three packaging attributes cannot be clearly classified into specific dimensions, as two categories have been close to tied: these characteristics have been defined as "combination" (Lee and Newcomb, 1997). They have been product leakage (combination of indifferent and one-dimensional), resealability (combination of attractive and one-dimensional) and ease of opening (combination of must-be and one-dimensional). According to the quality attribute life cycle introduced by Kano (2001), product leakage is evolving from indifferent to one-dimensional attribute, resealability seems to be changing from attractive to one-dimensional and ease of opening is moving from one-dimensional to must-be quality.

For each packaging quality attribute, it has been calculated a better and a worse average value, that indicate whether customer satisfaction can be increased by satisfying a certain requirement (better) or whether fulfilling this requirement merely may prevent the customer dissatisfaction (worse) (Berger et al., 1993).

$$\text{Better average} = \frac{\sum_{i=1}^{n}(A+O)}{\sum_{i=1}^{n}(A+O+M+I)} \qquad \forall j$$

$$\text{Worse average} = \frac{\sum_{i=1}^{n}(M+O)}{\sum_{i=1}^{n}(A+O+M+I)} \qquad \forall j$$

where:

i=1,…,n is the number of responses for each packaging quality attribute

j=1,…,m represents packaging quality attributes

The maximum value of better and worse average is 1. The closer the value is to 1, the greater is the influence on customer satisfaction. A value near 0 means that the customer is not influenced by a certain quality attribute (Matzler et al., 1996). In order to provide an overview of packaging characteristics, both the better and the worse values of the investigated quality attributes have been plotted in a Worse-Better Diagram (Figure 3.5).

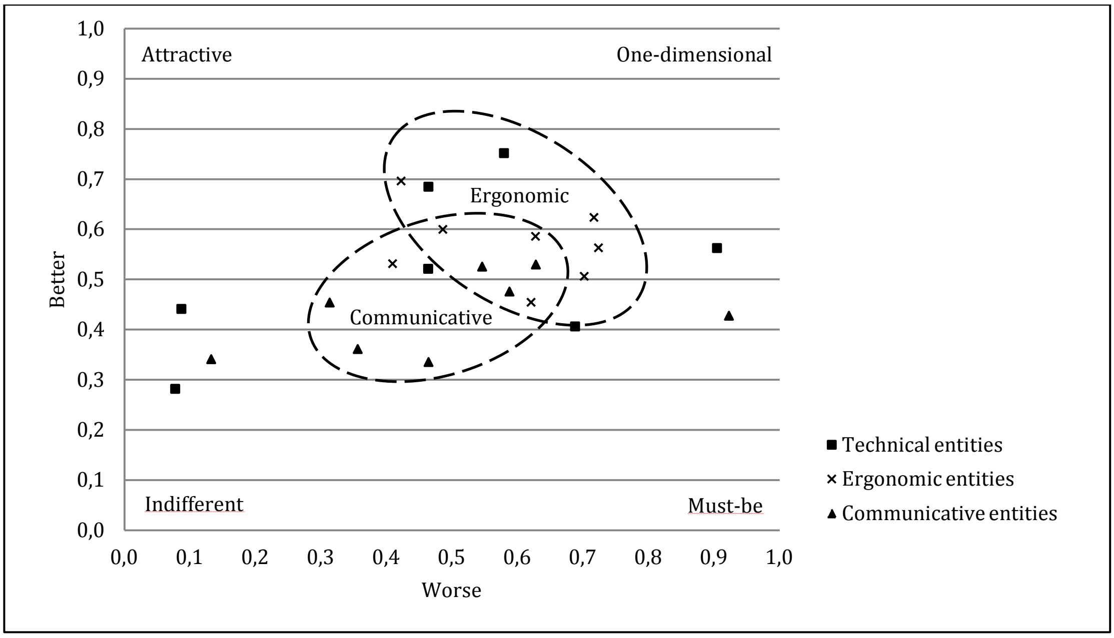


Figure 3.5. Worse-Better Diagram for Italian perception of quality attributes

The Worse-Better Diagram focuses on technical, ergonomic and communicative entities. Contrary to the ergonomic and communicative entities, it has been not possible to identify a definite cluster for the technical group, since the packaging quality attributes are scattered in the diagram, moving from one-dimensional (e.g. recyclable materials) to indifferent (e.g. additional functions) to must-be (e.g. protection).

Ergonomic and communicative entities, instead, define definite clusters in the Worse-Better Diagram: the packaging quality attributes belonging to the ergonomic entity are classified mainly as one-dimensional. They are distinctive attributes, important during the use of the product; customers consider them during the purchase of a product, comparing different brands. Italian customers locate the communicative quality attributes in the middle of the diagram. They delineate a specific cluster, but it is not clear the dimension to which they belong.

The questionnaire also has pointed out the importance that Italian customers give to each quality attribute, choosing a value between 1 (not important) and 10 (very important). The highest values of importance have been assigned to the protection of the product (9.59) and the open-dating (9.47) (according to their classification as must-be attributes) and to the hygienic feature (9.52). Italian customers seem to be interested neither in the aesthetics of packaging (the attractive and nice looking print and the aesthetic appeal have low levels of importance: 4.52 and 5.00 respectively) nor in the additional functions (5.80).

3.2.4 Comparison between Italian and Swedish perception of primary packaging

The results of the questionnaire have been compared with a similar survey conducted in Sweden by Löfgren and Witell (2005). Both Italian and Swedish customers have classified protection of the product and declaration of expiry date as must-be packaging quality attributes. According to Matzler et al. (1996), the must-be quality (M) is considered the most important category among one-dimensional (O), attractive (A), must-be and indifferent (I) (M>O>A>I). These two attributes (protection and expiry date) must always be satisfied because they are taken for granted when fulfilled, but result in dissatisfaction when not achieved. The handleability is another element considered in the same manner by the two countries: both Italians and Swedes consider the ease of grip, ease of opening and user-friendliness as one-dimensional attributes, in which companies may compete (Gustafsson, 1998). Unlike Swedish users that have defined resealability, the use of recyclable materials and containment of the right quantity as attractive, Italian customers have considered only the ease of dosing as attractive. Italians have defined the resealability as a combination of attractive and one-dimensional, the use of recyclable materials as one-dimensional and the containment of the right quantity as indifferent. They are interested in the theme of recyclability, since they are satisfied if products are made by recyclable materials and dissatisfied if this quality attribute is not achieved.

Analysing the Worse-Better Diagram, unlike the Italian situation, the technical packaging qualities cover a clearer position for Swedish customers: they may be viewed as creators of attractive quality. Concerning the communicative entity, Italian and Swedish customers have different perception: Swedish users have located the communicative packaging quality attributes between one-dimensional and must-be categories and they think that communicative attributes contribute little in creating customer satisfaction. Italians have located these attributes in the middle of the diagram; they do not define a specific classification for communicative quality characteristics, as it is not clear the dimension to which they belong. Similar observations can be made for the ergonomic entity. Italian and Swedish customers have a similar behaviour: both perceive ergonomic characteristics (e.g. ease of grip, ease of opening, user-friendly) as distinctive attributes that they consider when comparing different brands, that lead to purchase a product and that are important during the use.

Considering the level of importance of all packaging quality attributes, Swedes have a similar behaviour to Italian customers, since they consider very important the protection of the product (9.47) and the open-dating (9.65), in addition to the product leakage (9.82) and to the declaration of contents (9.20). In the same way, the aesthetics and the additional functions are not relevant, neither for Italians nor for Swedes, while the hygienic attribute is considered less important by Swedish users than by Italian ones (8.73 *vs* 9.52).

4. *The second packaging key driver: Design*

4.1 Packaging design and development

After the analysis of the marketing aspect, it has been necessary to deal with the packaging design because it assumes a relevant role in the definition of packaging specifications (e.g. choice of materials, shape, protection degree, etc.). Packaging design could be considered the core packaging function, since a well-designed packaging system improves the company efficiency as well as reduces costs by eliminating product damages, makes easier handling solutions and better resource utilisations, and increases revenue by consumer fascination and satisfaction from the marketing point of view (Dominic, 2010). According to Dowlatshahi (1996), the package should be designed to be compatible with the logistics facilities of the buyer; it should be designed with proper consideration given to disposability and re-usability issues; and it should lend itself to biodegradable and recyclable materials. Finally, packaging design influences the efficiency of the entire supply chain in terms of function, feature, information, and cost (Dowlatshahi, 1996; Olsson et al., 2008).

Without an understanding of the influence of packaging design on the performance of the supply network, a valuable component in solving the supply network challenges for sustainable development will be lost (Olsson et al., 2007).

Several authors analysed the topic of packaging design. In 1996, Ge described three approaches to develop an efficient packaging design in logistics. The first is to concentrate on the primary package, trying to reduce the used materials and to increase the protection function. The second approach is to reduce the amount of secondary package and minimise board area. Finally, the last approach regards the optimisation of the space on the pallet and in the container during the transport. In 2002, ten Klooster described the processes and methods available for a more efficient and effective packaging design, paying attention to the need to consider all functional requirements for packaging system in the design process. In the same year, Young (2002) analysed possibilities and limits of packaging design, suggesting some specific steps that managers could take to build collaborative and productive relationships among packaging designers and decision makers. The main phases of a packaging design process have been identified in order to improve the effectiveness of the process. Gracía and Prado (2008) proposed a methodology based on four closely interlinked cornerstones: defining the design requirements as a prior stage in developing packaging; defining an organisational structure for the design, development and control of packaging; applying good practices in the design in line with entrepreneurial strategy; and, lastly, establishing control mechanisms that make it possible to improve packaging on a continuous improvement basis. In the same way, Bramklev (2009) defined seven phases for the packaging development process: packaging planning; packaging system development; packaging concept development; packaging design; production ramp-up; packaging system integration and packaging system production ramp-up. Recently, Azzi et al. (2012) provided a framework based on literature review to grant a holistic perspective on packaging design that leads to improve the efficiency of the whole supply chain.

4.2 Product and packaging co-design

The link between product and packaging development is a fundamental issue to take into account in order to make an efficient supply chain. Packaging is often considered very late in the development of new products (Olander-Roese and Nilsson, 2009; Olsson and Larsson, 2009). Indeed, at the present, the development of the package is normally carried out after the product has been fully designed (Bramklev, 2004; Bramklev et al., 2004; Esse, 1989; Jönson, 1999; Kooijman, 1995; ten Klooster, 2002).

According to Olsson and Larsson (2009), the integration between product and packaging development is not well established and immature. Today, the product and packaging developers constitute different parties in the supply chain with different core focuses and different development processes (Olsson and Larsson, 2009). In the technological development and innovation aspects, packaging design and development traditionally start when the core product is ready for production in the commercial launch phase (Jönson, 1993). Very few companies consider the integration of packaging development into the product development model (Motte et al., 2007a). According to Motte et al. (2007a), the barriers to such integration of packaging and product development seem to be twofold. First, packaging is not considered an integral part of the product, so it is not part of the product "culture" of the company (Motte et al., 2007a; Motte et al., 2007b). Secondly, although there are multiple ways to integrate packaging into product development, no general decision-making supports are available to develop a thorough policy in favour of this integration (Motte et al., 2007a).

Many authors (e.g. Bjärnemo et al., 2000; Bramklev et al., 2004; Olsson et al., 2008; Sonneveld, 2000a; Sonneveld, 2000b) identified the need for an integrated product and packaging development, particularly with respect to market differentiation and value addition. Integrated product and packaging development is also needed from a quality and efficiency perspective throughout the supply chain (Olsson and Larsson, 2009). The concurrent packaging and product design is expected to increase efficiency and effectiveness of the development process in terms of reduced lead-time, reduced consumption of raw materials for packaging, and a costly product solution (Bjärnemo et al., 2000; Bramklev et al. 2004; Bramklev, 2007; Olsson et al., 2008).

Bramklev et al. (2004) and Bramklev and Hansen (2007) proposed a literature review on product and packaging co-design, showing the need for research into integrated product and packaging development. Bjärnemo et al. (2000) proposed an integrated concept of the design of product and packaging; Motte et al. (2007a) studied the interaction between product and package during the whole product life cycle, defining a set of packaging related factors. Olsson and Larsson (2009) highlighted important challenges concerning the concurrent product packaging development related to improve value creation in the product/service system paradigm. Bramklev (2010) emphasised the importance and the need of an integrated development of the packaging system by proposing a survey performed in Swedish mechanical, pharmaceutical and food industries. Moreover, several studies proposed models and procedures for facilitating the concurrent design of product and packaging (Bramklev et al., 2005; Bramklev, 2009; Motte et al., 2007b).

4.3 Packaging design and logistics function

Packaging not only has to provide information to the consumer and differentiate the product on the shelf, but it has to preserve the product and facilitate handling (Holdway et al., 2002). Therefore, the packaging designer has to take into account a wide variety of often-conflicting interests as the strategic and operational design stages (Holdway et al., 2002).

Packaging design has the capacity to facilitate logistics activities, but the potential is usually not fully utilised because of product design limitations (Saghir, 2004). Olsson et al. (2007) suggested the importance of the integration between product packaging development and the logistics system. Since logistics activities are affected by packaging utilities (Bowersox et al., 1999), effective distribution and material handling require a proper packaging solution (Klevås, 2005). Packaging is usually not considered until the product design has been decided upon (Bjärnemo et al., 2000), which makes the packaging design limited by the product design (ten Klooster, 2002), hence restraining possible logistics solutions throughout the supply chain.

Dowlatshahi's work (1996) focused on facilitating the interface and collaboration between designers and the logisticians, considering four interesting areas, out of all the packaging design. Klevås (2005) showed empirically how the organisation structure of packaging competence and product development affects the combined impact of packaging and product on logistics. Chan et al. (2006) reviewed the major functions and roles of packaging, and suggested a systematic approach for packaging logistics. They proposed a methodology for considering the packaging design in order to integrate packaging into product development process and logistics system. Klevås (2006) bridged the gap between disciplines of engineering design, packaging and logistics by empirically testing the Design For Packaging Logistics approach, suggested by Klevås and Saghir (2004), and based on the product development process of IKEA. Olsson et al. (2008) highlighted the benefits regarding the integrated packaging development and logistics as a concurrent activity with product development for increased effectiveness and efficiency in the core production, from raw material suppliers to the final assembly of the product. A holistic system view, including the concurrent development and integrated production is emphasised because packaging logistics is becoming increasingly important in the development of sustainable business in supply networks (Olsson et al., 2008).

4.4 Eco-design

As the awareness that products and services cause serious environmental degradation has increased, the attention has shifted from finding end-of-pipe solutions to designing products that prevent such degradation from occurring in the first place or reduce such problems. Eco-design is an example of such an approach (Svanes et al., 2010).

Eco-design can be defined as the incorporation of environmental considerations into design (Holdway et al., 2002). The broad intention is to reduce overall life cycle impacts while maintaining performance and value for money (Holdway et al., 2002). For the packaging sector, this means design for resource minimisation (e.g. materials, energy, water, etc.), reduced hazards (such as heavy metals), re-use, recycling, and waste reduction (Holdway et al., 2002).

Holdway et al. (2002) suggested the way to overcome barriers to sustainable packaging and outlined perspectives and processes that help development teams maximise results in this increasingly important aspect of design: the environment. The design and choice of packages have become an essential strategy for the reduction of waste in order to minimise negative environmental impact (Andel, 1996; Stock, 1998; Wu and Dunn, 1995). These changes put pressure on how to design packages that are material efficient and easy to recycle, provide efficient transportation, warehousing and handling, and better possibilities for branding and communication (Jahre and Hatteland, 2004). Svanes et al. (2010) described a holistic methodology for sustainable packaging design, which takes into consideration important requirements on packaging solutions, grouped into five categories (i.e. environmental sustainability, distribution cost, product protection, market acceptance, and user friendliness).

According to the sustainability aspect, packaging is being asked to consume less material as possible in order to reduce the environmental impact. For instance, by replacing a cardboard carton and a plastic inner sleeve with a polypropylene film pack, UK supermarket chain Sainsbury's removed a layer of packaging from its own brand garlic bread. This reduced packaging weight by 70%, improved transit pack efficiency by 20%, and still protected the product (Holdway et al., 2002). This is an example of how it is possible to reduce packaging materials by designing a better package, maintaining the same protection level and improving the transportation efficiency.

Another interesting example for reducing the environmental impact of packaging is represented by the re-use of packaging materials for the same protection and containment function or for fulfilling a different function from their primary one (for example designing objects to be used in the everyday life).

4.5 Packaging materials

Packaging comes in a wide assortment of materials depending on the type of content it will hold. The main purpose of packaging is to keep its contents safe and intact during shipping and storage. Different kinds of packaging materials are used for retail products that will be put on display and sold. Packaging for bulk shipping and storing of products is designed from materials that are sturdy and meant to protect the contents. Retail packaging is designed to be attractive to consumers and advertise the product itself.

In order to satisfy the demand to protect, distribute and inform a great number of packaging materials is available. According to the mechanical[2], chemical[3] and climatic[4] properties, packaging materials can be classified in flexible, semi-rigid and rigid materials. The flexible packaging materials may be defined as the group of materials that are so soft that they are possible to form

[2] Mechanical properties represent the strength against impacts, vibrations and compressions.
[3] Chemical properties represent the material possibilities to avoid contamination of food as well as possibilities to avoid biological degradation and corrosion.
[4] Climatic properties represent the material possibilities to protect against light, moisture and radiation.

around the product. Semi-rigid materials can change their shape only in particular conditions and if stressed. Finally, rigid packaging materials cannot be curved nor change their shape.

The most common packaging materials can be classified in (Bolton, 2013):

Plastic gained popularity as a packaging material due to its light weight and durability. Plastic is moisture resistant and often used in food packaging to keep out air, which can lead to spoilage. The main disadvantage of using plastic packaging is the accumulation of waste in nature and its transference into the product under certain conditions. Plastic is used a lot in the form of polystyrene, as found in fast food product package.

Cardboard is a very light packaging material that is popular because of how inexpensive it is to manufacture. While many products use other types of materials for packaging, they are often stored and transported in cardboard packaging. Certain types of groceries, such as milk, are packed in cardboard containers that are specially coated to be fluid resistant. Cardboard is also a common type of packaging material for dry goods.

Glass is a material mostly used for packaging of liquids, beverages, cosmetics. Glass is good for protecting its content from moisture, but comes with the danger of being fragile and easily broken. The advantage of using glass for packaging is that it is re-usable and versatile in its colour and form.

Metal such as aluminium is a popular packaging material due to its low cost. Aluminium provides good protection for its content and prevents any microorganism from entering and contaminating the product. Aluminium plated tin cans are used for the packaging of tinned food. Metal drums are also used as packaging material for certain liquid products during shipping.

Using less material as possible can minimise the environmental impact, reducing pollutant emission. Recent innovations in packaging material continue to allow more to be done with less through lower impact solutions that simply use less (Dent, 2011).

4.6 The design perspective: a prototype of a dip sauce packaging

During the period spent at Lund University (Sweden) a packaging prototype has been realised by using the PaperLite® material by Flextrus.

Flextrus is a European company leader in flexible packaging solutions. Their solutions protect, preserve and reinforce the quality of customer products and brands in the food, healthcare and other demanding industries (Flextrus, 2013).

In 2007, Flextrus introduced a new packaging material called PaperLite®. It is a unique packaging concept with the ability to thermoform a real paper based substrate that comes from certified sustainable sources. Flextrus PaperLite® is a paper-based packaging material that puts a pack with the attractive look and feel of paper in the hands of consumers. Its real natural paper look and feel gives the opportunity to differentiate the products and attract consumers who prefer fibre-based packaging. According to a study conducted by Media Analyzer GmbH (2007), consumers prefer paper to plastic: 87% out of 7,970 European consumers interviewed declared to prefer paper before plastic; 79% of them finds paper more appealing and 93% regards paper as more sustainable.

Several advantages can be realised by using Flextrus PaperLite® instead of a standard polymer-based thermoforming material, such as:

- It is a real natural paper look and feel;
- It allows more than 25% weight reduction;
- It consists of sustainable and renewable paper;
- It is easily recyclable as paper;
- It is customisable in agreement with customers' needs;
- It is printable on both sides with full colour and text options for customer communication;
- It can be applied to many applications as food and healthcare packaging.

These advantages allow environmental benefits, the reduction of transportation cost and an efficient material handling.

4.6.1 The packaging prototype realisation

The packaging prototype chosen to realise has been a dip sauce packaging for the big market of fast food restaurant by using Flextrus PaperLite®. The traditional dip sauce packages are made in PET (PolyEthylene Terephthalate) plastics, a material more pollutant than the Flextrus PaperLite®. Figure 4.1 shows the difference in CO_2 emissions between PET plastic and Flextrus PaperLite®.

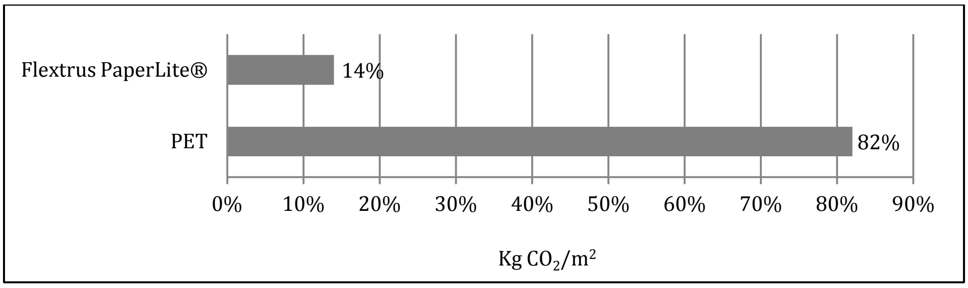


Figure 4.1. Difference in CO_2 emission between PET plastic and Flextrus PaperLite®

The model for the packaging prototype of a dip sauce has been realised by using AutoCAD software[5] and it is shown in Figure 4.2. After the realisation of the AutoCAD model, the prototype has been realised by using a three-dimensional printer. Figure 4.3 shows the realised prototype.

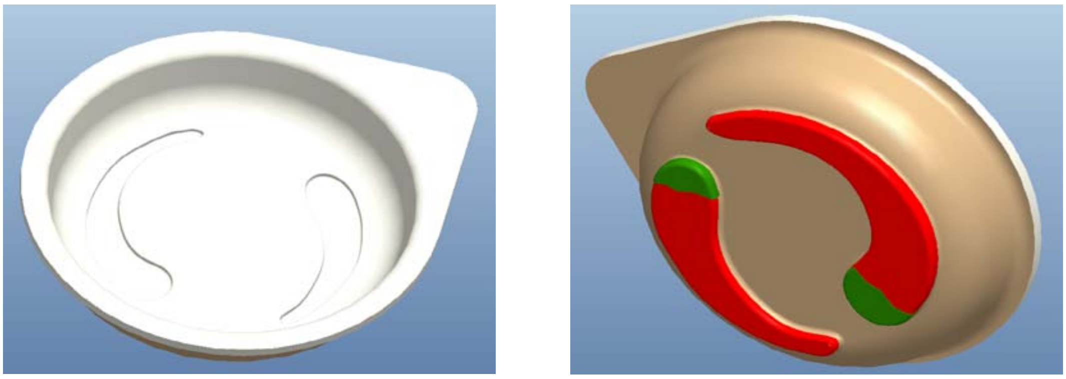


Figure 4.2. Model for the packaging prototype of a dip sauce

[5] AutoCAD is a software application for both 2D and 3D Computer-Aided Design (CAD) and drafting.

Figure 4.3. The realised packaging prototype of a dip sauce

The developed dip sauce can bring important advantages in terms of marketing, logistics and environmental aspects. From the marketing perspective, Flextrus PaperLite® is easily printable to both sides to be attractive and communicative to consumers. Moreover, the new package is easy to open and user-friendly so as to increase the handleability level and consequently customer satisfaction. Flextrus PaperLite® produces benefits from the logistics point of view, since it allows more than 25% weight reduction, facilitating material handling and transport, and more than 6% volume reduction, increasing the number of products transported in each truck with a consequent reduction in transportation and warehousing costs. The environment also benefits from the use of Flextrus PaperLite®: it is a first step to reduce the use of plastics packages composed mainly by pollutant materials, it is easy to recycle (since it is possible to recycle as paper), and the weight reduction allows the minimisation of CO_2 emission and consequently of environmental impact.

5. The third packaging key driver: Logistics

5.1 Packaging for logistics optimisation

Packaging logistics is a new concept that, during last years, has developed and gained increased attention by both industry and scientific community (Henriksson, 1998; Johnsson, 1998; Öjmertz, 1998; Saghir, 2002b; Twede, 1992; Twede and Parsons, 1997). The concept of packaging logistics is a value adding process in the supply chain, meeting customer demands by considering the packaging system in various logistics processes (Dominic, 2010).

Packaging logistics was defined by Johansson et al. (1997) as:

[…] aiming at developing (creating) packaging and packaging systems that support the objectives of logistics to plan, implement and control the efficient and effective material flow.

Bjärnemo et al. (2000) defined packaging logistics as:

[…] the interaction and relations between the logistics system and the packaging system that add values to the combined, overall system – the Enterprise.

Some years later, Saghir (2002b) suggested the following definition of packaging logistics:

[…] the process of planning, implementing and controlling the coordinated packaging system of preparing goods for safe, secure, efficient and effective handling, transport, distribution, storage, retailing, consumption and recovery, re-use or disposal and related information combined with maximising consumer value, sales and hence profit.

Packaging logistics focuses on the potential of achieving improved supply chain efficiency and effectiveness, since it is an interface between the activities in the supply chain and consumers (Hellström and Saghir, 2007; Saghir, 2002b).

The packaging system, in its entirety, fulfils a fundamental role in logistics, assuring the availability *of the right product, in the right quantity, in the right conditions, in the right place, at the right time, to the right customer, at the right price* (Shapiro and Heskett, 1985).

Packaging affects the performance of every logistics activity throughout the supply chain (Bowersox and Closs, 1996; Jahre and Hatteland, 2004; Nilsson et al., 2011); its specifications affect material handling, inbound logistics operations, purchasing, manufacturing, filling, warehousing, transportation, and retailing (Jahre and Hatteland, 2004). Moreover, packaging directly influences the time required for completion of operations (Lee and Lye, 2003), which ultimately affects product lead-time and due date performance (delivery) to the consumer (Lockamy, 1995).

During the years, several authors dealt with packaging logistics topic. Bramklev et al. (2001) analysed the interaction of packaging and logistics as an integrated discipline and put the packaging and logistics definitions into a model framework based on Porter's value chain (Porter, 1985) and Christopher's network theory (Christopher, 1998). Saghir and Jönson (2001) analysed several packaging handling evaluation methods in the grocery retail industry and pointed out the lack of specific evaluation methods concerning packaging concepts from a logistics point of view. Saghir (2004) identified packaging logistics parameters along the retail supply chain and developed a conceptual analysis model, in order to explain the concept of packaging logistics. Gracía et al. (2006) attempted to justify the following statement "projects to rationalise packaging contribute to the realisation of such strategies because of their implications for logistics and sales" from a logistics viewpoint, presenting the methodology and actions used for packaging innovations in a case study. A study to elaborate the actor experience from the added service of one technical food packaging innovation was presented by Olsson (2010). In 2011, Hellström and Nilsson identified and described the strategic potential of logistics-driven packaging innovation in retail supply chain, providing practitioners with a better basis on which to make strategic packaging and logistics decisions.

In order to facilitate an integrative approach of assembly and material supply systems, packaging could pay a key role because there are several interactions between packaging and logistics throughout the supply chain (Lockamy, 1995; Twede, 1992). In workstations, where the assembly and material supply systems can be physically integrated, considerable time and cost savings can be obtained by adjusting the packaging system to the assembly situation and to the components used (Harit et al., 1997; Liker, 2004). The impact of packaging decisions on logistics costs illustrates the need for strategic thinking in the assessment of packaging options. In addition, the combination of more demanding legislation suggests that packaging decisions must be viewed strategically within the logistics planning process (Lockamy, 1995).

According to Dowlatshahi (1996), logistics requirements for packaging should be incorporated at the design phase with marketing and manufacturing requisites. Hellström and Saghir (2007) provided an overview on the interactions between the packaging system and logistics process in the retail supply chain. Dominic (2010) stated that there are still many gaps to study about the interaction of logistics and packaging. The main gap consists of marrying packaging and logistics related to development of packaging and logistics activities such as easier handling for consumers (Dominic, 2010). Further understanding on packaging system performing throughout the supply chain with other agents such point of sale or distributor (Dominic, 2010). The problem is that each agent considers its own packaging without considering packaging on an inter-organisational level (Dominic, 2010). In order to bridge these gaps, Dominic (2010) introduced a tool named *PackaPerforma* that indicates the performance of packaging during its interactions with the agents and suggests improvement alternatives for packaging designers. In order to evaluate packaging performance throughout the supply chain, Olsmats and Dominic (2003) developed a systematic evaluation method (called *Packaging Scorecard*) from the Balanced Scorecard method by Kaplan and Norton (1996), and tested it with two case studies. The results indicated that the method could be very useful to get a systematic overview of packaging performance throughout the product supply chain.

The proper use and exchange of the right packaging-related information in a grocery supply chain is critical to achieve (Saghir, 2002b). The use of well-defined packaging-related information available for all the actors in the supply chain also facilitates an integrated and supply chain orientated packaging development (Saghir, 2002b). Saghir (2002b) discussed what kind of information is required to properly evaluate the packaging concept, what parameters are missing and how the information should be used in the supply chain. Finally, he suggested a procedure for packaging logistics performance.

5.2 Reverse logistics function of packaging

Traditional logistics has been changed substantially for legislation and environmental awareness and in turn, its attention to the backward movement or return of goods is increased (Yang and Zhou, 2008). Issues as reverse logistics, product recovery, re-manufacturing, and re-using have received growing attention since last decades (Yang and Zhou, 2008). The field of reverse logistics contains all logistics processes beginning with the take-back of used products from customers up to re-usable products and waste disposal (Handfield and Nicols, 1999; Minner and Kleber, 2001; Wu and Dunn, 1995). Reverse logistics refers to the logistics management skills and activities involved in reducing, managing and disposing of hazardous or non-hazardous waste from packaging and products. It includes reverse distribution, which causes goods and information to flow in the opposite direction from normal logistics activities, and processing used products and processing returned merchandise due to damage, seasonal inventory, re-stock, re-calls, and excess inventory (Kroon and Vrijens, 1995; Xiangru and Hua, 2009). Implementing an efficient reverse logistics can produce tangible and intangible value and can lead to better corporate image (Carter and Ellram, 1998; Xiangru and Hua, 2009).

Since the 1990s, several authors have started to study the reverse logistics of packaging. Kroon and Vrijens (1995) considered the re-use of secondary packaging material a practical application of reverse logistics. The authors presented several numerical approaches that may be used to create a return logistics system for returnable packaging. Yang and Zhou (2008) proposed a general returned logistics network for packaging materials during the storage and transportation process. Pålsson et al. (2011) developed a theoretical evaluation model for comparing cost efficiency and environmental impact of one-way and returnable packaging systems in supply chain. Xiangru and Hua (2009) described how to organise reverse logistics network. Regarding returnable packaging systems, several studies suggested that the impact of packaging on the environment could be improved in many contexts through more efficient material handling, improved cube use and reduce amounts of packaging materials (Maloney, 2001; Twede and Clarke, 2004). Several studies also argued for the logistical and financial advantages of returnable packaging (e.g. Mollenkopf et al., 2005; Twede, 1999).

5.3 The packaging traceability within indoor environments

Next paragraphs will present a case study by using the Radio Frequency (RF) transmission in order to trace packaging flows within indoor environments, mapping in real time position, path and velocity. Firstly, a brief description of the Radio Frequency IDentification technology used in the case study is presented.

5.3.1 The traceability of items through Radio Frequency IDentification (RFID) technology

Generally, companies provide goods and/or services to customers, purchasing raw materials from suppliers. In order to increase productivity and efficiency within the supply chain, the parties (suppliers, manufacturers, and customers) have to exchange materials and information between them (Manzini et al., 2008; Persona et al., 2004). The traceability of flows of materials and information within a company is a crucial aspect that has to be optimised (Gamberi et al., 2009; Regattieri et al., 2007).

In a typical supply chain, logistics flows can be classified into *physical* and *informative*. Physical flows include operative activities (e.g. transport, storage of raw materials, semi-finished and finished products, etc.). A great purpose of the optimisation of these flows is the reduction of transport and storage costs. Information flows concern the information on the demand, logistics, and production planning. Figure 5.1 shows a graphical representation of a typical supply chain, underlining physical and informative flows.

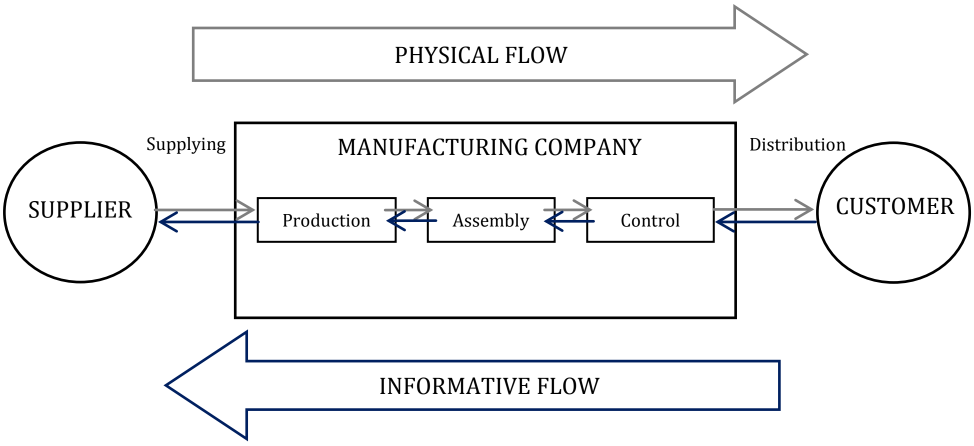


Figure 5.1. General scheme of a typical supply chain, underlining material and information flows

Within the supply chain, it may be essential to know both the position and the movements of operators, pallets, tools, and packages. Traditionally, the process of traceability of goods has been performed through the asynchronous and automatic fulfilment of doorways by materials (e.g. bar code) or totally manually by an operator who identifies and measures all movements between work centres, assembly and control workstations, and warehouses. This system implies approximate measurements, full-time effort and time wasted by the operator, and the possibility of human error (Finkenzeller, 2003). In order to improve the performance in the traceability process and to reduce costs optimising the internal flows, companies are beginning to use automatic identification procedures based on Radio Frequency (RF) transmission such as Radio Frequency IDentification (RFID) technology.

In recent years, RFID systems have become very popular (Liu et al., 2007) for locating the position and mapping the movements of goods and people. The application of RFID has attracted considerable interest among scientists as well as managers faced with the problem of optimising production processes in several industries (Finkenzeller, 2003, Singh et al., 2008; Wu et al., 2009). RFID system has enormous economic potential, which many manufacturers (e.g. Wal-Mart, Tesco, Marks & Spencer and other retailers) have already recognised and started to successfully use the system (Collins, 2004; Collins, 2005; Pruitt, 2004).

Radio frequency identification is a method for storing and retrieving data through electromagnetic transmission to a compatible integrated circuit (Lin and Lin, 2005). By describing RFID components and their functions, it is possible to understand the technology and issues that influence the application of an RFID system. A typical RFID consists of three components: RFID tag (the data-carrying device located on the object to be identified), RFID reader (it has the overall function of reading and translating data emitted by RFID tags) and the host computer (it communicates with the reader and information management system).

The RFID components and their connections are shown in Figure 5.2 (Finkenzeller (2003) version modified by Hellström (2004)).

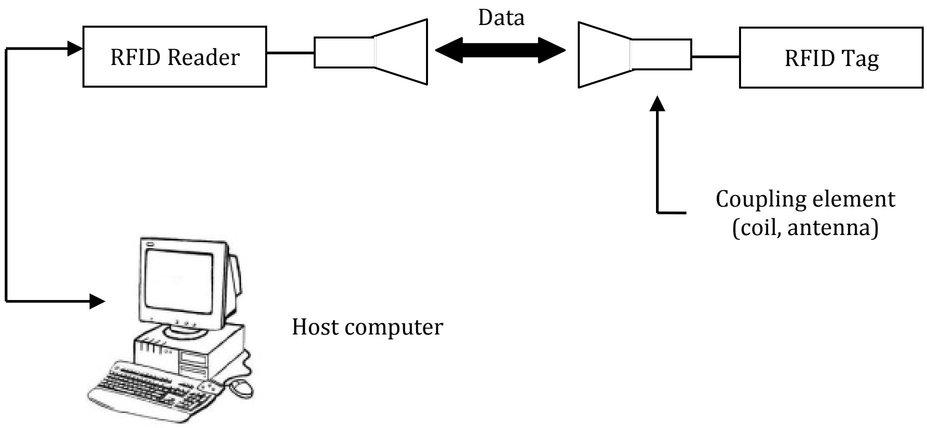


Figure 5.2. Components of an RFID system (Finkenzeller (2003) version modified by Hellström (2004))

RFID – Ultra Wide Band (UWB)

Out of all RFID technologies, Ultra Wide Band (UWB) is the most accurate and fault tolerant system. It can have a widespread usage in indoor localisations. RFID-UWB is an emerging radio technology marked by accuracy in the estimation of the position, and the precision with which it is possible to obtain that accuracy.

According to the most influential and widespread definition, provided by the Federal Communications Commission Regulation (2002), an UWB system is defined as any intentional radiator having a fractional bandwidth greater than 20% or an absolute bandwidth greater than 500 MHz. These requirements mean that a band-limited signal, with lower frequency f_L and upper frequency f_H, must satisfy at least one of the following conditions:

$$\frac{2(f_L - f_H)}{(f_L + f_H)} > 20\%$$

$$f_L - f_H > 500\ MHz$$

According to Gezici et al. (2005), the main characteristics of an RFID-UWB system are the transmission of a signal over multiple frequency bands simultaneously and the brief duration of that transmission. RFID-UWB system requires a very low level of power and can be used in close proximity to other RF signals without causing or suffering interferences. At the same time, the signal passes easily through walls, equipment and clothing (Fontana, 2004; Gezici et al., 2005; Molish, 2005) and more than one position can be tracked simultaneously. Moreover, RFID-UWB systems overcome limitations due to reflection, refraction, and diffraction phenomena, using pulses for the broadband transmission. The use of RFID-UWB offers other advantages, such as no line-of-sight requirements, high accuracy and resolution, lighter weight (the weight for each tag is less than 12 g) and the possibility to trace multiple resources at the same time, real-time and three-dimensionally.

Introducing RFID-UWB system represents an opportunity to improve inventory management, returns management, tracking and tracing systems, process control, security, sales, and enhance consumer experiences (Fleisch and Tellkamp, 2005; Jones et al., 2004; Lumsden and Acharjee, 2005; McFarlane and Sheffi, 2003; Smith, 2005; Wong and McFarlane, 2007). Despite this, there are several adoption barriers to realise supply chain benefits by using RFID-UWB system, including cost, and the regression to share vital information with other actors along the supply chain (Fusaro, 2004; Hellström, 2009; Lai et al., 2005).

5.3.2 RFID technology applied to the packaging system

RFID technology has been introduced in the packaging sector due to the logistics advantages regarding the utilisation of automatic identification systems. This introduction mainly focuses on the secondary and tertiary packaging levels because the utilisation in the item level (product identification) has been difficult to justify in economics terms (Aliaga et al., 2011). Specifically, 250-300 millions of tags were used in 2006 in the tertiary level (IDTechEx, 2006). Furthermore, Thoroe et al. (2009) have predicted that in 2016 there will be 450 times more RFID tags in use than today. Therefore, a rapid increase in RFID tag consumption is expected in the packaging sector.

Technological developments in recent years, along with a reduction in tag price and emerging standards have facilitated trials and rollouts of RFID technology in packaging. A study conducted by IDTechEx Limited (IDTechEx, 2002a) stated that the main benefits of the RFID technology in packaging are better service and lower costs.

Packaging incorporating RFID technology is usually referred to as *smart packaging* (called also *active* or *intelligent packaging*) and it is commonly used to describe packaging with different types of added value technologies, for example placing in the package a smart label or tag. The term smart packaging was used by Yam (2000; 2005) to emphasise the role of packaging as an intelligent messenger or an information link. According to the Smart Packaging Journal (IDTechEx, 2002b), smart packaging is described as

> [...] *packaging that employs features of high added value that enhances the functionality of the product*

and its core is a responsive feature. Smart packaging is often used to refer to electronic responsive features where data are electronically sensed on the package from a distance, using an automatic identification system as the RFID technology.

The application of RFID to packaging allows more frequent and automatic identification of packages (e.g. pallets, cases, and items) increasing the accuracy of the system, reducing the labour and time needed to perform the identification of packages and enabling near real time visibility, which in turn facilities the coordination of activities within and between processes. The costs of RFID technology in packaging and potential benefits can be variable in accordance with the packaging level that is tagged. Figure 5.3 (modified version of Hellström (2004)) illustrates the influence that tagging different packaging levels has on the retail supply chain processes.

