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Material Logistics Management: Strategies and Methodologies Development for Economic and Environmental Optimization

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By

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ABSTRACT

This thesis is focused on finding solutions able to maximize logistics processes efficiency and reduce the impact of transportation on the environment at the same time.

The main purposes of the research have been two: finding strategies and methodologies for the reduction of the standard container management complexity and the development of a model for the selection of the optimal container solution both from an economic and environmental perspective.

The model has been implemented into a tool able to automate all the computations and evaluations. The outputs of the model/tool have been operationally validated using data from Chrysler and Fiat operations. The results have illustrated the consistency with real industrial applications and the importance to use a multi criteria decision making model, like the one developed, to select the optimal solution when the interaction of several parameters make it difficult to predict the overall result.

DEDICATION

To my parents,

for their love and endless support.

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LIST OF ABBREVIATIONS / SYMBOLS

CKD	Completely Knocked Down
GEO	Geographic Shipment
GHG	Greenhouse Gases
ILC	Integrated Logistics Center
IND	Indirect Flow
JIS	Just In Sequence
JIT	Just In Time
JNAP	Jefferson North Assembly Plant
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LTL	Less Than Truck Load
NVAA	Not Value Added Activities
OEM	Original Equipment Manufacturer
SHAP	Sterling Heights Assembly Plant
TIS	Transport Information Service
TL	Truck Load
TNAP	Toledo North Assembly Plant
WCL	World Class Logistics
WCM	World Class Manufacturing

NOMENCLATURE

C_{c_r}	Daily cost for container rental
C_{m_1}	Cost for container unloading from the transport vessel and storing in the warehouse
C_{m_2}	Cost for picking up the container from the rack in the storage area and placing it on the dolly, entire program
C_{m_3}	Cost for delivering the container from the warehouse/buffer to the line or kitting/re-packing area
C_{m_4}	Cost for picking up the empty container from the line and delivering it to the storage area
C_{m_5}	Cost for picking up the empty container or unit load (of empty totes) and load the transport vessel
$C_{m_{tot}}$	Total manpower cost for container handling, entire duration of the program
C_{p_m}	Cost per mile
C_{CR}	Cost for container rental (entire duration of the program)
C_S	Total shipping cost, entire duration of the program
C_c	Container cost
d	Decision
D	Set of available decision
d_{opt}	Optimal decision
D_{c_c}	Container density correction

D_{s_p}	Distance from supplier to assembly plant
D_c	Container density (number of parts contained)
E	E-Index, environmental performance comparison index
E_c	Number of available excess containers
F_r	Repair Factor
F_s	Service Factor
$\mathrm{H_c}$	Height of the container
$\mathrm{H_t}$	Height of the transport vessel load unit
I_C	Investment for containers
I_l	Inventory level for the container solution
I_{l_max}	Maximum inventory level
INT	Integer
$K_{CO2_{g/l}}$	Kilograms of carbon dioxide for gallon or liter of fuel consumed
$\mathrm{L_c}$	Length of the container
$\mathrm{L_t}$	Length of the transport vessel load unit
$M_{g/l}$	Average mileage per gallon or liter for the selected mode of transport
$N_{h_{c_e}}$	Number of empty containers handled at the same time for transport vessel loading
$N_{h_{c_f}}$	Number of full containers handled at the same time for transport vessel unloading
$N_{c_{mt}}$	Number of container that can be loaded in the selected

	mode of transport
N_{c_n}	Number of containers needed
N_{c_p}	Number of containers to purchase
N_{p_v}	Number of parts used per vehicle
$\mathrm{N_{tv_e}}$	Number of transport vessels of empty containers that have to be shipped, entire duration of the program
$\mathrm{N_{tv_f}}$	Number of transport vessels of full containers that have to be shipped, entire duration of the program
$\mathrm{N_{tv_{tot}}}$	Total number of transport vessel to be shipped for full and empty containers, entire duration of the program
$N_{t_{y_i}}$	Number of container turns, i-year
$N_{v_{p_{h_i}}}$	Number of vehicle produced per hour, i-year
N_{wd_y}	Number of working days per year
o	Outcome
O	Set of all possible outcomes
R	R-Index, total cost comparison index
R_{c_m}	Manpower cost rate
$\mathrm{R_{e_f}}$	Full/empty volume ratio of the container
S_{d_p}	System days at plant location
$S_{d_{tot}}$	Total system days
T_1	Time for container or unit load unloading from the transport vessel and storing in the warehouse
T_2	Time for picking up the container from the rack in the