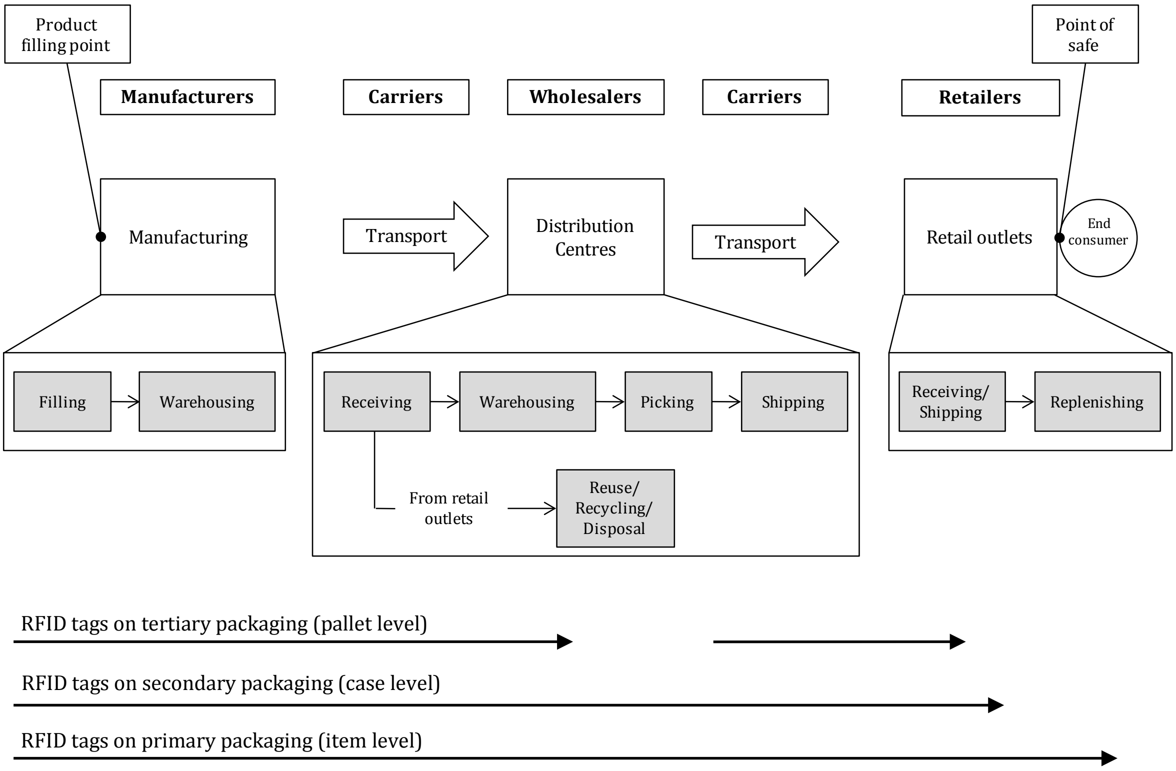


Figure 5.3. The influence of tagging different packaging levels along the supply chain (modified version of Hellström (2004))

As can be noted in Figure 5.3, RFID tags on tertiary packages may be used from the filling to the storing process. Furthermore, the tags on tertiary packages may be used from the shipping process of the distribution centre to the receiving and shipping process of the retail outlet. RFID tags on secondary packages could be used further downstream in the supply chain than tagged tertiary packages, i.e. from the filling process and all the way to the replenishing process. Irrespective of the activities within the replenishment processes, tagging of primary packages may be used in the whole supply chain, from the point of filling by the manufacturer to the point of sale in the retail outlet. Tagging of primary and secondary packages could also provide opportunities beyond the point of sale in retail outlets e.g. recycling, re-using, and post-sale service and support. The model presented in Figure 5.3 indicates that a manufacturer who applies tags to packages can gain direct benefits from primary and secondary packages tagging. According to Hellström (2004), the average time to pick an order decreases by roughly 25% when RFID technology is used in secondary packages. This means that the workforce conducting the picking activity, which is the core and the most labour-intensive activity in distribution centres could be reduced by approximately 25%. Hellström (2004) also stated that the ability to generate automatically orders by capturing the inventory levels through tagging of primary packages could reduce out-of-stock situations by approximately 50%.

6. *The fourth packaging key driver: Cost*

6.1 Packaging cost evaluation

Packaging follows the product through the supply chain from the production to consumption and has a crucial impact on the costs for handling, storing, transport and damage. A damaged product generally causes costs that exceed the value of the product. If the packaging system is correctly designed, it can give benefits to the product and competitive strength on the market.

Total packaging cost is a combination of the costs for materials, equipment, operations and labour. The packaging cost can also include the cost of product re-calls, failure to re-purchase by the customer and the cost of re-packing the product if not appropriately packed (Ge, 1996). Packaging affects almost all of the cost items in supply chain. Packaging costs mainly refer to the packaging material costs and labour costs (Lee and Lye, 2003). Packaging has also a significant impact on the efficiency of logistics system (Ebeling, 1990; Fernie and Sparks, 2004; Gustafsson et al., 2006; Jahre and Hatteland, 2004; Lancioni and Chandran, 1990; Lockamy, 1995; Twede, 1992) and it affects every logistics activity such as manufacturing, distribution, storage and handling (Ballou, 2004; Bowersox and Closs, 1996; Bowersox et al., 2002; Chan et al., 2006; Fernie and McKinnon, 2003; Hellström and Saghir, 2007; Jahre and Hatteland, 2004; Lambert et al., 1998; Saghir, 2004), which thus affects both efficiency and effectiveness in supply chain (Nilsson et al., 2011). Despite this, packaging-related costs in the logistics system are frequently overlooked by packaging designers (Twede, 1992).

Nowadays, the choice of the type of packaging is usually subject to considerations involving cost reduction (Gracía and Prado, 2008; Klevås, 2006). Packaging costs can be reduced through the re-design of products, re-design of logistics system and implementation of loss control strategies (Lockamy, 1995). A comprehensive loss control program should be developed to examine the impact of packaging on several factors (e.g. marketing, environment, design, logistics, production, etc.), and view packaging as a key strategic variable in the prevention of in-transit losses.

A very few works are found in the literature on the evaluation of packaging costs. Ge (1996) investigated the possibilities of cost reduction in packaging logistics, from primary to tertiary packages. Mollenkopf et al. (2005) developed a model to determine the combination of packaging and logistics costs for assessing the packaging choice decision and evaluated the relative influence of several factors. Lai et al. (2008) proposed a framework to integrate financial and environmental analyses of alternative packaging and logistics solutions. The value stream map is adapted to model material flow of both parts and packages, and an integrated material flow analysis is used as the common basis for cost analysis.

During the year, some authors dealt with the cost of re-usable packaging. According to Mollenkopf et al. (2005), re-usable packaging not only may minimise the ecological footprint of companies, but many firms also found that they can significantly reduce cost as well. Several studies (e.g. Cozart, 1997; Findlay, 1997; Parsons, 2002; Turvey, 1998) compared the cost of re-usable packaging systems to recyclable systems for a particular product in a specific manufacturing and logistics system before a packaging decision is made. Anecdotal evidence suggesting that re-usable packaging systems offer cost reduction opportunities over recyclable packaging thanks to their longer life (Andel, 1996; Trunk, 1995). When the initial cost of a re-usable packaging is amortised over its life, the cost of packaging material is usually lower than that of a recyclable disposable packaging (Mollenkopf et al., 2005).

The nature of re-usable packaging systems is dynamic as a two-way flow system is required (Mollenkopf et al., 2005). A number of handling, movements, and consolidation activities make up the two-way distribution system, and the costs of many of these operations are influenced by the packaging characteristics (Mollenkopf et al., 2005). Packaging cost affects the cost of packing, handling, transport, storage, and unpacking operations for all involved channel members (Rogers and Tibben-Lembke, 1999; Stock, 1998). The use of re-usable packaging eliminates the disposal cost and the need to purchase repeatedly packaging material (Mollenkopf et al., 2005). In many cases, it also reduces logistics operation costs since the re-usable packaging can be designed to increase cubic efficiency for transport and storage as well as easy packing, handling, and unpacking (Mollenkopf et al., 2005). Re-usable packaging can also be designed to provide higher levels of product protection (Mollenkopf et al., 2005).

6.2 The cost perspective: the questionnaire on company perception of packaging system

6.2.1 The methodology

In order to understand the packaging perception of Italian companies, an experimental study on packaging development and logistics has been realised by adopting a questionnaire submitted to several Italian companies.

The questionnaire (shown in Appendix B) has been made by personal interviews, after a previous contact by phone. For this reason, all the companies have filled in the questionnaire with a response rate of 100%.

The questionnaire is divided in two main parts: a first general description of the sample and several specific sections about packaging, which include:

- Physical characteristics of packaging;
- Packaging functions;
- Development of product and its integration with packaging;
- Relationship between packaging and environmental impact;
- Packaging logistics;
- Problems, necessities and requirements for the future.

For each section, several questions are included in the questionnaire and discussed during the interviews.

The questionnaire has been distributed to a sample of Italian companies, coming from several industrial sectors, like food and beverage, electronics and mechanical products.

The collected data have been studied by quantitative content analysis that has been allowed to understand and analyse the way in which companies manage packaging. After the analysis on the Italian situation, findings have been compared with those of a similar study led in Swedish industries and dealt in literature (Bjärnemo et al., 2000; Bramklev, 2004).

The questionnaire has been submitted to 23 Italian companies that have been divided in small (30.4%), medium (17.4%) and large companies (52.2%), in agreement with the European Union classification by annual sales.

Figure 6.1 shows the distribution of company annual sales: 70% of the interviewed companies has been declared to have revenues between 10 and 200 millions €. In the box plot of Figure 6.1, the grey box represents the values from 25° to 75° percentile.

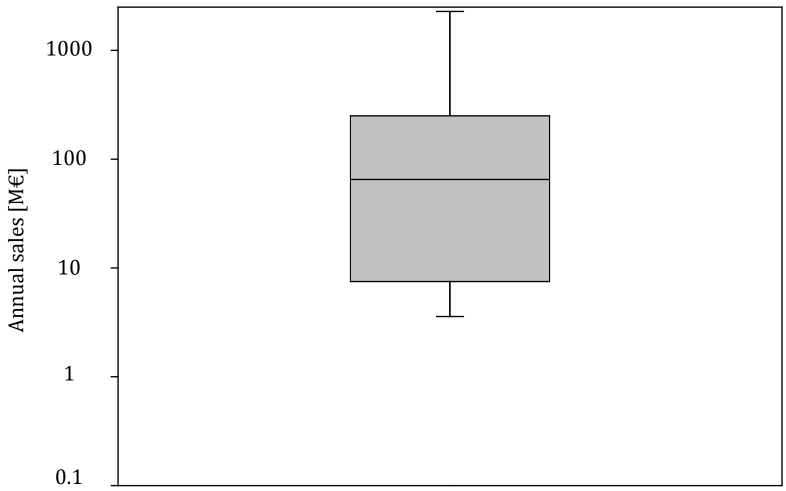


Figure 6.1 Distribution of company annual sales

The analysed companies have been manufacturing firms (82.6%), retailers (8.7%) and service providers (8.7%). As it is possible to see from Figure 6.2, the main sector from which the companies come is *mechanical* (30.4%), followed by *food* (17.4%) and *other* (17.4%). The latter consists of package producers, eyewear manufacturers and companies in trade of industrial parts.

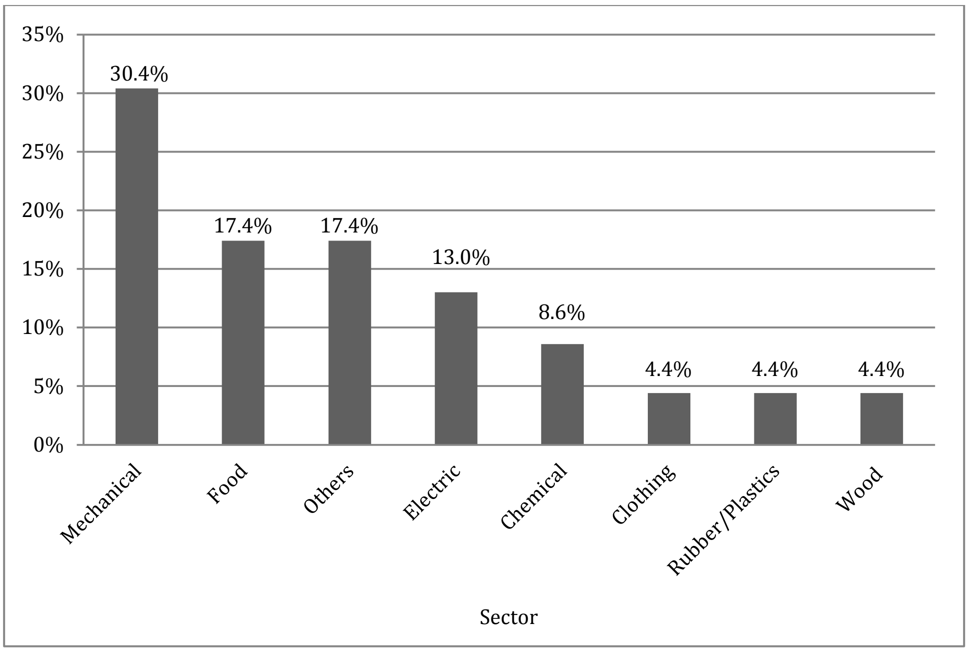


Figure 6.2 Companies divided by sector

In order to understand the annual sale generated per employee, an *Annual Sales Employees Index* (*ASEI*) has been obtained by considering the ratio between the annual sales and the number of employees for each sector.

$$\text{ASEI} = \frac{\sum_j Annual\ sale_j}{\sum_j Number\ of\ employees_j} \qquad \forall j$$

where j=1,…,m represents industrial sector.

The distribution of *ASEI* by sector is shown in Figure 6.3: the average value is about 133,000 € per employee, and the highest value is represented by companies coming from clothing sector.

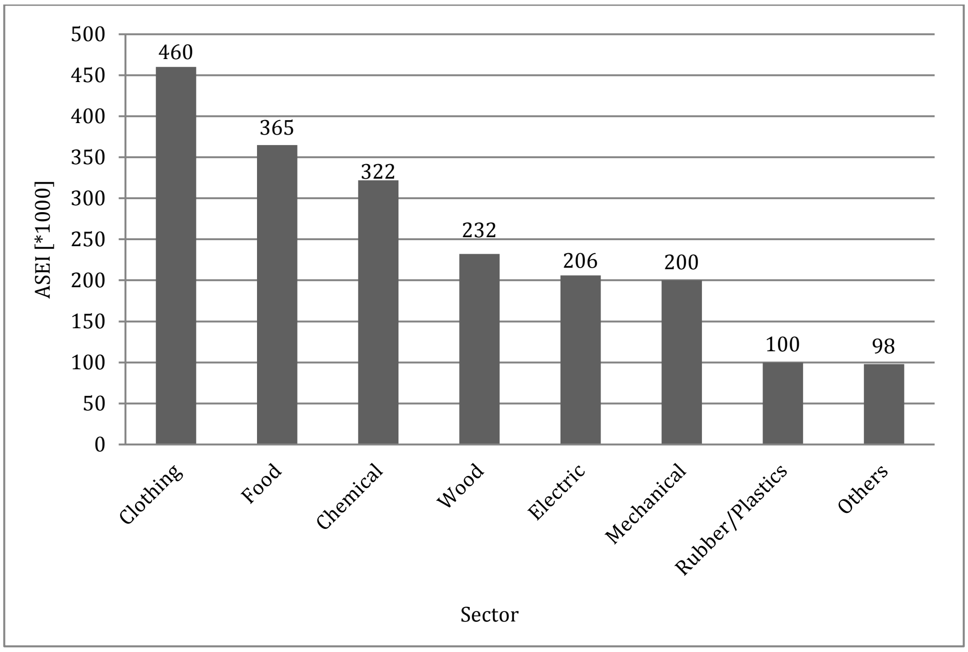


Figure 6.3. ASEI distribution by sector

6.2.2 Results and discussion

The research has wanted to point out the importance that packaging covers for Italian companies; in order to achieve this intent, the questionnaire presents some specific questions focused on this aspect. More than half of the sample considers packaging and its functions critical (52.1%) and 52.2% thinks that the sales of their products even depend on packaging: among them, 66.7% are large companies, 8.3% are medium and the last 25% are small companies (Figure 6.4).

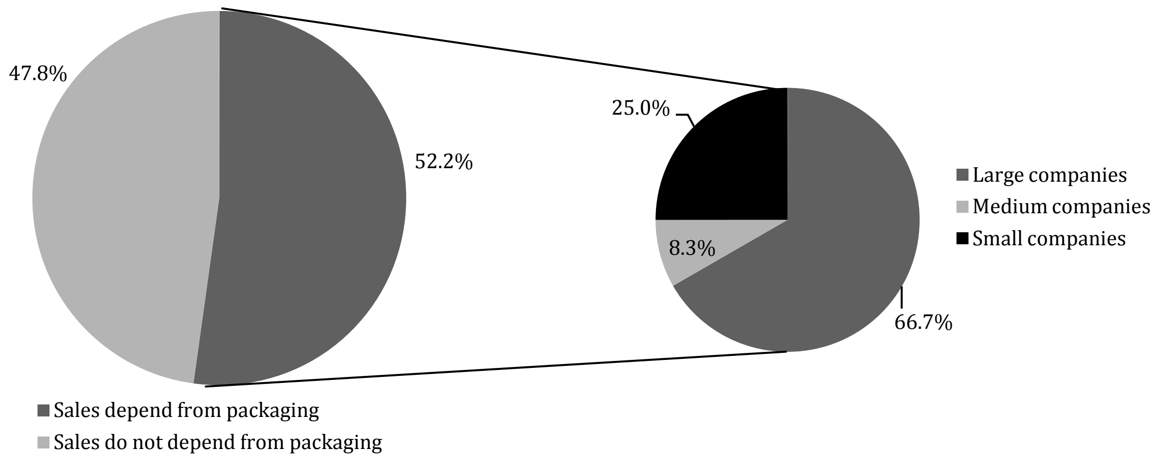


Figure 6.4. Classification of companies thinking that sales even depend on packaging

In Sweden, the role of packaging as an added value element has been recognised by large and medium sized companies, while small industries have limited knowledge of the potential effects that the package has in promoting the product and brand name (Olsson et al., 2011).

The second interesting analysis has been related to packaging functions: the companies have had to choose three main functions of packaging, assigning them three levels of priority (I, II and III) among the eight functions presented in the questionnaire. Considering only the highest level of priority (level I), the most relevant functions have been the *protection* (35.9%) and the *containment of the product* (25.5%) (Figure 6.5).

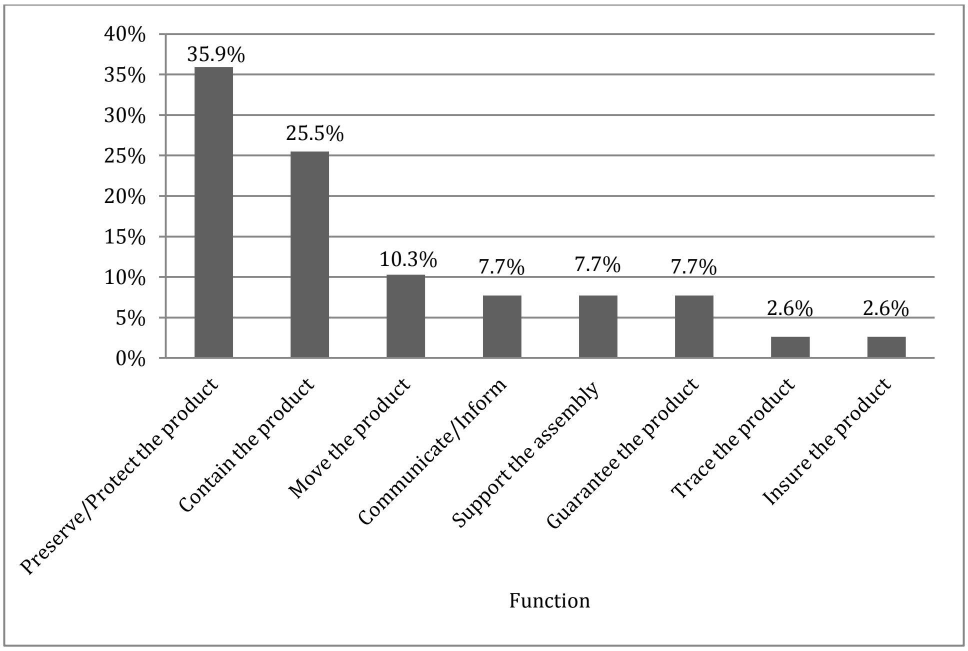


Figure 6.5. Classification of I priority functions

Considering all the levels of priority, *product handling* has been the most important function and *communication and marketing* function has had relevant importance (Figure 6.6).

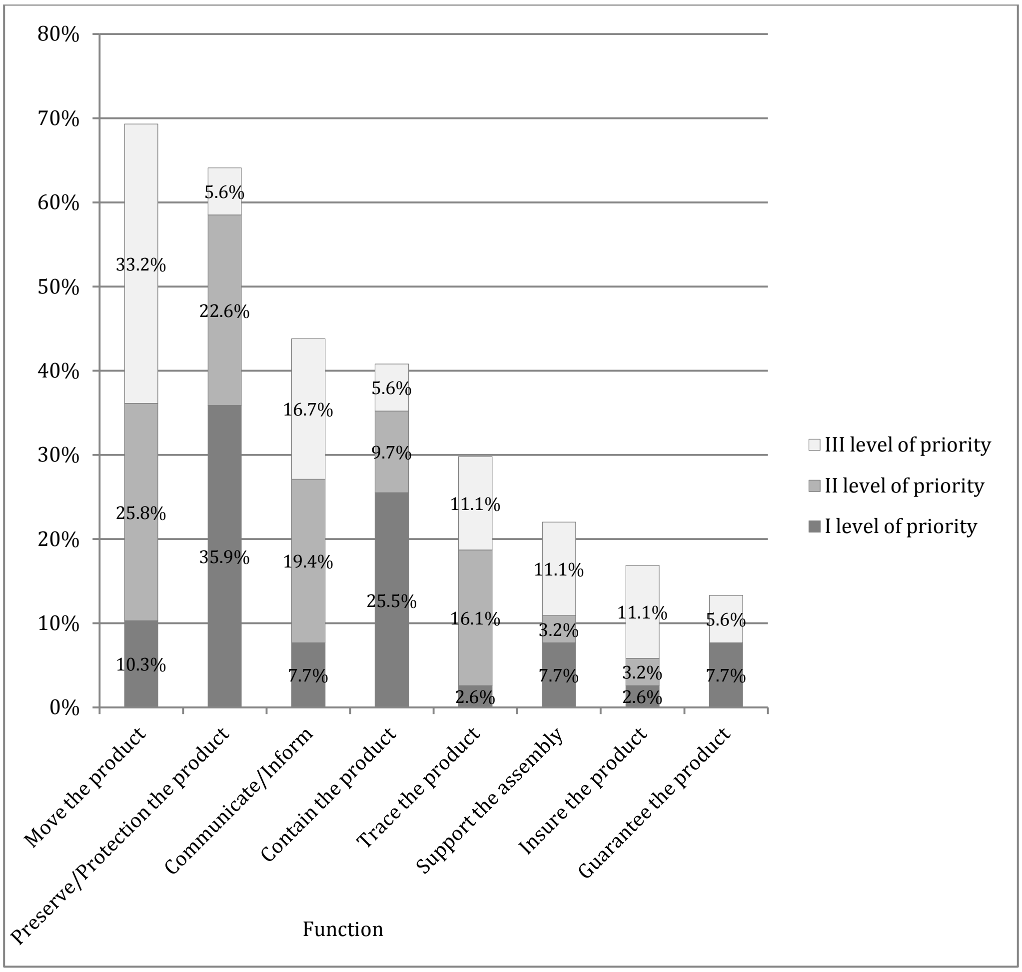


Figure 6.4. Classification of packaging functions (all levels of priority)

As for Italian companies, the most frequently packaging function mentioned by Swedish industries is the *protection of the product* (because it effects all the activities throughout the supply chain), and the second one is the *information about the product*. Considering all the levels of priority (I, II and III), *product handling* is the most important function. It means that Italian companies consider the relationship between logistics function and packaging as critical. In order to obtain significant results on product handling function, it is necessary to co-design product and packaging. On the contrary, from the analysis it has emerged that the development of the product and the design of packaging are often two separate processes, made by different industrial actors. Indeed only 34.8% of the sample has declared to develop package and product at the same time. Companies usually develop package after the study of the product.

Deepening the design process of package and product, from the questionnaire analysis it has emerged that companies consider interesting the coordination of packaging and product design processes. In particular, 82.8% of them has stated that this integration is possible. Dividing these companies in three clusters, 47.4% are large companies, 21.1% and 31.5% are respectively medium and small companies (Figure 6.7).

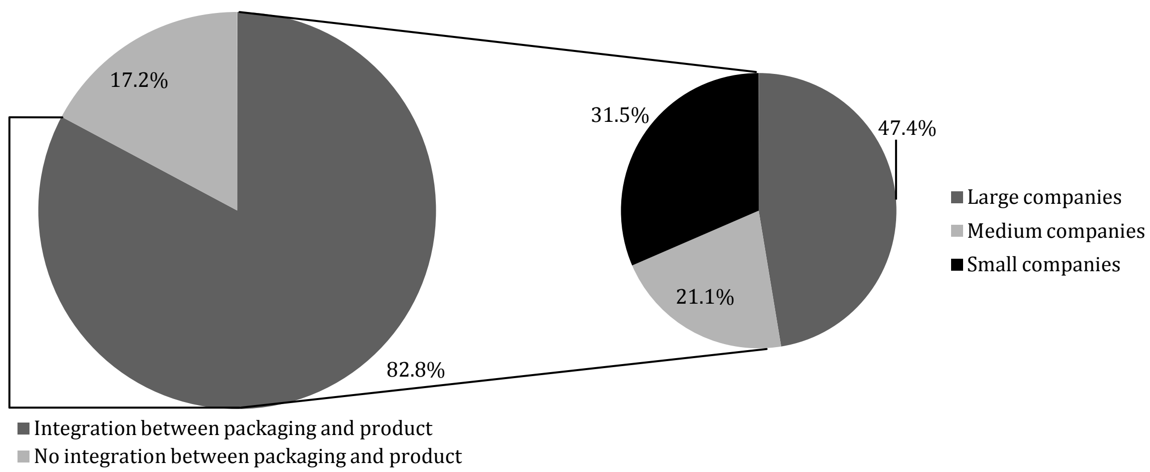


Figure 6.7. Classification of companies supporting the integration between packaging and product

A large percentage of the participants to the analysis (72.8%) has declared to believe that a concurrent study of package and product could reduce costs during the product life cycle, mainly in warehousing (32.3%), production (17.6%) and handling (17.6%) processes. In agreement with the companies, the reduction of costs depends mainly on the possible decrease of materials and time production (28.2% and 25% respectively). The survey performed in Sweden has shown that companies are aware of the importance of the relation between package and product: indeed 90% of them declare to recognise the added value of integrating product and packaging development. They also have noted some possible advantages due to the integration of the product development with package, such as the reduction of costs and the prevention of the superfluous packaging materials. This is difficult when small or medium sized companies are supposed to work together with large sized packaging companies, and when companies do not have an internal packaging development division (Olsson et al., 2011). From the data comparison, it has been resulted that the co-design of product and package is considered an adding value element for both Italian and Swedish companies.

The major part of the respondents has declared to act a manufacturing process (i.e. forming, printing, assembling, etc.) on package (69.6%), while the last 30.4% purchases it from a packaging producer. Moreover, 73% of the industries develop package inside their own company and 77.2% has declared to evaluate several packaging alternatives before choosing the final one. All the interviewed Swedish companies except one (98.3%), develop the package within the company, but many small and medium sized companies (especially in the food sector) have claimed to have minor possibilities to affect the packaging design because packaging producers are often large global companies that provide standard packaging (Olsson et al., 2011). Unlike Swedish industries, that produce package inside the company in almost all cases, more than 25% of Italian companies have declared to use external supplier for their packaging. Figure 6.8 shows the percentage of Italian and Swedish industries that produce packaging inside their own company.

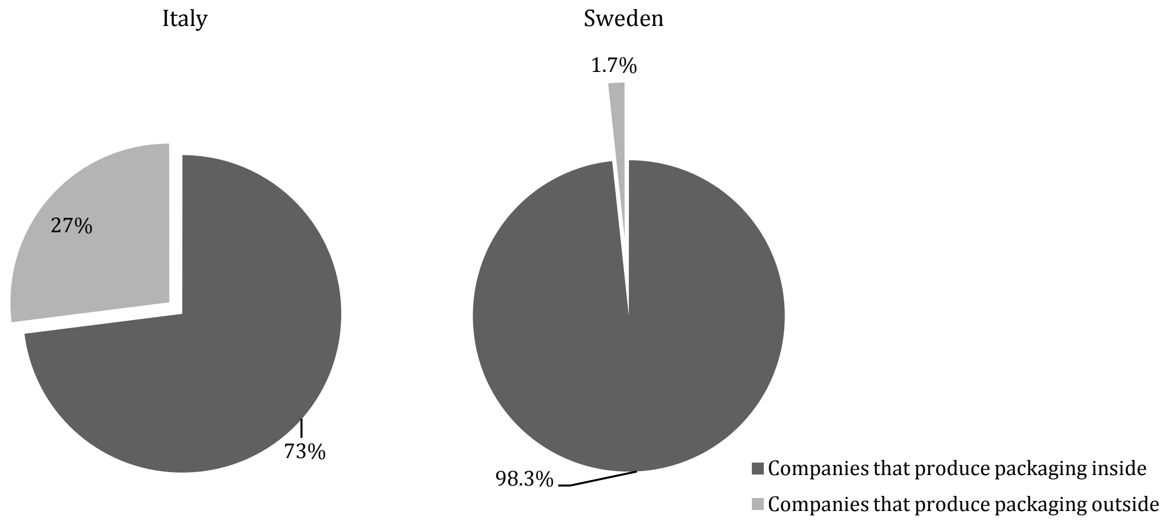


Figure 6.8. Internal/External packaging production process (Italy *vs* Sweden)

A procedure for developing and studying package could be very useful, because it could help analyse the best solution in terms of packaging size and shape as well as the effect the design has on transport and distribution of goods. About half of the companies (52.2%) has declared to adopt a procedure for studying package, while only 17.4% to use dedicated software.

In the same way of the Swedish industries, even Italian companies consider logistics and transport an important packaging function. Indeed, 86.3% of analysed companies has declared to evaluate packaging costs from the transport point of view, focusing on compatibility with vehicles and protection of goods (Figure 6.9).

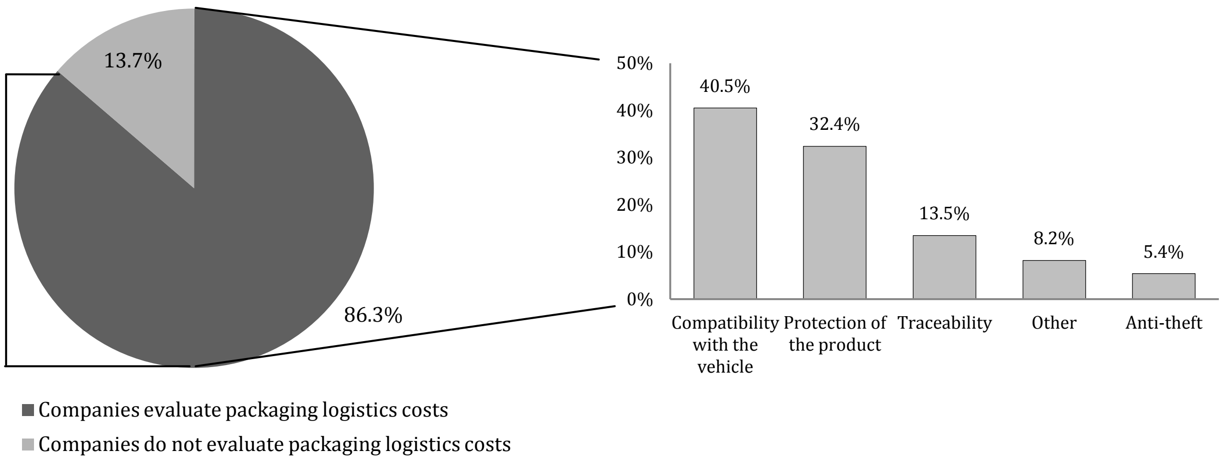


Figure 6.9. Classification of companies evaluating packaging logistics costs

These data underline the importance of the link existing between packaging and logistics: the companies know that packaging (in terms of material, shape and size) influences storage, transport and distribution of goods. Although the major part of respondents has declared to evaluate packaging costs from the logistics point of view, only 39.1% of them has declared to compute the total packaging cost. The average impact of packaging costs on annual sales (*APCS*) (year 2011), obtained considering the ratio between packaging costs (design process and management costs) and annual sales of the whole sample, is about 0.000645.

$$\text{APCS} = \frac{1}{N}\sum_{i=1}^{N}\frac{Packaging\ cost_i}{Annual\ sale_i}$$

where i=1,…,N is the number of companies responding to the question.

Figure 6.10 shows the distribution of this value and the linear regression between *APCS* and annual sale for each company.

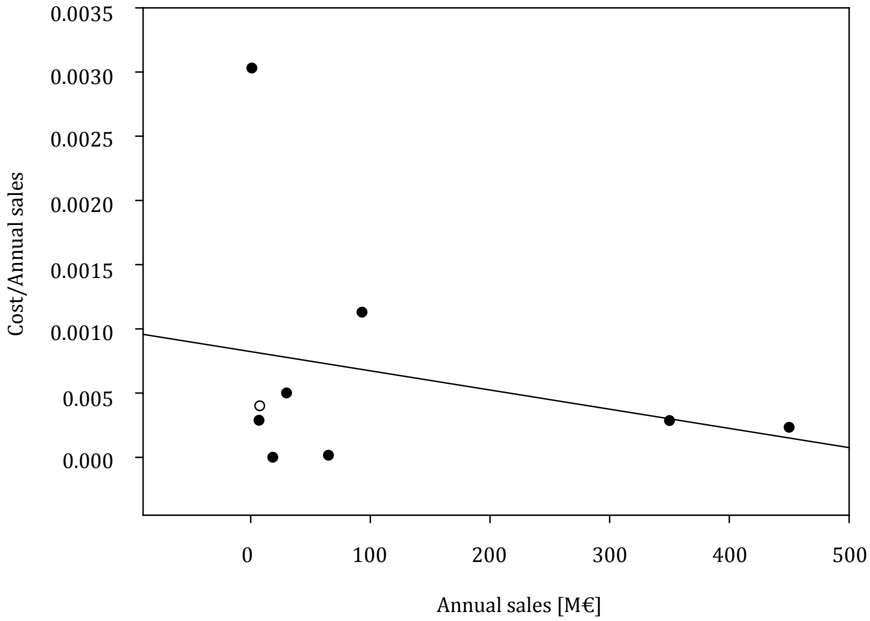


Figure 6.10. Distribution of packaging costs related to annual sales (year 2011)

Moreover, the questionnaire analysis has evaluated the importance that companies assign to the environmental aspect that is increasing since the last decades. 56.5% out of respondents has declared to recycle packaging materials and 77.3% has stated to use methods and applications for evaluating the environmental impact. In Sweden, packages are recycled largely, with 90% of glass, 73% of metal and 74% of paper and carton packages (Helander, 2010).

Linked to the environmental aspect, the materials mainly used by Italian companies for product packages at all levels of the packaging system (i.e. primary, secondary and tertiary) have been analysed. *Cardboard* is very common for primary (32.5%) and secondary (64.7%) package, while the materials mainly used for tertiary package are *wood* (56.2%) and *plastic* (25%) (Figure 6.11).

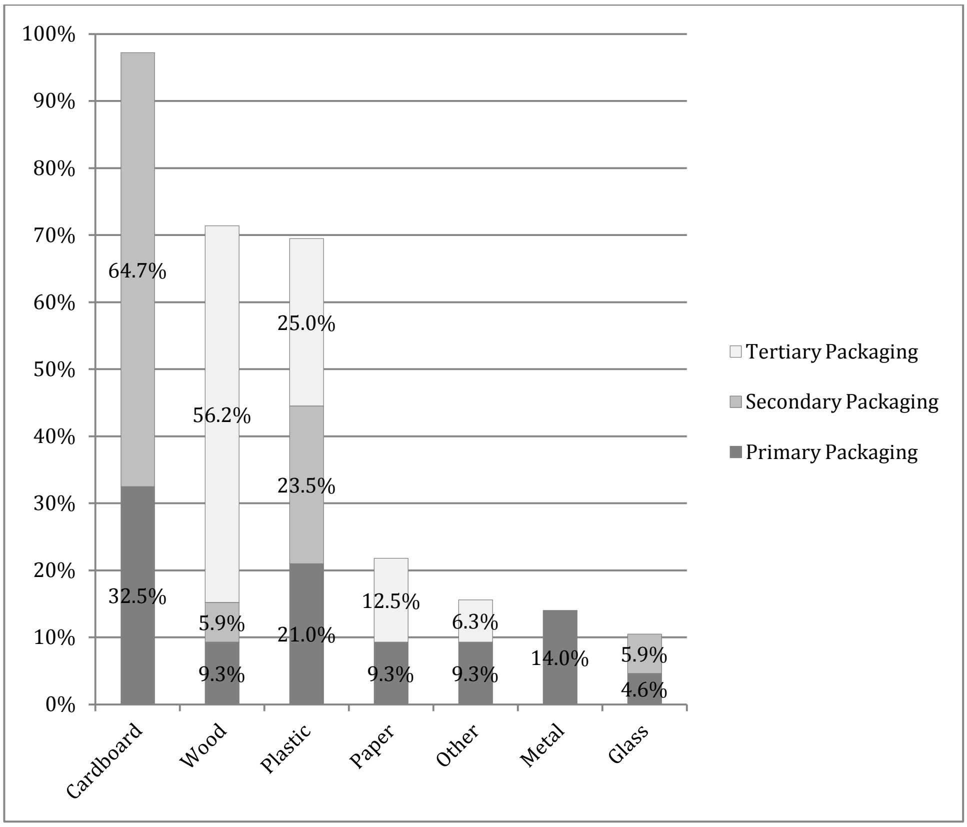


Figure 6.11. Classification of material used for packaging by Italian companies

Comparing these results with the Swedish survey, it is possible to note that the corrugated board is a frequently used material for mechanical and food sectors (70% and 100% respectively), in addition to wooden boxes for mechanical companies and plastics for food products. Pharmaceutical sector more frequently uses plastics as packaging material. The use of fibre based material in Sweden might relate to the strong position of the Swedish forest industry, where about 5,000 millions€ in turnover goes into the Swedish cardboard and paper production industry (Helander, 2010). The two situations are very similar in terms of packaging material: indeed, for both Italian and Swedish industries, corrugated board is the material mainly used for primary and secondary package, and wooden box is used for tertiary package, mainly for transport and distribution.

By the questionnaire, companies have had to suggest the area they would want to improve and the main problems that they have to face considering the packaging system along the supply chain. The major part of them has recognised the protection of product (26.2%) and the reduction of costs (20.3%) as the main needs to improve, and costs (20.4%) and damage of the product (16.9%) as the main problems to solve in the future.

7. The fifth packaging key driver: Environment

7.1 The environmental impacts of packaging

Since the 1990s, the environmental function of packaging has started becoming relevant for both academics and industries. According to Robertson (1990), the environment influences packaging decisions from the development phase to its disposal or recycling. For instance, the shape and the dimension of packaging affect cube utilisation efficiency in transport, the choice of material influences waste handling and recycling, and the protectiveness of packaging affects the amount of waste in the supply chain (Pålsson et al., 2012).

The environmental impact of packaging is an increasingly important issue for business (Livingstone and Sparks, 1994; Svanes et al., 2010; Verghese and Lewis, 2007). Min and Galle (2001) stressed that a demand for green purchasing affects packaging, which in turn affects logistics. Consequently, packaging influences product production, development and design (Bramklev, 2007; Griffin et al., 1985). For this reason, packaging should be evaluated also from the environmental point of view.

Throughout their life cycle, the packaging system consumes renewable and non-renewable resources and energy, creates waste, generates emissions and emits pollutants (Early et al., 2009; Verghese and Lewis, 2007). For these reasons, more efforts must be made to encourage reduction (i.e. modifying or limiting the way in which packaging is manufactured or used), packaging re-use and recycling of packaging materials (Azzi et al., 2012).

A wide range of packaging materials is used every year (Davis and Song, 2006; Yang and Zhou, 2008), including metal, glass, wood, paper, cardboard and plastics (Davis and Song, 2006). They are applied in the three packaging level (Davis and Song, 2006). Secondary and tertiary packaging materials are normally in larger quantities, present less material variation, and thus are relatively easier to collect and sort by wholesaler or retailers for recycling or re-using purposes (Davis and Song, 2006). Primary packaging materials are largely mixed, contaminated and often damaged, and thus impose problems in recycling or re-using materials (Davis and Song, 2006). According to Yang and Zhou (2008), packaging materials cause an enormous flow of waste, since they have already fulfilled their function at the beginning of the use phase of the respective product and then turned into waste (Gasol et al., 2008). Thus, the environmental relevance of packaging materials is increasingly important.

In order to reduce waste due to packaging materials, there is a global trend to use returnable packages instead of disposable packaging. With the adoption of returnable packages, generation of waste at the final customer can be reduced or eliminated, minimising risks to the environment (Silva et al., 2013). From the other hand, Leite (2009) recognised some disadvantages due to the use of returnable packages, as the major transportation costs – direct and reverse –, flow management of returnable packaging, cleaning cost, repairing and storage costs. Despite this, the development of light and resistant packages could reduce the cost of returnable packages, since many shipping costs are associated to the load weight and the need for secure packages to prevent damage in transit (Silva et al., 2013). Moreover, the use of standardised returnable packages could be an advantage to optimise the use of space during product transportation and reduce transportation costs (Ko et al., 2011).

During the years, several authors dealt with the environmental issue of packaging. Gray and Guthrie (1990) described the most important environmental-ethical issues of packaging during the 1990s. Some authors discussed the importance of the holistic view of packaging, including the environment: Lockart (1997) provided a paradigm for packaging in order to describe the interactions between packaging functions and the environment. Verghese and Lewis (2007) argued that environmental innovation in industrial packaging systems requires a cooperative supply chain and efficiencies optimised for the chain as a whole.

Furthermore, the impact of packaging on the environment was described. Franey et al. (2010) provided an analysis that shows the impact of product packages on overall reliability and environmental performance. Wever et al. (2010) studied how packaging design influences littering behaviour in order to utilise it as an additional tool in reducing littering. Langley et al. (2011) conducted a variety of tests to identify attributes of packaging that influence the eventual waste routes. Zhang and Zhao (2012) described a new form of packaging (called *green packagin*g), underlining the negative impact of traditional packaging on the environment. Green packaging was defined as environmental friendly package, completely made by natural plants, can be circle or second use, be prone to degradation and promote sustainable development, even during its whole life cycle. In short, green packaging is the appropriate packaging that can be re-used or recycled and does not cause pollution in the environment (Zhang and Zhao, 2012).

7.1.2 The environmental factor of packaging sustainability

Another relevant environmental aspect linked with packaging concerns the sustainability. Sustainability is an issue of increasing importance in the packaging industry (Wever et al., 2010). Sustainability in packaging is based on the most commonly applied definition of sustainable development by the Brundtland Commission in 1987:

[...] development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The definition involves addressing three principles of sustainability: economic, social and environmental factors and their interdependence in a decision-making process and activities (Efficient Consumer Response, 2009). For the packaging system, it means integrating the broad objectives of sustainable development to business considerations and implementing strategies that address social as well as environmental aspects related to the packaging system, its entire life cycle throughout each stage of the supply chain (Nordin and Selke, 2010). Through its functions for product protection, waste prevention, enabling efficient business and providing safe use of product, packaging can make a valuable contribution to environmental, economic and social sustainability (Efficient Consumer Response, 2009).

Environmental impact due to the packaging use is not sustainable in the long term (Verghese and Lewis, 2007). Impacts include consumption of non-renewable resources, generation of air emissions in production, transport and use, and production of solid waste requiring disposal in landfill (James et al., 2005). As goods pass through industrial supply chains, the associated packaging waste is often forgotten or ignored. This results in litter, poor recycling or re-use rates and unnecessary waste to landfill (Verghese and Lewis, 2007).

The packaging industry sustainability mantra has become "reduce, re-use, recycle" (Jingzhong, 2009; Peattie and Shaw, 2007).

Reduce. It requires persisting in reducing the quantity of packaging materials to flow from the production to the consumption process (Jingzhong, 2009). Examples can be found in the light-weighting of bottles and cans (Lewis et al., 2001; Holdway et al., 2002) and refillable packaging (Lofthouse et al., 2009). Moreover, tailor-made packaging and product design can contribute to a reduction of packaging waste (Bjärnemo et al., 2000; ten Kloster, 2002). Packaging reduction is an activity that has been ongoing for some years in order to reduce costs and for environmental reasons, saving resources from initial sources in reducing pollutants.

Re-use. It follows the principle to use the waste repeatedly for improving the using efficiency of products and services. It is required to decrease the pollution of one-off product package in its initial condition. According to McKerrow (1996), there are several benefits deriving from re-usable packaging, the most obvious is the cost saving thanks to the reduction in purchase and waste disposal costs of one-trip package. Other important benefits of re-usable packaging are the reduction of product damage, improving vehicle utilisation, standardisation of storage facilities, and reduction of energy inputs.

Recycle. It is a way to recycle the outputs, requiring getting them into reproducible resources after the consumption (Jingzhong, 2009). The recycling process of packaging materials allows reducing stocking costs and minimising pollutant emissions when packaging waste is incinerated or landfilled.

The sustainability issue has been dealt with since few years ago. Although the majority of discussions on sustainable packaging only address the environmental and economic perspectives (Wever et al., 2010), Nordin and Selke (2010) explored the social perspective of the sustainable packaging concept, analysing the customer perception on the impact of packaging on the environment. In 2012, Pålsson et al. developed an evaluation model for the selection of packaging system in supply chain from a sustainable perspective; they tested the model in a case study, comparing the use of newly developed, one-way package with the sustainability of returnable packages.

Several authors dealt with the reduction, recycling and re-using of packaging materials. Davis and Song (2006) discussed the potential impact of biodegradable packaging materials on waste management in terms of landfill, incineration, recycle/re-use and composting. Jingzhong (2009) showed two problems in the recycling and re-using process of product packages: the simplification and standardisation of product packages, and the design of logistics system. Van Sluisveld and Worrell (2013) expanded the understanding of packaging source reduction, analysing 131 available options implemented in the Netherlands in the period 2005-2010. Light weighting has been identified as the most frequently applied packaging source reduction method. Finally, Silva et al. (2013) presented a case study on reverse flow of returnable packages to replace a disposable packaging system used by a company in Brazil. The study demonstrated that returnable packaging consumed 18% less material than the disposable packaging, reducing costs.

8. *The application of the packaging framework to real case studies*

8.1 Introduction to the chapter

The purpose of *Chapter 8* is to explain and discuss three of the five packaging key drivers (i.e. logistics, cost and environment) through three different case studies. The case study is one of the best methods for analysing specific issues and translating them into the reality. The use of the case study methodology can speed up the understanding of the issue thanks to the possibility to test the studied and developed approaches or strategies in the reality, and help academics and practitioners increase their knowledge about the analysed topic.

The first case study concerns the logistics and its interaction with the packaging system. An RFID-UWB system has been developed and applied to a manufacturing company in order to trace the packaging flows within its assembly area. The second case study regards the evaluation of the packaging costs, applying the mathematical approach (*Chapter 6*) to a manufacturing company. The analysis of the packaging cost parameters and the application of the mathematical approach can allow the optimisation of the company efficiency. Finally, the last case study has been developed in order to improve the understanding of the importance of the link existing between the packaging system and the reduction of the environmental impact. The case study has been applied to a humanitarian organisation occupying itself to send items to countries affected by natural and manmade disasters. The intent is to validate the feasibility of the re-use of product packages for a purpose different from their primary function of protection and containment. The case study has demonstrated that one of the possibilities allowing the minimisation of the environmental impact due to product packages is the re-use of packages.

8.2 The logistics perspective: packaging traceability through RFID-UWB systems

An automatic RFID-UWB system, able to trace in continuous manner material flows, mapping position, path and velocity in real time, has been developed. In order to perform and validate the RFID-UWB system, several static and dynamic tests have been realised within the Mechanical Laboratory of the University of Bologna (for the first testing phase) and in the assembly area of an Italian manufacturing company (for the final system validation).

8.2.1 Components of the developed RFID-UWB system

The system comprises sensors, tags, and the software location platform, described below.

- *Sensors:* RFID-UWB sensors receive pulses from tags. Each sensor can determine the azimuth point and the arrival angulations thanks to the *Angle Of Arrival* (AOA) technique. In this case, if only one sensor receives the signal, the system can determine the 2D location of the tag. Instead, if the signal is captured by more than one sensor, connected each other, it is also possible to find out the *Time Difference Of the signal Arrival* (TDOA) and obtain the 3D location of the tags. Figure 8.1 shows the sensors used in the experimental application.

Figure 8.1. Sensors used in the experimental application (courtesy of Ubisense Group plc)

- *Tags:* they are small and robust devices worn by a person or attached to an object to be accurately located within an indoor environment. Tags transmit brief RFID-UWB pulses that are received by sensors and are used to determine their position. The use of RFID-UWB pulses ensures both high precision (approximately 15 cm) and great reliability in complex indoor environments, characterised by noises like reflection from walls or the presence of metallic objects in indoor environments. Figure 8.2 shows the tags used in the experimental application.

Figure 8.2. Tags used in the experimental application (courtesy of Ubisense Group plc)

- *Software Location Platform* is used to control and calibrate the system, to manage the locations of data generated by tags and received by sensors, and to analyse, communicate and inform users on the data system. The software platform is made up of the *Location Engine Calibration* and *Location Platform*.
  - *Location Engine Calibration* (*LEC*) allows the sensors to be set, calibrated, and configured in cells using a graphical user interface. The Location Engine allows the creation and loading of maps, the setup of tags and sensors (deciding master and slave sensors), and the calibration of the system sensitivity (fixing the "noise threshold").

Tests are performed by a set of parameters that regulate the tags behaviour. These parameters are as follows:

- Updating rate of the system. It indicates how often the system is updated. If a tag moves quickly, it may be possible to have a high update rate for more precise localisation; on the other hand, if the tag moves slowly, the update rate could be reduced to minimise battery use;
- Frequency of transmission. It represents the frequency with which the signal is transmitted from the system to the tags. It is expressed in Hz;
- Filters. They can be applied to a single tag or a group of tags. Location Engine presents one algorithm without a filter and four-filtered algorithms. They are:

1. *No filtering algorithm*: in this configuration, no filter is applied. This means that the position is evaluated only by measuring AOA and TDOA at a specific moment. In this way, any previous data are not processed and the path and speed of movements are not considered. Not using filters does not allow optimal measurements to be obtained.

Filtered algorithms try to interpret tag movements in order to predict their positions during further measurements. Information coming from AOA and TDOA techniques is analysed and compared with the expected position that will be used in further measurement. The filter can eliminate measurements that can be deteriorated by reflection or disturbed by external noises. In order to do so, it is necessary to identify a movement pattern for the filter that defines the limitations to which the measured object has to be subjected. The higher the number of applied limitations, the better the robustness of the measurement.

The four filtered algorithms are presented below:

2. *Information filter*: the tag can move along three directions but, if it is not seen for a period, the movement pattern assumes that it is continuing to move according to the last speed value and along the last detected direction. This algorithm is used for assets that move with predictable speed and without direction limitations;

3. *Fixed height information filter*: the tag is free to move horizontally, but the vertical movements have to remain close to a predetermined threshold height. In this case, if contact with the tag is lost, it is assumed that it continues to move with equal speed along the horizontal direction, remaining close to the vertical predetermined height. Like the previous algorithm, the level of uncertainty of the location increases with the time. This algorithm is mainly used for vehicles moving at high speed and in two directions;

4. *Static information filter*: the tag is free to move in three directions. If the tag is not detected, its position is identified with the last one and the level of uncertainty of localisation increases with the time. This algorithm is used for assets that do not normally move or move in an unpredictable way, such as operators. The algorithm does not have any spatial limitations, allowing the detection of 3D movements (for example the movement of people climbing the stairs);

5. *Static fixed height information filter:* the tag is free to move horizontally, but it is limited to the vertical direction. If the tag is not seen, it is assumed that its position is the last one detected and the height is close to the prefixed limit. This algorithm is used for targets that do not normally move or move in unpredictable way. Because of its vertical limitation, it is used for vehicles, tools, and people that move in two dimensions.

It is possible to underline the difference between static and dynamic filtering algorithms. In the case of dynamic filter, there can be long straight lines that identify the period in which the sensors lose track of the tag and find it again later. Consequently, the measurement accuracy is low, mainly in the computing of distances travelled, which may be compromised. In the case of static filter, the traced path is very close to the real one, without straight lines, since the tag is always under control. Figure 8.3 shows an example of tracking of the same path by using a dynamic filtering algorithm (on the left) and a static filtering algorithm (on the right).

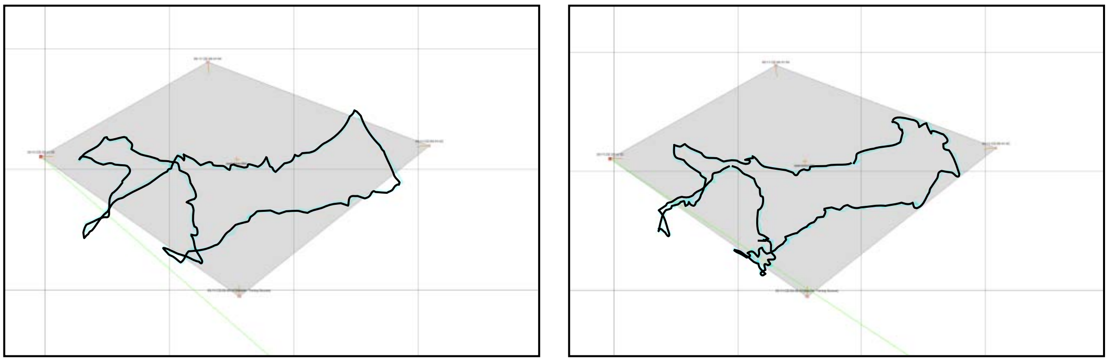


Figure 8.3. Path traced with dynamic filtering algorithm (on the left) and static filtering algorithm (on the right)

- *Location Platform* is software that collects and processes data from sensors and tags, viewable thanks to a graphical interface. In this way, it is possible to obtain 2D and 3D maps of the environment and detected assets. The collected data can be sent to other systems for further analysis and stored within the platform to act as a database.

8.2.2 Installation and calibration of the system

The sensors should be located as close as possible to the ceiling of the building to guarantee maximum coverage of the space and their angulations should be directed towards the centre of the building. The sensors are grouped into rectangular cells, where they are connected to the Ethernet switch that guarantees the power that is in turn linked with the host computer (Figure 8.4). Each cell is characterised by a main sensor (master) that coordinates the activities of the other sensors (slave) and communicates with the tags. The master sensor has to be connected with the slaves by CAT-5 cables (Figure 8.5), in order to ensure the time synchronisation. When the connection is made, the Location Engine Configurator is set to "Running" mode and the system is ready to work.

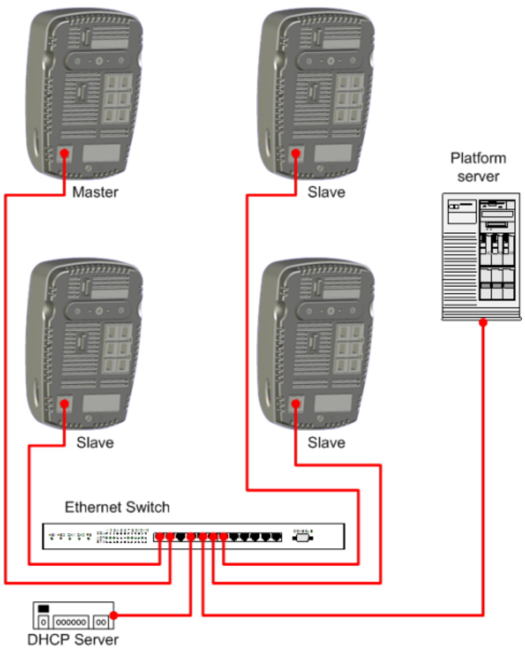


Figure 8.4. Connection of sensors with the system

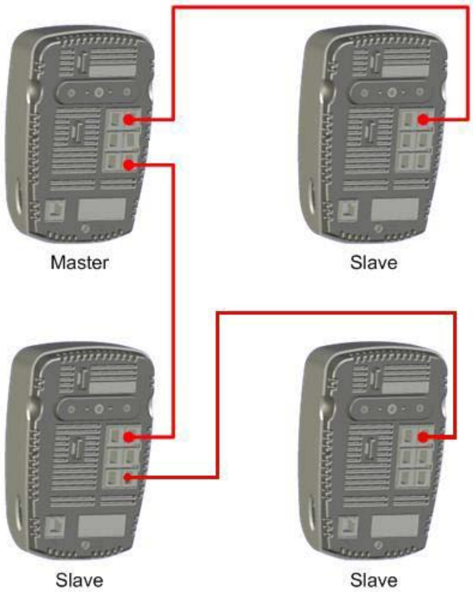


Figure 8.5. Connection between master and slave sensors

The threshold level of the "background noise" has to be decided, so to allow the system to distinguish valid signals from environmental noises. In order to calibrate the sensors, the power level detected by them is measured, verifying that the "background noise" remains below the threshold level. After that, it is possible to calibrate the sensor orientation. The sensors are oriented to a known tag, taken as reference. Figure 8.6 shows the sensor calibration through AOA. The black lines connect each sensor to the detected position of the tag.

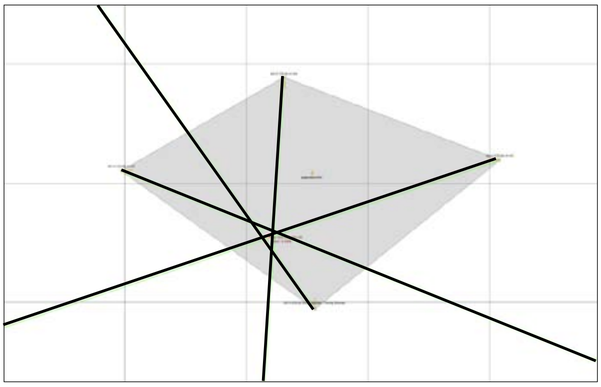


Figure 8.6. Calibration of sensors

In order to activate the localisation through TDOA, it is necessary to calibrate cables that synchronise all the slave sensors with the master. When the cable calibration is completed, blue strips are added to the black lines, one for each pair of sensors (Figure 8.7).

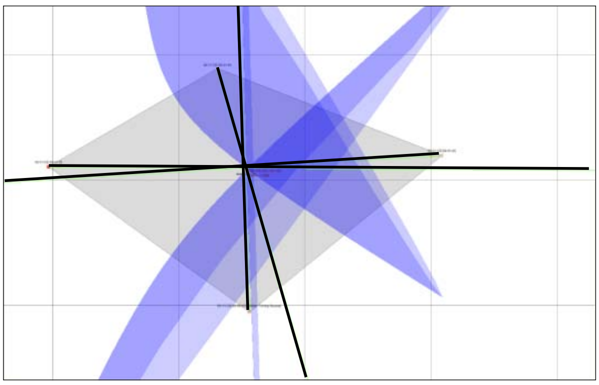


Figure 8.7. Calibration of cables

After that, the system has to be connected with the layout of the area to be monitored. When the map is loaded into the system, the coordinates of the sensors positions and some reference points within the area to be monitored have to be determined. A corner of the building is identified as the axis of origin and it is indicated by (0;0;0); the other corners will be identified with (*X*;0;0) and (0;Y;0) where X and Y are the lengths of the building sides. The level of floor is set as Z=0 so to use the 3D localisation capacity of the system. In order to connect the position of the sensors with the coordinates of the laboratory corner, the object localisations have to be calibrated, by using known points as reference. After that, the software will provide a 3D image of the area to be monitored.

In order to complete the calibration and verify the absence of errors, it is important to test the system, moving a tag within the area and ensuring that the sensors work correctly and that all necessary data are displayed.

8.2.3 Experimental evidences

The experimental evidences have concerned the validation of the prototype RFID-UWB system, developed by the University of Bologna. The system has been applied to product packages, instead of each product, in order to evaluate the effects produced in terms of the increase of efficiency in internal and external transport, and storage and reduction of cost traceability.

Several tests have been realised within the Mechanical Laboratory of the University of Bologna (for the first testing phase) and within the assembly area of an Italian manufacturing company (for the final system validation).

8.2.3.1 Tests in the Mechanical Laboratory of the University of Bologna

In order to pre-test the realised prototype system, the RFID-UWB system has been tested within the Mechanical Laboratory of the University of Bologna. Figure 8.8 and Figure 8.9 show the 2D and the 3D maps of the laboratory, where the red squares indicate the position of the sensors. The optimal configuration needs sensors to be installed in the four corners of the building, but, because of the presence of obstacles in the corners of the laboratory, they have been installed according to a rhombus distribution, able to guarantee total coverage of the area.

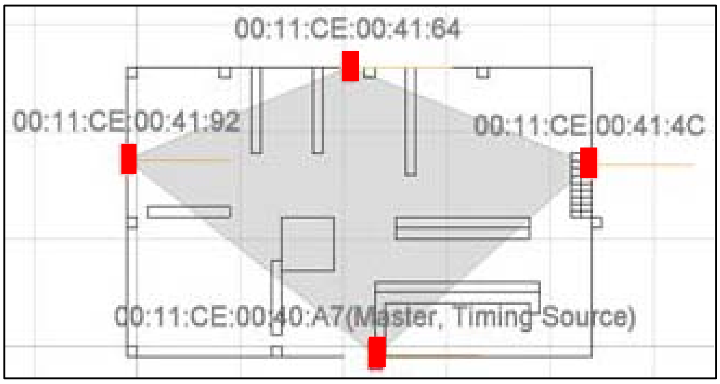


Figure 8.8. 2D map of the area to monitor

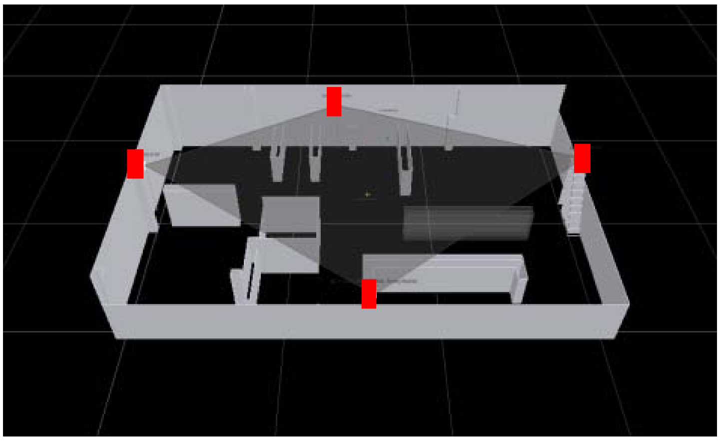


Figure 8.9. 3D map of the area to monitor

The coordinates of sensors are presented in Table 8.1.

Sensors name	X [m]	Y [m]	Z [m]
00:11:CE:00:40:A7 (master)	15.618	-0.582	4.336
00:11:CE:00:41:4C (slave)	30.868	11.945	4.545
00:11:CE:00:41:64 (slave)	13.085	18.898	4.336
00:11:CE:00:41:92 (slave)	-0.308	11.039	4.651
STA (reference point)	15.409	10.833	2.100

Table 8.1. Coordinates of sensors in the Mechanical Laboratory of University of Bologna

The research has been consisted of several tests, static and dynamic. The *static tests* have been consisted of the identification of different points (where product package on which a tag is attached has been located) within the area to monitor. The sensors have had to detect the tag coordinates to compare the estimated and detected point coordinates. The *dynamic tests* have been consisted of the application of a tag to a product package located on a trolley that has moved around the area to monitor. The operator has followed prefixed paths, and the route and distance travelled by him have been compared with the estimated values, measured in advance.

Static and dynamic tests within the Mechanical Laboratory of the University of Bologna are presented in the next paragraphs.

Static tests

In order to undertake the accuracy and precision of the proposed RFID-UWB system, the first step has been the measurement of known point coordinates through a laser. 16 points within the monitored area, chosen according to the characteristics of visibility, proximity to metal objects and position, have been identified.

The static tests have been performed according to the variation of some tag parameters, such as:

- Filter used (*No-filter, Information Filter, Fixed Height Information Filter, Static Information Filter, Static Fixed Height Information Filter*);
- Update each four time slot;
- Frequency: 37 Hz;
- All tests are performed by putting the asset on a support 0.5 m high, except point 13, which is placed 2 m high.

Figure 8.10 shows the considered 16 points represented in the map of the laboratory.

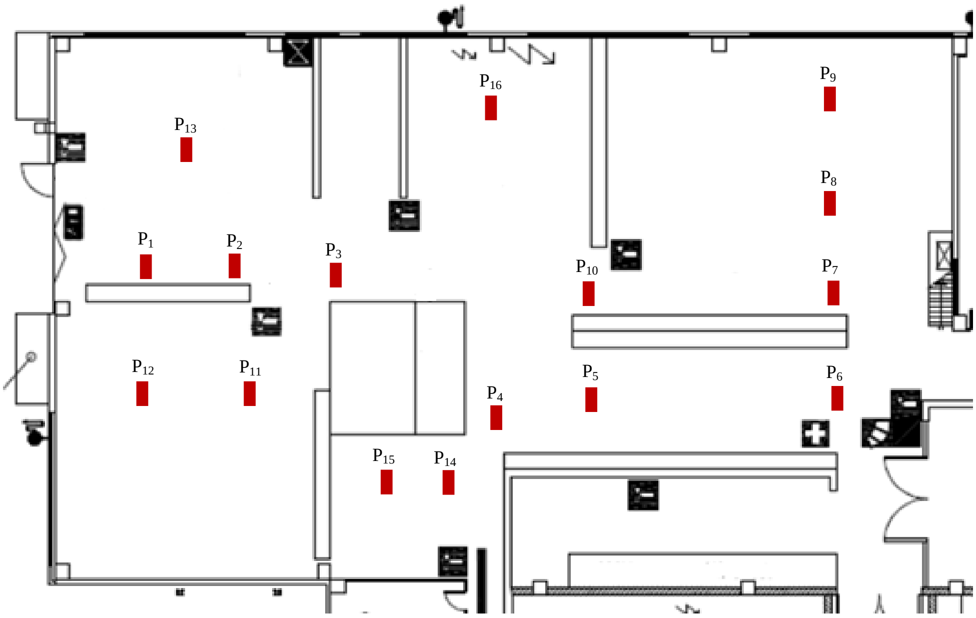


Figure 8.10. Reference points for static tests

For each point, four tests have been performed in order to understand the average error between the estimated and detected coordinates.

Test 1

- Filter used: *Static Fixed Height Information Filter;*
- Update each 4 time slot;
- Frequency: 37 Hz.

Table 8.2 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [%]
1	5.826	11.113	6.1007	11.0112	0.2930
2	7.976	10.991	7.6250	10.7717	0.4138
3	11.389	11.207	11.5024	11.0014	0.2347
4	15.693	7.138	15.9791	7.2085	0.2946
5	18.627	7.138	18.6374	7.1973	0.0602
6	26.39	7.138	26.1077	7.4651	0.4320
7	26.39	11.204	26.5720	10.8224	0.4227
8	26.39	14.028	26.2713	13.4417	0.5980
9	26.39	16.6	29.1303	18.6123	3.3998
10	19.347	11.207	19.5315	10.5318	0.6999
11	8.17	7.113	7.8618	7.2394	0.3330
12	3.415	7.05	3.7401	8.0534	1.0548
13	3.399	15.739	3.3871	14.3100	1.4289
14	16.397	2.748	14.9795	3.2646	1.5085
15	11.367	2.748	11.7532	4.3628	1.6602
16	15.637	15.187	15.8656	14.9317	0.3426

Table 8.2 Analysis of static *Test 1*

The average error of *Test 1* is 0.8236 m.

The points located in the best positions in terms of visibility (excluding points 9, 12, 13, 14 and 15) have been detected with high accuracy and have presented an average error of 37 cm. The worst result of point 9 has been due to the presence of numerous obstacles around the considered area that have been made the tag visible only to one sensor. The same causes also have influenced the detection of points 12, 13, 14 and 15, although with lower impact.

Test 2

- Filter: no filter applied;
- Update each 4 time slot;
- Frequency: 37 Hz.

Table 8.3 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [%]
1	5.826	11.113	5.8597	10.9974	0.1203
2	7.976	10.991	7.9914	11.1263	0.1362
3	11.389	11.207	11.4886	11.1252	0.1289
4	15.693	7.138	15.8387	7.2311	0.1729
5	18.627	7.138	18.4915	7.0736	0.1499
6	26.39	7.138	21.3617	3.6867	6.0987
7	26.39	11.204	28.4824	11.4226	2.1038
8	26.39	14.028	25.6281	13.6126	0.8676
9	26.39	16.6	28.6270	9.2454	7.6872
10	19.347	11.207	19.4776	10.3303	0.8863
11	8.17	7.113	7.7177	7.6014	0.6656
12	3.415	7.05	6.5425	5.6330	3.4335
13	3.399	15.739	3.5185	14.9626	0.7855
14	16.397	2.748	14.7514	2.9406	1.6567
15	11.367	2.748	10.9230	4.2645	1.5800
16	15.637	15.187	15.7053	15.1101	0.1028

Table 8.3. Analysis of static *Test 2*

The average error of *Test 2* is 1.661 m.

The absence of filters has meant that the oscillations of the tag positions have been not damped. This has been lead to the worst result of all the tests. From Table 8.3, it is possible to note that the easily reachable and visible points present low error values, while for the most critical points the system performance is worse, even reaching high error values (in order of some metres).

Test 3

- Filter: *Static Information Filter;*
- Update each four time slot;
- Frequency: 37 Hz.

Table 8.4 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [%]
1	5.826	11.113	6.0484	10.8824	0.3203
2	7.976	10.991	7.4876	11.0006	0.4884
3	11.389	11.207	11.3885	10.9646	0.2423
4	15.693	7.138	15.9165	6.9975	0.2640
5	18.627	7.138	18.6268	7.0524	0.0855
6	26.39	7.138	21.5961	4.4598	5.4912
7	26.39	11.204	26.5539	10.9868	0.2720
8	26.39	14.028	25.7937	13.2303	0.9959
9	26.39	16.6	22.0670	9.2817	8.4996
10	19.347	11.207	20.3456	10.0280	1.5450
11	8.17	7.113	7.1760	7.0652	0.9950
12	3.415	7.05	3.4986	7.7185	0.6737
13	3.399	15.739	3.1959	14.0444	1.7067
14	16.397	2.748	14.9009	2.8403	1.4989
15	11.367	2.748	12.5534	3.8802	1.6399
16	15.637	15.187	15.8690	14.8410	0.4166

Table 8.4. Analysis of static *Test 3*

The average error of *Test 3* is 1.5709 m.

As it is possible to note from Table 8.4, like *Test 1* and *Test 2*, points 6 and 9 present largely incorrect values, because of the condition of the area in which they are located. The other values are in line with the estimated measurements.

Test 4

- Filter: *Information Filter;*
- Update each four time slot;
- Frequency: 37 Hz.

Table 8.5 presents the estimated and detected coordinates of the 16 points, specifying the error between them.

Point	X [m]	Y [m]	X detected [m]	Y detected [m]	Error [%]
1	5.826	11.113	6.0484	10.8474	0.3913
2	7.976	10.991	7.4876	11.1165	0.5798
3	11.389	11.207	11.3885	11.0003	0.2197
4	15.693	7.138	15.9165	7.0616	0.1043
5	18.627	7.138	18.6268	7.1121	0.0860
6	26.39	7.138	21.5961	4.3934	6.6738
7	26.39	11.204	26.5539	10.9065	0.3283
8	26.39	14.028	25.7937	9.2591	5.9963
9	26.39	16.6	22.0670	17.1635	1.1424
10	19.347	11.207	20.3456	10.7986	0.4484
11	8.17	7.113	7.1760	7.2697	2.6607
12	3.415	7.05	3.4986	7.3234	0.6786
13	3.399	15.739	3.1959	14.5849	1.1573
14	16.397	2.748	14.9009	3.0857	1.4668
15	11.367	2.748	12.5534	3.4522	0.8554
16	15.637	15.187	15.8690	15.1152	0.1212

Table 8.5. Analysis of static *Test 4*

The average error of *Test 4* is 1.4319 m.

In this case, the results have been better than *Test 2* and *Test 3*, but the problems regarding the presence of obstacles in the area to be monitored, noted during the other tests, remain.

From a comparison between the four static tests (Table 8.6), it is possible to note that the best algorithm in terms of the lowest average error between estimated and detected tag positions is *Test 1* that uses a *Static Fixed Height Information Filter*.

Filter used	Average error [%]
Static Fixed Height Information Filter	0.8236
Any filter applied	1.661
Static Information Filter	1.5709
Information Filter	1.4319

Table 8.6. Comparison between the average errors of static tests

Dynamic tests

Dynamic tests have been performed by applying a tag to a product package located on a trolley that has moved around the laboratory following prefixed paths. The length of these paths, measured in advance, has been compared with the real distance travelled. In this way, it has been possible to evaluate the precision of each known point.

The first part of the paragraph presents the results obtained by dynamic tests using a static filter (*Static Information Filter*), while the second part shows the same results using a dynamic filter (*Information Filter*) that are compared with those reached by using a static filter.

Dynamic tests using *Static Information Filter*

Four tests have been performed, according to the following parameters:

- Filter: *Static Information Filter*;
- Update each four time slot;
- Frequency: 37 Hz;
- Threshold speed: 2 m/s;
- Velocity of tag: 2 m/s at a constant height of 1.5 m.

In order to completely cover the interested area, several proof paths have been decided and measured in advance.

Test 1

The path is 28.8 m long: as it possible to note from Figure 8.11, the first part is made up of an area with good coverage by sensors without obstacles, while in the second part the operator has to cross an area with numerous obstacles and metallic materials. Figure 8.11 shows the estimated (on the left) and the detected path travelled by the product package located on a trolley, obtained by using LEC software (on the right).

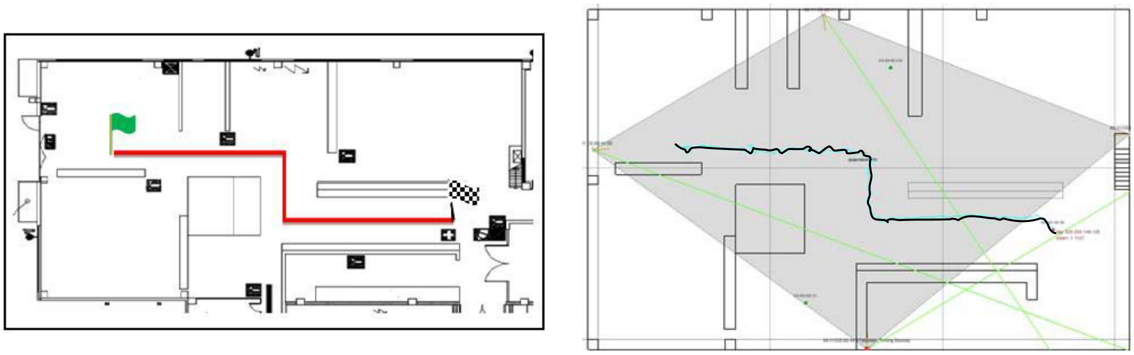


Figure 8.11 Estimated (on the left) and detected (on the right) path of dynamic *Test 1* using a static filter

Table 8.7 shows the detected and measured distances and the error between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
28.8	31.22	2.421	8.408

Table 8.7. Synthesis of dynamic *Test 1*

Test 2

The path is 30 m long and it is travelled around a metallic shelf in the centre of the laboratory. Figure 8.12 shows the estimated (on the left) and the detected path travelled by the product package located on a trolley, obtained by using LEC software (on the right). As can be seen from Figure 8.12 on the right, the black line representing the path, presents some noises, due to the momentary loss of the signal.

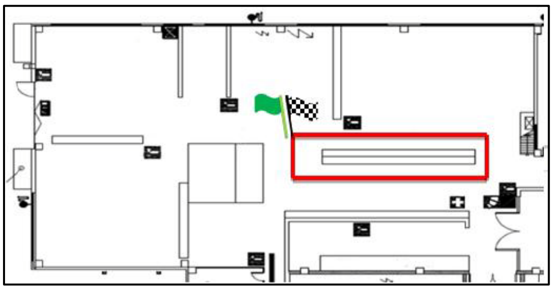
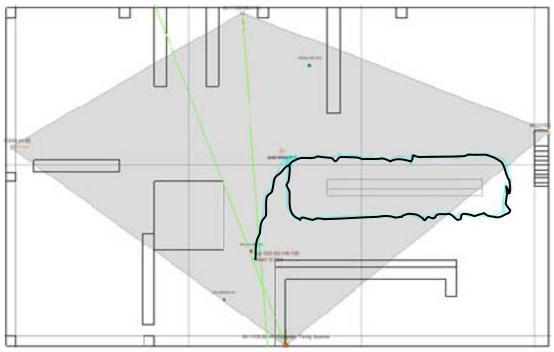



Figure 8.12. Estimated (on the left) and detected path (on the right) of dynamic *Test 2* using a static filter

Table 8.8 shows the detected and measured distances and the error between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
30	30.45	0.4594	1.5315

Table 8.8. Synthesis of dynamic *Test 2*

Test 3

The path is 23.5 m long: as it possible to note from Figure 8.13, the first part is made up of an area with low coverage, because of the presence of walls, shelves and several metallic machines and objects. In the final part, the path is made up of an area surrounded by machineries and this make difficulty the correct localisation of the tag. Figure 8.13 shows the estimated (on the left) and the detected path travelled by the product package located on a trolley, obtained by using LEC software (on the right).

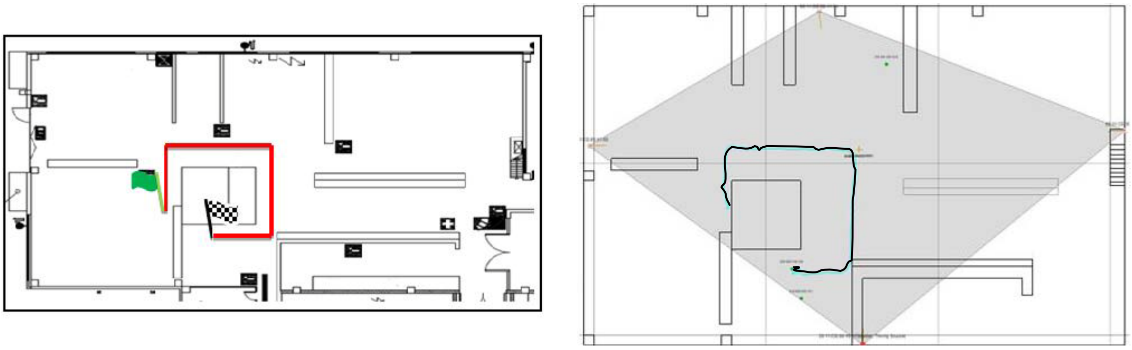


Figure 8.13. Estimated (on the left) and detected path (on the right) of dynamic *Test 3* using a static filter

Table 8.9 shows the detected and measured distances and the error between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
23.5	24.02	0.5199	2.2125

Table 8.9. Synthesis of dynamic *Test 3*

Test 4

The path is 11.5 m long. It is situated in a complex environment, characterised by the presence of walls and several machines that strongly hinder correct signal reception by the sensors. Indeed, it is possible to observe the irregular trend that causes problems in the correct evaluation of the distance travelled. Figure 8.14 shows the estimated (on the left) and the detected path travelled by the product package located on a trolley, obtained by using LEC software (on the right).

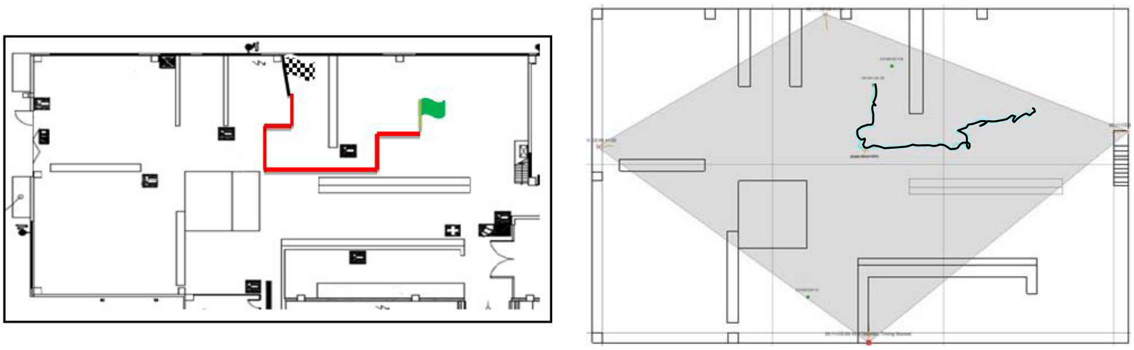


Figure 8.14. Estimated (on the left) and detected path (on the right) of dynamic *Test 4* using a static filter

Table 8.10 shows the detected and measured distances and the error between them.

Distance estimated [m]	Distance travelled [m]	Error [m]	Error [%]
11.5	14.42	2.9285	25.465

Table 8.10. Synthesis of dynamic *Test 4*

Dynamic tests with *Information Filtering*

It has been decided to realise the same tests by applying a dynamic filter, called *Information Filter,* to the algorithm, in order to compare the results with those obtained by using a static filter. If the sensors lose the signal, the static filter maintains the last detected position and updates it when a valid signal arrives. The dynamic filter, instead, stores the velocity and the direction of the tag all the time and, in case of absence of valid signals, it assumes that the target continues to move in the same direction and at the same velocity as the last measurement. The use of a dynamic filter results in lower performance of operations for the reconstruction of trajectories, since the paths do not reflect the real tag movements.

The tests have been performed according to the same parameters and the same path lengths as the dynamic tests with a static filter:

- Filter: *Information Filter*;
- Update each four time slot;
- Frequency: 37 Hz;
- Threshold speed: 2 m/s;

– Velocity of tag: 2 m/s at a constant height of 1.5 m.

Test 1

The application of a dynamic filter has not heavily modified the results, except for the central stretch and the last part of the path, since it is made up of metallic materials. Figure 8.15 shows the comparison between the maps obtained by using LEC software, in the case of static (on the left) and dynamic filter (on the right). The red arrows underline the main differences between the paths travelled by using a static and a dynamic filter.

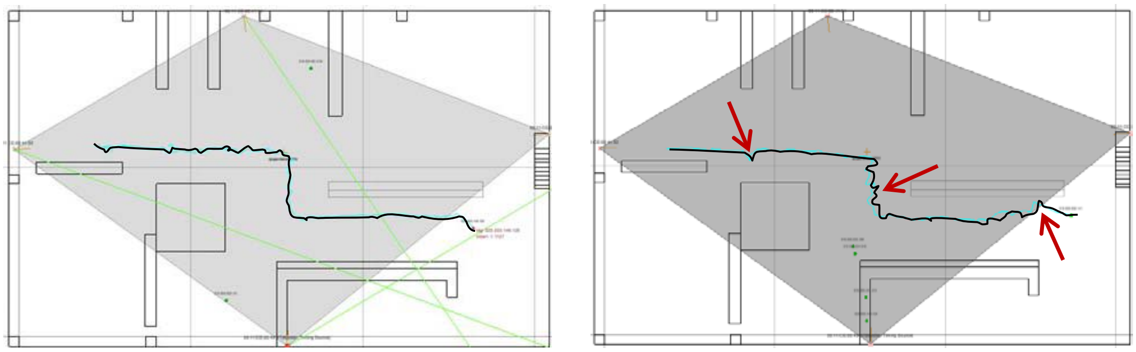


Figure 8.15. Path travelled by using static (on the left) and dynamic filter (on the right) for dynamic *Test 1*

The path travelled by the product package located on a trolley by using a dynamic filter, has presented more noise than that travelled by using a static filter. From Figure 8.15, it is possible to note some peaks along the path, due to the loss of the signal. Indeed the *Information Filter* allows the product package to move along the three dimensions, but, if it is not seen for a period, the system assumes that it is moving along the same direction and at the same velocity.

Test 2

In this case, the path has been strongly modified at the point where the signal is lost. In particular, from Figure 8.16, it is possible to observe the formation of straight lines that indicate that sensors have not been able to detect the tag presence for some seconds. In this way, the last trajectory is maintained, but it does not reflect the real path travelled by the product package. Figure 8.16 shows the comparison between the maps obtained by using LEC software, in the case of static (on the left) and dynamic filter (on the right). The red arrows show the main differences between the paths travelled by using a static and a dynamic filter. The straight lines on the maps in the right side, are due to the loss of the signal.