	storage area and placing it on the dolly
T_3	Time for delivering the container from the warehouse/buffer to the line or kitting/re-packing area
T_4	Time for picking up the empty container from the line and delivering it to the storage area
T_5	Time for picking up the empty container or unit load (of empty totes) and load the transport vessel
U_d	Utility of a decision
U_o	Utility if an outcome
$V_{d_{p_i}}$	Daily production volume, i-year
V_m	Volume mix
$W_{e_{l_b}}$	Ergonomic weight limit for bulk container
$W_{e_{l_t}}$	Ergonomic weight limit for tote
W_{lc_d}	Dolly load capacity
W_c	Weight of the container
W_{do}	Dolly weight
W_{du}	Dunnage weight
W_{lc_c}	Container load capacity
W_{limit}	Most stringent weight limit
W_o	Overall weight (weight loaded on the transport vessel for shipment), entire duration of the program
W_p	Weight of the part

W_{parts}	Weight of parts inside the container
$\mathrm{W_t}$	Width of the transport vessel load unit
W_{tot_b}	Total weight for bulk container
W_{tot_t}	Total weight for tote

CHAPTER 1

INTRODUCTION

1.1 Introduction

The increasing focus on sustainability to introduce solutions that are environmentally friendly and economically viable and, consequently, aimed at reducing shipping cost, increasing logistics efficiency, safeguarding health, reducing traffic congestion, and conserving natural resources, is one of the Fiat and Chrysler Group's principal priorities as summarized in their World Class Logistic and Green Logistic Principles.

The challenge for logistics managers is to coordinate the activities of moving materials, components and products along the supply chain, from suppliers to manufacturing sites and out to the sales network in a way that meets corporate and customer requirements, maximizes efficiency, and reduces the impact of transport on the environment.

The efficiency and environmental sustainability of logistics processes are key factors in creating value. Together with minimizing costs and optimizing freight flows, the Group's efforts are centered on reducing environmental impact by reducing logistics-related emissions and minimizing the use of non-reusable packaging.

Packaging has a significant impact on the efficiency and effectiveness of the supply chains. Improvements can be achieved through improving and developing novel packaging logistics. In order to enable these improvements, innovative models are needed to facilitate creative and preferred packaging solution along the supply chain.

A significant amount of capital is often locked in automotive parts packaging. In the automotive industry, packaging for inbound parts usually costs 2%–4% of the total part value. Thus, the value of packaging for annual North American part flows alone is estimated to be $5B–$10B, with approximately 30%–40% of that in standard returnable plastic containers. The value of packaging is growing 5%–10% year-over-year as North American production ramps up and automotive Original Equipment Manufacturers (OEMs) increase focus on local part sourcing (data from BIS World Automotive Parts

Data and based on Deloitte primary research interviews conducted through their Automotive Study). [1]

All these issues highlight that selecting the best packaging solution is an important and complex process which, if carried out optimally, can lead to considerable advantages by reducing the costs related to the container management, increasing the efficiency of transport, and reducing the environmental impact.

1.2 Problem Statement

Fiat Group Automobiles and Chrysler LLC are currently not using a model/tool for selecting the best packaging solution from both economic and environmental perspectives. When a new vehicle model program is launched, selecting the packaging solution for each of the parts listed in the bill of materials can take a very long time. The packaging solution selection process usually starts as soon as an electronic bill of material is created by the Engineering Department and is fully completed just before the start of production (Job 1) or sometimes even later. Consequently, there is considerable room for increasing the efficiency and effectiveness of the selection and decision process.

Economic and environmental evaluations are not carried out during this selection process: the focus is on material flow and operational requirements. For example, the economic and environmental impacts in selecting an expendable versus a returnable packaging solution is not explicitly considered. These same evaluations are not carried out in selecting between different possible standard containers that meet material flow and operational requirements. One packaging solution could better optimize the saturation, or “full use” of a mode of transport with respect to another, or,it can reduce the investment in buying more containers, or decrease the manpower cost due to the handling. However, these considerations and computations are not currently part of the container selection process.