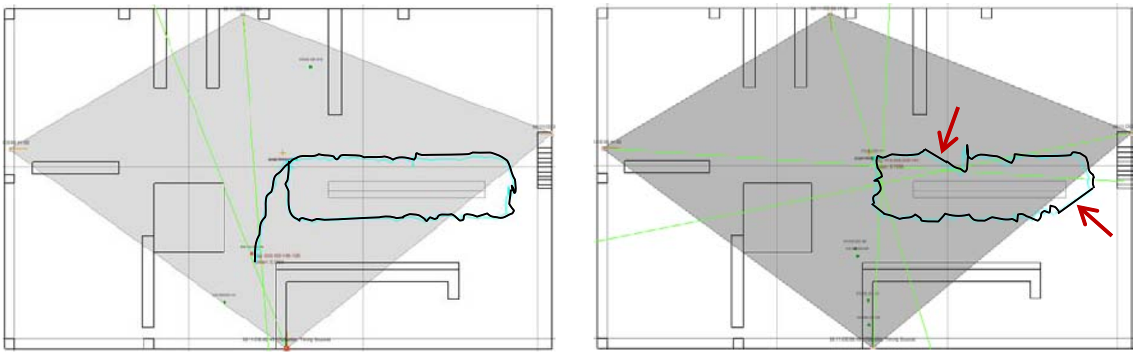


Figure 8.16. Path travelled by using static (on the left) and dynamic filter (on the right) for dynamic *Test 2*

Test 3

In this case, the errors in the traceability of the path are less evident than in *Test 2*, but it is possible to note that the line appears more indented (Figure 8.17). This is an indication of more noises during localisation. Moreover, in the final part, the trace overlaps with a wall, underlining the limits of the localisation with the dynamic filter. Figure 8.17 shows the comparison between the maps obtained by using LEC software, in the case of static (on the left) and dynamic filter (on the right). The red arrows show the main differences between the paths travelled by using a static and a dynamic filter.

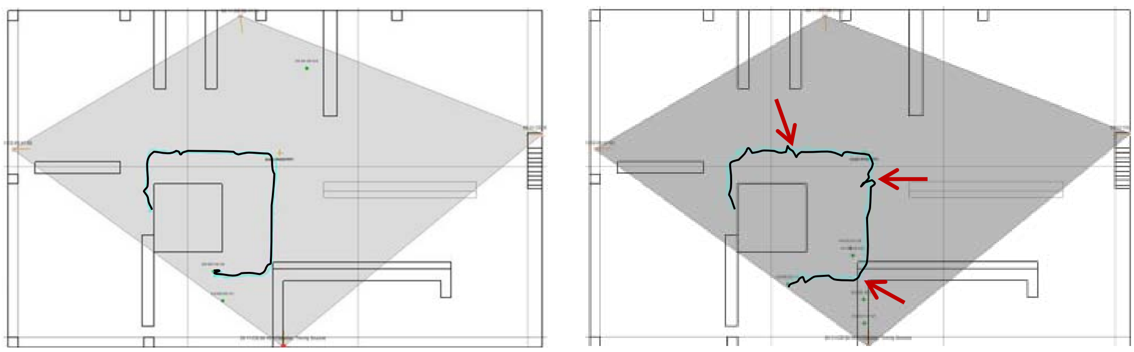


Figure 8.17. Path travelled by using static (on the left) and dynamic filter (on the right) for dynamic *Test 3*

Test 4

In this case, the errors in the traceability of the path are evident, because of the critical environment in which the path is travelled. In the middle of the path, the signal is lost and found again only in the proximity of the final part of the path. This leads to the creation of a straight line that does not reflect the real movement of the tag. Figure 8.18 shows the comparison between the maps obtained by using LEC software, in the case of static (on the left) and dynamic filter (on the right). The red arrows underline the main differences between the paths travelled by using a static and a dynamic filter.

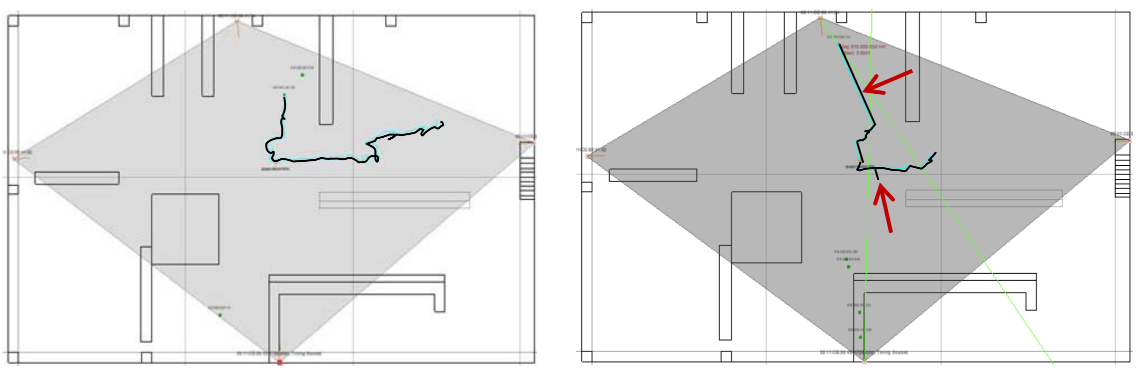


Figure 8.18. Path travelled by using static (on the left) and dynamic filter (on the right) for dynamic *Test 4*

The algorithm using a static filter has provided better results than that using the dynamic filter. The comparison between the two algorithms have showed that if the sensors lose the tag signal for a period, the system assumes that the tag continue to move according to the last velocity value and along the last direction of movement. The greater the moment of no-detection of tag position, the higher the inaccuracy of the system that causes a distortion of the path.

8.2.3.2 Tests within the assembly area of a manufacturing company

In the same way, the developed RFID-UWB system has been set within the assembly area of an Italian manufacturing company in order to identify the product flows and to evaluate the precision level with which the developed RFID-UWB system detects the tag inside the product package.

Figure 8.19 shows the map of the area to monitor. Red bullets represent the four sensors located at the corners of the area.

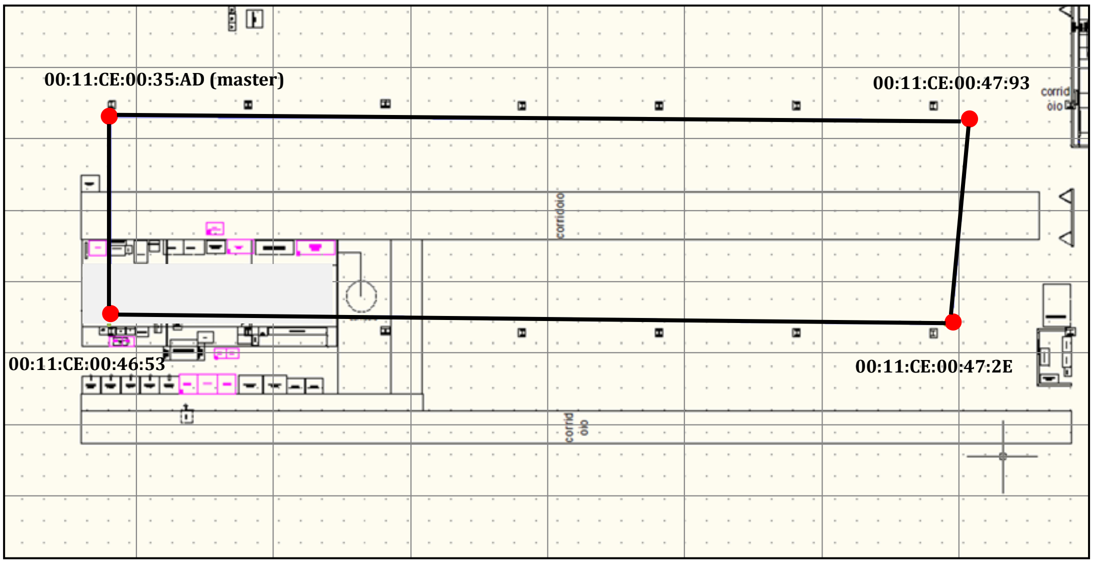


Figure 8.19. Map of the area to control within the manufacturing company

Table 8.11 shows the coordinates of the sensors.

Sensors name	X [m]	Y [m]	Z [m]
00:11:CE:00:35:AD (master)	8.00	31.65	4.60
00:11:CE:00:47:93 (slave)	70.70	31.35	5.43
00:11:CE:00:47:2E (slave)	69.35	17.03	5.1
00:11:CE:00:41:92 (slave)	8.00	17.74	4.66

Table 8.11. Sensor coordinates in the assembly area of a manufacturing company

Static and dynamic tests have been realised within the monitored area so as to evaluate the accuracy level of the system.

Static tests

Static test have been realised without using any filter and fixing the signal update each four time slot. The tests have been performed by attaching the tag on a product package located on a support 2 m high. 17 points within the monitored area have been identified, as shown in Figure 8.20.

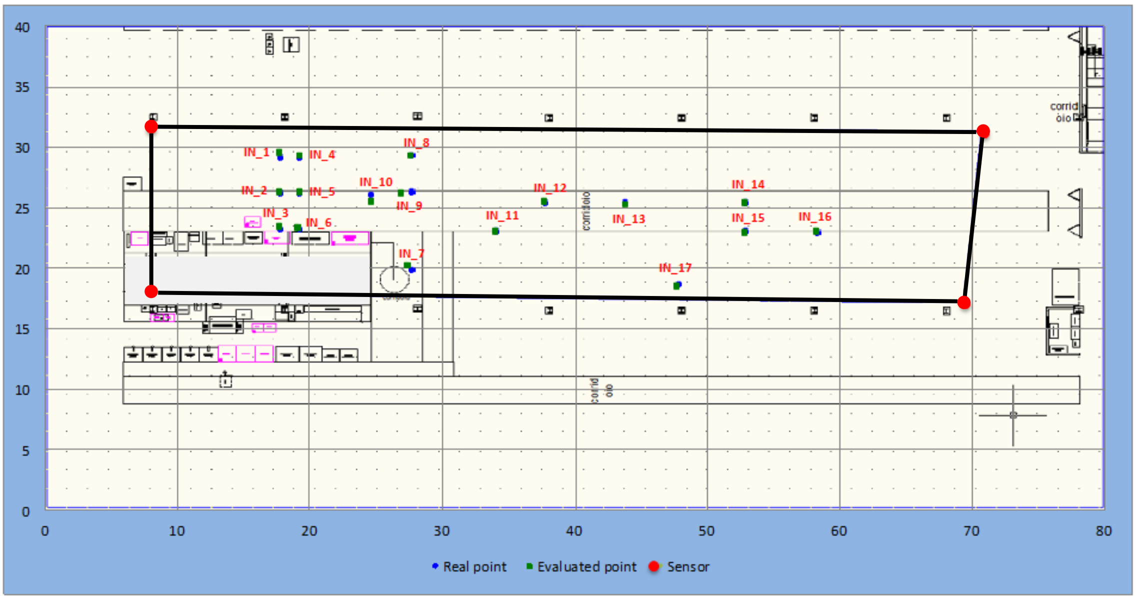


Figure 8.20. Reference points for static tests in the area to control

Table 8.12 shows the coordinates of the estimated and detected points, specifying the error between them.

Point	X [m]	Y [m]	Z [m]	X detected [m]	Y detected [m]	Z detected [m]	Average error [m]
1	17.79	29.18	2.00	17.64	29.47	1.80	0.32650
2	17.79	26.18	2.00	17.66	26.29	1.91	0.17029
3	17.79	23.18	2.00	17.67	23.38	1.70	0.23324
4	19.29	29.18	2.00	19.21	29.25	1.40	0.10630
5	19.29	26.18	2.00	19.18	26.32	1.31	0.17804
6	19.29	23.18	2.00	19.10	23.27	1.69	0.21024
7	27.72	19.82	2.00	27.42	20.13	0.64	0.43139
8	27.72	29.27	2.00	27.69	29.22	1.20	0.05831
9	27.72	26.26	2.00	26.89	26.14	1.77	0.83936
10	24.72	25.96	2.00	24.66	25.55	1.88	0.41437
11	34.13	22.97	2.00	34.05	22.99	2.09	0.08246
12	37.79	25.40	2.00	37.66	25.48	1.93	0.15264
13	43.89	25.40	2.00	43.83	25.23	2.55	0.18028
14	52.96	25.33	2.00	52.83	25.42	1.71	0.15811
15	52.96	22.97	2.00	52.84	22.95	1.87	0.12166
16	58.36	22.96	2.00	58.24	22.99	2.30	0.12369
17	47.81	18.68	2.00	47.78	18.56	2.43	0.12369

Table 8.12. Analysis of static tests within the monitored area

The average error of the 17 static tests is 0.2299 m (≈0.55%).

Considering that the static tests have been realised without applying any filter, that means the oscillations of the tag positions have been not damped, the average error between all the points is low (0.2299 m). As it is possible to note from Table 8.12, the most critical points are 7, 9 and 10 because they are close to the door (that separates the warehouse from the manufacturing and assembly area) that influences the signal captured by the sensors.

Dynamic tests

Dynamic tests have been performed by applying a tag on a product package located on a trolley that has moved around the monitored area of the manufacturing company following prefixed paths. The length of these paths, measured in advance, has been compared with the real distance travelled by the operator. In this way, it has been possible to evaluate the precision of each known point and test the capacity of the system to reconstruct the trajectory.

Each test has been performed by using two different filters: a static filter (*Static Information Filter*) and a dynamic filter (*Information Filter*). Each test has been performed according to the following parameters:

- Update each four time slot;
- Frequency: 37 Hz;
- Threshold speed: 2 m/s;
- Velocity of tag: 4 m/s at a constant height of 2 m.

Test 1

The path is 54.73 m long: during the first part of the path (left side of Figure 8.21), the tag crosses the door that influences the visibility of the sensors. After this first part, the tag is more visible by the sensors because it moves without meeting any obstacle. Figure 8.21 shows the detected path when using the static filter (green line) and the dynamic filter (red line).

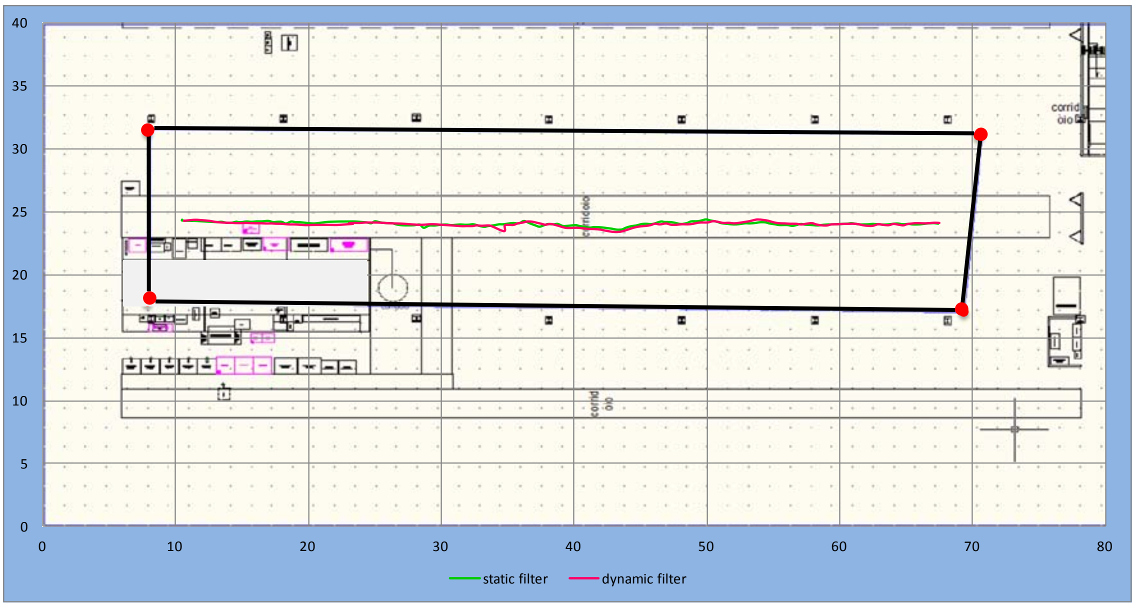


Figure 8.21. Detected path of dynamic *Test 1* when using the static filter (green line) and the dynamic filter (red line)

Table 8.13 shows the detected and measured distances and the average error between them using both static and dynamic filter.

	Static Filter			Dynamic Filter		
Estimated distance [m]	Detected distance [m]	Average error [m]	Average error [%]	Detected distance [m]	Average error [m]	Average error [%]
54.73	57.88	3.15	5.76%	58.52	3.79	6.93%

Table 8.13. Synthesis of dynamic *Test 1*

Test 2

The path is 25.88 m long. In this case, the average error is very low with both static and dynamic filter, because the tag does not cross the door that minimises the visibility of the sensors. Figure 8.22 shows the detected path when using the static filter (green line) and the dynamic filter (red line).

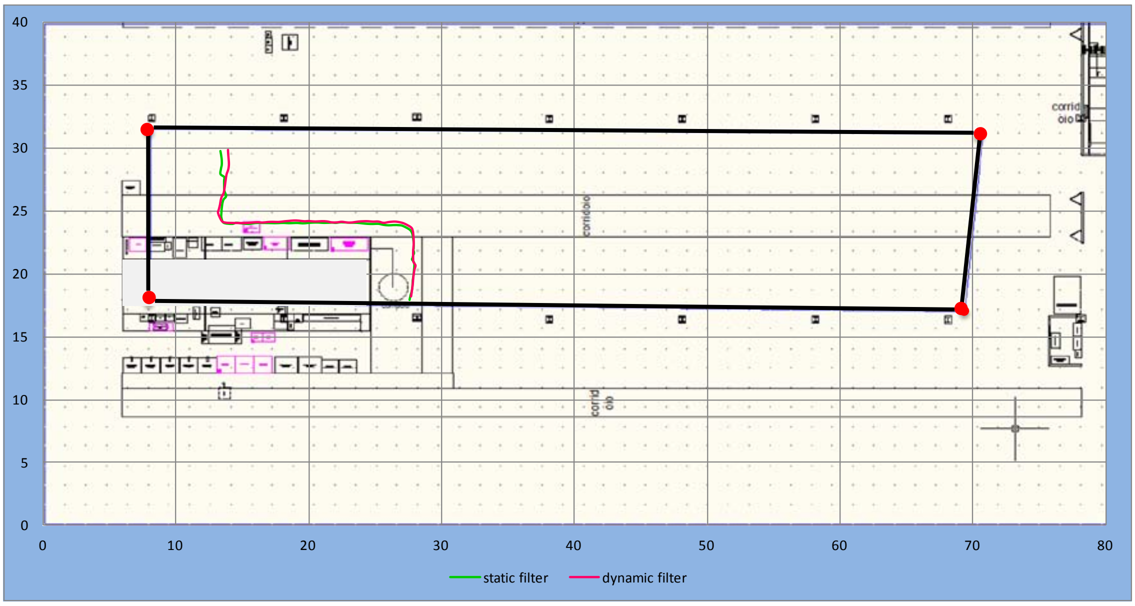


Figure 8.22. Detected path of dynamic *Test 2* when using the static filter (green line) and the dynamic filter (red line)

Table 8.14 shows the detected and measured distances and the average error between them using both static and dynamic filter.

	Static Filter			Dynamic Filter		
Estimated distance [m]	Detected distance [m]	Average error [m]	Average error [%]	Detected distance [m]	Average error [m]	Average error [%]
25.88	25.85	0.02	0.11%	25.74	0.13	0.52%

Table 8.14. Synthesis of dynamic *Test 2*

Test 3

The path is 15.04 m long. Figure 8.23 shows the detected path when using the static filter (green line) and the dynamic filter (red line).

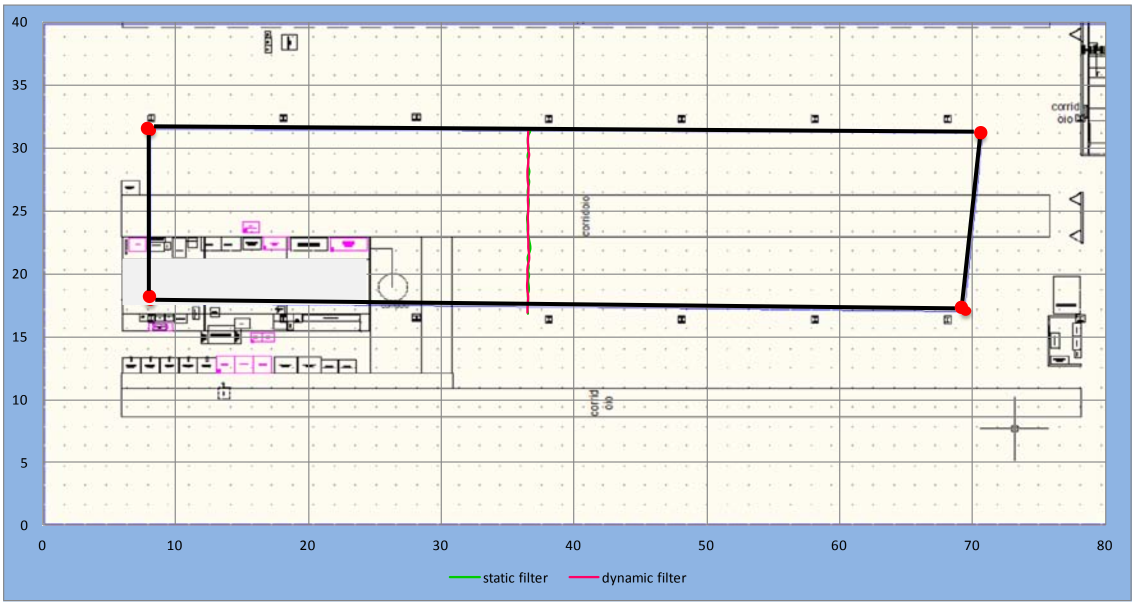


Figure 8.23. Detected path of dynamic *Test 3* when using the static filter (green line) and the dynamic filter (red line)

Table 8.15 shows the detected and measured distances and the average error between them using both static and dynamic filter.

	Static Filter			Dynamic Filter		
Estimated distance [m]	Detected distance [m]	Average error [m]	Average error [%]	Detected distance [m]	Average error [m]	Average error [%]
15.04	14.71	0.32	2.19%	14.48	0.55	3.71%

Table 8.15. Synthesis of dynamic *Test 3*

Test 4

The path is 53.21 m long. Figure 8.24 shows the detected path when using the static filter (green line) and the dynamic filter (red line).

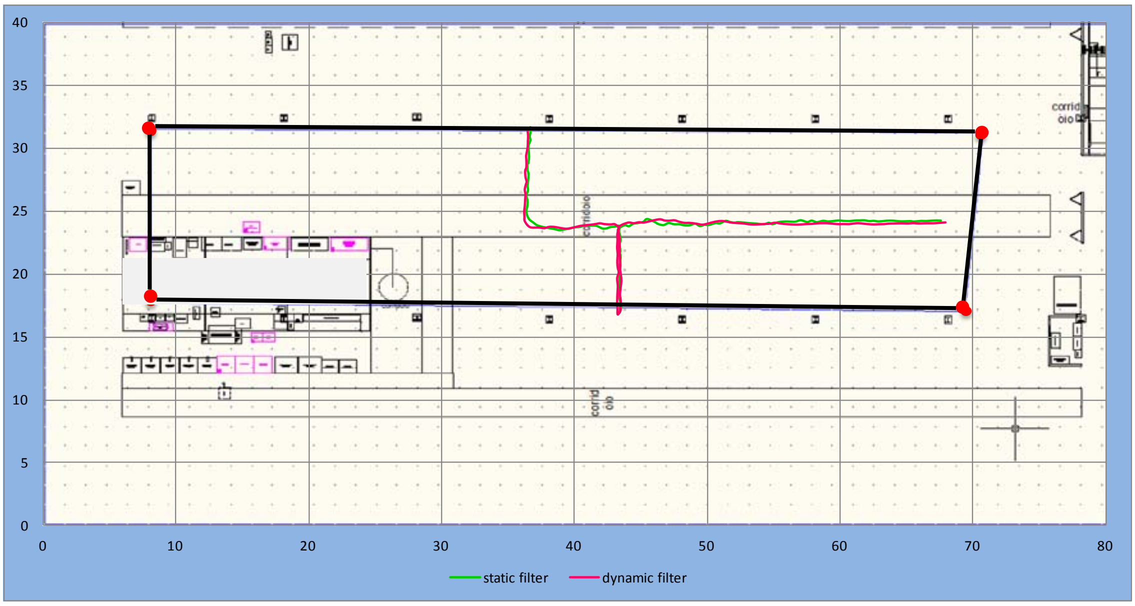


Figure 8.24. Detected path of dynamic *Test 4* when using the static filter (green line) and the dynamic filter (red line)

Table 8.16 shows the detected and measured distances and the average error between them using both static and dynamic filter.

	Static Filter			Dynamic Filter		
Estimated distance [m]	Detected distance [m]	Average error [m]	Average error [%]	Detected distance [m]	Average error [m]	Average error [%]
53.21	53.31	0.10	0.19%	53.51	0.30	0.58%

Table 8.16. Synthesis of dynamic *Test 4*

Test 5

The path is 43.06 m long. Figure 8.25 shows the detected path when using the static filter (green line) and the dynamic filter (red line).

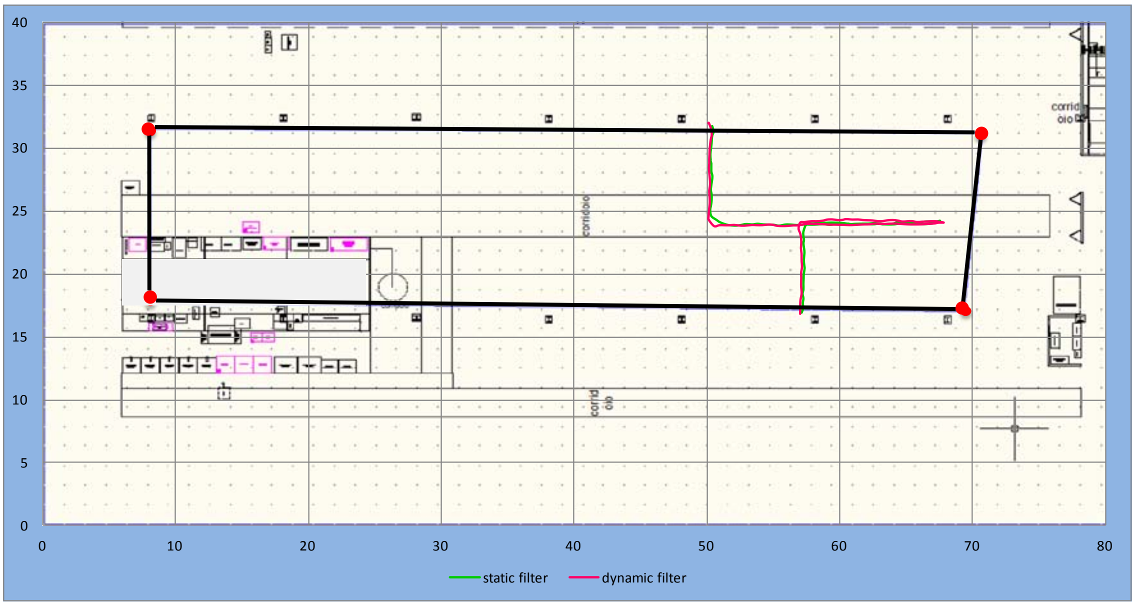


Figure 8.25. Detected path of dynamic *Test 5* when using the static filter (green line) and the dynamic filter (red line)

Table 8.17 shows the detected and measured distances and the average error between them using both static and dynamic filter.

	Static Filter			Dynamic Filter		
Estimated distance [m]	Detected distance [m]	Average error [m]	Average error [%]	Detected distance [m]	Average error [m]	Average error [%]
41.99	43.06	1.06	2.47%	43.94	0.88	2.04%

Table 8.17. Synthesis of dynamic *Test 5*

Test 6

The path is 53.64 m long. Figure 8.26 shows the detected path when using the static filter (green line) and the dynamic filter (red line).

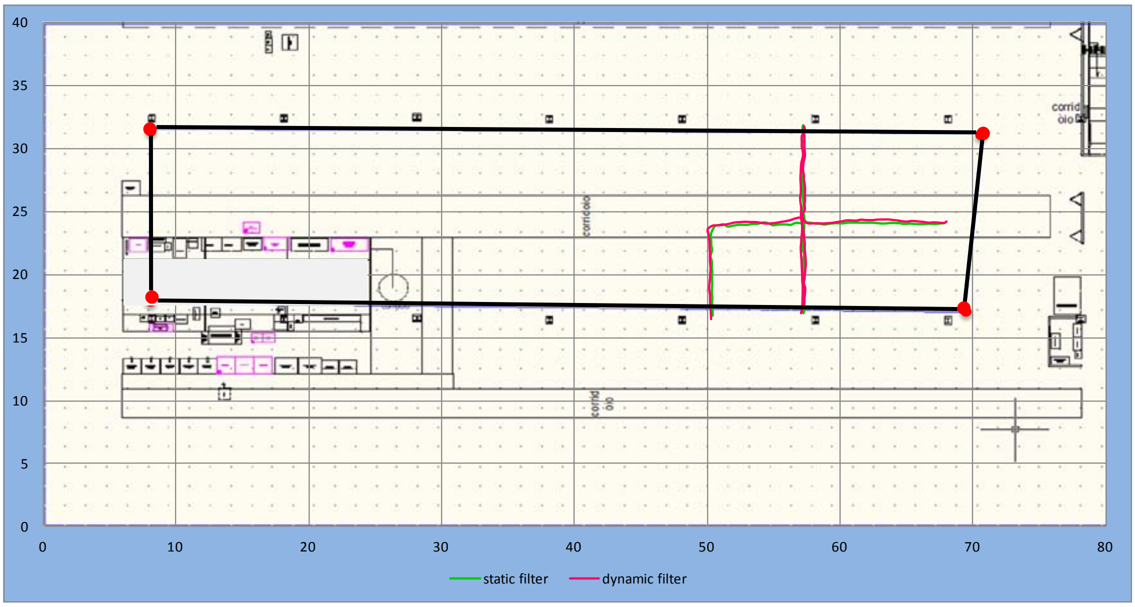


Figure 8.26. Detected path of dynamic *Test 6* when using the static filter (green line) and the dynamic filter (red line)

Table 8.18 shows the detected and measured distances and the average error between them using both static and dynamic filter.

	Static Filter			Dynamic Filter		
Estimated distance [m]	Detected distance [m]	Average error [m]	Average error [%]	Detected distance [m]	Average error [m]	Average error [%]
53.64	54.17	0.53	0.99%	55.25	1.61	3.01%

Table 8.18. Synthesis of dynamic *Test 6*

Test 7

The path is 36.48 m long. Figure 8.27 shows the detected path when using the static filter (green line) and the dynamic filter (red line).

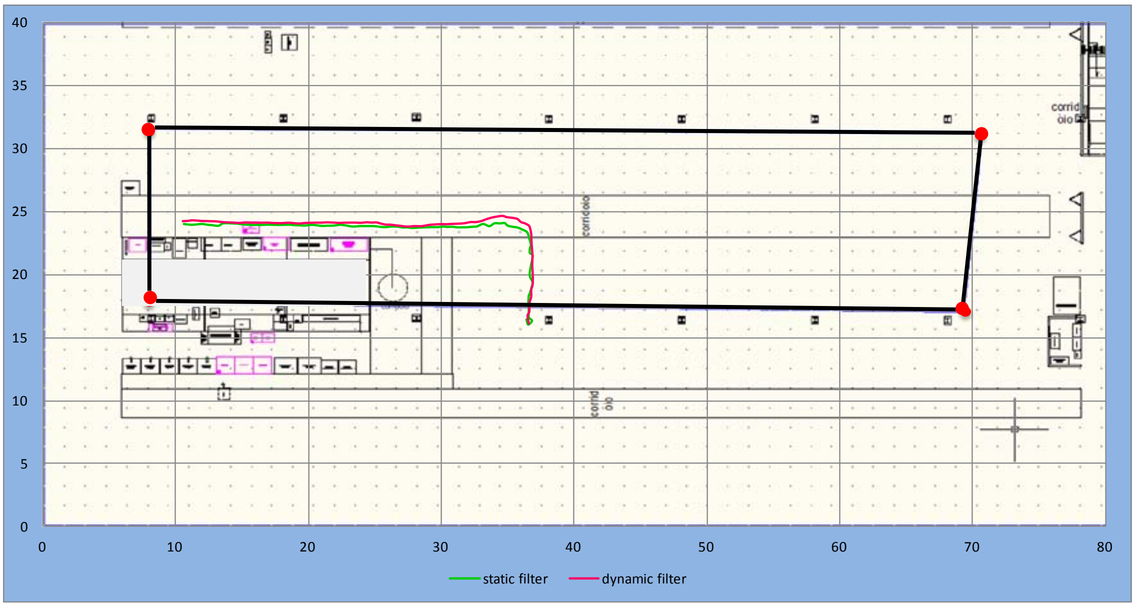


Figure 8.27. Detected path of dynamic *Test 7* when using the static filter (green line) and the dynamic filter (red line)

Table 8.19 shows the detected and measured distances and the average error between them using both static and dynamic filter.

	Static Filter			Dynamic Filter		
Estimated distance [m]	Detected distance [m]	Average error [m]	Average error [%]	Detected distance [m]	Average error [m]	Average error [%]
36.48	34.50	1.91	5.40%	34.16	2.31	6.34%

Table 8.19. Synthesis of dynamic *Test 7*

Test 8

The path is 70.52 m long. Figure 8.28 shows the detected path when using the static filter (green line) and the dynamic filter (red line).

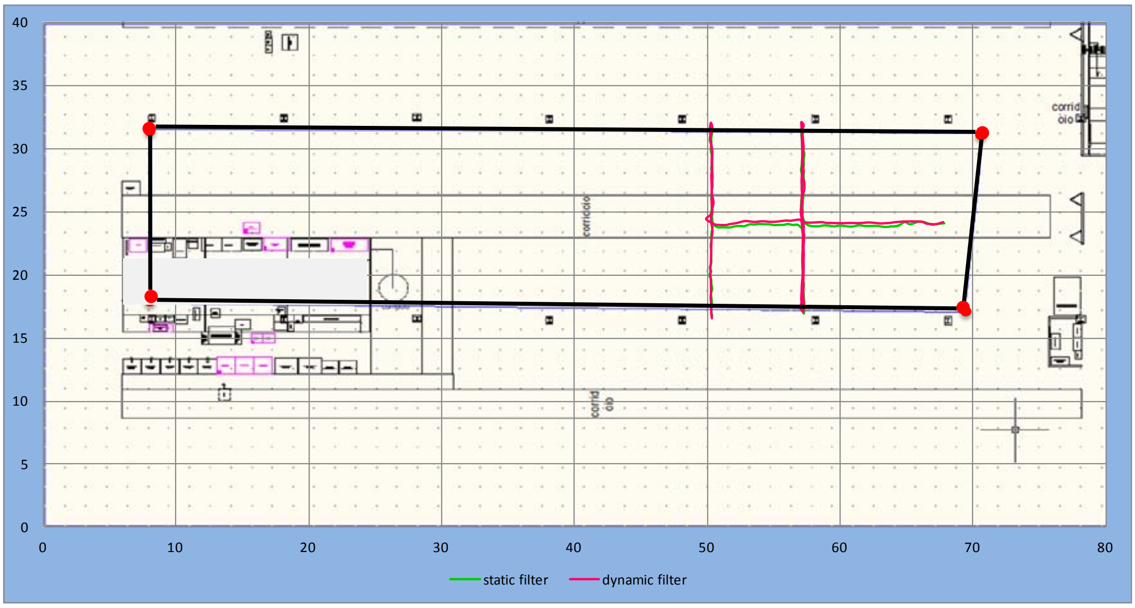


Figure 8.28. Detected path of dynamic *Test 8* when using the static filter (green line) and the dynamic filter (red line)

Table 8.20 shows the detected and measured distances and the average error between them using both static and dynamic filter.

	Static Filter			Dynamic Filter		
Estimated distance [m]	Detected distance [m]	Average error [m]	Average error [%]	Detected distance [m]	Average error [m]	Average error [%]
70.52	69.35	1.16	1.65%	71.76	1.24	1.76%

Table 8.20. Synthesis of dynamic *Test 8*

Test 9

The path is 32.11 m long. Figure 8.29 shows the detected path when using the static filter (green line) and the dynamic filter (red line).

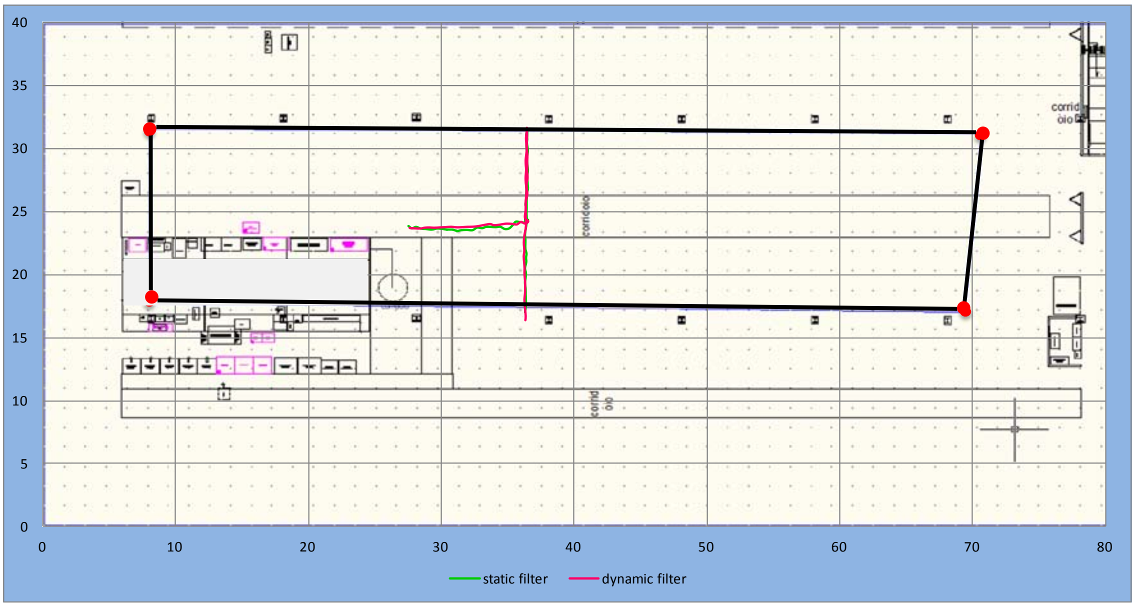


Figure 8.29. Detected path of dynamic *Test 9* when using the static filter (green line) and the dynamic filter (red line)

Table 8.21 shows the detected and measured distances and the average error between them using both static and dynamic filter.

	Static Filter			Dynamic Filter		
Estimated distance [m]	Detected distance [m]	Average error [m]	Average error [%]	Detected distance [m]	Average error [m]	Average error [%]
32.11	31.85	0.25	0.80%	31.95	0.15	0.47%

Table 8.21. Synthesis of dynamic *Test 9*

Test 10

The path is 61.00 m long. Figure 8.30 shows the detected path when using the static filter (green line) and the dynamic filter (red line).

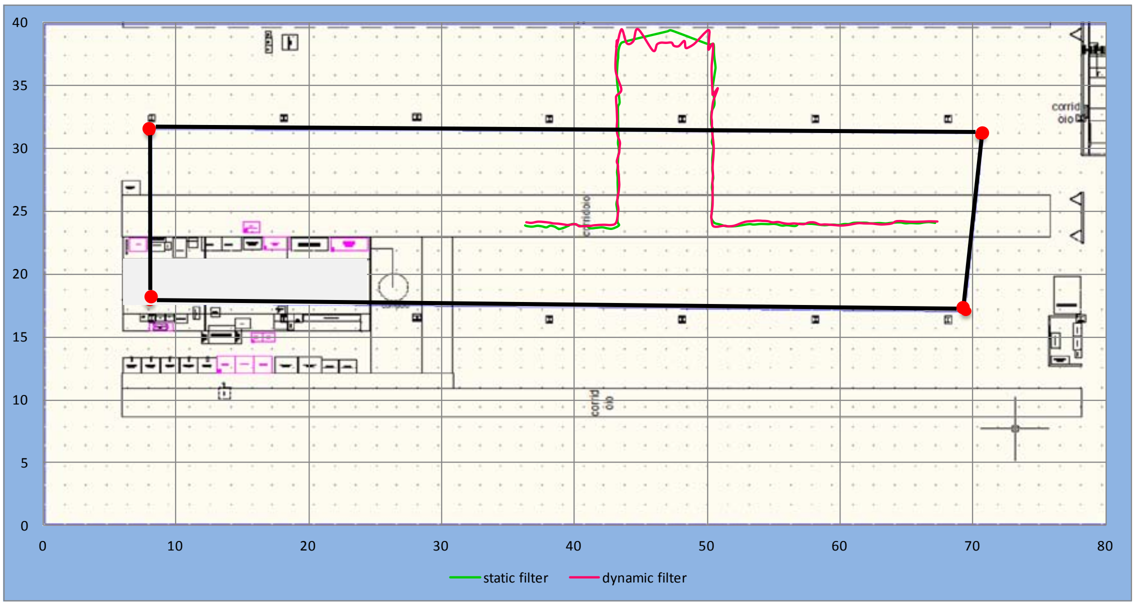


Figure 8.30. Detected path of dynamic *Test 10* when using the static filter (green line) and the dynamic filter (red line)

Table 8.22 shows the detected and measured distances and the average error between them using both static and dynamic filter.

	Static Filter			Dynamic Filter		
Estimated distance [m]	Detected distance [m]	Average error [m]	Average error [%]	Detected distance [m]	Average error [m]	Average error [%]
61.00	60.42	0.57	0.93%	69.03	8.03	13.16%

Table 8.22. Synthesis of dynamic *Test 10*

8.2.4 Results and discussion

The realised tests have demonstrated the high accuracy of the RFID-UWB system.