Moreover, there is not a standard procedure for this selection/decison: many times, previous solutions, especially for carry-over parts or parts similar to the ones used for previous programs, are re-used, without evaluating whether new or substantially different packaging solutions that might be better from an operational, economic and environmental point of view.

Finally, a benchmarking study between Fiat Group Automobiles and Chrysler LLC highlights that Fiat is using significantly fewer container types when compared to the list of standard containers used by Chrysler. Arguably, handling fewer containers should simplify the management complexity, improve the level of standardization, and obtain greater economic and environmental benefits.

1.3 Objectives and Hypothesis

This project is aimed at developing a selection and decision process that when modeled, will enable Fiat and Chrysler LLC to use this model/tool for selecting the preferred packaging solution for each part of the bill of materials, and reduce the time needed for this evaluation process. Significant economic and environmental aspects, which have not been considered until now, will be explicitly incorporated from the first stages of the container selection process.

Selecting the optimal container solution should bring savings in the total cost through a better understanding and subsequent streamlining (and ideally reduction of) the investment for new containers, logistic shipping (better saturation of the mean of transport) and handling. Moreover, elements of a life-cycle assessment approach, along with cost analysis, will underscore key factors to understand in what cases (depending on parameters such as distance, production volume, etc.) it is more convenient, both from an environmental and economic perspective, to use expendable or returnable packaging and to select the preferred *macro-family* of container types (plastic or steel, cardboard or wood).

A reduced environmental impact can be achieved in different ways. Sometimes activities aimed at reducing the cost and increasing efficiency also result in environmental improvements. Improved *saturation* of the mode of transport (less round-trip travels) could be an example. Also reducing the time needed to assign the appropriate container solution to all of the parts listed in the bill of materials will reduce or even eliminate the amount of temporary expendable containers needed, resulting in less overall environmental impact.

The reduction of the number of standard container types (rationalization) could be the first step towards increased logistic efficiency and sustainability. Also this action will bring savings to the Company and decrease environmental impacts, thanks to the decreased complexity in the container selection and management, possibility to increase container pooling, improved standardization of all the handling and storage equipment, reduced stocks and room occupied for each container type, as well as reducing the risk of having excess containers that cannot be used anymore when a program ends and a new one is launched.

1.4 Major Steps and Issues

First, a review of the various packaging/containerization solutions as well as all possible material flow types and their requirements in Automotive Industry (Fiat and Chrysler case studies and benchmarking process) will be conducted and presented. There are many practical cases from Fiat and Chrysler plants, logistic consolidation centers (Villanova S.p.A. and Detroit Linc) and Tier-1 suppliers in the automotive industry that showcase what are the solutions currently used and how they can be benchmarked.

All current North American vehicle programs (by plant, both in the US, Canada and Mexico) have been analyzed to determine what are the containers most/least used to provide an initial scan of the container types that could be maintained and the ones that could be deleted or reduced for future programs.

A focus on a new program (Chrysler UF program) has revealed what are the parameters and criteria to be considered in the container selection process. Many meetings with the members of the Ghafari company (Chrysler's tier-1 supplier in charge of carrying out the container selection process for new programs), with the UF program manager, with the members of Sterling Heights Assembly Plant Logistics team and Material Logistics Management team as well as with the suppliers, have provided significant additional information about the current situation and what are the main research requirements and issues to be addressed.

The methodology then examines the definition and issues for the *macro-methodology* for container selection is then defined. Then the methodology focuses on each requirement that has to be met by a standard container, and setting objective measures/indices to be used for comparing different solutions. In order to test and validate the model, a real case study is examined. has been considered.

Finally, a study of selected, significant is undertaken of the economic and environmental aspects of each archetype of material flow/container macro-family using aspects of Life Cycle Assessments (LCA) and through the supply chain. One main objective is to determine which key factors that, given the parameters influencing the situation, indicate what could be the best macro-family solution of packaging (expendable or returnable, plastic or steel, cardboard or wood), both from an economic and environmental point of view. Finally, the model, which is focused on standard containers, has also been implemented into an automated tool to help evaluate and then select the preferred packaging solution.

The main challenges and issues stem from the situation complexity: packaging influences many costs and environmental impacts through the whole supply chain and, because of that, it has been very difficult to analyze and account for all of them. At the same time, this work has required the contributions from many people and experts from multiple company departments and locations at Chrysler as well as from other companies (such as suppliers and tier-1s): coordinating all of them in order to obtain the data needed for developing the project and to reach the objectives has been challenging and exciting at the same time.

1.5 Thesis Organization

The remainder of the thesis is organized into the following chapters.

Chapter 2 contains a literature survey related to packaging solutions, costs and environmental issues, with a focus on the automotive field. Firstly, a background about packaging classifications and materials is provided, illustrating the main pros and cons of each solution. Then, the main packaging demands and functions on packaging and requirements to be fulfilled have been highlighted. In order to explain how a high logistic efficiency and a low environmental impact can be achieved at the same time, the main life-cycle costs affected by a packaging solution as well as the main environmental factors are described. Finally, previous research, carried out in the packaging logistics field, are reported and their results discussed.

Chapter 3 explains the packaging types and related activities carried out within Fiat Group Automobiles and Chrysler LLC. This overview serves as a basis for understanding the issues concerning different packages, and how the packages may be handled.

Chapter 4 reviews the material flow types and how components flow through the supply chain, and presents the various shipping dynamics and issues that would be significant to the automotive industry.

Chapter 5 outlines how various factors and issues are incorporated into the model, and develops the series of equations that form the computations within the model. Aspects of decision theory and Multi Criteria Decision Analysis are introduced. The chapter outlines the steps followed to develop the model and how it is implemented as a selection tool.

Chapter 6 provides the results of the research and their analysis. First the output of the analysis for the reduction of standard container types is discussed. Then, key factors for environmental evaluation of returnable versus one way packaging as well as for the choice of packaging material are discussed. Finally, the testing of the model using both Fiat and Chrysler practical cases as well as the sensitivity to its parameters is discussed.

Chapter 7 presents the conclusions and the recommendations. The research activity is summarized, highlighting the future activities that might be conducted to further develop the study as well as the actions that might be undertaken to further increase the benefits.

CHAPTER 2

REVIEW OF LITERATURE

2.1 Definitions

2.1.1 Packaging

According to Paine, packaging is defined as a coordinated system of preparing goods for transport, distribution, storage, retailing and end-use. [2] Another definition is provided by the EC Directive 94/EC of the European Parliament and the Council on Packaging and Packaging Waste: “packaging shall mean all products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer”. [3] This definition highlights different important issues related to packaging: packaging materials, functions of the packaging, type of products contained in a package, and the role of different parties involved in the packaging supply chain. The above terms can be defined within this research as:

- Packaging materials considered in this research project are limited to wood, plastic, cardboard and metal, since they are the most common in the automotive industry.
- Packaging has several functions that influence the effectiveness and efficiency of logistics activities. A total cost analysis is usually performed considering different functions and costs that a packaging solution offers through several steps within the supply chain.
- As far as the products are concerned, most of the parties considered in this thesis are from the automotive industry (Fiat and Chrysler). Thus, the packaging studied in this thesis is meant to support the transportation of motor vehicle parts along the supply chain. These “parts” can consist of products with very different characteristics, from small size nuts, bolts, and fasteners, to large size components, modules, and systems. The type of goods affects the packaging requirements and expected functions, and so this issue has to be carefully considered when assessing packaging functions and solutions.

- Finally, there is a differentiation between different types of users of packaging. In general, there are two major categories in business relations: business-to-business (B2B) and business-to-customer (B2C). The marketing function of the packaging has little or no importance in the analysis of business-to-business arrangements like the situations addressed in this research. Instead, logistical performance and environmental issues are usually the main source of requirements on B2B packaging. [4]

2.1.2 Packaging Solution

Various packaging alternatives are generally referred to as *packaging solutions*. These solutions range from a simple pallet to complete packaging units like containers. Small plastic totes and cardboard boxes are also considered as packaging solutions. In other words, every single or set of shaped materials that is used for product containment can be considered as a potential packaging solution.

2.2 Industrial Packaging Classification and Taxonomy

Because this research will address different types of packaging solutions used in the automotive field, it helps to classify or group them into macro-categories.

2.2.1 Primary Packaging

Because of there are no consumers in the industrial packaging system in its common sense, the expression “packaging user” can be used to represent users at this primary level of packaging. [5] Marketing requirements of packaging, such as attractiveness, are not considered in this case. Instead, adaptability to the rack shelves of the warehouse, compatibility of the packaging dimensions to assembly line equipment, packing facilities and distribution arrangements are the important issues. Ergonomics would also be important if a user needs to pick up and lift packages repeatedly throughout a day. Finally, the package should also provide adequate protection for the contained products.