The average error between the estimated and detected measurements of static tests performed within the Mechanical Laboratory of the University of Bologna has been approximately 3.7%. In order to evaluate the accuracy of the RFID-UWB system, the points located outside the optimal coverage area have been eliminated and a considerable improvement in the accuracy has been obtained, reaching an average error between the estimated and detected points of 1.5%. Unlike the static tests, during the dynamic tests, it has been necessary to control the typology of filters used that influence the tag behaviour. The results show that the best performance has been obtained by using a static filter (*Static Information Filter*) with an error of 5.0% between the estimated and the real distance travelled, rather than a dynamic filter (*Information Filter*).

The results obtained during the static tests within the assembly area of the manufacturing company have showed that the average error between the estimated and detected measurements is approximately 0.55%. Regarding dynamic tests, several paths have been travelled all around the area, using two different filters (static and dynamic). The use of the static filter has allowed better performance in terms of minimum average error (2.05%) if compared with that obtained using the dynamic filter (average error of 3.86%).

In conclusion, it is possible to confirm the high level of accuracy and precision of the developed RFID-UWB system applied to product package. The optimal results achieved have confirmed the good visibility of the tags inside product packages, creating benefits in terms of minimisation of the costs (the use of only one tag instead of one for each product), increase of effectiveness and efficiency of the system.

Although the RFID-UWB system is an expensive technology, it provides good performance in terms of flow transparency (i.e. it is possible to know where the products are in real time and in continuous) with a consequent reduction in distance travelled that in turn allows a relevant cost reduction in transportation and warehousing. Moreover, the RFID-UWB system allows managing the product and package flows, evaluating the transportation time, the wait and idle time of the trolleys.

8.3 The cost perspective: a mathematical approach for the packaging cost evaluation

An innovative mathematical approach for the evaluation of the total packaging costs of a manufacturing company has been developed. The model takes into account the entire packaging system (primary, secondary and tertiary package and accessories) and the entire packaging supply chain. Figure 8.31 shows the parties of the supply chain considered by the model.

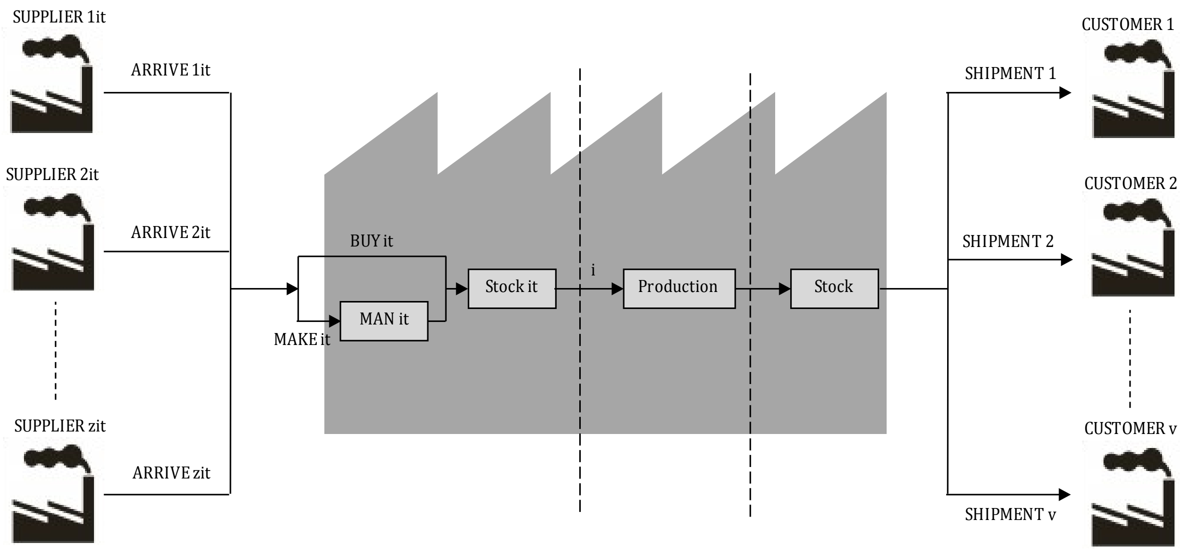


Figure 8.31. The packaging supply chain of a manufacturing company

As shown in Figure 8.30, the manufacturing company can produce packages internally or can purchase/rent them. When the materials arrive (raw materials and/or packages), they are received in the manufacturer receiving area, sorted and stored within the warehouse. If the company has to produce packages, raw materials are picked and brought to the manufacturing area, where packages are made and subsequently stored in the warehouse. The raw materials not used during the manufacturing stage are brought back to the warehouse, creating a reverse flow of materials. When the finished products are produced, packages are picked from the warehouse and brought to the manufacturing area to pack finished products. The packages not used during the manufacturing stage are brought back to the warehouse, creating a reverse flow of materials. If raw materials or packages are damaged during the use, they can be disposed of at landfill.

Table 8.23, 8.24 and 8.25 describe the indices, variables and parameters (in alphabetical order) used for the development of the mathematical approach.

Index	Domain	Description
i	1,…,4	Packaging level: i=1 (primary package) i=2 (secondary package) i=3 (tertiary package) i=4 (accessories)
t	1,…,m	Different packages for each level i

Table 8.23. Indices of the mathematical approach for the evaluation of packaging cost

Variable	Unit	Description	Domain
$C_{COND\ it}$	[€/piece]	Cost of sorting raw materials to produce package *i* type *t* (in case of internal manufacturing of packages). Cost of sorting package *i* type *t* (in case of purchase/rent of packages).	i=1,…,4 t=1,…,m
$C_{DISP\ it}$	[€/piece]	Cost of disposing damaged package *i* type *t* during the packing phase (in case of both internal manufacturing of packages and purchase/rent of packages).	i=1,…,4 t=1,…,m
$C_{ENG\ it}$	[€/piece]	Engineering cost for studying package *i* type *t*.	i=1,…,4 t=1,…,m
$C_{EXT\ TRAN\ it}$	[€/piece]	Transportation cost of raw materials to produce package *i* type *t* from the supplier to the manufacturer (in case of internal manufacturing of packages).	i=1,…,4 t=1,…,m
$C_{INT\ TRAN\ it}$	[€/piece]	Transportation cost of raw materials to produce package *i* type *t* from the manufacturer receiving area to the warehouse (in case of internal manufacturing of packages). Transportation cost of package *i* type *t* from the manufacturer receiving area to the warehouse (in case of purchase/rent of packages).	i=1,…,4 t=1,…,m
$C_{INT\ TRAN^1\ it}$	[€/piece]	Transportation cost of raw materials to produce package *i* type *t* from the warehouse to the manufacturing area (in case of internal manufacturing of packages).	i=1,…,4 t=1,…,m
$C_{INT\ TRAN^2\ it}$	[€/piece]	Transportation cost of package *i* type *t* produced by the company from the manufacturing area to the warehouse (in case of internal manufacturing of packages).	i=1,…,4 t=1,…,m
$C_{INT\ TRAN^3\ it}$	[€/piece]	Transportation cost of package *i* type *t* purchased or rent by the company from the warehouse to the manufacturing area (in case of purchase/rent of packages).	i=1,…,4 t=1,…,m
$C_{MAN\ it}$	[€/piece]	Production cost of package *i* type *t* (in case of internal	i=1,…,4

		manufacturing of packages).	t=1,…,m
$C_{ORD\ it}$	[€/piece]	Cost of purchase orders to buy raw materials to produce package *i* type *t* (in case of internal manufacturing of packages). Cost of purchase orders to buy package *i* type *t* (in case of purchase/rent of packages).	i=1,…,4 t=1,…,m
$C_{PICK\ it}$	[€/piece]	Cost for picking raw materials to produce package *i* type *t* (in case of internal manufacturing of packages). Cost for picking package *i* type *t* (in case of purchase/ rent of packages).	i=1,…,4 t=1,…,m
$C_{PICK^1\ it}$	[€/piece]	Cost for picking package *i* type *t* produced by the company (in case of internal manufacturing of packages).	i=1,…,4 t=1,…,m
$C_{PUR\ it}$	[€/piece]	Purchasing cost of raw materials to produce package *i* type *t* (in case of internal manufacturing of packages). Purchasing cost of package *i* type *t* (in case of purchase/rent of packages).	i=1,…,4 t=1,…,m
$C_{REC\ it}$	[€/piece]	Receiving cost of raw materials to produce package *i* type *t* (in case of internal manufacturing of packages). Receiving cost of package *i* type *t* (in case of purchase /rent of packages).	i=1,…,4 t=1,…,m
$C_{RENT\ it}$	[€/piece]	Cost to rent package *i* type *t*.	i=1,…,4 t=1,…,m
$C_{REV\ EXT\ COND\ it}$	[€/piece]	Cost of re-conditioning of package *i* type *t* after the shipment (in case of both internal manufacturing of packages and purchase/rent of packages).	i=1,…,4 t=1,…,m
$C_{REV\ EXT\ TRAN\ it}$	[€/piece]	Cost of external reverse transport of package *i* type *t* from the customer to the company (in case of both internal manufacturing of packages and purchase/rent of packages).	i=1,…,4 t=1,…,m
$C_{REV\ INT\ COND^1\ it}$	[€/piece]	Cost of re-conditioning of raw materials not used to produce package *i* type *t* to make them re-usable (in case of internal manufacturing of packages).	i=1,…,4 t=1,…,m
$C_{REV\ INT\ COND^2\ it}$	[€/piece]	Cost of re-conditioning of package *i* type *t* not used during the packing phase (in case of purchase/rent of packages).	i=1,…,4 t=1,…,m
$C_{REV\ INT\ TRAN^1\ it}$	[€/piece]	Cost of internal reverse transport of raw materials not used to produce package *i* type *t* (in case of internal manufacturing of packages).	i=1,…,4 t=1,…,m
$C_{REV\ INT\ TRAN^2\ it}$	[€/piece]	Cost of internal reverse transport of package *i* type *t* not used during the packing phase (in case of purchase/rent of packages).	i=1,…,4 t=1,…,m
$C_{STOCK\ it}$	[€/piece]	Cost for storing raw materials to produce package *i* type *t* (in case of internal manufacturing of packages). Cost for storing package *i* type *t* (in case of purchase/rent of packages).	i=1,…,4 t=1,…,m
$C_{STOCK^1\ it}$	[€/piece]	Cost for storing package *i* type *t* produced by the company (in case of internal manufacturing of packages).	i=1,…,4 t=1,…,m
$N_{EXT\ TRAN\ it}$	[trips/year]	Number of trips of raw materials to produce package *i* type *t* from the supplier to the manufacturer (in case of internal manufacturing of packages). Number of trip of package *i* type *t* from the supplier to the manufacturer (in case of purchase/rent of packages).	i=1,…,4; t=1,…,m
$N_{INT\ TRAN\ it}$	[trips/year]	Number of trips of raw materials to produce package *i* type *t* from the manufacturer receiving area to the warehouse (in case of internal manufacturing of packages). Number of trip of package *i* type *t* from the manufacturer receiving area to the warehouse (in case of purchase/rent of packages).	i=1,…,4 t=1,…,m
$N_{INT\ TRAN^1\ it}$	[trips/year]	Number of trips of raw materials to produce package *i* type *t* from the warehouse to the manufacturing area (in case of internal manufacturing of packages).	i=1,…,4 t=1,…,m

$N_{INT\ TRAN^2\ it}$	[trips/year]	Number of trips of package *i* type *t* produced by the manufacturer and transported from the manufacturing area to the warehouse (in case of internal manufacturing of packages).	i=1,…,4 t=1,…,m
$N_{INT\ TRAN^3\ it}$	[trips/year]	Number of trips of package *i* type *t* from the warehouse to the area to pack finished products (in case of both internal manufacturing of packages and purchase/rent of packages).	i=1,…,4 t=1,…,m
$N_{REV\ EXT\ TRAN\ it}$	[trips/year]	Number of trips of package *i* type *t* from the customer to the manufacturing company (in case of both internal manufacturing of packages and purchase/rent of packages).	i=1,…,4 t=1,…,m
$N_{REV\ INT\ TRAN^1\ it}$	[trips/year]	Number of trips of raw materials not used to produce package *i* type *t* from the manufacturing area to the warehouse (in case of internal manufacturing of packages).	i=1,…,4 t=1,…,m
$N_{REV\ INT\ TRAN^2\ it}$	[trips/year]	Number of trips of package *i* type *t* not used during the packing of finished products from the manufacturing area to the warehouse (in case of both internal manufacturing of packages and purchase/rent of packages).	i=1,…,4 t=1,…,m
w_{it}	[pieces/year]	Quantity of package *i* type *t* rent by the company.	i=1,…,4 t=1,…,m
x_{it}	[pieces/year]	Quantity of raw materials bought by the company to produce package *i* type *t*.	i=1,…,4 t=1,…,m
x'_{it}	[pieces/year]	Quantity of package *i* type *t* produced by the manufacturing company from raw materials x_{it}.	i=1,…,4 t=1,…,m
y_{it}	[pieces/year]	Quantity of package *i* type *t* bought by the company.	i=1,…,4 t=1,…,m

Table 8.24. Variables of the mathematical approach for the evaluation of packaging cost

Parameter	Nomenclature	Unit	Description
C_{COND}	Cost of Conditioning	[€/year]	Cost for sorting raw materials and/or packages before storing them in the warehouse. It includes the labour costs and depreciation of mechanical devices (if used), for example for unpacking and re-packing products.
C_{DISP}	Cost of Disposal	[€/piece]	Cost of disposal of damaged packages during the manufacturing phase. It comprises the cost of disposal, the cost of transporting damaged packages from the company to the landfill (labour costs, depreciation of vehicles used (e.g. truck), cost of the distance travelled).
C_{ENG}	Cost of Engineering	[€/year]	Cost for studying each type of packaging and for realising prototypes. It includes the labour costs of engineering the product.
$C_{EXT\ TRAN}$	Cost of External Transport	[€/travel]	Cost for transporting raw materials and/or packages from the supplier to the manufacturer: it comprises labour costs, depreciation of vehicles (e.g. truck), cost of the distance travelled.
$C_{INT\ TRAN}$	Cost of Internal Transport	[€/travel]	Cost for transporting raw materials and/or packages from the manufacturer receiving area to the warehouse. It includes the labour costs, depreciation of vehicles (e.g. forklift), cost of the distance travelled.
$C_{INT\ TRAN^1}$	Cost of Internal Transport[1]	[€/travel]	Cost for transporting raw materials from the warehouse to the manufacturing area to produce the packages. It includes the labour costs, depreciation of vehicles (e.g. forklift), cost of the distance travelled.
$C_{INT\ TRAN^2}$	Cost of Internal Transport[2]	[€/travel]	Cost for transporting the packages produced by the company from the production area to the warehouse. It includes the

			labour costs, depreciation of vehicles (e.g. forklift), cost of the distance travelled.
$C_{INT\ TRAN}^3$	Cost of Internal Transport[3]	[€/travel]	Cost for transporting packages from the warehouse to the manufacturing area. It includes the labour costs, depreciation of vehicles (e.g. forklift), cost of the distance travelled.
C_{MAN}	Cost of Packages Manufacturing	[€/piece]	Cost for producing packages internally. It includes the labour costs, depreciation of production plants and utilities (e.g. electricity, water, gas, etc.).
C_{ORD}	Cost of Purchase Order	[€/order]	Cost for managing the internal purchase orders if the manufacturer produces packages internally; otherwise it represents the purchase orders for buying and/or renting packaging from suppliers. It includes the labour costs for making the order.
C_{PICK}	Cost of Picking[1]	[€/piece]	Cost for picking raw materials from the warehouse to produce packages. It includes the labour costs and depreciation of vehicles (e.g. forklift) for picking the products.
C_{PICK}^1	Cost of Picking[1]	[€/piece]	Cost for picking packages (produced/bought/rented) from the warehouse. It includes the labour costs and depreciation of vehicles (e.g. forklift) for picking the packages.
C_{PUR}	Cost of Purchasing	[€/piece]	Purchase cost of raw materials (to produce packaging) and/or packages.
C_{REC}	Cost of Receiving	[€/year]	Cost for receiving raw materials and/or packages. It includes the labour costs and depreciation of vehicles (e.g. truck, forklift) used to unload products.
C_{RENT}	Cost of Rent	[€/piece]	Cost to rent packages.
$C_{RE\text{-}USE}$	Cost of Re-Use	[€/year]	Cost of re-using packaging after the delivery of finished products to the customer. It includes: $C_{REV\ EXT\ TRAN}$: the cost of transport for coming back to the company. It comprises the labour costs, depreciation of vehicles used (e.g. truck), cost of the distance travelled; $C_{REV\ EXT\ COND}$: the cost of conditioning packages to make them re-usable. It comprises the labour costs and depreciation of mechanical devices (if used), for example for unpacking and re-packing products.
C_{REV}^1	Cost of Internal Reverse Logistics[1]	[€/travel]	Cost of transport for bringing raw materials not used during manufacturing phase back to the warehouse. It includes: $C_{REV\ INT\ TRAN}^1$: the cost of transport for coming back to the warehouse. It comprises labour costs, depreciation of vehicles used (e.g. forklift), cost of the distance travelled; $C_{REV\ INT\ COND}^1$: the cost of conditioning raw materials to make them re-usable. It comprises the labour costs and depreciation of mechanical devices (if used), for example for unpacking and re-packing products.
C_{REV}^2	Cost of Internal Reverse Logistics[2]	[€/travel]	Cost of transport for bringing packages not used during the packing of finished products back to the warehouse. It includes: $C_{REV\ INT\ TRAN}^2$: the cost of transport for coming back to the warehouse. It comprises the labour costs, depreciation of vehicles used, cost of the distance travelled; $C_{REV\ INT\ COND}^2$: the cost of conditioning packages to make them re-usable. It comprises the labour costs and depreciation of mechanical devices (if used), for example for unpacking and re-packing products.
C_{STOCK}	Cost of Stocking	[€/piece]	Cost for storing raw materials and/or packages in the warehouse. It includes the labour costs and the cost of the space to store packages.
C_{STOCK}^1	Cost of Stocking[1]	[€/piece]	Cost for stocking packages produced internally by the company. It includes the labour costs and cost of the space for storing the packages.

N_{ORD}	Number of Order	[orders/ year]	Number of orders to buy raw materials and/or packages.

Table 8.25. Parameters of the mathematical approach for the evaluation of packaging cost

Equation 8.1 introduces the general formula for the model.

$$C_{TOT} = C_{ENG} + C_{ORD} + C_{PUR} + C_{RENT} + C_{EXT\ TRAN} + C_{REC} + C_{COND} + C_{INT\ TRAN} + C_{STOCK} + C_{PICK} + C_{INT\ TRAN^1} + C_{MAN} + C_{REV^1} + C_{INT\ TRAN^2} + C_{STOCK^1} + C_{PICK^1} + C_{INT\ TRAN^3} + C_{REV^2} + C_{RE-USE} + C_{DISP} \quad (8.1)$$

Equation 8.2 presents the mathematical approach, explaining each cost parameter in details.

$$
\begin{aligned}
C_{TOT} = \Bigg[& \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{ENG\ it}\right) + \left(N_{ORD} \cdot \sum_{i=1}^{4}\sum_{t=1}^{m} C_{ORD\ it}\right) + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{PUR\ it} \cdot (x_{it} + y_{it})\right) \\
& + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{RENT\ it} \cdot w_{it}\right) + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{EXT\ TRAN\ it} \cdot N_{EXT\ TRAN\ it}\right) + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{REC\ it}\right) \\
& + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{COND\ it}\right) + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{INT\ TRAN\ it} \cdot N_{INT\ TRAN\ it}\right) \\
& + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{STOCK\ it} \cdot (x_{it} + y_{it} + w_{it})\right) + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{PICK\ it} \cdot x_{it}\right) \\
& + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{INT\ TRAN^{1} it} \cdot N_{INT\ TRAN^{1} it}\right) + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{MAN\ it} \cdot x'_{it}\right) \\
& + \left(\left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{REV\ INT\ TRAN^{1} it} \cdot N_{REV\ INT\ TRAN^{1} it}\right) + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{REV\ INT\ COND^{1} it}\right)\right) \\
& + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{INT\ TRAN^{2} it} \cdot N_{INT\ TRAN^{2} it}\right) + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{STOCK^{1} it} \cdot x'_{it}\right) \\
& + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{PICK^{1} it} \cdot (x'_{it} + y_{it} + w_{it})\right) + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{INT\ TRAN^{3} it} \cdot N_{INT\ TRAN^{3} it}\right) \\
& + \left(\left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{REV\ INT\ TRAN^{2} it} \cdot N_{REV\ INT\ TRAN^{2} it}\right) + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{REV\ INT\ COND^{2} it}\right)\right) \\
& + \left(\left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{REV\ EXT\ TRAN\ it} \cdot N_{REV\ EXT\ TRAN\ it}\right) + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{REV\ EXT\ COND\ it}\right)\right) \\
& + \left(\sum_{i=1}^{4}\sum_{t=1}^{m} C_{DISP\ it} \cdot (x_{it} + x'_{it} + y_{it})\right)\Bigg] \qquad (8.2)
\end{aligned}
$$

The mathematical approach could contribute to provide companies with a tool that allows them to analyse packaging costs, in order to understand the potential packaging cost reductions and consequently to reduce total company costs. Moreover, the model could help companies find out overlooked and oversized packaging factors, improving their efficiency.

8.3.1 The application of the mathematical approach to a manufacturing company

The model has been applied to an Italian manufacturing company operating in the food sector. The company has never considered the impact of packaging costs on its total costs. To confirm this, the total number of primary packages used was 100 and each one could be contained in more than 30 secondary packages. In addition, each package was transported for several kilometres per year (~ 3,500 Km/year) within the warehouses. Figure 8.32 shows the link between primary and secondary packages.

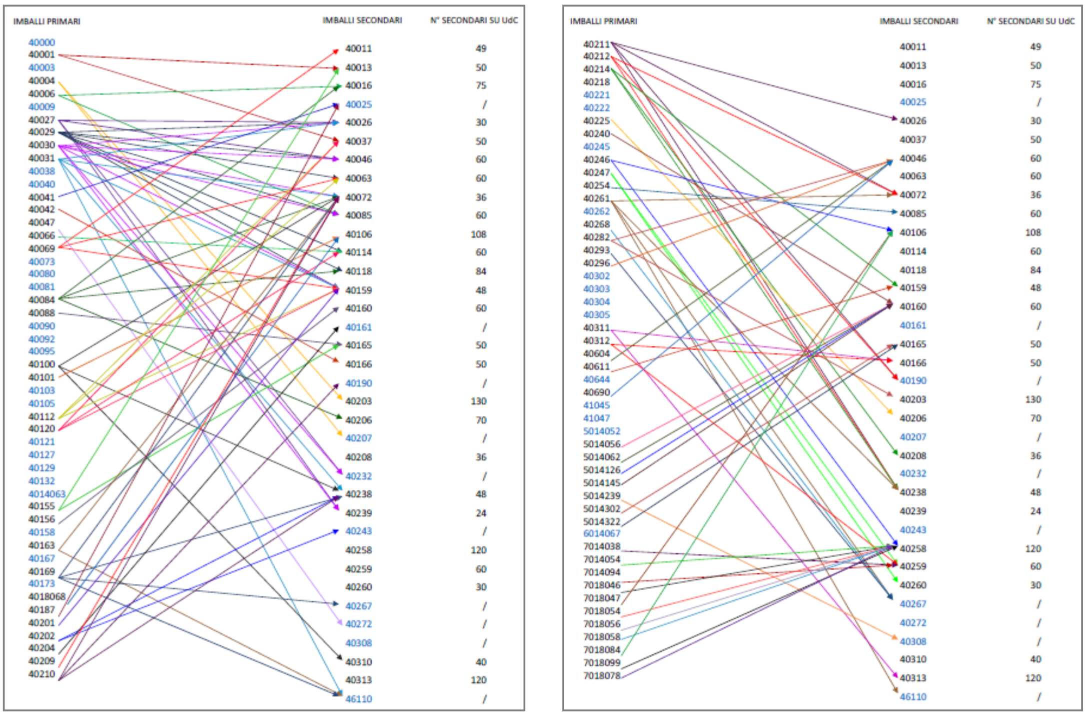


Figure 8.32. Link between primary and secondary packages in the manufacturing company

Among all the product families, it has been chosen one that uses three primary packages, that can be contained within two different secondary packages and one kind of tertiary package (i.e. pallet). The accessories used are plastic film. The packaging cost parameters of the model have been considered and computed, as shown in Table 8.26.

Cost parameters	Cost [€/year]	Cost [%]
Cost of engineering	28,785	4.45%
Cost of purchasing:		
Cost of order	33,090	5.12%
Cost of purchasing	264,000	40.82%
Cost or rent	25,000	3.87%
Cost of external transport	49,089	7.59%
Cost of sorting:		
Cost of receiving	28,996	4.48%
Cost of conditioning	63,290	9.79%
Cost of internal transport	27,154	4.20%
Cost of warehousing (cost of stocking and picking)	83,457	12.90%
Cost of manufacturing	-	0.00%
Cost of internal reverse transport	20,365	3.15%
Cost of re-use	-	0.00%
Cost of disposal	1,513	0.23%
Other costs (e.g. re-labelled, etc.)	22,003	3.40%
TOTAL	**646,742**	**100%**

Table 8.26. Packaging cost parameters with the relative costs

Before the application of the mathematical model, the total packaging costs was 646,742 €/year.

Figure 8.33 shows a graphical representation by value [€/year] of the packaging cost parameters. The major cost is represented by the warehouse management (stocking and picking of products), while the most insignificant packaging cost is represented by the cost of disposal (in addition to the manufacturing and re-use cost that are 0 €/year because the company buys the packages from packaging producers).

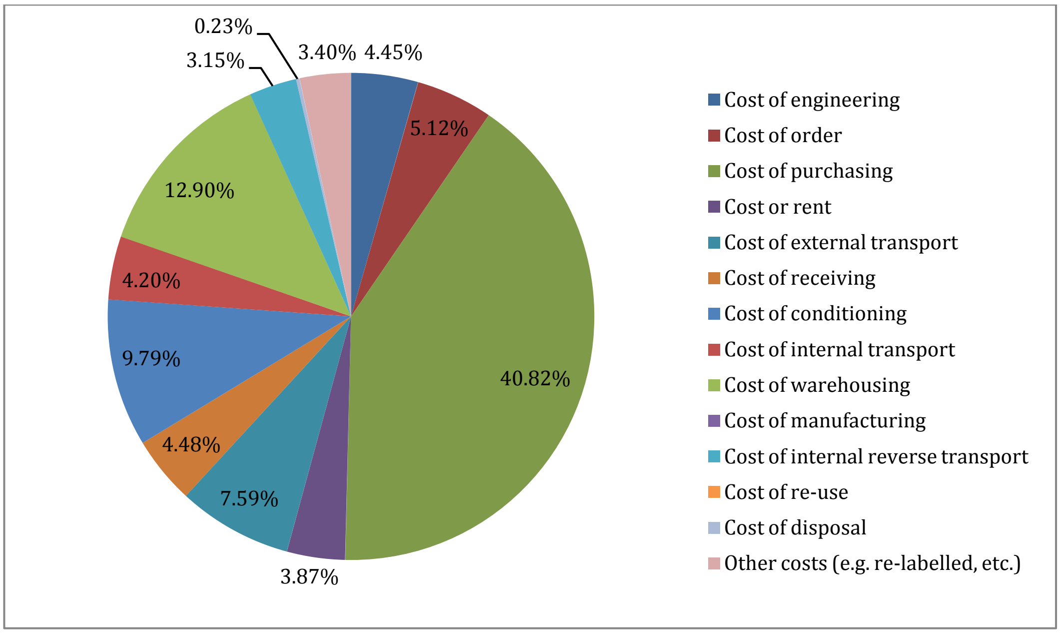


Figure 8.33. Graphical representation by value [€/year] of the packaging cost parameters

The analysis of the packaging system of the company has pointed out the critical management of packaging (e.g. warehousing, sorting) by the company. The weight of the packaging costs on the total company costs is significant because of the following reasons:

- The large number of primary and secondary packages managed (high necessary stocking space and difficult management);
- The stock-out due to the no-optimal management of the packaging system;
- The great distance travelled by packages because they are stocked in different parts of the company warehouse and they usually come back if not used.

Thanks to the conducted analysis and to the re-design of the packaging system, the company has decreased its total packaging cost by 16%.

8.4 The environmental perspective: the fundamental function of re-using packaging in humanitarian logistics

An in-depth literature analysis on humanitarian logistics and packaging has underlined the lack of study of packaging in humanitarian logistics. After the direct contact with several humanitarian organisations acting worldwide (e.g. UNHRD (WFP-ONU), Save the Children, MSF, Action Aid, COOPI, etc.) the importance to analyse and study the application of packaging to humanitarian logistics topic has been emerged.

In collaboration with United Nations Humanitarian Response Depot (UNHRD, a section of World Food Programme, UN) it has been studied a way to optimise secondary packages during an emergency.

Firstly, it has been evaluated the quantity and the typology of packages shipped to the staging areas[6] by analysing ten packing list. Table 8.27 shows the summary of the analysis of transported packages.

Packing list N.	Wooden box [Kg]	Carton box [Kg]	Steel crate [Kg]	Plastic [Kg]	Pallet [Kg]	PW/GR [%]
1	-	102	720	-	20	10.00
2	-	-	360	-	40	4.78
3	-	-	-	-	60	0.84
4	2,320	592	200	1,533	1,302	19.21
5	1,421	344	200	33	1,230	16.91
6	-	24	120	-	-	6.88
7	594	1,706	-	2,500	2,200	22.40
8	-	640	-	-	-	6.50
9	-	1,920	-	-	480	9.84
10	200	-	-	-	-	10.81
Total	4,535	5,328	1,600	4,066	5,332	

Table 8.27. Quantity and typology of transported packages

[6] The staging area is the area close to the disaster area where goods are sorted to be distributed.

where:

PW indicates the packaging weight per packing list [Kg/packing list]

GR indicates the gross weight per packing list [Kg/packing list]

As it is possible to note from Table 8.27, among the analysed packing lists, the percentage of packaging weight on the gross weight of a single ship goes from 0.84% to 22.40% with an average value of 10.81%. The percentage of packages used for the protection and containment of items to be sent to the staging areas on the total weight of the ship is high. Thinking that a mission by plane costs approximately 200,000 $, around 20,000÷40,000 $ are packages that, after they have accomplished their primary function of protection and containment, are thrown away.

According to this, the study has been focused on the re-use of packages arriving at the staging areas in order to fulfil a function different from protection and containment of products. The re-use of secondary packages could lead to several benefits for both the humanitarian organisations and local people. Some benefits concern the minimisation of environmental impact and pollutant emissions, the reduction of packaging waste (because more packages (e.g. cardboard, wood, plastics, etc.) are used to build up several objects, instead of to be disposed as waste), and the increase of the number of local people occupied in doing something.

Next paragraph presents the analysis of the realisation of several objects by re-using secondary and tertiary packages arriving at the staging areas.

At the beginning, the main requirements and needs of people affected by disasters have been studied and analysed. From this, it has been possible to decide some important items useful for the life in the camp that can help people living in the emergency camp to improve their daily life. Six different prototypes have been realised: a backpack, a pair of slippers, a stool, a cradle, a solar cooker and a Waterless Composting Toilet (WCT) model.

The prototypes have been realised in the Mechanical Laboratory of the University of Bologna, starting from carton boxes and pallets. Next paragraphs will describe the realised prototypes in details.

8.4.1 The carton backpack

The first prototype realised by re-using packaging arriving at the camp has been the backpack. People living in an emergency camp have to go to the staging area in order to bring rise or any other kind of food, or carry several objects useful for their daily life. A resistant backpack can help them realise these activities.

The carton box has been cut and attached along the shorter side through brown scotch. Four brown scotch layers have been used for creating the braces. Figure 8.34 shows the carton backpack.

Figure 8.34. The carton backpack prototype

It has been tested the resistance of the carton backpack. It can contain until 10 Kg while a person jumping.

8.4.2 The carton slippers

The major part of the people living in an emergency camp walks without any kind of shoes. For this, it has been thought to realised pairs of slippers starting from carton boxes arriving at the camp.

Two are the versions realised: the first has been developed by using one carton-layer. The foot profile has been drawn on the carton and cut. In order to create the bandage for the top side of the foot, a carton strip has been drawn attached to the foot profile. Finally, the slippers have been covered with the brown scotch in order to be water resistant. Figure 8.35 shows the first version of the realised slippers.

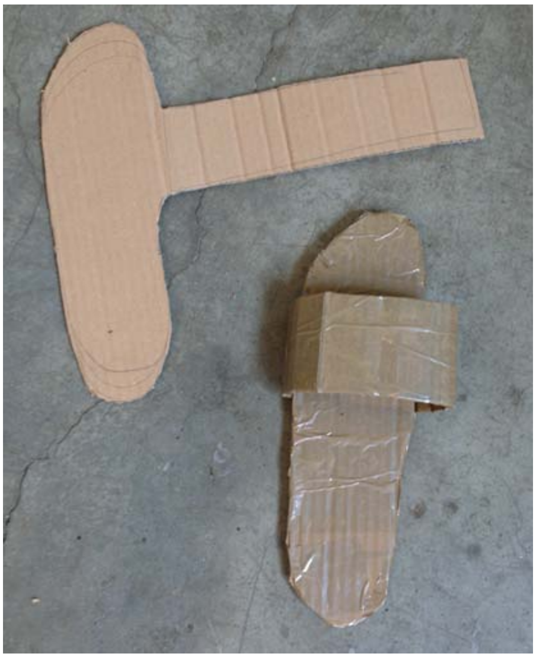


Figure 8.35. One carton-layer slipper prototype

The second version has been realised by using two carton-layers so as to be more resistant. Two mirrored foot profiles have been designed on the carton and cut. Also in this case, in order to create the bandage for the top side of the foot, a carton strip has been drawn attached to the foot profile. Finally, the slippers have been covered with the brown scotch in order to be water resistant. Figure 8.36 shows the second version of the slippers realised.

Figure 8.36. Two carton-layer slipper prototype

8.4.3 The carton stool

The third realised prototype has been the stool. Firstly, two equal covers have been realised, overlapped three circular carton-layers (in order to increase the resistance degree). After that, a carton cylinder has been developed (of the same diameter of the cover) and a carton tube realised. The carton tube helps the stool stand up. Figure 8.37 shows all the elements composing the stool (i.e. two covers, a cylinder and a tube), and Figure 8.38 presents the carton stool prototype.

Figure 8.37. The elements composing the carton stool (from the left side: the first cover, the cylinder, the tube and the second cover)

Figure 8.38. The carton stool prototype

It has been tested that a person of 80 Kg can safely sit and swing on the stool without breaking.

8.4.4 The carton cradle

Many are the children in an emergency camp and many of them are infants. For this, it has been thought to realise a carton cradle. Starting from a carton box, the two headboards and the two other rectangular sides of the cradle have been drawn and cut (Figure 8.39). After having attached the four sides of the cradle, another rectangular carton has been cut and transversely mounted on the cradle so as to become a sort of carton mattress. Figure 8.40 shows the carton cradle prototype.

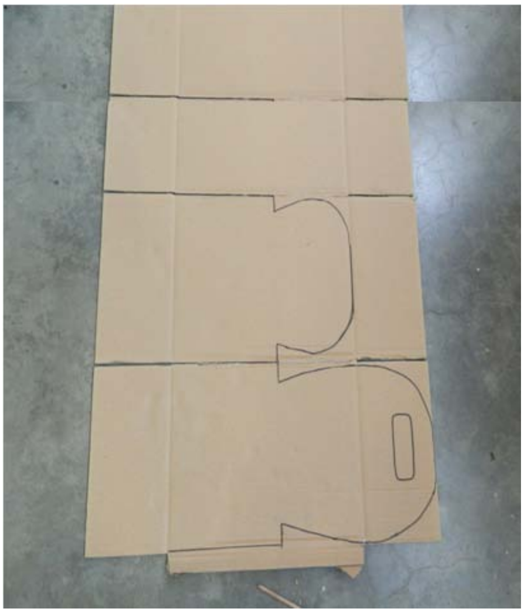


Figure 8.39. The elements composing the carton cradle (from the top: the two rectangular carton sides and the headboards)

Figure 8.40. The carton cradle prototype

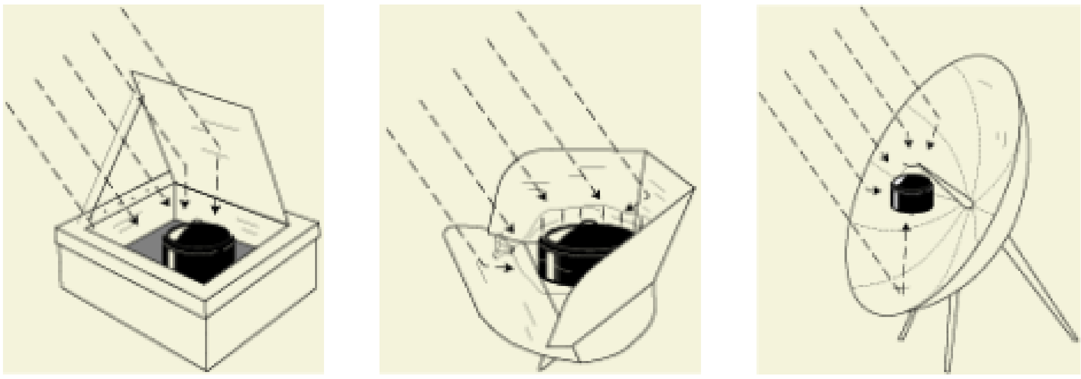
The carton cradle can hold up to 15 Kg.

8.4.5 The carton solar cooker

Cooking is the prime necessity for all people across the world (Panwar et al., 2012). In developing countries, cooking energy requirement is meeting through fuel-wood, which resulted in deforestation, fuel-wood shortage, increased costs of fuels and adverse environmental effects (Panwar et al., 2012). Solar energy is considered a suitable alternative to supplement or substitute the energy supply from other sources. It is a largest renewable resource, freely available everywhere in adequate amounts, and it is a promising option capable of being one of the leading energy sources for cooking (Biermann et al., 1999; Wentzel and Pouris, 2007). Solar cooking is the most direct application of solar energy (Panwar et al., 2012) and offers an effective method of utilising solar energy for meeting a considerable demand for cooking energy.

Solar cooking systems essentially work on a simple rule of converting light energy into heat energy. The use of solar cookers is the simplest, safest, most convenient way to cook food without consuming fuels (Panwar et al., 2012).

Different types of solar cookers have been developed all over the world. They usually are classified in (a) box solar cooker (solar oven); (b) panel solar cooker; (c) parabolic solar cooker (Figure 8.41).



(a) Box solar cooker (b) Panel solar cooker (c) Parabolic solar cooker

Figure 8.41. Different types of solar cooker

The main advantages of using solar cookers for cooking food are:

- Null cost, because they use solar energy and it does not have to fetch or pay for firewood gas, electricity or other kind of fuels;
- Durability and simplicity to operate;
- Reduction of pollutant emissions and environmental impact, because they do not use any kind of pollutant fuels;
- Minimisation of deforestation and habitat loss, because they reduce firewood use.

For all these advantages, solar cookers can be introduced in refugee camps with ease and without causing any adapting problem.

According to its ease of realisation, the panel solar cooker has been built on which several tests have been performed.

How to build a panel solar cooker

In order to build a panel solar cooker, a cube-shaped cardboard is necessary.

The main realisation phases of a solar cooker are described below. The cube-shaped cardboard box has to be cut in order to obtain two large rectangular panels. Each panel is made up of one square face of the box together with one flap. After that, six fold lines have to be drawn each one of 15° from the two packaging corners, as showing in Figure 8.42.

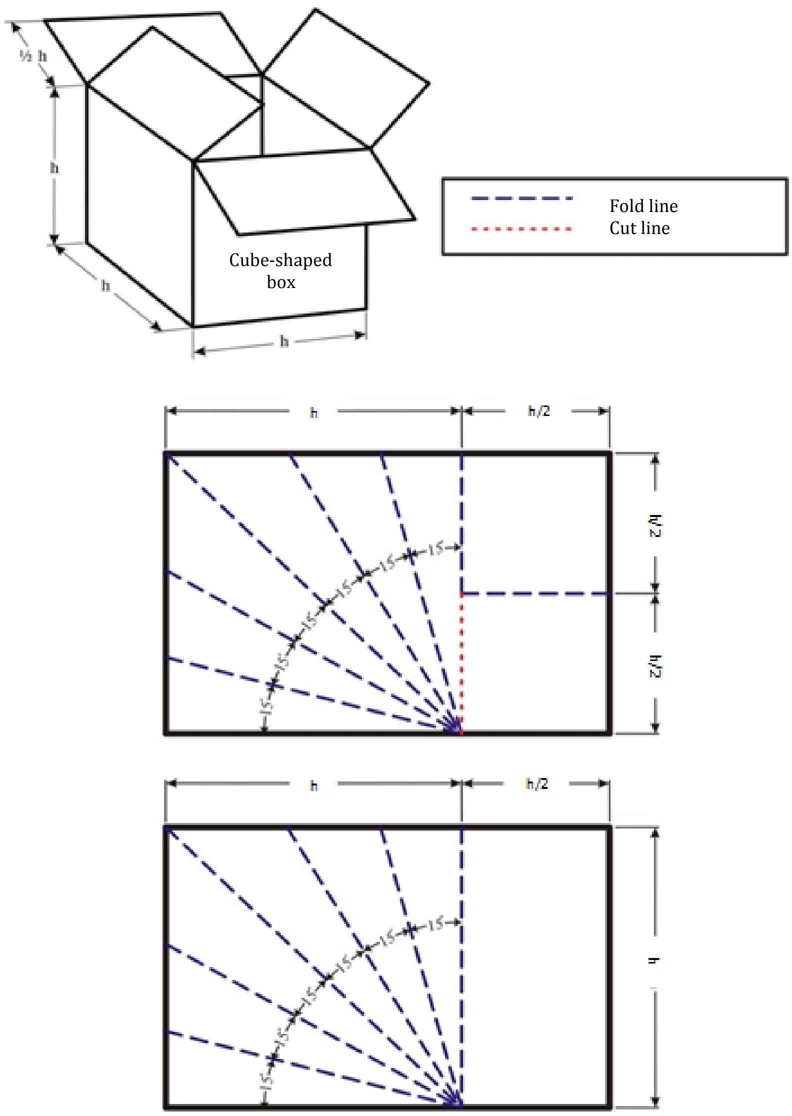


Figure 8.42. The first realisation phase of the solar cooker

After that, it is necessary to cut the cut lines and glue the aluminium foils onto the inner side of the two large rectangular cardboard panels. After that, folding the fold lines and assembling the two large rectangular panels, as shown in Figure 8.43.