Corrugated cardboard boxes or containers, wooden containers, small lot plastic totes, plastic and steel bulk bins are examples of primary packaging. These packages can be large enough to be able to put into distribution packaging systems directly without the need for multi-unit (secondary) packaging or they can be grouped in unit loads (a very common solution adopted for plastic totes).

2.2.2 Secondary Packaging

A number of primary packages are placed into distribution packaging mainly to achieve storage, handling and transportation efficiency. Examples of distribution packaging are wooden or plastic pallets, wooden or steel containers and large plastic containers. Small boxes like corrugated cardboard or plastic totes can be first filled with smaller products and then loaded into distribution packaging (unit loads). This arrangement provides further protection, product information, ergonomic efficiency, and so on, in addition to facilitating handling, storage and transportation. Using packaging aids/components – often called *dunnage* - to help prevent products from moving about and to provide further interior protection is quite common in order to fulfill all the required functionality of packaging, including protection for quality issues.

2.3 Returnable Packaging, Expendable Packaging, and Packaging Materials

In the following sections, an overview is provided on various packaging materials that are commonly used in the automotive field. Materials and their characteristics usually utilized for returnable packaging will be presented first, followed by the most used materials adopted for expendable packaging.

Each packaging material has its own unique features and properties. Some materials are light weight, some are heavy, some provide good protection, and so forth. These materials can be used either individually or in combination with each other.

2.3.1 Returnable Packaging

The returnable packaging should be reusable a certain number of times before it is discarded. Returnable packaging may be of different types, such as plastic or steel containers, plastic totes and pallets.

Figure 2.1 - Example of returnable packaging. *[6]*

2.3.1.1 Plastic

Plastic is the most used material used for returnable packaging. "Plastic" refers to a range of materials with different properties, which in turns are also characterized by a wide price range. Polyethylene (PE) and polypropylene (PP) are commonly used for packaging mainly because they provide a good balance between quality and price (they are relatively inexpensive). Packages made of these plastic materials range from simple plastic bags and warping to more structured plastic totes and containers.

Polyethylene is usually classified by density into low density (PE-LD) and high density (PE-HD). Low density polyethylene has a density of approximately 0.93 - 0.94 g/cm^3 and it is produced by a low pressure process while high density polyethylene has a density of approximately 0.94 - 0.96 g/cm^3 and it is produced usually with a high pressure manufacturing process. [7]

The usual melting point temperature for polyethylene usage is approximately 105 °C for low density, while for high density is approximately 120 °C. [7] Finally, every kind of polyethylene is water resistant, so plastic packages can be used also in environments with high humidity without losing their functionality and mechanical properties.

2.3.1.2 Metal

Another material commonly used for returnable packaging is metal. As for plastic, "metal" refers to a wide variety of materials. Steel is the most common metal used in packaging, followed by aluminum.

Steel is an alloy of iron, which has carbon content lower than 2%. Due to its high strength, steel could be also used just for specific support parts in large packages. Steel is generally considered stronger and cheaper than aluminum but it is also much heavier.

The most important differences between aluminum and steel are the lighter weight and higher resistance to corrosion of the former with respect to the latter. However, aluminum is much more expensive since significant energy is required in its production process. The high energies required to produce new aluminum are in contrast to recycling recovered aluminum (by melting): a much smaller percentage of energy is needed. Pure aluminum cannot be used for packaging applications because it tends to be too soft and plastic: alloys of aluminum, which are strengthened, are used instead.

2.3.2 Expendable Packaging

Cardboard boxes or containers can be used as primary or secondary packaging material. Since cardboard boxes can be used only once, they are defined as one-way or expendable packaging material. Expendable packaging can be made of other materials than cardboard, such as wood. The common characteristic for one-way packaging is that it is usually discarded after it has been used once.

Figure 2.2 - Example of one-way packaging. *[8]*

2.3.2.1 Cardboard

Corrugated fiberboard is a very common material used for expendable packaging mainly because of its quite low purchasing price. Generally, these packages are characterized by a very light weight but they are also able to provide a good protection for the components contained inside. Corrugated fiberboard is made of a corrugated layer (called fluting), glued to the flat layers (called liners). The plane layer makes provides strength while the corrugated layer ensures the protection against impacts.

Four different types of corrugated fiberboards can be generally distinguished and selected depending on the application needs: single-faced has one-liner and fluting, single wall has two liners on both sides of the fluting, double wall has two layers of fluting and, finally, triple wall has three layers of fluting. The higher the number of flutings is, the greater the protection against impacts.

Tests are usually performed to assess mechanical properties of paperboard packaging materials. The most important are: puncture resistance (measured as the force applied for a puncture tool to pass through a test specimen), edge crush resistance (defined as the resistance to crushing of a orthogonal test specimen of corrugated cardboard) and, finally, bursting strength (which is the resistance exerted by a specimen of cardboard to avoid the bursting when exposed to pressure). This technical info has been gathered from Transport Information Service [7]. When moisture is absorbed, mechanical characteristics of the cardboard package are affected and water absorption can also cause the damage of corrosive prone package contents.

2.3.2.2 Wood

Along with cardboard, wood is often used as expendable material in the automotive industry. Sometimes, it can also be used as returnable packaging (especially for food industry applications). As packaging material, wood is characterized by high strength and high stiffness ensuring at the same time a relatively light weight with respect to other rigid metal materials. The specific weight of wood is largely determined by the species of wood and moisture content. The average density of hard-woods can be generally assumed to be in the range between 650 kg/m^3 and 750 kg/m^3, while it is approximately 450 - 550 kg/m^3 for soft-woods. [7]

Wood generally requires little energy in the packaging manufacturing process and, being a natural resource, it does not pollute excessively as it bio-degrades when disposed. However, one of the major weaknesses of this material is its inability to resist to water and moisture. If the wood is in a relatively dry environment, it tends to release water vapor and conversely, it absorbs water vapor in a relatively moist environment, drastically changing its dimensions and losing its mechanical properties.

Wooden packages are especially suited for small-scale production and can be manufactured in various forms including containers, small boxes, crates and pallets. Moreover, for large-scale production, it is predominately used as oversea transport packages, to eliminate the significant costs associated with the return of empties.

2.4 Demands on Packaging

Packaging has always to meet various demands and requirements. These demands can be divided into three main aspects: logistical, environmental and marketing, as illustrated in Figure 2.3. [9]

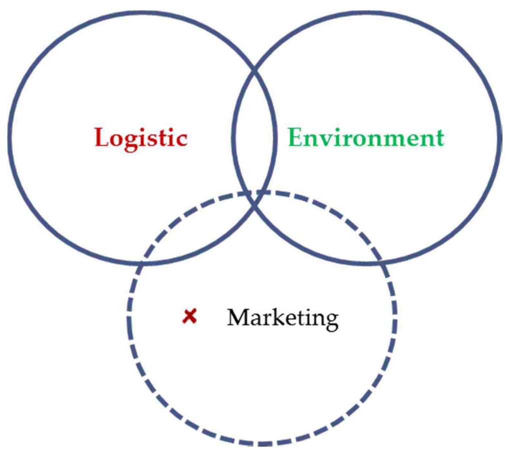


Figure 2.3 - Three main aspects of packaging. *[9]*

Generally, the marketing aspect is a major concern for the retail industry, but usually automotive companies (such as Fiat and Chrysler focused in this thesis work) do not take marketing function into account if the consumer is not directly involved

2.4.1 Logistical Aspects

The logistical function contributes to efficient handling in the supply chain. Technical characteristics (such as load capacity), internal and external material flows compatibility (including the return of empties), ease to accomplish packing, unpacking and re-packing activities, etc., are all part of this important function. There is an increasing trend to view packaging in terms of the value that it provides in logistics, rather than in terms of traditional materials for the simple containment of products. [10] In fact, packaging is part of the overall logistics system and process. The goal is to minimize the cost of packaging materials as well as to reduce the cost of damage, waste and the cost of performing logistics operations. Packaging adds value mainly by providing all the required functions (presented in the section 2.5) and ensuring at the same time the lowest possible economic impact (total cost generated).