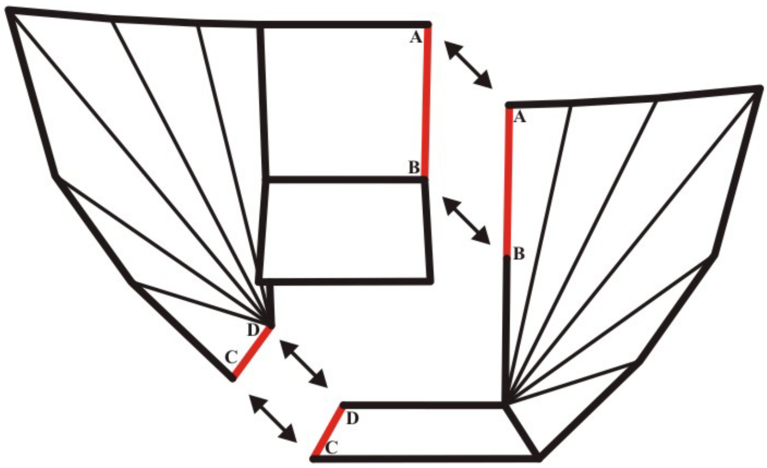


Figure 8.43. The assembly phase of the two large rectangular panels

Finally, in order to support the panel, it could be necessary to realise a small cardboard, pushing forward the lower edge of the centre square panel by a distance of 10 cm from the rear edge (Figure 8.44).

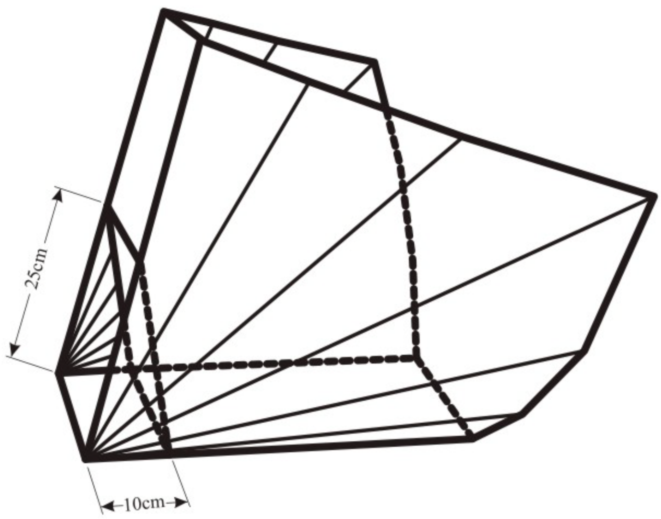


Figure 8.44. The small cardboard of support

The next paragraph will discuss the tests performed by using the available carton boxes provided by the humanitarian organisation.

Experimental evidences

The main idea has been to build a solar cooker starting from the kitchen set carton (that is a set for cooking composed by forks, knifes, pots, etc.) of 35x34x40(h) dimension, shown in Figure 8.45.

Figure 8.45. The kitchen set carton used for the tests

Five different tests have been realised in order to evaluate the solar cooker performance. The first three tests have been performed by using the kitchen set carton covered by aluminium foils that increase the captured sunrays. After that, the main data have been shared with the supplier of kitchen set carton and it has been decided to realise a metallised carton with which the other two tests have been realised. Figure 8.46 shows the metallised carton.

Figure 8.46. The metallised carton used for the last two tests

For each test, some performance parameters have been evaluated:

$$Q = M \cdot \Delta T \cdot c$$

$$P = \frac{Q}{t}$$

where:

Q is the exchanged heat [Kcal]

M is the heated mass [Kg]

ΔT is the change in temperature of the mass between the initial and the final temperature [°C]

c is the heat capacity of the substance [Kcal/Kg · °C]

P is the power of the changed heat in a period of time [W]

t is the time spent to exchange a certain heat Q [s]

Test 1

After opening the kitchen set carton box, fold and cut lines have been drawn onto the carton, 15° far each other, as shown in Figure 8.47.

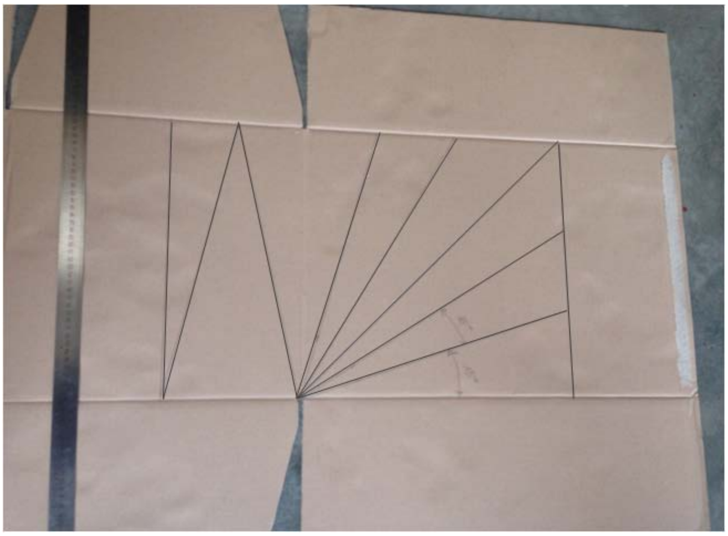


Figure 8.47. Cut and fold lines on the kitchen set carton

After that, the two panels have been cut (Figure 8.48) and fold along the fold lines (Figure 8.49).

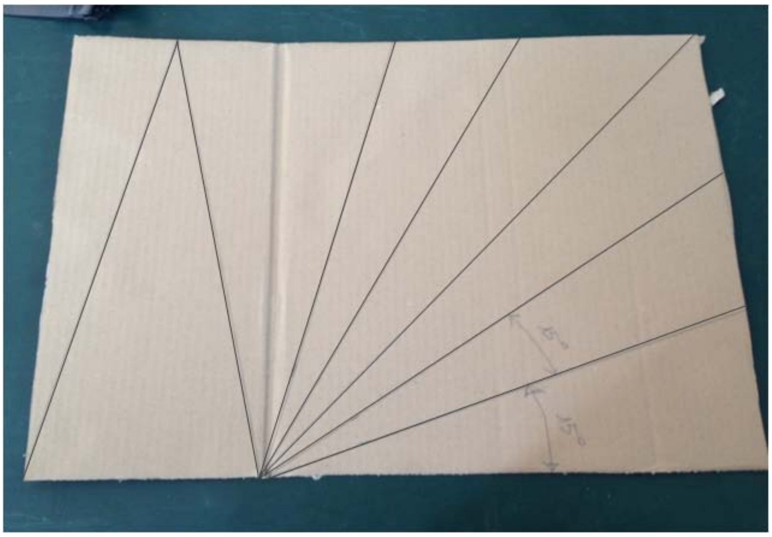


Figure 8.48. The panel after the cutting

Figure 8.49. Folding of the carton along the fold lines

When the two rectangular panels have been ready, the aluminium foils have been glued on one size of the panel (Figure 8.50).

Figure 8.50. Bonding of the aluminium foils to the two panels

Figure 8.51 shows the realised solar cooker.

Figure 8.51. The solar cooker of *Test 1*

Test 1 has been realised on July 9, 2013 in front of the Mechanical Laboratory of the University of Bologna. It has been consisted on heating 300 gr of water at an initial temperature of 28.9 °C from 10 a.m. to 1 p.m. Table 8.28 shows the measured temperatures, while Figure 8.52 the trend of the temperature for *Test 1*.

Time	Temperature [°C]
10.00 a.m.	28.9
10.45 a.m.	43.7
11.05 a.m.	50.3
11.25 a.m.	53.6
11.40 a.m.	57.5
12.05 p.m.	58.2
12.25 p.m.	59.1
12.40 p.m.	58.6
1.00 p.m.	54.1

Table 8.28. The measured temperatures of *Test 1*

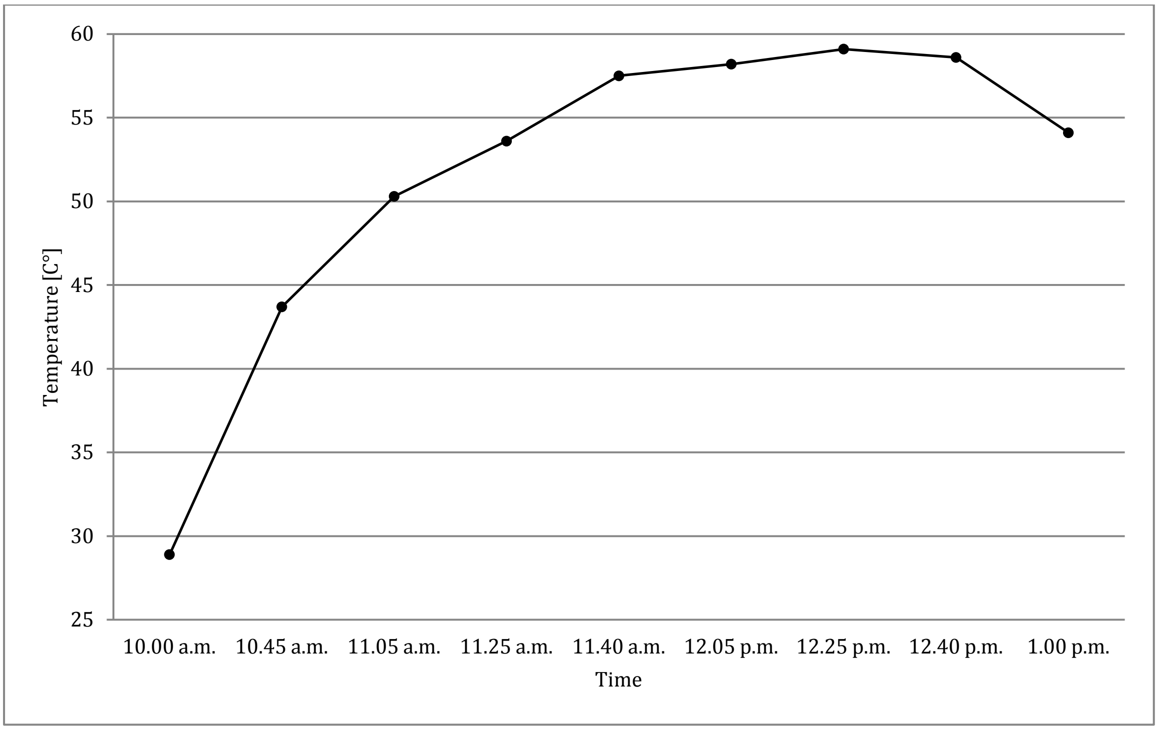


Figure 8.52. Trend of the temperature for *Test 1*

As it is possible to note from Table 8.28 and Figure 8.52, the temperature has been started to decrease since 12.25 p.m. because it has been started to be cloudy.

Evaluation of the performance parameters

M = 0.3 Kg

ΔT = 30.2 °C

c = 1 Kcal/Kg · °C

t = 8,400 s

$$Q = 0.3 \cdot 30.2 \cdot 1 = 9.06\ Kcal = 37.8708\ KJ = 37{,}870.8\ J$$

$$P = \frac{37{,}870.8}{8{,}400} = 4.5084\ W$$

Test 2

Test 2 has been realised on July 9, 2013 in front of the Mechanical Laboratory of the University of Bologna. It has been used the same solar cooker of *Test 1*. The amount of water to heat has been 100 gr at an initial temperature of 29.1°C from 11 a.m. to 1 p.m. Table 8.29 shows the measured temperatures, while Figure 8.53 the trend of the temperature for *Test 2.*

Time	Temperature [°C]	Time	Temperature [°C]
11.00 a.m.	29.1	11.50 a.m.	49.5
11.05 a.m.	33.9	11.55 a.m.	51.6
11.10 a.m.	36.8	12.00 p.m.	52.6
11.15 a.m.	39.8	12.05 p.m.	54.5
11.20 a.m.	42.3	12.10 p.m.	55.1
11.25 a.m.	42.5	12.15 p.m.	55.2
11.30 a.m.	44.7	12.20 p.m.	56.0
11.35 a.m.	46.1	12.25 p.m.	56.8
11.40 a.m.	46.9	12.40 p.m.	54.5
11.45 a.m.	47.4	1.00 p.m.	47.6

Table 8.29. The measured temperatures of *Test 2*

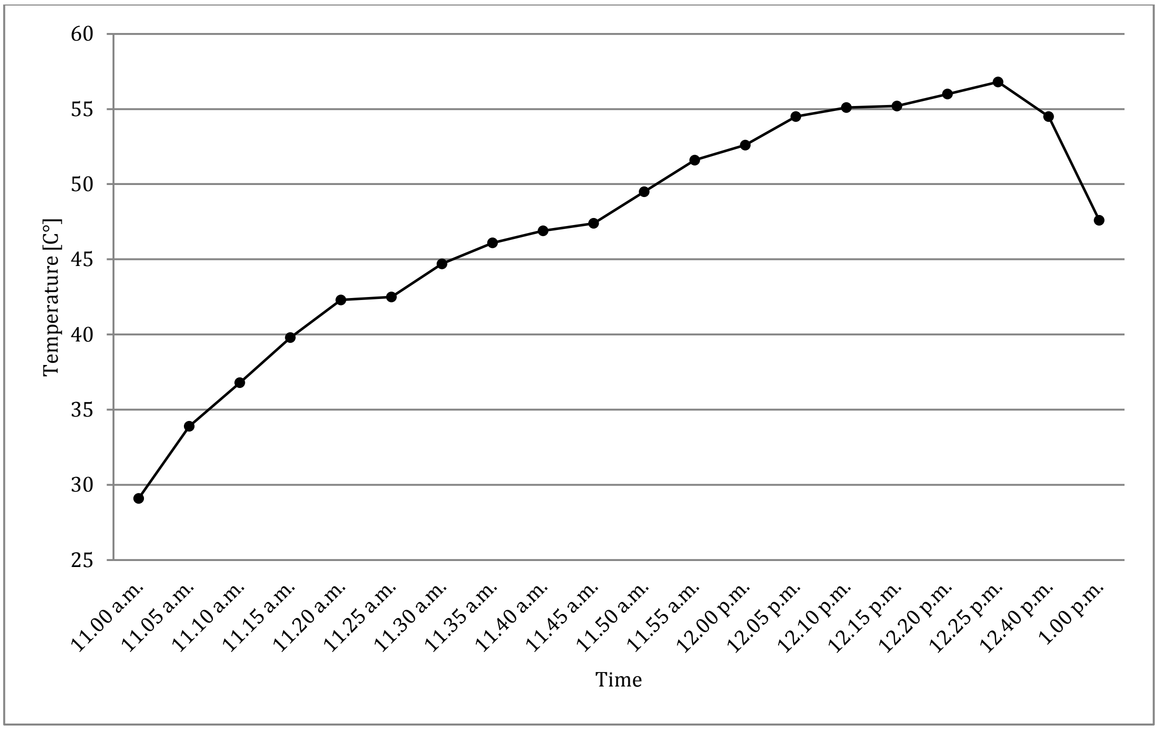


Figure 8.53. Trend of the temperature for *Test 2*

As it is possible to note from Table 8.29 and Figure 8.53, also in this case the temperature has been started to decrease since 12.25 p.m. because it has been started to be cloudy.

Evaluation of the performance parameters

M = 0.1 Kg

ΔT = 27.7 °C

c = 1 Kcal/Kg · °C

t = 5,100 s

$$Q = 0.1 \cdot 27.7 \cdot 1 = 2.77\ Kcal = 11.5786\ KJ = 11{,}578.6\ J$$

$$P = \frac{11{,}578.6}{5{,}100} = 2.2703\ W$$

Test 3

Test 3 has been realised on July 9, 2013 in front of the Mechanical Laboratory of the University of Bologna. Figure 8.54 shows the solar cooker used for this test and realised following the same steps of the one used for *Test 1* and *Test 2*, but with several folding of the carton.

Figure 8.54. The solar cooker of *Test 3*

The amount of water to heat has been 100 gr at an initial temperature of 29.1°C from 12.10 p.m. to 1 p.m. Table 8.30 shows the measured temperatures, while Figure 8.55 the trend of the temperature for *Test 3.*

Time	Temperature [°C]
12.10 p.m.	29.1
12.20 p.m.	36.2
12.30 p.m.	39.4
12.45 p.m.	39.0
1.00 p.m.	46.3

Table 8.30. The measured temperatures of *Test 3*

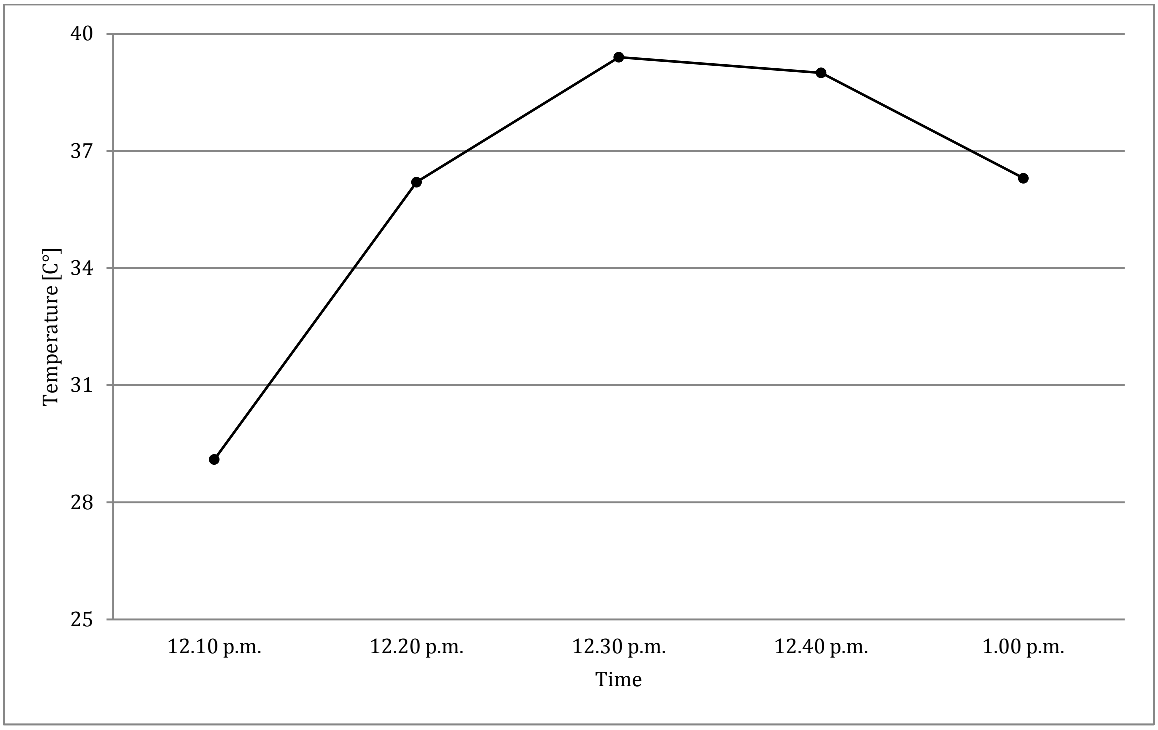


Figure 8.55. Trend of the temperature for *Test 3*

As it is possible to note from Table 8.30 and Figure 8.55, also in this case the temperature has been started to decrease since 12.30 p.m. because it has been started to be cloudy.

Evaluation of the performance parameters

M = 0.1 Kg

ΔT = 10.3 °C

c = 1 Kcal/Kg · °C

t = 1,200 s

$$Q = 0.1 \cdot 10.3 \cdot 1 = 1.03\ Kcal = 4.3054\ KJ = 4{,}305.4\ J$$

$$P = \frac{4{,}305.4}{1{,}200} = 3.5878\ W$$

Test 4

Test 4 has been realised on September 20, 2013 in front of the Mechanical Laboratory of the University of Bologna. For *Test 4* the metallised carton has been used. The solar cooker has been realised through two semi-circumferences attached each other and folded in eight parts, as shown in Figure 8.56.

Figure 8.56. One of the two semi-circumferences for realising the solar cooker

Two flaps have been overlapped in order to assume the wanted shape. Figure 8.57 shows the solar cooker used for the test.

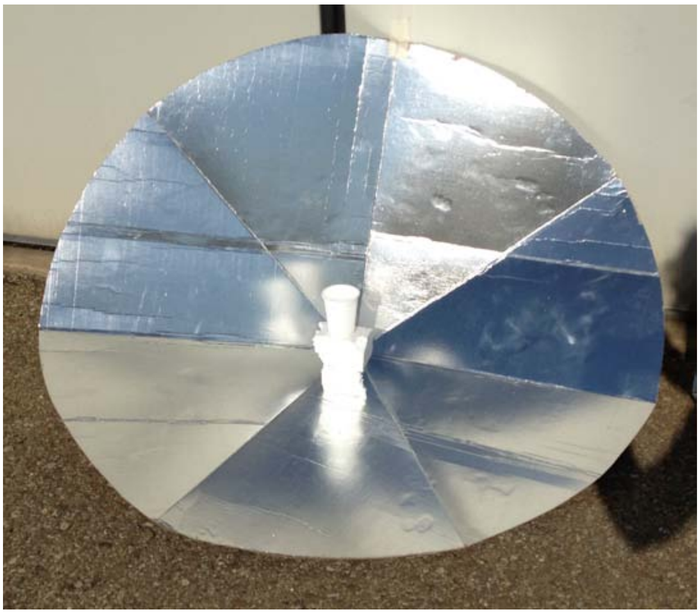


Figure 8.57. The solar cooker of *Test 4*

The amount of water to heat has been 100 gr at an initial temperature of 25.7°C from 9.00 a.m. to 1 p.m. Table 8.31 shows the measured temperatures, while Figure 8.58 the trend of the temperature for *Test 4.*

Time	Temperature [°C]
9.00 a.m.	25.7
10.00 a.m.	30.6
11.00 a.m.	33.0
11.30 a.m.	34.4
12.00 p.m.	36.3
12.30 p.m.	41.6
1.00 p.m.	44.5

Table 8.31. The measured temperatures of *Test 4*

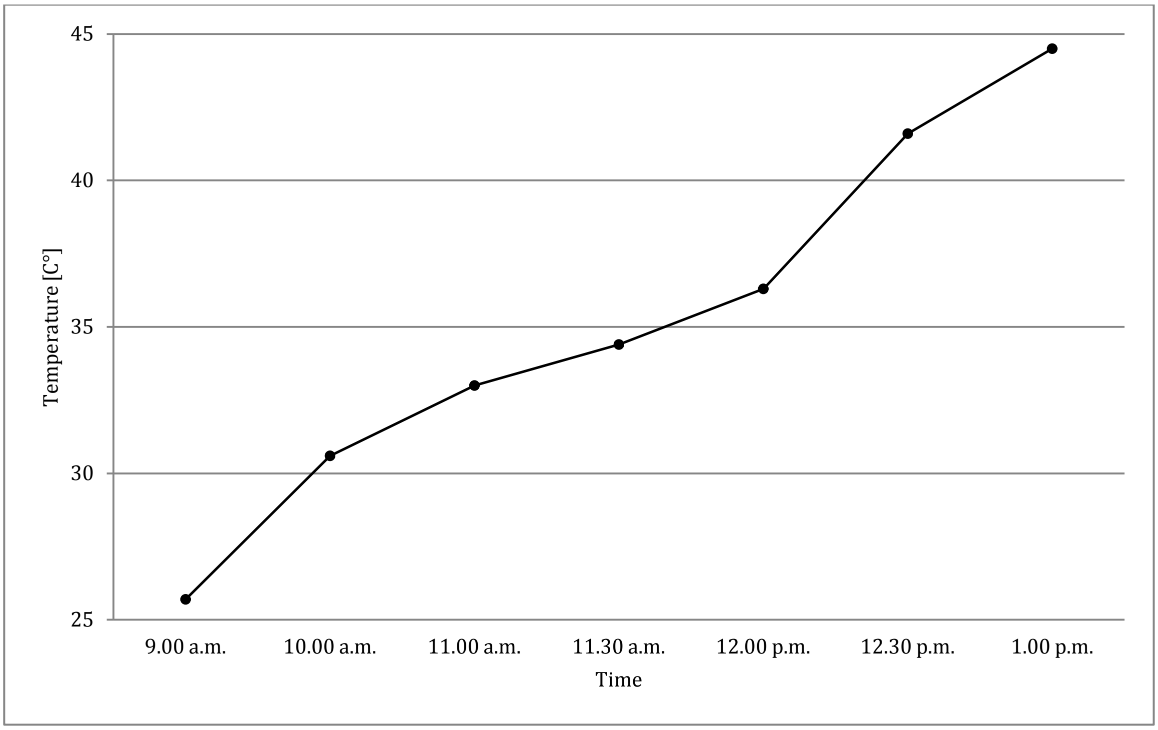


Figure 8.58. Trend of the temperature for *Test 4*

<u>Evaluation of the performance parameters</u>

M = 0.1 Kg

ΔT = 18.8 °C

c = 1 Kcal/Kg · °C

t = 14,400 s

$$Q = 0.1 \cdot 18.8 \cdot 1 = 1.88\ Kcal = 7.8584\ KJ = 7{,}858.4\ J$$

$$P = \frac{7{,}858.4}{14{,}400} = 0.5457\ W$$

Test 5

Test 5 has been realised on September 20, 2013 in front of the Mechanical Laboratory of the University of Bologna. For *Test 5*, as for *Test 4*, the metallised carton has been used. The solar cooker has been realised folding some flaps on the metallised carton in order to capture more heat as possible. Figure 8.59 shows the solar cooker used for the test.

Figure 8.59. The solar cooker used for *Test 5*

The amount of water to heat has been 100 gr at an initial temperature of 26.3°C from 9.00 a.m. to 1 p.m. Table 8.32 shows the measured temperatures, while Figure 8.60 the trend of the temperature for *Test 5.*

Time	Temperature [°C]
9.00 a.m.	26.3
10.00 a.m.	33.0
11.00 a.m.	35.5
11.30 a.m.	36.9
12.00 p.m.	38.5
12.30 p.m.	43.7
1.00 p.m.	47.0

Table 8.32. The measured temperatures of *Test 5*

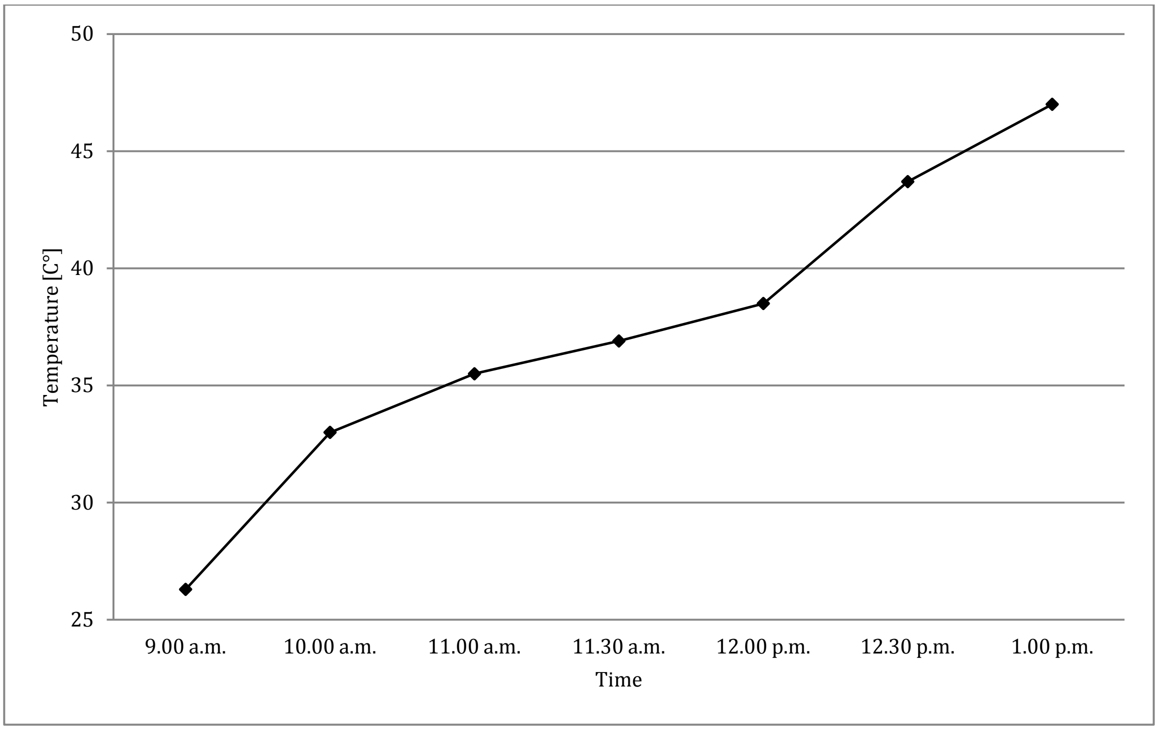


Figure 8.60. Trend of the temperature for *Test 5*

<u>Evaluation of the performance parameters</u>

M = 0.1 Kg

ΔT = 20.7 °C

c = 1 Kcal/Kg · °C

t = 14,400 s

$$Q = 0.1 \cdot 20.7 \cdot 1 = 2.07\ Kcal = 8.6526\ KJ = 8{,}652.6\ J$$

$$P = \frac{8{,}652.6}{14{,}400} = 0.6008\ W$$

Comparison between the obtained and real energy emitted

The energy obtained by solar cookers has been compared with the real energy emitted. The comparison has been possible thanks to PVGIS web site (http://re.jrc.ec.europa.eu/pvgis/) that provides the global and diffuse power (from which it is possible to evaluate the direct power and the emitted energy) each 15 minutes. Table 8.33 shows the energy (Q [KJ]) obtained by the solar cookers and that really emitted by the sunrays for each test.

Test	Date [dd.mm.aa]	Duration of the test [s]	Starting temperature [C°]	Achieved temperature [C°]	Energy emitted by the solar cooker [KJ]	Real energy emitted by sunrays [KJ]	Effiency [%]
1	09.07.13	8,400	28.9	54.1	37.87	1,122.37	3.37
2	09.07.13	5,100	29.1	47.6	11.57	753.96	1.54
3	09.07.13	1,200	29.1	36.3	4.30	377.76	1.14
4	20.09.13	14,400	25.7	44.5	7.68	9,328.18	0.08
5	20.09.13	14,400	26.3	47.0	8.65	7,572.61	0.11

Table 8.33. A comparison between the energy obtained by the solar cooker and that really emitted by the sunrays

As it is possible to note form Table 8.33, the efficiency of the realised solar cookers can be defined good if considering the efficiency of shape, roughness, reflection, and sun orientation. Moreover, for the aim of the study, it is not important to have a high efficiency, but the possibility to heat water and other kind of food for people hunted by a disaster. The tests have demonstrated the possibility to reach high temperature (~ 55 °C) able to heat and pasteurise water.

The efficiency of the realised solar cookers compared with the optimal shape in terms of reflection of sunrays

The realised solar cookers can be considered as a conic shape. The optimal shape in terms of best reflection of sunrays is the parabola, since all the sunrays reflect on its focus. This is not completely true for the cone, and it has been necessary to establish a unitary target (drawn in yellow) around the focus of the parabola in order to find the quantity of sunrays that reflects the cone (Figure 8.61).

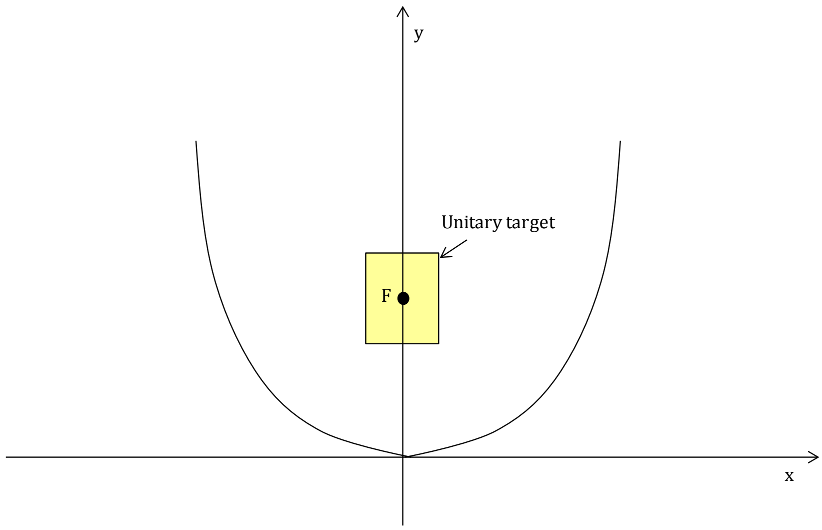


Figure 8.61. The representation of the unitary target (drawn in yellow)

Looking at Figure 8.62, $y = mx$ represents a side of the solar cooker, assumed to be a cone. The ray of incidence is represented by the red line and arranges the angle of incidence γ that, for the Snell's law is equal to the angle of reflection. For geometric assumptions, the angle of incidence γ is equal to α, that is the angle between the the line $y = mx$ and x axis.

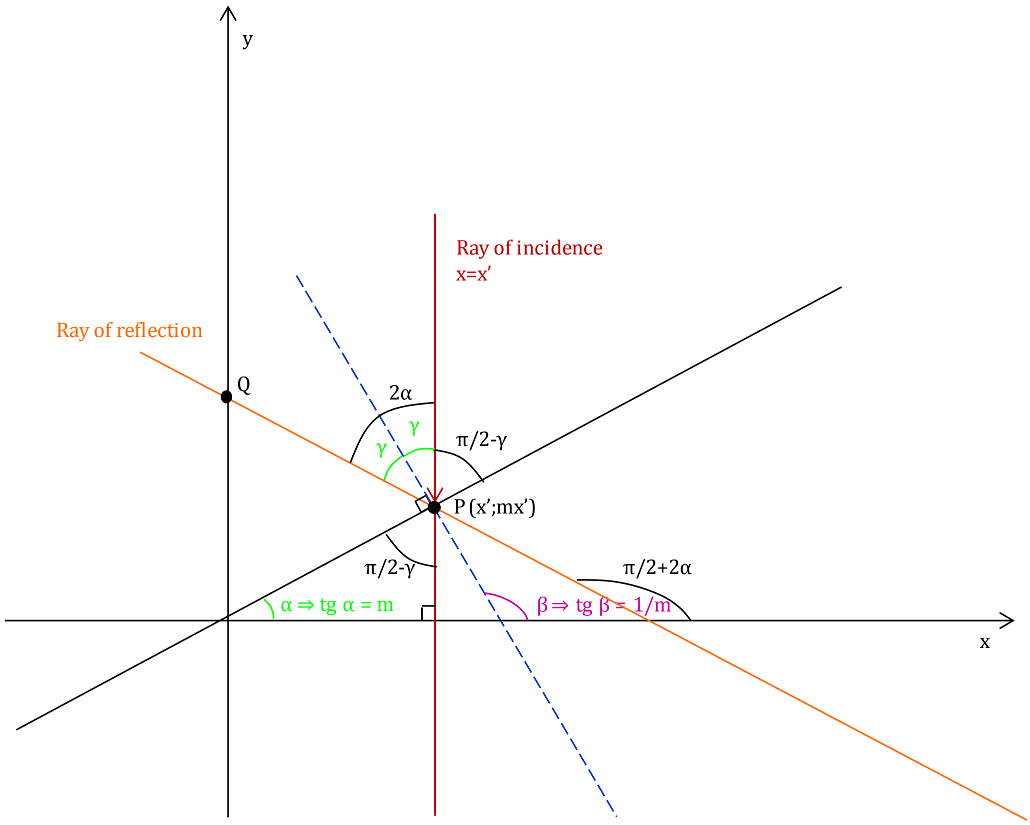


Figure 8.62. Graphical representation used for the computations

In order to find the intersection point Q between the unitary target and the line of the reflection angle, it is necessary to continue in this way: the angle between the ray of incidence and the line of reflection angle is 2α and, for geometric assumption, the angle between the line of reflection angle and x axis is $\left(\frac{\pi}{2}+2\alpha\right)$. The angular coefficient of the reflection ray m' is:

$$m' = tg\left(\frac{\pi}{2}+2\alpha\right) = -cotg(2\alpha) = -\frac{1}{tg(2\alpha)}$$

and according to the duplication formulae of the tangent[7], m' becomes:

$$m' = \frac{tg\alpha^2 - 1}{2tg\alpha}$$

Moreover, it is known that $tg\alpha = m$ (the angular coefficient of the line $y = mx$), thus:

$$m' = \frac{m^2 - 1}{2m}$$

[7] The duplication formula of the tangent is: $tg(2\alpha) = \frac{2tg\alpha}{1-tg^2\alpha}$

that is the angular coefficient of the reflection ray.

The equation of the reflection ray is:

$$y - mx' = \frac{m^2 - 1}{2m}(x - x')$$

$$y = \frac{m^2 - 1}{2m}x + mx' - \frac{m^2x' - x'}{2m}$$

As shown in Figure 7.28, the unitary target is located in the y axis, thus $x = 0$ and the intercestion point Q has coordinates:

$$Q\left(0\,;\; mx' - \frac{m^2x' - x'}{2m}\right)$$

$$Q\left(0\,;\; \frac{x'(m^2 + 1)}{2m}\right)$$

Because of the linearity of the function, the whole cone is illuminated with the same intensity, thus the intersection point Q becomes:

$$Q\left(0\,;\; \frac{x_{max}(m^2 + 1)}{2m}\right)$$

where x_{max} is the intersection between the continuation of the extreme point of the cone and x axis (Figure 8.63).

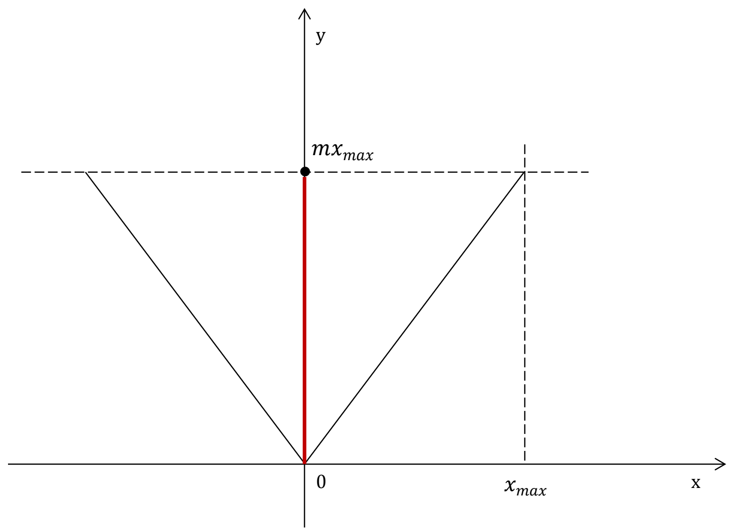


Figure 8.63. Bidimensional representation of the cone

The reflected part is all inside the cone and it is included between 0 and mx_{max}, as shown by the red line in Figure 7.30. This means that:

$$0 < x_{max}\left(\frac{m}{2} + \frac{1}{2m}\right) < mx_{max}$$

Since the unitary target d is located along the red line and the length of the red line is $\frac{x_{max}(m^2+1)}{2m}$, the efficiency of the cone (i.e. the realised solar cookers) compared with the optimal shape in terms of the best reflection (i.e. parabola) is:

$$\frac{d}{\frac{x_{max}(m^2+1)}{2m}}$$

$$\frac{2md}{x_{max}(m^2+1)}$$

Application of the formula $\frac{2md}{x_{max}(m^2+1)}$ *to the realised solar cooker*

The application of the formula $\frac{2md}{x_{max}(m^2+1)}$ allows the evaluation of the efficiency of the solar cooker compared with the optimal shape for the reflection of the sunrays. For hypothesis, it has been assumed to consider a unitary target $d = 1$.

The main data are:

$d = 1$

$h = 46\ cm$

$\alpha = \frac{h}{x} = \frac{46}{43} = 45°$

$m = tg\alpha = 1.62$

$x_{max} = \frac{h}{m} = \frac{46}{1.619} = 28.4\ cm$

Thus, the efficiency per unitary target of the realised solar cooker compared with the optimal shape is:

$$\frac{2md}{x_{max}(m^2+1)} = \frac{2 \cdot 1.62 \cdot 1}{28.4 \cdot (1.62^2+1)} = 3.15\%$$

Considering a target of 10 cm height (as the glass of water that has been heated), the efficiency becomes 31.5% that, after removing all kinds of errors (e.g. micro-errors, optical errors, geometric errors, etc.), arrives to be around 4÷5% as obtained from the experimental tests.

As it is possible to imagine, the more the cone is narrow, the more are the sunrays that incise on the target. On the other hand, it is not possible to draw a too narrow cone because the rays of incidence cannot achieve the surface. Thus, a trade-off is necessary to have the maximum percentage of sunrays that incise on the cone.

In order to find the optimal height for the realised solar cooker, several heights have been varied. Table 8.34 shows the percentage of sunrays on the unitary target for several height of the solar cooker (the yellow row represents the real height).

Height of the solar cooker [cm]	Percentage of sunrays that incise on the unitary target [%]
10	0.541%
20	3.380%
30	6.508%
40	3.399%
46	3.148%
50	1.088%
60	0.009%

Table 8.34. Percentage of sunrays on the unitary target for several heights of the solar cooker

Figure 8.64 shows the trend of the percentage of sunrays on the unitary target varying the height of the solar cooker. The red circle indicates the percentage of sunrays that incise on the unitary target for the realised solar cooker.

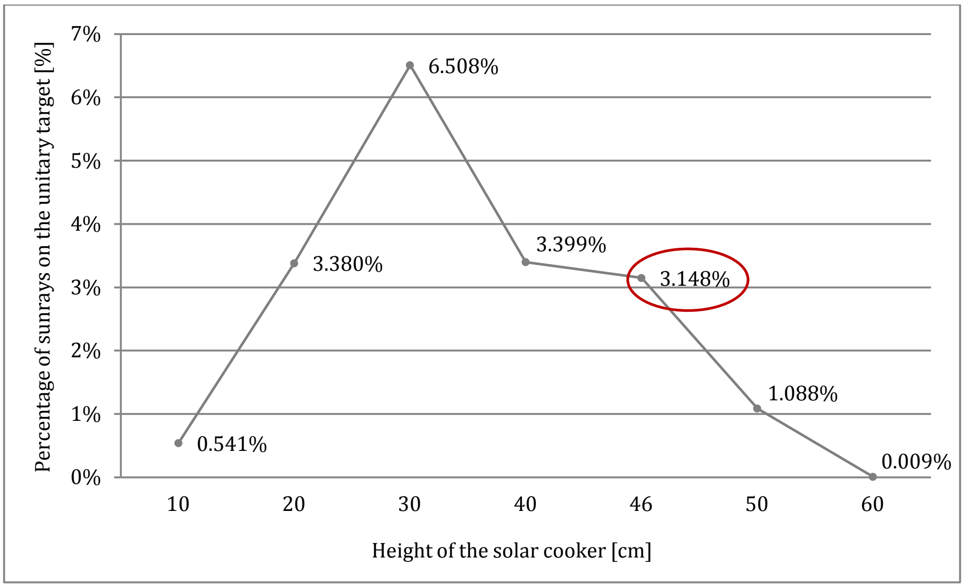


Figure 8.64. The trend of the percentage of sunrays on the unitary target for several heights of the solar cooker

From Figure 8.63, it is possible to see that the height that allows a major percentage of sunrays that reach the unitary target is 30 cm.

8.4.6 Waterless Composting Toilet for an emergency camp

Packaging waste management

During last decades, the management of waste has become an issue of critical importance mostly due to the complexity of waste streams and steadily increasing produced volume. Waste management can be defined as the collection, transport, processing, recycling or disposal, and monitoring of waste materials (Bacinschi et al., 2010; Eshet et al., 2006). Waste produced during production, transportation, use, disposal activities, creates numerous global, regional, and local disruptions, such as the emission of greenhouse gases and pollution to air, soil, and water.

According to Achillas et al. (2013), many are the wastes produced everyday and the most common can be classified as municipal solid waste, electrical and electronic equipment waste, water waste, construction and demolition waste and packaging waste.

Among all, packaging waste generation has increased and it is expected to continue to climb with growing population, wealth, and consumerism throughout the world. The evolution of packaging waste question has resulted in the introduction of government policies and regulations internationally to promote stewardship and increase levels of recycling (Verghese and Lewis, 2007).

The European Packaging and Packaging Waste Directive 94/62/EC of 20 December 1994 (European Commission, 1994) deals with the problems of packaging waste and provides measures aimed at limiting the production of packaging waste and promoting recycle, re-use and other forms of waste recovery. The European Directive 94/62/EC (1994) and, later, Packaging Legislation (2003) require the encouragement of the use of recycled packaging materials in the manufacturing of packaging and other products and that packaging placed on the market with essential requirements that are: the limitation of weight and volume of packaging in order to meet the required level of safety, hygiene and acceptability for consumers; the reduction of the use of hazardous substances in packaging materials and accessories; the adoption of re-usable and recoverable packaging, so as to reduce the packaging impact on the environment.

The continue research of approaches and methodologies to solve the packaging waste problem has led to consider the re-use of packaging waste as fundamental input in the realisation of a Waterless Composting Toilet (WCT) model for an emergency camp during disaster situations.

Introduction to the Waterless Composting Toilet

Many types of compost toilets are available today. They are designed to suit a variety of customs, cultures and climates. Composting of human faeces is as old as the hills – it is the Nature's way of safely reintegrating human waste with the soil (Calvert, 2003).

Contrary to popular opinion, compost toilets can be very clean and hygienic and do not smell. They save huge quantities of water in a world where water is becoming an increasingly precious resource. For example, a family with a water flush toilet use at least 100,000 litres of water a year for flushing. They prevent surface and ground water contamination and protect people's health in areas where open defecation on the ground or directly into water bodies has been the norm (Calvert, 2003).

A composting toilet is a dry toilet that uses a predominantly aerobic processing system that treats excreta, typically with no water or small volumes of flush water, via composting or managed aerobic decomposition (Jenkins, 2005). Composting toilets are simple, low-tech, waterless toilets

(Del Porto and Steinfeld, 2000). They may be used as an alternative to flush toilets in situations where there is no suitable water supply or waste treatment facility available or to capture nutrients in human excreta.

According to Depledge (1997), Calvert (2003) and Crennan (2007), the main advantages of a Waterless Compost Toilet (WCT) can be listed as follows:

- WCT does not need external infrastructure;
- WCT does not pollute the ground or surface water of the soil;
- WCT does not produce flies or smell when properly used and maintained;
- WCT uses less water than any other toilet;
- WCT totally self-contains sewage treatment on site. There are no sewage pipes, no septic tanks, and no dangerous emptying of hazardous sludge;
- WCT produces safe, useful, no-odorous compost.

Although these advantages, carefully operations are essential, since compost could be a health hazard if it is removed before decomposition is complete.

In order to create a favourable habitat for biological agents that destroy pathogens and convert faeces and urine into compost, five primary actors are necessary. They are nitrogen, carbon, oxygen, temperature and moisture (Del Porto and Steinfield, 2000). Nitrogen is present in human faeces and especially in urine. Carbon is included in sawdust, dry leaves, and straw and shredding or chopping these materials provides greater surface area for the decomposition organisms and facilitates the absorption of moisture. Oxygen is provided either through mechanical means (stirring or tumbling) or by adding coarse carbonaceous cover material, which provides air spaces throughout the compost. The temperature of the composting chamber should ideally be in the range of 25°C to 40°C, although the temperature of the compost itself may be higher, depending on the type of microorganisms that predominate. Finally, moisture should ideally be controlled between 40÷60%: too dry, and the mass decomposes slowly or not at all; too wet and anaerobic organisms thrive, creating undesirable odours. One of the most common causes for poor decomposition in composting toilets used in arid lands is the lack of sufficient moisture distributed uniformly throughout the compost (Del Porto and Steinfeld, 2000).

A WCT should provide methods of ventilation that move air from the room, through the waste container, and out a vertical pipe, venting above the enclosure roof. This air movement (via convention or fan forced) will vent carbon dioxide and odours and helps create the necessary aerobic conditions by ensuring sufficient oxygen.

The simplified general construction steps for building a Waterless Composting Toilet are listed below (Crennan, 2007).

1. Choosing the site where building the WCT;
2. Preparing the site, levelling the ground where the WCT will be built, and digging the holes on the ground;
3. Realising the main structure of the WCT to be positioned in accordance with the holes;
4. Realising the floor and the toilet bowls of the WCT;
5. Extending a layer of gravel on the basis of the holes and covering the sides of the holes with a layer of plastic film;
6. Making the aeration tubes to be placed in the backside of the WCT in contact with the holes.

Next section will describe the realisation of the WCT model following the general construction steps defined by Crennan (2007).

The Waterless Composting Toilet model

The WCT model does not require electricity or great investment and it has been realised by using secondary and tertiary packages that can be found among the real ones arriving at emergency camps during disaster situations. They are iron cage, wooden pallets, wooden crates, carton boxes and plastic films. The main activities performed to realise the WCT model are described below.

The WCT model has been thought to be built with two chambers for simplicity of construction and operation. The two chambers can be used alternatively; decomposition continuing in the full one until it is emptied just prior to the other one becoming full. Each chamber has its own opening for removal of mature, non-odorous compost. The chambers have been designed to have an accumulation time of about 9-12 months to allow thorough composting of the contents and elimination of pathogens. The WCT combines the urine and faeces.

Firstly, the iron cage model (Figure 8.65) has been developed to act as the basic structure of the WCT.

Figure 8.65. The iron cage of the WCT model

After building the main structure of the WCT model, the accessories have been realised. The pallets have been built starting from pieces of wood, glued together (Figure 8.66) and they represent the support in the ground. The two toilet bowls have been developed from a piece of plywood, cut and glued to form a cube (Figure 8.67).

Figure 8.66. The pallets used as ground supports

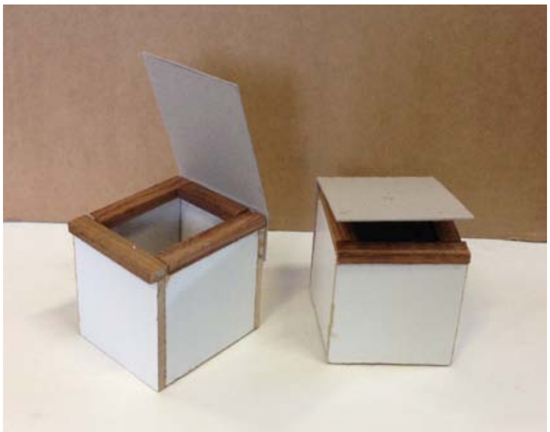


Figure 8.67. The two toilet bowls

In order to simulate the ground, a piece of polystyrene has been kept and digged for realising the holes in which faeces and urine will accumulate. Within the holes, a layer of plastic film has been leaned against the sides of the hole, and a layer of gravel has been put inside the holes (Figure 8.68).

Figure 8.68. The polystyrene to simulate the ground with the holes

Figure 8.69 shows the realisation of the WCT model, step by step.

1. The polystyrene that simulates the ground on which the WCT lies has been prepared;
2. The pallets have been put over the holes as ground support;

3. The toilet bowls have been placed over the pallets;
4. The iron cage has been located over the polystyrene.

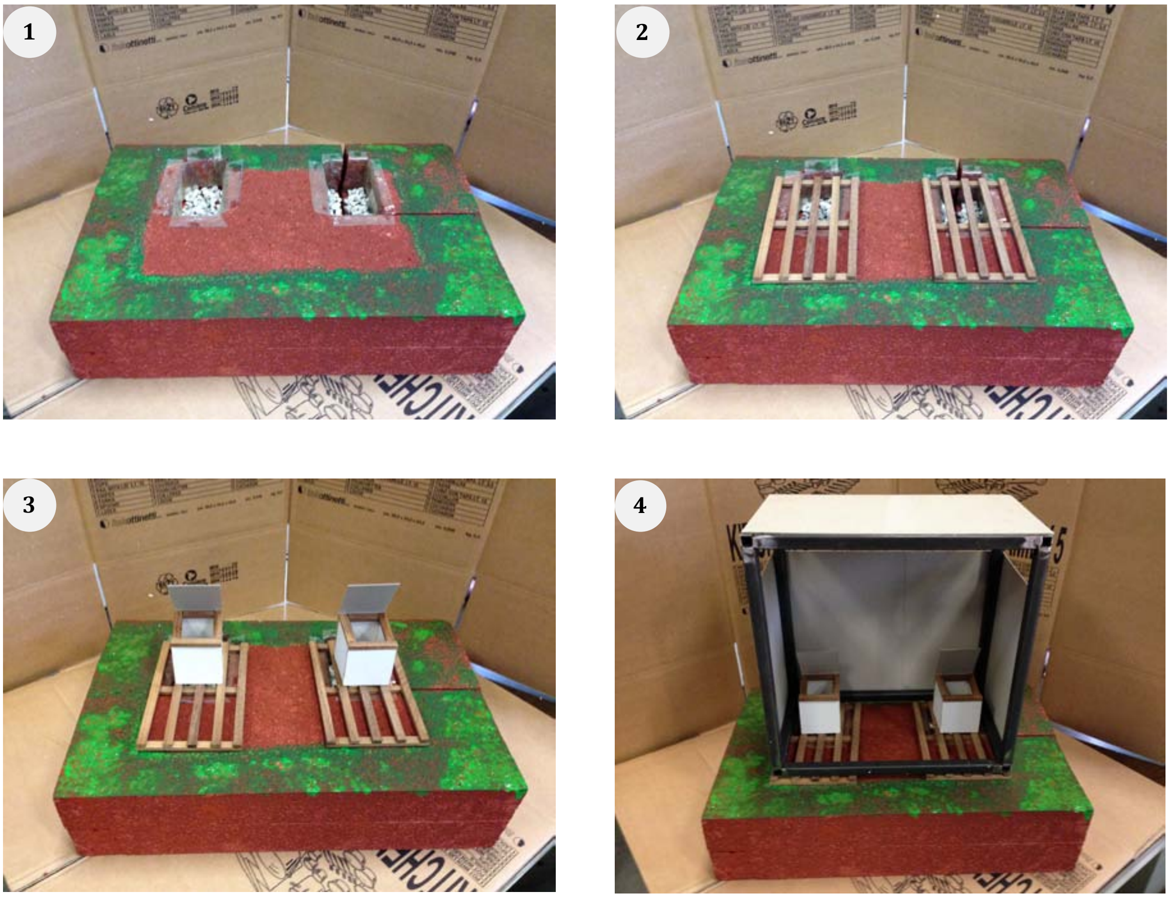


Figure 8.69. The realisation of the WCT model step by step

All the sides of the iron cage have been covered by using a layer of plywood. In the backside, two aeration tubes have been installed in order to improve the composting process (Figure 8.70).

Figure 8.70. The backside of the iron cage

The model represents a starting point for the construction of the WCT in emergency camps during disaster situations.

WCT model vs WCT real

In order to make feasible the WCT construction in the reality, the elements of the WCT model have been compared with the packages available in an emergency camp.

Table 8.35 shows the typology and quantity of materials necessary for realising the WCT model, while Table 8.36 describes the relative materials and quantity of packages necessary to realise a WCT in the reality.

Parts of the WCT model		Dimension [cm] L	W	H	Packaging material
Iron cage		30	18	32.4	Iron
Pallet		12	18	2	Wood
Toilet bowls	Wooden box	6	6	6	Wood
	Carton box	6	12	Carton thickness	Carton
Plastic film		7	Film thickness	6	Plastic film
Aeration tube		7	3	25	Wood

Table 8.35. Typology and quantity of materials necessary to realise the WCT model (where L=length, W= width, H=height)

Parts of the real WCT		Dimension [cm] L	W	H	Needed dimension [cm] L	W	H	Packaging weight [Kg/unit]	Number of unit needed	Weight of the needed packages [Kg/WCT]
Iron cage		200	120	216	200	120	216	200	1	200
Pallet		80	120	15	80	120	15	20	2	40
Toilet bowls	Wooden box	120	40	35	40	40	40	12	1	12
	Carton box	35	34	40	40	40	-	1.5	2	3
Plastic film		82	56	32	46	80	40	0.5	2	1
Aeration tube		120	40	35	46	20	166	12	2	24
									Total [Kg/WCT]	**280**

Table 8.36. Typology and quantity of packages necessary to realise the WCT in the reality (where L=length, W= width, H=height)

The total packaging weight utilised for realising the real WCT is 280 Kg.

Next figures show each part of the WCT model and the relative necessary packages used to build it in the reality, chosen among those shipped to an emergency camp. The iron structure of the WCT can be realised by using a steel crate acting at containing items during the transport (Figure 8.71); the pallets are simple to find because many of them are used to hold the items during the transport and distribution (Figure 8.72); the toilet bowls can be realised by using wooden and carton boxes (Figure 8.73); the plastic film that rolls up the blankets can be used as plastic film to cover the sides of the holes (Figure 8.74); finally, the aeration tubes can be developed by using wooden boxes (Figure 8.75).

Figure 8.71. The iron cage of the WCT model (on the left) and the steel crate to build the WCT for an emergency camp (on the right)

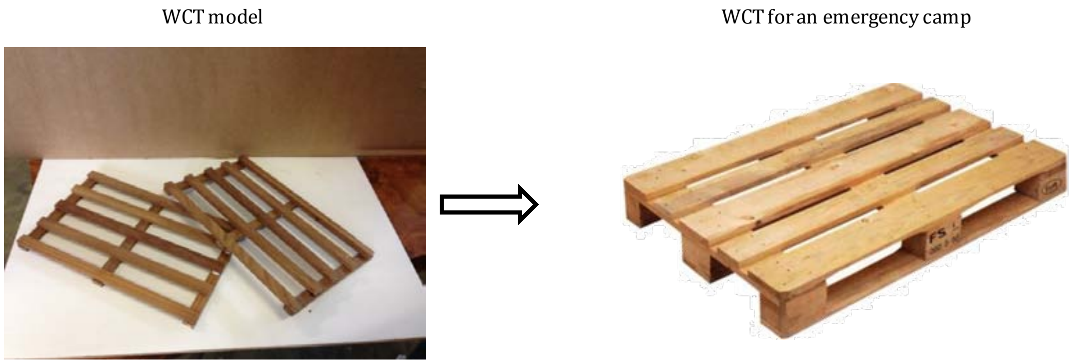


Figure 8.72. The pallet of the WCT model (on the left) and of the WCT for an emergency camp (on the right)

Figure 8.73. The toilet bowls of the WCT model (on the left) and the wooden and carton boxes to realise them for the WCT in an emergency camp (on the right)

WCT model

WCT for an emergency camp

Figure 8.74. The plastic film of the WCT model (on the left) and that used to build the WCT in an emergency camp (on the right)

WCT model

WCT for an emergency camp

Figure 8.75. The aeration tubes of the WCT model (on the left) and the wooden boxes used to realise them for the WCT in an emergency camp (on the right)

As it is possible to see from Figure 7.38 to Figure 7.42, the WCT can be built by re-using packages utilised to transport and protect items. In this way, the WCT becomes an important means to help people affected by a disaster and to reduce the environmental impact produced by packages.

8.5 Discussion of the findings

The chapter discussed the case studies applied to industrial companies and humanitarian organisations with the intent to explain the importance of the validation of the developed approaches, strategies, methodologies in the reality. Thanks to the three case studies, it was possible to analyse the opportunity to improve the state of the art about the packaging system.

From the logistics perspective, it was the first time that an RFID-UWB system was applied to product packages with a great cost reduction (i.e. reduced number of tags used for the traceability, possibility of reduced distances travelled and transportation time, with a consequent reduction in transportation cost), and a high improvement in the company efficiency.

Sometimes companies are not usual to evaluate the costs linked with packaging because it is not considered an important aspect. On the contrary, the case study demonstrated the importance for companies to evaluate packaging costs through the application of the mathematical approach. It allowed increasing the company efficiency, reducing by 16% (in the specific case) the total company cost.

Finally, the case study applied to the humanitarian organisation demonstrated the importance of packaging consideration also to reduce the environmental impact. The re-use of product packages for a purpose different from their primary function of protection and containment, provided important benefits for both the environment (by reducing the percentage of the emitted CO_2) and people affected by disaster (by providing them objects usable for daily life).

In conclusion, it is possible to say that the use of case studies for studying the issues dealt with is a fundamental approach for understanding the main dynamics that guide the studied topic and for speeding up their improvements and increasing benefits.

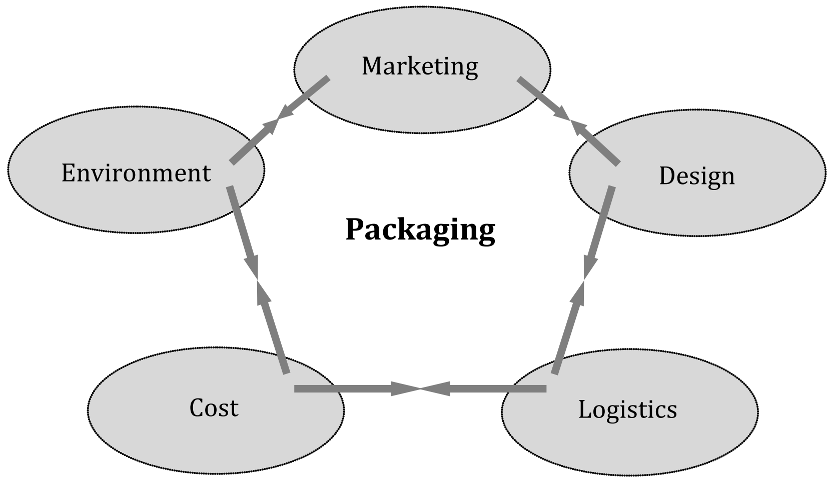
9. The future of packaging: E-commerce

9.1 The packaging system in web-operations

As underlined in *Chapter 2*, the packaging system assumes a great relevance in web-operations because it has to fulfil important functions as the preservation and containment of products from the retailer's warehouse to the consumers' house. The marketing function is not always considered in web-operations, since the function of packing products in an attractive manner becomes less important for e-commerce business (Holdway et al., 2002; Korzeniowski and Jasiczak, 2005; Sarkis et al., 2004) because consumers do not see the product packages until the products arrive at their homes. Other fundamental functions to take into account when analysing packaging for e-commerce are design, cost and environment.

9.2 A reference framework on packaging for e-commerce

Based on the framework on packaging presented in *Chapter 2* (Figure 2.4, p. 21), a framework on packaging for e-commerce has been developed. It is based on the same pillars of that in Figure 2.4: marketing, design, logistics, cost and environment, even if with some differences. Figure 9.1 reports the reference framework on packaging for e-commerce.



Marketing	Design	Logistics
Communication Customer satisfaction	Dimensions Volume Weight Materials Accessories Protection and containment Resistance Handleability	Order management Management of the warehouse Lead time Shipment Traceability Protection against in-transit theft Reverse logistics

Cost	Environment
Efficiency Cost parameters	Reduction of packaging waste Pollution Bio-degradability Recycling Re-use

Figure 9.1. Reference framework on packaging for e-commerce

First, the ***marketing*** function of packaging is analysed. The marketing aspect for e-commerce, assumes less importance if compared with the traditional commerce, but some relevant characteristics should be analysed. The first aspect of marketing function of packaging for e-commerce is the *communication*. In accordance with the classification of communication defined by

Olsson and Larsson (2009), the main communication function of packaging for e-commerce concerns communicating all the necessary information (e.g. content, expiration date, materials, etc.) about the product and the package to stakeholders and consumers. The communication of promotion and the communication to consumers assume less importance for e-commerce as the products are not exposed on the shelves. For the same reason, function of packing products in an attractive manner becomes less important for e-commerce business (Holdway et al., 2002; Korzeniowski and Jasiczak, 2005; Sarkis et al., 2004) because consumers cannot see the packages before to sell the products and packages cannot affect consumers during their purchase decision.

Even if the marketing aspect is not as important as for the traditional shopping, the *customer satisfaction* should be achieved, delighting and surprising customers.

The packaging **design** is a fundamental pillar for the definition of a reference framework on packaging for e-commerce and the physical and mechanical characteristics should be taken into account.

Dimensions, *volume* and *weight* are three fundamental aspects to consider in packaging design: a package for e-commerce should have narrow and standard dimensions, low weight and minimal void space, in order to minimise the number of shipments and vehicles, and consequently the environmental impact and costs. Packaging *materials* constitute another important aspect: the package should be mono-material to ease the recycling of products, and bio-degradable to reduce the pollutant emissions. Another class of required information deals with the *accessories* used to protect and contain products: it may be important to minimise the number of accessories used and the environmental impact produced by using, for example, easily recyclable components. The accessory function is of fundamental importance, since if they are not designed in the right manner, the package could reach customers in poor conditions; this could consequently reduce customer satisfaction and trust in the company.

From a mechanical point of view, a package for e-commerce should cover traditional functions, like *protection and containment* of products and high *resistance* to vibrations and shocks. Another important aspect to consider is the *handleability*.

A framework on packaging for e-commerce must consider the **logistics** aspect. The first important characteristic is relative to e-commerce *orders*: compared to traditional commerce, they are more frequent and comprise a higher number of different products in smaller quantities. The small quantities of products to distribute and the high frequency of the orders, could modify the picking that could lead to a new allocation of products within the warehouse, and consequently to a review of the *warehousing management*. Moreover, customers buying online request quick delivery, thus the *lead time* should be reduced in order to promptly respond to market requirements.

With the advent of e-commerce, the number of *shipments* and consequently the number of vehicles have increased. Thus, it is of fundamental importance to analyse the distribution of products, trying to optimise the number of vehicles and routes, and reduce wasted trips. In recent years the *traceability* of packages and protection against in-transit theft has become important requirements. During the transport, packages could be subject to thefts, so it may be necessary to evaluate the possibility to trace packages throughout distribution and to use some expedients to *prevent thefts*.

In the e-commerce business, customers can return unwanted and/or faulty products more frequently, so companies should analyse the *reverse logistics* aspect.

The fourth fundamental pillar concerns the ***cost*** evaluation. First, it should be operated for reducing costs as much as possible, increasing the company *efficiency*. Packaging involves several industrial areas and several packaging *cost parameters* should be taken into account. They are related to cost of engineering, purchasing cost, transportation cost, warehousing cost, cost due to the reverse logistics, and cost of disposal. In order to minimise the total packaging cost, it could be necessary to integrate all the industrial areas involved in the process of packaging realisation, making a trade-off between them.

The fifth fundamental pillar concerns the **environment**. Packages should be developed by using as little material as possible to *reduce waste* and minimise *pollutant emissions* when packaging waste is incinerated or landfilled. Of great importance is the use of *biodegradable materials* in order to minimise the environmental impact of packaging. Other classes of information required deal with the possibility to *recycle* and/or *re-use packages*.

The framework on packaging for e-commerce has been tested with five companies selling online since few years in order to understand what they think about it. Two have been the questions turned to the companies: the first sensation about the framework and its main criticalities. After the analysis of the framework and its main characteristics, the companies have been enthusiastic about them because it could be an important starting point for those companies wanting to enter e-commerce business. Indeed, the framework considers all packaging characteristics to take into account. From the other hand, this has been also the most common criticality done to the framework. A large number of characteristics to consider can be an advantage since it allows having the entire issue under control, but, at the same time, it can be also a disadvantage because the consideration of a large number of aspects simultaneously can lead to a confused management of the entire system.

9.3 A mathematical approach for the evaluation of e-commerce costs

In order to evaluate e-commerce business in terms of costs, a mathematical approach for the evaluation of total packaging costs along the supply chain has been developed, based on that developed for the evaluation of total packaging costs proposed in *Chapter 6*.

The proposed approach could represent a valid tool for analysing the impact of packaging in the e-supply chain in a complete and systematic way, and determining critical aspects and areas for improvement.

Figure 9.2 shows a diagram of the e-supply chain.

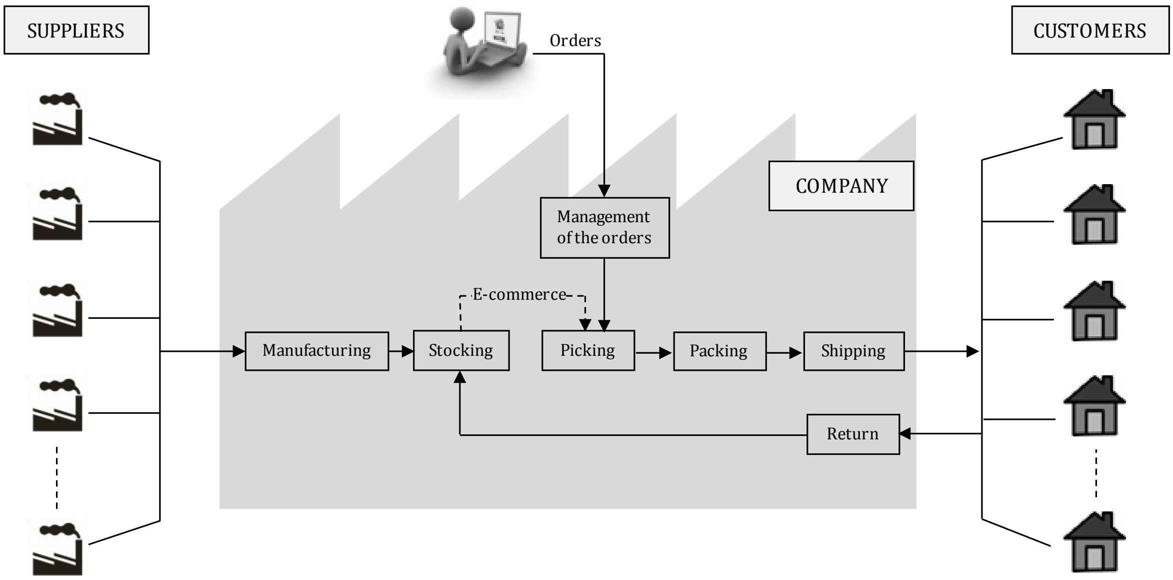


Figure 9.2. Scheme of e-supply chain

When a company receives an online order, it picks the requested products, packs them in a package (i.e. box, pallet, etc.), that could be new or re-used, and ships the order to the end consumers. The model considers the possibility that the consumer returns the products because they are damaged and/or not congruent with what he asked for.

Table 9.1, 9.2 and 9.3 describe the indices, variables and parameters used in the model.

Index	Domain	Description
i	1,…,m	Products to be sold online
j	1,…,n	Orders
k	1,…,s	Packages used for the shipping
r	1,…,q	Accessories used to protect and contain products in the package

Table 9.1. Indices of the mathematical approach for the evaluation of e-commerce cost

Variable	Unit	Description	Domain
$C_{ACC\ jr}$	[€/piece]	Cost of accessories to fill in packages. Purchasing cost of the accessory *r* used to protect the product of the order *j*.	j=1,…n r=1,…,q
$C_{DISP\ jk}$	[€/piece]	Cost of disposal. Cost to dispose the package *k* if the customer requests a new package for the order *j*.	j=1,…n k=1,…,s
$C_{MAN\ i}$	[€/piece]	Cost of the products. Manufacturing costs of the product *i*.	i=1,…,m

$C_{PACK\ jk}$	[€/piece]	Cost of package. Purchasing cost of the package *k* to contain the order *j*.	j=1,…n k=1,…,s
$C_{PALL\ i}$	[€/pallet location]	Cost of a pallet location. Cost of pallet locations to store product *i*.	i=1,…,m
$C_{RET\ j}$	[€/return]	Cost of the return. Cost of the return shipment of the order *j*.	j=1,…n
$C_{SHIP\ j}$	[€/shipment]	Cost of the shipment. Cost to ship the order *j*.	j=1,…n
N_i	[pieces/year]	Number of products of type *i* produced by the company.	i=1,…,m
$N_{ACC\ jr}$	[pieces/year]	Number of accessories of type *r* used to arrange the order *j*.	j=1,…,n r=1,…q
$N_{PACK\ k}$	[pieces/year]	Number of packages of type *k* bought by the company to contain the products.	k=1,…,s
$N_{PALL\ i}$	[pallet locations/year]	Number of pallet locations to allocate product *i*.	i=1,…,m
$T_{PICK\ j}$	[h/order]	Time to pick. Average time to pick the order *j* from the shelves.	j=1,…n
$T_{STOCK\ i}$	[h/piece]	Time to store. Average time to store the product *i*.	i=1,…,m
$T_{WRAP\ j}$	[h/order]	Time to pack. Average time to pack the order *j*.	j=1,…n
x_{jk}	[1;0]	{ 1, if the customer requests a new package *k* for the order *j* 0, otherwise	j=1,…n k=1,…,s
y_j	[1;0]	{ 1, if the customer gives back the order *j* 0, otherwise	j=1,…n

Table 9.2 Variables of the mathematical approach for the evaluation of e-commerce cost

Parameter	Nomenclature	Unit	Description
C_{ACC}	Cost of accessories	[€]	Cost of the accessories used to protect and contain products inside the package.
C_{DISP}	Cost of disposal	[€]	Cost to dispose packages.
$C_{h\ EQ}$	Hourly cost of equipment	[€/h]	Hourly cost of the equipment required to pack products.
$C_{h\ OP1}$	Hourly cost of the operator to store products	[€/h]	Hourly cost of the operators responsible for storing products.
$C_{h\ OP2}$	Hourly cost of the operator to pick products	[€/h]	Hourly cost of the operators responsible for picking products.
$C_{h\ OP3}$	Hourly cost of the operator to pack products	[€/h]	Hourly cost of the operators responsible for packing products.
$C_{h\ TR1}$	Hourly cost of the trolley to transport products to store	[€/h]	Hourly cost of the trolleys that transport products to be stored.
$C_{h\ TR2}$	Hourly cost of the trolley to transport	[€/h]	Hourly cost of the trolleys that transport picked products.

	picked products		
C_{MAN}	Manufacturing cost	[€]	Cost to produce the products to be sold online.
C_{ORD}	Cost of the order	[€/order]	Cost to manage the orders received by the customers. It includes the labour cost.
C_{PICK}	Cost to pick the order	[€]	Cost to pick the order. It includes the labour cost and the depreciation of the infrastructure.
C_{RET}	Cost of the return	[€]	Cost of the return order. It includes the labour cost, the depreciation of the vehicle and the costs relating to the whole process of re-using or disposing packages.
C_{SHIP}	Shipping costs	[€]	Cost to ship the order. It includes the labour cost and the depreciation of the vehicle.
C_{STOCK}	Stocking costs	[€]	Cost to stock products. It includes the cost of pallet location, the labour costs and the depreciation of infrastructure.
C_{UP}	Cost to update the web site	[€/update]	Cost to update the web site (e.g. in order to modify the selling catalogue). It includes the labour cost.
C_{WRAP}	Cost to pack the order	[€]	Cost to pack the order. It includes the labour cost and the depreciation of the equipment used.
$C_{WEB\ SITE}$	Cost to create the web site	[€]	Cost to create the web site. It includes the labour cost and the operative costs. It is an investment cost.
N_{ORD}	Number of orders	[orders/year]	Number of online orders received by customers.
N_{UP}	Number of updates	[updates/year]	Number of updates made by an operator to update the web site.

Table 9.3. Parameters of the mathematical approach for the evaluation of e-commerce cost

Equation (9.1) introduces the general formula for the model and equation (9.2) presents the complete mathematical approach, explaining each cost parameter in detail.

$$C_{TOT} = C_{WEB\ SITE} + C_{UP} + C_{ORD} + C_{MAN} + C_{STOCK} + C_{PICK} + C_{WRAP} + C_{PACK} + C_{ACC} + C_{SHIP} + C_{RET} + C_{DISP} \quad (9.1)$$

$$C_{TOT} = C_{WEB\ SITE} + (N_{UP} \cdot C_{UP}) + (N_{ORD} \cdot C_{ORD}) + \left(\sum_{i=1}^{m} N_i \cdot C_{MAN\ i}\right)$$
$$+ \left[\left((C_{h\ OP1} + C_{h\ TR1}) \cdot \sum_{i=1}^{m} T_{STOCK\ i}\right) + \left(\sum_{i=1}^{m} N_{PALL\ i} \cdot C_{PALL\ i}\right)\right]$$
$$+ \left[(C_{h\ OP2} + C_{h\ TR2}) \cdot \sum_{j=1}^{n} T_{PICK\ j}\right] + \left[(C_{h\ OP3} + C_{h\ EQ}) \cdot \sum_{j=1}^{n} T_{WRAP\ j}\right]$$
$$+ \left(\sum_{j=1}^{n}\sum_{k=1}^{s} N_{PACK\ jk} \cdot C_{PACK\ jk} \cdot x_{jk}\right) + \left(\sum_{j=1}^{n}\sum_{r=1}^{q} N_{ACC\ jr} \cdot C_{ACC\ jr}\right) + \left(\sum_{j=1}^{n} C_{SHIP\ j}\right)$$
$$+ \left(\sum_{j=1}^{n} C_{RET\ j} \cdot y_j\right) + \left(\sum_{j=1}^{n}\sum_{k=1}^{s} C_{DISP\ jk} \cdot x_{jk}\right) \quad (9.2)$$

The mathematical approach allows companies to have a complete tool for analysing their total costs for e-commerce business in order to understand possible cost reductions and improvements.

9.4 A case study: the re-use of packaging in the e-commerce business

The framework on packaging system for e-commerce and the mathematical approach have been applied to an Italian company that has decided to sell online.

Traditionally, the company receives goods from suppliers in the receiving area; the goods are unpacked, sorted and stored in the warehouse. When a retailer asks for products, they are picked from the shelves, packed and dispatched to the retailer who in turn sells the products to end consumers in “real shops”. All the received packages are recycled and/or disposed for producing energy from waste. Figure 9.3 shows the main activities of the company for the traditional commerce.

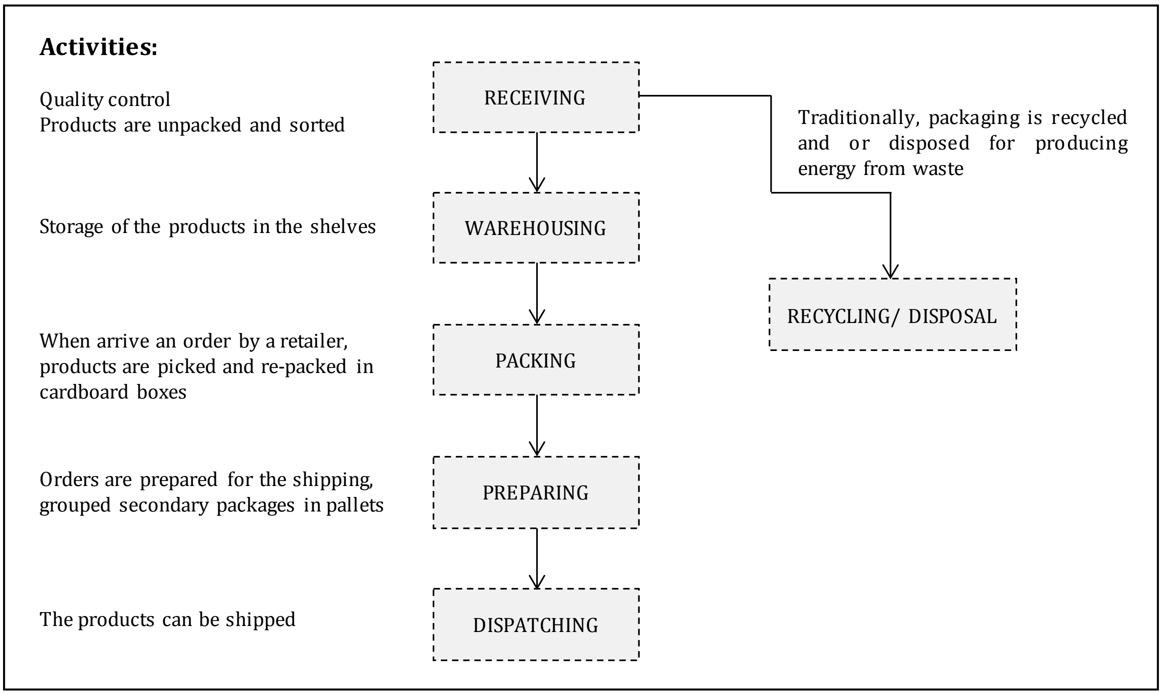


Figure 9.3. Main activities of the company for the traditional commerce

When the company has started to sell online, some of its main activities changed. Figure 9.4 shows the main activities of the company for e-commerce business.

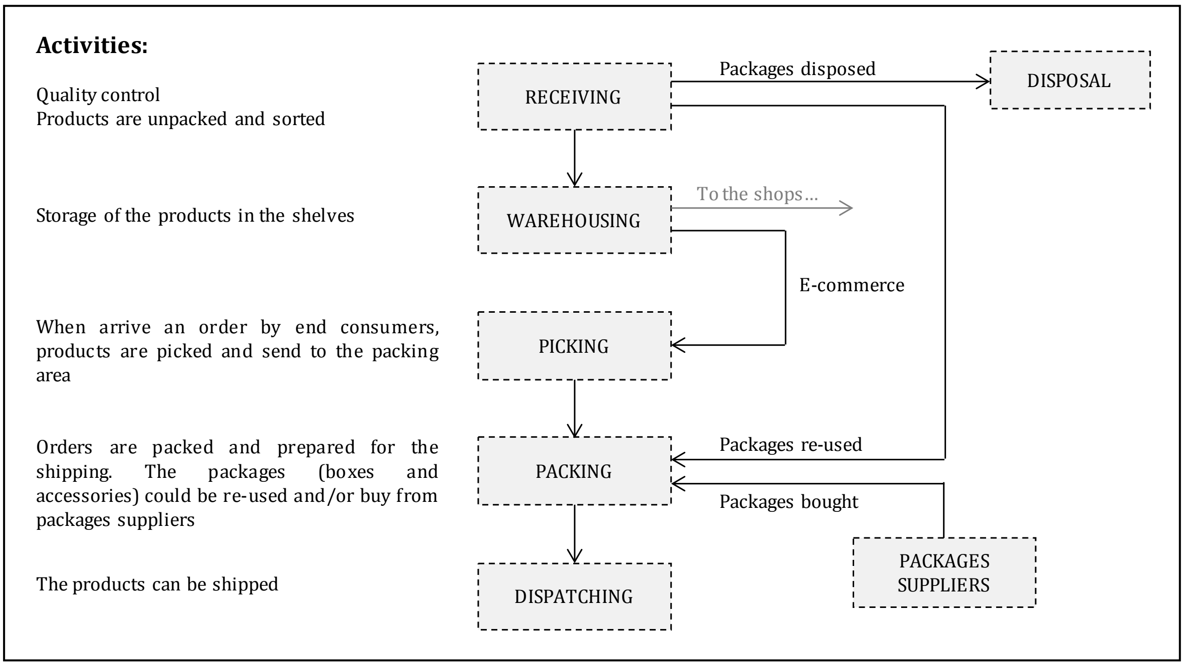


Figure 9.4. Main activities of the company for e-commerce business

As it is possible to see from Figure 9.2 and 9.4, the company receives the products from suppliers that are unpacked, sorted and stored in the warehouse. When a consumer makes an online order, the products are picked from the shelves, packed and dispatched to the end user. In order to pack the products, the company can choose to use secondary packages of the products coming from the suppliers or to buy them. The packages arriving at the receiving area and not used for packing the products are disposed. For the new packaging system, the company has identified the need to study a new packaging system for e-commerce, in terms of size of the secondary packages and accessories used for protecting and containing products.

The new packaging solution should be able to optimise the costs and logistics aspects (i.e. protection of the product, security during the shipment and re-use of packages). According to Visser (2002), the marketing aspect is not hold in much consideration during the creation of a packaging solution for e-commerce, first of all because the company is responsible only for the secondary packages (it receives the products from manufacturers and cannot decide on the primary packages); moreover, secondary packages does not greatly influence consumers' choice in buying products.

Several activities has been realised in order to define a new packaging system for e-commerce business. They are described below.

Packaging analysis. In order to define a new packaging solution for e-commerce, it is necessary to analyse the packages and accessories offered by the market, and evaluate the possibility to re-use incoming secondary packages in order to contain the products and create the accessories for protecting them.

The company has defined some "typical" orders useful to identify the size of the secondary packages, also evaluating the possibility to re-use incoming secondary packages in order to reduce costs and environmental impact. Table 9.4 shows the main data of some "typical" orders identified by the company.

Order	N. Box	Gross weight [Kg]	Packaging weight [Kg]	Volume [dm^3]	Packaging saturation [%]
1	1/3	1.23	0.45	6.37	12.3%
	2/3	6.91	0.51	20.71	57.2%
	2/3	2.45	0.51	17.73	47.9%
2	1/1	7.98	0.52	27.50	40.5%
3	1/2	12.11	0.40	25.61	91.5%
	2/2	6.36	0.66	14.50	44.9%
4	1/3	6.55	0.60	27.40	79.4%
	2/3	5.61	0.45	26.65	74.3%
	3/3	6.64	0.52	15.49	42.6%
5	1/2	5.96	0.63	28.00	51.4%%
	2/2	11.6	0.50	20.90	55.8%
6	1/2	2.31	0.79	18.00	30.9%
	2/2	12.79	0.37	25.00	75.8%
7	1/1	1.51	0.46	22.75	57.2%
8	1/1	5.96	0.52	17.40	44.0%
9	1/1	2.42	0.53	9.82	37.2%
10	1/2	8.27	0.50	28.92	74.6%
	2/2	10.89	0.57	32.44	79.0%

Table 9.4. Main data of some “typical” orders

From the analysis of the volume, weight and packaging saturation of the orders, three standard dimensions of packages have been identified, also according to the dimensions of the incoming secondary packages:

- Small package [cm]: 22x22x25 (h)
- Medium package [cm]: 26x38x30 (h)
- Large package [cm]: 26x38x40 (h)

Shipping test. In order to analyse the conditions in which the products reach the consumers, the company has sent some orders to the Mechanical Laboratory of the University of Bologna and some products arrived in poor conditions, as it is possible to see from Figure 9.5. These tests highlighted the need to define functional accessories to protect the products inside the packages.

Figure 9.5. Examples of products arrived at the Mechanical Laboratory of the University of Bologna

Definition of accessories. Several accessories have been studied, analysing both new accessories (e.g. pluriball, air pillows, etc.) and those created by re-using incoming secondary packages (e.g. cardboard strips, cardboard dividers, etc.). Four different accessories have been tested in order to understand the advantages and disadvantages of each one:

- The use of small thin cardboard strips deriving from the cutting of advertising leaflets (Figure 9.6).

Figure 9.6. Cardboard strips deriving from the cutting of advertising leaflets used as accessories

No products have arrived damaged, but the configuration has led to an excessive amount of dust and it may be difficult to find small products inside the package, because of the large number of strips. Moreover, the solution is not aesthetically pleasing.

- The use of small cardboard strips deriving from the cutting of incoming secondary packages (Figure 9.7).

Figure 9.7. Cardboard strips deriving from the cutting of incoming secondary packages used as accessories

Also in this case, no products have arrived damaged and the solution is better than the previous one. The aesthetic is pleasing, but also this solution creates a large amount of dust, although less than the previous one.

- The use of polystyrene chips bought from packaging suppliers (Figure 9.8).

Figure 9.8. Polystyrene chips used as accessories

No products have arrived damaged; there has been no trace of dust and the solution is aesthetically pleasing, but it is not convenient for end consumers to empty the polystyrene chips out of the packages.

- The use of air pillows bought by packaging suppliers (Figure 9.9).

Figure 9.9. Air pillows used as accessories

No products have arrived damaged; there is no trace of dust; the solution is aesthetically pleasing and it is convenient for end consumers.

The new packaging solution. According to the application of the reference framework on packaging for e-commerce and the evaluation of different alternatives in terms of costs, it has been chosen to re-use incoming secondary packages for the distribution of products. Despite this, the company has wished to maintain the possibility to use new secondary packages for customers that request them.

As accessories, air pillows have been chosen for the protection of products during transport. Air pillows are an excellent filling solution, since they are resistant to humidity and provide excellent protection. One important characteristic is their recyclability: they are 99% of air and 1% plastic material. End consumers will appreciate this environmentally friendly feature. From the company point of view, air pillows are a space saving solution, since they are bought in reels and blown up only when necessary.

In order to face the problem relative to possible thefts of products during transport, the company has decided to close the secondary packages with a customised strip.

The implementation of the solution. The new packaging solution has been implemented by the company, leading to several benefits: an increase in sales, a reduction in transaction costs and an increase in customer satisfaction thanks also to the environmentally friendly packaging.

10. Conclusion and final remarks

Nowadays, and even more in the next decades, the topic of packaging has assumed and will continue to assume a fundamental role. A good management of the packaging system may present a great potential for an efficient supply chain.

The present Ph.D. dissertation focuses on the packaging system, deepening strategies, methods and showing innovative approaches for the effective design, management and reduction of total packaging costs.

The resource path, summarised in the present dissertation, firstly proposed a general overview on the packaging topics analysing in details its origins, its functions and its role along throughout the supply chain, and defining a reference framework on packaging after identifying five packaging key drivers: marketing, design, logistics, cost and environment, on which packaging plays a fundamental role (*Chapter 2*). Considering the reference framework as the starting point of the Ph.D. dissertation, it went ahead dealing with each packaging key drivers, using different methodologies to approach the problem. In accordance with the reference framework on packaging, marketing was the first analysed key driver. The analysis of the questionnaire on packaging perception by Italian users presented interesting results and tried to underline the most relevant packaging aspects on which companies should compete to increase customer satisfaction and their selling, and in turn their profit (*Chapter 3*). The realisation of the packaging prototype (for the design packaging key driver) brought important benefits: the use of the Flextrus PaperLite® material allowed more than 25% weight reduction, facilitating material handling and transport, and more than 6% volume reduction, reducing in turn transportation and warehousing costs (*Chapter 4*). Further, the traceability of packages within indoor environment was presented (*Chapter 5*), through a developed RFID-UWB system. The results confirmed the strong potential of the RFID-UWB system applied to the traceability of packaging according to the high tested accuracy and precision. The traceability of material flows through the RFID-UWB system provided important benefits in terms of flow transparency (i.e. possibility to know where the products are in real time and in continuous) with a consequent reduction in distance travelled that in turn allowed a relevant reduction in transportation and warehousing cost. Moreover, the RFID-UWB system allowed managing material flows, evaluating the wait and idle time of the trolleys and the transportation time (*Chapter 8*). The realisation of a mathematical approach (*Chapter 8*) for the evaluation of packaging costs represented an added value for the companies to estimate the total costs of packaging system and consequently its impact on total company costs. The application of the mathematical approach to a case study, the total packaging cost decreased that in turn allowed a reduction of the total company costs. The study of the re-use function of packaging allowed the realisation of several objects starting from secondary packages (e.g. carton boxes, wooden crates, plastics, pallets, etc.) (*Chapter 8*). The study focused on the re-use of packages in emergency camps during disaster situations. The re-use of packages in emergency camps can provide an improvement of the life of people affected by a disaster, thanks to the realisation of new objects, useful for their everyday life, and to the fact that people can learn new notions that can apply subsequently to other situations. Another fundamental result was the reduction of CO_2 emissions provided by the re-use of packages, and in turn the environmental pollutant. The last chapter (*Chapter 9*) identified the main characteristics of the packaging system for e-commerce business and defined a mathematical approach for the evaluation of packaging cost for e-commerce. The application of both the framework and the mathematical approach to an Italian retailer allowed understanding the main packaging characteristics that companies should consider before entering e-commerce business and the importance to take into account the packaging system for reducing company costs.

10.1 Practical and scientific contribution

The present Ph.D. dissertation provides both practical and scientific contribution.

The practical contribution could be identified in the great potential that the methodologies and approaches presented in this Ph.D. dissertation represent in order to decrease the resource utilisation, reduce costs, and minimise the environmental impact of the entire packaging system. The Ph.D. dissertation provides evidence that a system view of the interaction between packaging and the main industrial functions (e.g. marketing, design, logistics, etc.) is necessary to consider further industrial developments, for increasing the industrial efficiency and reducing costs, but it is not yet fully verified. Moreover, the applied methodologies to explain the five packaging key drivers allowed the relevant function that the right management of the packaging system can assume along the whole industrial supply chain. The application of the traceability system to industrial plants may provide important benefits in terms of minor distance travelled and thus minor internal transportation costs, and major visibility of the material flows. The development of the packaging prototype as containment of a dip sauce may provide a reduction in transportation costs thanks to the reduction in the packaging volume. The mathematical approach applied to a manufacturing company allowed the reduction of packaging costs by 16%. Thus, the Ph.D. thesis contributes to the industrial field because it represents a source for the increasing efficiency of the company. The re-use of packaging in disaster countries has a broader view that overcomes the industrial conception. Firstly, the research may assume a fundamental role in the prevention of the environmental disaster (thanks to the reduction of the emitted CO_2) that the Man is stocking; secondly, it may be much useful to people affected by natural and manmade disasters for improving their daily life and trying to come back to the normality.

The scientific contribution could be identified in the continuous understanding of the necessity to integrate the management of the packaging system with other industrial functions. In addition, it represents an aid in showing how packaging-related decisions might affect the entire supply chain. This research serves as a fundamental step towards adopting a holistic packaging approach. It implies that understanding packaging interactions makes it possible to make decisions such as changing the packaging system or logistics system or the marketing approach, based on a holistic packaging approach. The present Ph.D. dissertation may represent an important starting point for further analysis concerning the packaging system, from a holistic point of view or from each key driver perspective.

10.2 Further developments

Starting from the topics investigated in the present Ph.D. dissertation, a set of future developments are encouraged to continue and expand the research on the described models, approaches, strategies and realised packaging prototypes.

With references to the empirical study presented in *Chapter 3* and *Chapter 8* (the mathematical approach for the evaluation of the packaging cost), further research should be focused on the cooperation with companies in order to identify methodologies devoted to the integration of packaging development with the management of the entire supply chain, and to evaluate the company packaging costs, identifying the most critical cost parameters. The final goal should be an improvement of technical and ergonomic performance of product packages in manufacturing, reducing the total packaging costs and the environmental impact of packaging.

Considering the packaging prototype presented in *Chapter 4*, further development should be focused on the study of new materials and shape of packaging so as to reduce the packaging volume and in turn the transportation and warehousing costs. In line with this, is the theme dealt with in *Chapter 8* (the case study on the re-use of packages in emergency camps). Both academics and practitioners should focus on the continuous optimisation of approaches and methodologies for the re-use of packages in new and different applications after covering their primary function of protection and containment of products. The re-use of packages may provide important benefits, as the reduction of the environmental impact of packaging and the possibility to help people affected by a disaster from a psychological and a practical point of view. Moreover, focusing on the solar cooker project it could be interesting to analyse the temperature behaviour adding a Fresnel's lens on the top of the carton solar cooker. Concerning the traceability of packages within indoor environment (*Chapter 8*), further research should focus on the continuous optimisation of the RFID-UWB system in order to improve the traceability of packages and products, increasing the flow transparency and managing material flows in order to know the transportation time, wait and idle time. Finally, several modifications should be considered for future thinking concerning online packages (*Chapter 9*). In addition, the framework on packaging for e-commerce and the mathematical approach defined for the evaluation of packaging cost in case of online commerce may be applied to companies selling luxury products online, in order to analyse the main difference and similarities with the case of packages for everyday products.

The main requirements for the *packaging of the future* can be summarised in lighter packages, increase of the packaging productivity, reduction of waste packaging along the whole supply chain, recyclability and re-usability and more attention to the reduction of energy consumption and minimisation of CO_2 emissions. In order to achieve the packaging requirements, it is necessary to integrate packaging function with all the other industrial departments (logistics, marketing, design, etc.) with the intent to improve and increase company efficiency and reduce their costs.

Such a list of future developments points out some of the open issues coming from the topics investigated in the Ph.D. research path and that can drive the future studies.

The final goal of all the efforts is the continuous increase of the packaging importance along the whole supply chain, recognising it the integrative role of all the industrial functions.

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Appendix A: The questionnaire on customer perception of primary packaging

Sezione1 – Background

1.1 Età

1.2 Città di provenienza

1.3 Sesso

1.4 Stato civile

1.5 Livello di istruzione

- ☐ Diploma scuola elementare
- ☐ Diploma scuola media
- ☐ Diploma scuola superiore
- ☐ Laurea triennale
- ☐ Laurea specialistica
- ☐ Diploma post laurea (master, PhD…)

1.6 Professione

1.7 Presenta qualche disabilità che preclude il completo/corretto utilizzo del packaging?

☐ Si ☐ No

Se si, può descrivere brevemente la sua disabilità e come essa influenza l'uso del packaging?

Sezione2 – Caratteristiche del packaging (mettere una *x* sulla colonna di destra in corrispondenza della risposta scelta)

2.1 Prestazioni tecniche e design del packaging

1.1 Qual è la sua percezione di un imballaggio adibito alla protezione del prodotto?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
1.2 Qual è la sua percezione di un imballaggio che non prevede la funzione di proteggere il prodotto al suo interno?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

2.1 Qual è la sua percezione di un imballaggio che aderisce perfettamente al prodotto, non prevedendo la possibilità di perdite?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
2.2 Qual è la sua percezione di un imballaggio che non aderisce perfettamente al prodotto?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

3.1 Qual è la sua percezione di un imballaggio che prevede la chiusura dopo l'uso (ad esempio con l'utilizzo di un sigillo)?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
3.2 Qual è la sua percezione di un imballaggio che non prevede la chiusura dopo l'uso?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

4.1 Qual è la sua percezione di un imballaggio costruito con materiale riciclabile?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
4.2 Qual è la sua percezione di un imballaggio costruito con materiale non riciclabile?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

5.1 Qual è la sua percezione di un imballaggio con caratteristiche addizionali (un termometro per valutare la temperatura di un liquido)?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
5.2 Qual è la sua percezione di un imballaggio non avente caratteristiche aggiuntive?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

6.1 Qual è la sua percezione di un imballaggio che abbia un design alla moda?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
6.2 Qual è la sua percezione di un imballaggio non avente un design alla moda?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

7.1 Qual è la sua percezione di un imballaggio che sia igienico (che dia la percezione di pulito prima e dopo l'uso)?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
7.2 Qual è la sua percezione di un imballaggio non igienico?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

2.2 Packaging ergonomico

8.1 Qual è la sua percezione di un imballaggio facilmente maneggiabile?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
8.2 Qual è la sua percezione di un imballaggio non facilmente maneggiabile?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

9.1 Qual è la sua percezione di un imballaggio che sia facile da usare?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
9.2 Qual è la sua percezione di un imballaggio non facile da usare?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

10.1 Qual è la sua percezione di un imballaggio facilmente apribile?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
10.2 Qual è la sua percezione di un imballaggio non facilmente apribile?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

11.1 Qual è la sua percezione di un imballaggio che possa essere completamente svuotato?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
11.2 Qual è la sua percezione di un imballaggio che non possa essere completamente svuotato?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

12.1 Qual è la sua percezione di un imballaggio che permetta di dosare la quantità che si desidera?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
12.2 Qual è la sua percezione di un imballaggio che non permetta di dosare la quantità che si desidera?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

13.1 Qual è la sua percezione di un imballaggio che sia facilmente stoccabile negli scaffali della sua casa?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
13.2 Qual è la sua percezione di un imballaggio che non sia facilmente stoccabile negli scaffali della sua casa?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

14.1 Qual è la sua percezione di un imballaggio che contenga solo la giusta quantità per i suoi bisogni (ad esempio una singola porzione)?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
14.2 Qual è la sua percezione di un imballaggio che contenga poco o troppo rispetto ai suoi bisogni?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

15.1 Qual è la sua percezione di un imballaggio che sia facile da buttare nella spazzatura (facilmente piegabile, di dimensioni ridotte)?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
15.2 Qual è la sua percezione di un imballaggio che non sia facile da buttare nella spazzatura?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

2.3 Comunicazione del packaging

16.1 Qual è la sua percezione di un imballaggio contenente un prodotto distintivo?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
16.2 Qual è la sua percezione di un imballaggio che contiene un prodotto anonimo?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

17.1 Qual è la sua percezione di un imballaggio contenente istruzioni relative al suo utilizzo (ad esempio come si apre)?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
17.2 Qual è la sua percezione di un imballaggio che non contiene istruzioni relative al suo utilizzo?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

18.1 Qual è la sua percezione di un imballaggio che presenta una chiara simbologia, nel caso utilizzi simboli o codici?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
18.2 Qual è la sua percezione di un imballaggio senza una chiara simbologia?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

19.1 Qual è la sua percezione di un imballaggio che comunichi la data di produzione e di scadenza del prodotto al suo interno?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
19.2 Qual è la sua percezione di un imballaggio che non comunichi la data di produzione e di scadenza del prodotto al suo interno?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

20.1 Qual è la sua percezione di un imballaggio che sia esteticamente attraente (colore, forma)?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
20.2 Qual è la sua percezione di un imballaggio che non sia esteticamente attraente?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

21.1 Qual è la sua percezione di un imballaggio che sia facilmente distinguibile dagli altri contenenti uno stesso prodotto?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
21.2 Qual è la sua percezione di un imballaggio non sia facilmente distinguibile dagli altri contenenti uno stesso prodotto?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

22.1 Qual è la sua percezione di un imballaggio che comunichi la marca in modo chiaro?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
22.2 Qual è la sua percezione di un imballaggio che non comunichi la marca?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

23.1 Qual è la sua percezione di un imballaggio che sia coerente con il prodotto contenuto (ad esempio con un'immagine/una foto del prodotto)?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	
23.2 Qual è la sua percezione di un imballaggio che non sia coerente con il prodotto contenuto?	1. Penso sia positivo quando è così	
	2. Mi aspetto sia così	
	3. Non mi interessa/Sono neutrale	
	4. Posso accettare che sia così	
	5. Non mi piace quando è così	

Sezione 3 – Livello di importanza delle caratteristiche del packaging (mettere una *x* sulla risposta scelta; si ricorda che 1=per niente importante e 10=estremamente importante)

Proprietà del packaging	**LIVELLO DI IMPORTANZA**									
Quanto è importante che il packaging…	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
…protegga il prodotto?										
…aderisca perfettamente al prodotto?										
…possa essere richiuso dopo l'utilizzo?										
…sia costruito con materiale riciclabile?										
…abbia caratteristiche addizionali?										
…abbia un design alla moda?										
…sia igienico?										
…sia facilmente maneggiabile?										
...sia facile da usare?										
…sia facile da aprire?										
…sia completamente svuotabile?										
…sia facilmente dosabile nelle quantità desiderate?										
…sia facilmente stoccabile nello scaffale?										
…contenga la giusta quantità per i suoi bisogni?										
…sia facile da piegare per essere gettato nella spazzatura, che occupi poco spazio?										
…sia distintivo per il prodotto contenuto?										
…contenga istruzioni per il suo utilizzo?										
…presenti una chiara simbologia?										
…comunichi la data di produzione e di scadenza del prodotto?										
…sia esteticamente attraente?										
…sia facilmente distinguibili dagli altri packaging contenenti lo stesso prodotto?										
…comunichi la marca in modo chiaro?										
…sia coerente con il prodotto contenuto?										

Se ci sono altri commenti relativi al packaging o al questionario, si prega di riportarli di seguito. Fare clic qui per immettere testo.

Appendix B: The questionnaire on company perception of packaging

A – ANAGRAFICA DELL'AZIENDA

Domande A1 – A7

A1 – Generalità
Nome dell'azienda:
Sede dello stabilimento nel quale si svolge l'intervista (città/regione):
Personale intervistato (nome/ruolo):
E-mail:

A2 – Dimensioni dell'azienda
Numero di dipendenti:
Fatturato annuo [€×1000]:

A3 – Settore merceologico di appartenenza

- ☐ Abbigliamento
- ☐ Alimentare
- ☐ Calzaturifici/Maglifici
- ☐ Cartiere
- ☐ Chimico/Farmaceutico
- ☐ Cosmetico
- ☐ Elettrico/Elettronico
- ☐ Gomma e materiale plastico
- ☐ Laterizi
- ☐ Legno e sughero
- ☐ Meccanico
- ☐ Tessile
- ☐ Trasporti e distribuzione
- ☐ Vetro e ceramica
- ☐ Altro (specificare)

A4 – Prodotto/Servizio

Che tipo di prodotto viene venduto dall'azienda?

A5 – Certificazioni

La sua azienda è dotata di certificazioni di qualità?

☐ SI ☐ NO

Se si, di quali certificazioni è dotata l'azienda? (scelta multipla)

- ☐ ISO 9001
- ☐ ISO 14001
- ☐ OHSAS 18001
- ☐ UNI 16001

- ☐ EMAS
- ☐ Altro (specificare)

A6 – Calendario di apertura degli impianti

- ☐ 1 turno
- ☐ 2 turni
- ☐ 3 turni
- ☐ Altro (specificare)

- ☐ 5 giorni/settimana
- ☐ 6 giorni/settimana
- ☐ 7 giorni/settimana
- ☐ Altro (specificare)

A7 – Principali clienti

☐ B2B ☐ B2C ☐ Altro (specificare

B – CARATTERISTICHE DEL PACKAGING

Domande B1 – B7

B1 – Che materiale viene utilizzato per la costruzione degli imballaggi? (scelta multipla)

B1_1 Imballaggio primario

- ☐ Cartone ondulato
- ☐ Vetro
- ☐ Metallo/Alluminio/Latta
- ☐ Plastica
- ☐ Carta
- ☐ Gomma
- ☐ Legno
- ☐ Altro (specificare)

B1_2 Imballaggio secondario

- ☐ Cartone ondulato
- ☐ Vetro
- ☐ Metallo/Alluminio/Latta
- ☐ Plastica
- ☐ Carta
- ☐ Gomma
- ☐ Legno
- ☐ Altro (specificare)

B1_3 Imballaggio terziario

- ☐ Cartone ondulato

- ☐ Vetro
- ☐ Metallo/Alluminio/Latta
- ☐ Plastica
- ☐ Carta
- ☐ Gomma
- ☐ Legno
- ☐ Altro (specificare)

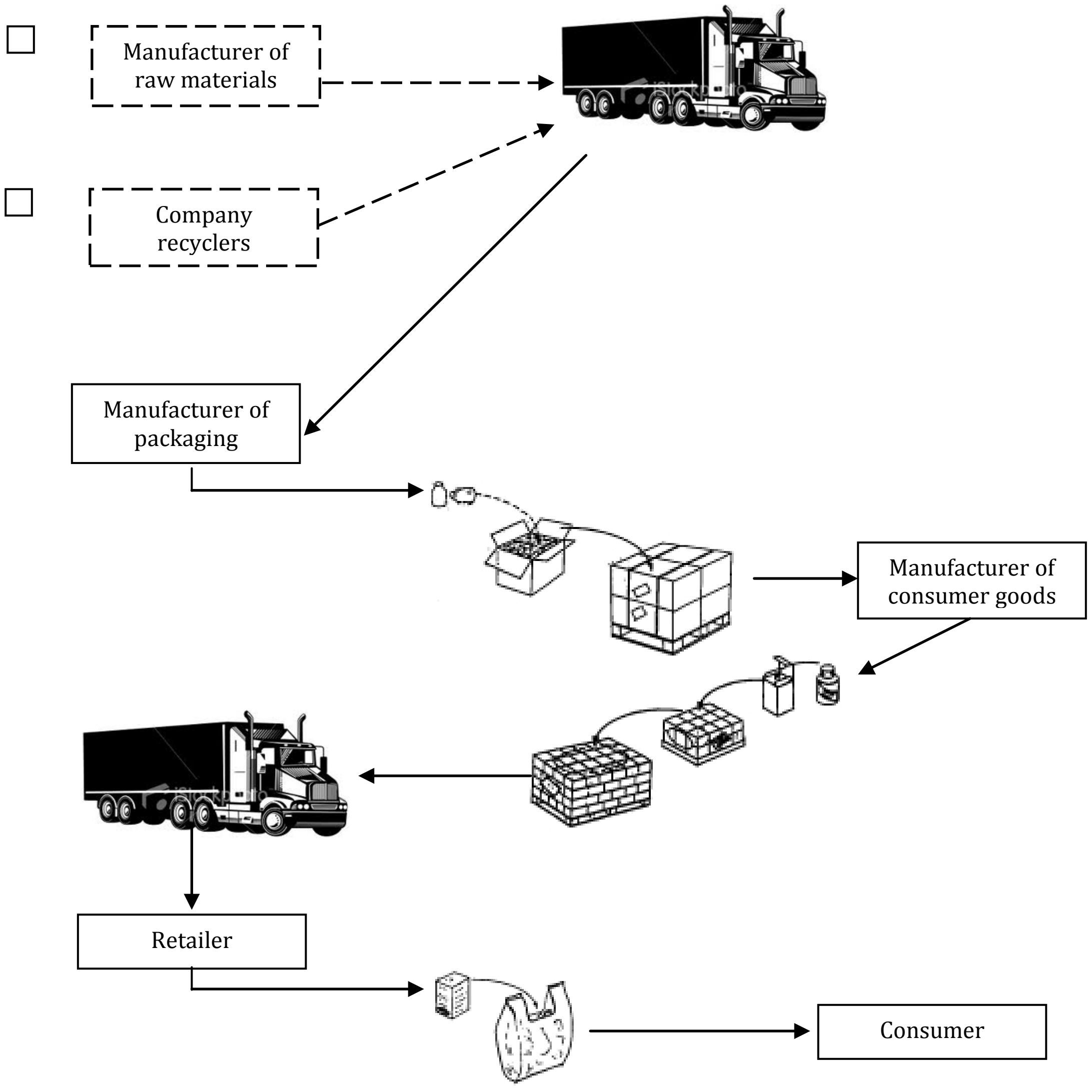
B2 – Vengono utilizzati accessori?

☐ SI ☐ NO

Se si, quali?

- ☐ Reggette
- ☐ Materiale plastico
- ☐ Fluido termoretraibile
- ☐ Pluriball
- ☐ Carta
- ☐ Altro (specificare)

B3 – Filiera del packaging più usato in azienda (scegliere una tra le seguenti filiere)



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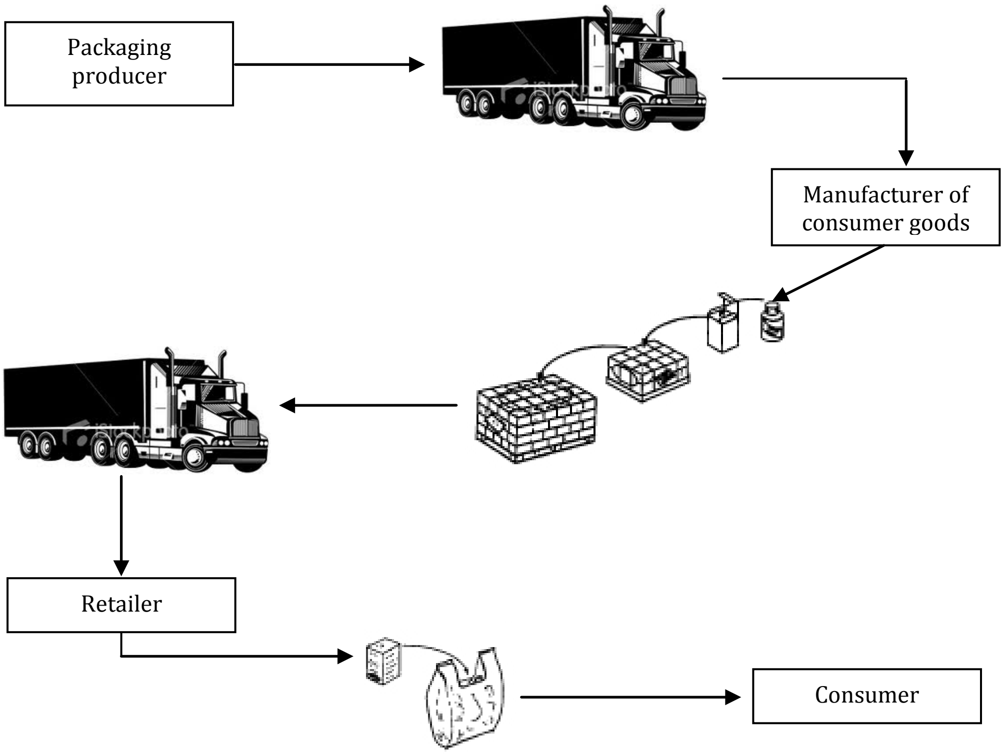

☐ Altro (specificare)

B4 – Numero di packaging diversi utilizzati in azienda:

B5 – Dimensioni dell'imballaggio primario (approssimativo)***:***

B6 – Di quanti imballaggi primari è costituito un imballaggio secondario? (approssimativo)

B7 – Di quanti imballaggi secondari è costituito un imballaggio terziario? (approssimativo)

C – FUNZIONE DEL PACKAGING

Domande C1 – C4

C1 – Che funzione ricopre preminentemente per l'azienda il packaging? (mettere *1* sulla funzione di primaria importanza, *2* su quella di secondaria importanza e *3* sulla funzione di terziaria importanza)

- ☐ Supportare l'assemblaggio
- ☐ Contenere il prodotto
- ☐ Preservare/Proteggere il prodotto
- ☐ Comunicare/Informare riguardo al prodotto
- ☐ Movimentare il prodotto (trasporto, stoccaggio,…)
- ☐ Garantire il prodotto
- ☐ Assicurare il prodotto
- ☐ Tracciare il prodotto
- ☐ Altro (specificare)

C2 – Quanto ritiene importanti il packaging e le sue funzioni?

- ☐ Molto poco
- ☐ Poco
- ☐ Molto
- ☐ Indispensabile

C3 – Pensa che le vendite relative ai suoi prodotti siano dovute, in parte, anche alla tipologia di packaging utilizzato? (materiale utilizzato, informazioni date nell'imballaggio,…)

- ☐ No, le vendite dei prodotti dell'azienda sono dovute esclusivamente al tipo di prodotto offerto
- ☐ Si, in parte
- ☐ Si, assolutamente

C4 – Nel ciclo di produzione aziendale, sono presenti imballaggi interni?

☐ SI ☐ NO

Se si:

C4_1 – Le materie prime/i semilavorati in acquisto hanno un packaging discusso con il fornitore?

☐ SI ☐ NO

Se no, per quale motivo? (scelta multipla)

- ☐ Indisponibilità del fornitore
- ☐ All'azienda non interessa che tipo di packaging utilizzano i fornitori
- ☐ Il packaging utilizzato dai fornitori non ha mai creato problemi all'azienda
- ☐ Altro (specificare)

C4_2 Gli imballaggi interni vengono progettati internamente all'azienda?

☐ SI ☐ NO

Se si, chi lo sviluppa?

- ☐ R&S
- ☐ Marketing
- ☐ Package Department
- ☐ Produzione
- ☐ Altro (specificare)

Se no, chi lo sviluppa?

- ☐ Studio esterno
- ☐ Azienda del gruppo
- ☐ Società di consulenza
- ☐ Altro (specificare)

C4_3 Che funzione svolge il packaging interno? (mettere *1* sulla funzione di primaria importanza, *2* su quella di secondaria importanza e *3* sulla funzione di terziaria importanza)

- ☐ Bloccaggio e riempimento
- ☐ Protezione
- ☐ Anticorrosione
- ☐ Trasporto semilavorati
- ☐ Supporto per lavorazioni meccaniche
- ☐ Tracciabilità
- ☐ Altro (specificare)

C4_4 Che tipo di materiale viene usato per la costruzione di imballaggi interni? (scelta multipla)

- ☐ Pluriball
- ☐ Patatine
- ☐ Poliuretano espanso
- ☐ Cartone alveolare
- ☐ Carta
- ☐ Acciaio/Alluminio/Latta
- ☐ Gomma
- ☐ Legno
- ☐ Plastica
- ☐ Altro (specificare)

D – PROCESSO DI SVILUPPO PRODOTTO/PACKAGING E LORO INTEGRAZIONE

Domande D1 – D11

D1 – Esiste una procedura aziendale per lo studio del packaging?

☐ SI ☐ NO

D2 – In quale momento viene studiato e sviluppato il packaging del prodotto finito in azienda?

- ☐ Dopo lo sviluppo del prodotto
- ☐ Simultaneamente allo sviluppo del prodotto
- ☐ Altro (specificare)

D3 – Pensa sia possibile integrare lo studio del prodotto con lo studio del packaging?

☐ SI ☐ NO

D4 – Pensa che l'integrazione tra lo sviluppo del prodotto e del packaging possa portare ad una riduzione dei costi nel ciclo di vita del prodotto?

☐ SI ☐ NO

Se si, dove?

☐ Sviluppo del prodotto
☐ Produzione
☐ Stoccaggio
☐ Distribuzione
☐ Movimentazione
☐ Vendita
☐ Utilizzo e consumo
☐ Altro (specificare)

Se si, per quale ragione?

☐ Miglior gestione dei rifiuti
☐ Riduzione del tempo di progettazione
☐ Riduzione del consumo dei materiali
☐ Riduzione dei tempi di produzione
☐ Eliminazione dei danneggiamenti
☐ Altro (specificare)

D5 – Il packaging del prodotto finito viene sviluppato internamente all'azienda?

☐ SI ☐ NO

Se si, chi lo sviluppa?

☐ R&S
☐ Marketing
☐ Package Department
☐ Produzione
☐ Altro (specificare)

Se no, chi lo sviluppa?

☐ Studio esterno
☐ Azienda del gruppo
☐ Società di consulenza
☐ Altro (specificare) ____________________

D6 – Vengono utilizzati dei supporti informatici/pratici sviluppati ad hoc per lo studio del packaging?

☐ SI ☐ NO

Se si, quali ____________________

D7 – Vengono valutate alternative di packaging e successivamente sottoposte a validazione tecnico/economica?

☐ SI ☐ NO

D8 – Il processo di sviluppo del packaging è condotto in partnership con un eventuale utilizzatore (B2B)?

☐ SI ☐ NO

D9 – Quanto costa attualmente lo studio completo del packaging all'azienda? (progettazione, sviluppo, costruzione, materiali utilizzati, …)

D10 – Pensa sia possibile migliorare il sistema di sviluppo del packaging in azienda, tramite l'innovazione?

☐ Per nulla
☐ Molto poco
☐ Poco
☐ Molto
☐ Sicuramente si

E – PACKAGING E IMPATTO AMBIENTALE

Domande E1 – E5

E1 – L'azienda recupera i materiali degli imballaggi al loro fine vita?

☐ SI ☐ NO

Se si, cosa?

Se no, per quale motivo?

E2 – Il fine vita degli imballaggi utilizzati dall'azienda, è sottoposto a prescrizioni di legge?

☐ SI ☐ NO

E3 – L'azienda utilizza dei metodi/applicazioni pratiche per valutare l'impatto ambientale?

☐ SI ☐ NO

Se si, quali metodi/applicazioni vengono utilizzati?

E4 – Pensa sia importante il processo di reverse logistics (vedi la sezione *Glossario* p.16 per avere una spiegazione)***?***

☐ Per nulla
☐ Molto poco
☐ Poco
☐ Molto
☐ Indispensabile

E5 – L'azienda implementa il processo di reverse logistics?

☐ SI ☐ NO

Se si, si appoggia a qualche azienda specializzata?

☐ SI ☐ NO

Se si, quale?

Se non ha ancora implementato il processo di *reverse logistics*, pensa di farlo nel futuro?

☐ SI ☐ NO

Se no, per quale ragione?

☐ All'azienda non interessano le ripercussioni sull'ambiente
☐ L'azienda non ha una quantità di scarti/rifiuti elevata
☐ L'utilizzatore si occupa dello smaltimento imballaggi
☐ Altro (specificare)

F – PACKAGING E LOGISTICA

Domande F1 – F5

F1 – L'azienda ha valutato il costo delle operazioni legate alla gestione complessiva del packaging?

☐ SI ☐ NO

F2 – L'azienda ha valutato il costo delle operazioni legate alle applicazioni del packaging sul prodotto?

☐ SI ☐ NO

F3 – La fase di imballaggio fa parte del ciclo di produzione del prodotto?

☐ SI ☐ NO

F4 – L'azienda valuta il packaging dal punto di vista del trasporto?

☐ SI ☐ NO

Se si, da quale punto di vista?

☐ Compatibilità con il mezzo di trasporto
☐ Protezione del prodotto
☐ Antifurto
☐ Tracciabilità
☐ Altro (specificare)

F5 – L’azienda utilizza gli stessi imballaggi per lo stoccaggio e per il trasporto (interno/esterno all’azienda)?

☐ SI ☐ NO

Se no, per quale ragione?

G – PRINCIPALI PROBLEMI, ESIGENZE, RICHIESTE PER IL FUTURO

Domande G1 – G3

G1 – Quali sono le principali esigenze aziendali relative al packaging?

G2 – Quali sono i principali problemi relativi al packaging?

G3 – Quali argomenti l’azienda ritiene possano essere interessanti da approfondire?

☐ Imballaggi riutilizzabili

☐ Sviluppo di un metodo/applicazione pratica per valutare l’impatto ambientale del packaging

☐ Riduzione dell’impatto ambientale

☐ Imballaggi biodegradabili

☐ Imballaggi espositivi

☐ Intelligent packaging (vedi la sezione *Glossario* p.16 per avere una spiegazione)

☐ Integrazione prodotto/packaging

☐ Integrazione packaging/funzione logistica

☐ Altro (specificare)

GLOSSARIO

- L'**imballaggio (packaging)**, per la normativa legale e regolamentare italiana, è il prodotto, composto di materiali di qualsiasi natura, adibito a contenere e a proteggere determinate merci, dalle materie prime ai prodotti finiti, a consentire la loro manipolazione e la loro consegna dal produttore al consumatore o all'utilizzatore, e ad assicurare la loro presentazione, nonché gli articoli a perdere usati allo stesso scopo (art. 35, lett. a), ex decreto legislativo 22/97, ora art. 218 del decreto legislativo 3 aprile 2006, n. 152 recante Norme in materia ambientale.)

- L'**imballaggio primario** è un imballaggio concepito in modo da costituire, nel punto di vendita, un'unità di vendita per l'utente finale o per il consumatore (art. 35, lett. b), d.lgs. n. 22/97.

- L'**imballaggio secondario** è un imballaggio concepito in modo da costituire, nel punto di vendita, il raggruppamento di un certo numero di imballaggi primari, indipendentemente dal fatto che sia venduto come tale all'utente finale o al consumatore, o che serva soltanto a facilitare il rifornimento degli scaffali nel punto di vendita. Esso può essere rimosso dal prodotto senza alterarne le caratteristiche (art. 35, lett. c), d.lgs. n. 22/97).

- L'**imballaggio terziario** è un imballaggio concepito in modo da facilitare la manipolazione ed il trasporto di un certo numero di imballaggi primari e/o secondari per evitare la loro manipolazione ed i danni connessi al trasporto, esclusi i container per i trasporti stradali, ferroviari, marittimi e aerei (art. 35, lett. d), d.lgs. n. 22/97).

- Per **reverse logistics** si intende la gestione di tutte le attività logistiche dedicate allo smaltimento dei rifiuti pericolosi e non, derivanti dagli imballaggi e dai prodotti stessi. Esso include una distribuzione inversa che induce i beni e le informazioni a viaggiare in direzione opposta rispetto alle normali attività logistiche.

- Il termine **intelligent packaging** si riferisce a sistemi volti ad estendere la vita del prodotto, a monitorare le sue condizioni, a migliorare la sicurezza e la tracciabilità e a dare informazioni relative alla qualità del prodotto, al trasporto e allo stoccaggio.

Informativa sul trattamento dei dati personale (art. D. Lgs. 196/2003)

1. I dati vengono richiesti ai fini di partecipare alla ricerca condotta dal Dipartimento di Ingegneria delle Costruzioni Meccaniche, Nucleari, Aeronautiche e di Metallurgia (DIEM – Università di Bologna).

2. Al termine della ricerca i partecipanti otterranno un report relativo alla loro collocazione rispetto all’aggregato delle risposte ottenute.

3. Titolare del trattamento dati è il Dipartimento di Ingegneria delle Costruzioni Meccaniche, Nucleari, Aeronautiche e di Metallurgia dell’Università di Bologna, Viale Risorgimento 2, 40136 Bologna.

4. I dati forniti non saranno diffusi né comunicati a terzi e saranno elaborati in maniera aggregata ed anonima dal Dipartimento di Ingegneria delle Costruzioni Meccaniche, Nucleari, Aeronautiche e di Metallurgia, a mano di vostra esplicita autorizzazione a riguardo.

5. All’interessato spettano i diritti previsti dall’art. 7 del D. Lgs. 196/2003.

6. Nel caso in cui il questionario sia stato spedito via posta elettronica, va compilato e rispedito a: giulia.santarelli3@unibo.it.

Consenso al trattamento dei dati personali

Il sottoscritto dichiara di aver ricevuto completa informativa ai sensi dell’art. 13 del D. Lgs. 196/2003, e attraverso l’invio del questionario acconsente al trattamento dei dati personali da parte del Dipartimento di Ingegneria delle Costruzioni Meccaniche, Nucleari, Aeronautiche e di Metallurgia dell’Università di Bologna, per le finalità indicate nell’informativa.

Data ______________________ Nome del rispondente ______________________

Nome del compilatore ______________________