2.4.2 Environmental Aspect

The environmental function focuses at improving resource economy, reducing environmental stresses (like carbon dioxide emissions) and facilitating the reuse of packaging. A systems approach is very important when deciding on how a packaging method meets the environmental demands. Usually life cycle assessments (LCA) are needed to obtain a comprehensive and consistent evaluation about the overall environmental impact generated. [11]

2.4.3 Marketing Aspect

Packaging fulfills the market function by helping make the product more attractive. Through an appealing design and layout, the packaging has the potentiality to attract more customers. [12] According to this definition, this function is an important concern of retail industry, which deals with final customers. However, in the automotive field, packages are only used by their business customers so this aspect is usually not considered, and will not be examined in this research.

2.5 Packaging Functions

As shown in Figure 2.4, packaging serves three main functions, which are logistical, environment, and market functions. These functions sometimes align with one another, but in other cases, they can conflict. [13] Johansson, one of the most active packaging logistics researchers, to underline this issue, stated that no other component in the distribution chain is exposed to so many, heavy and often conflicting demands as the packaging.

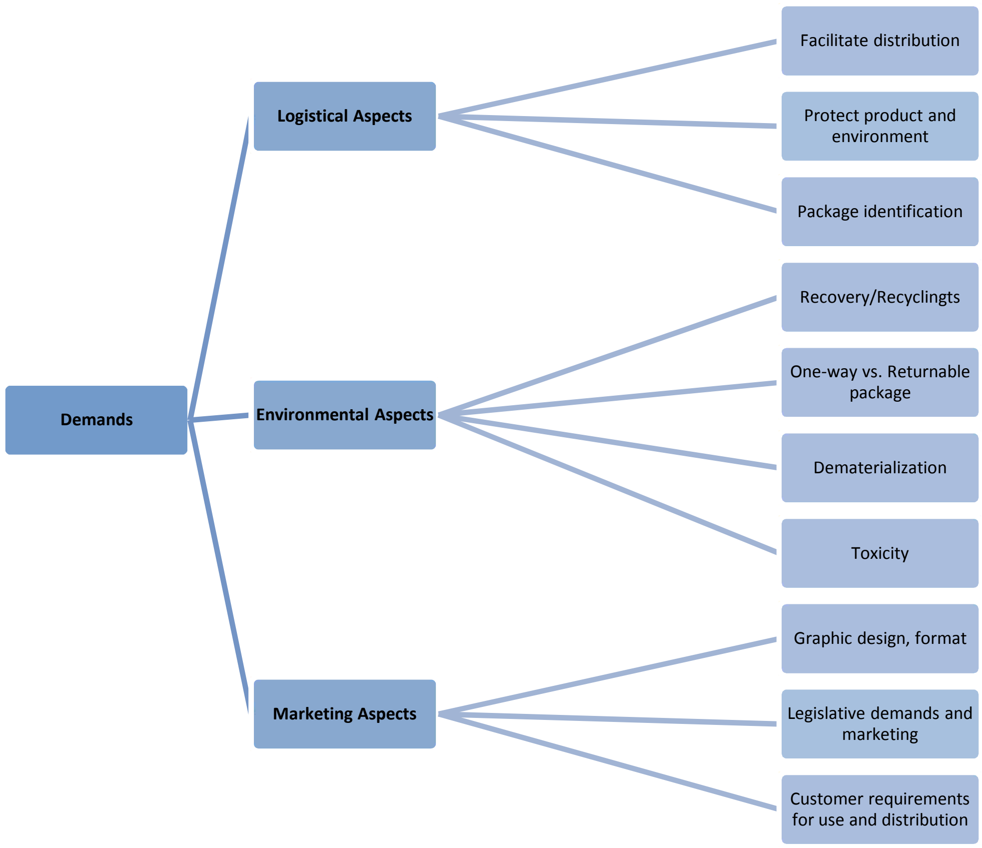


Figure 2.4 - Overview of packaging aspects and functions.

2.5.1 Utility Function

The utility function for packaging is a general term and is related to how packaging affects the productivity, efficiency and total cost of logistical operations along the supply chain. All the logistics and handling operations (such as truck loading, warehouse picking, line feeding, packaging waste reduction, etc.) are affected by packaging utility. Ergonomics can also be considered as a utility issue. In fact, healthy workers are generally more productive; conversely, personal injuries incur significant costs to the companies. The total cost for all logistics operations is affected by the utility functions of packaging, such as volume and weight efficiency, dimensional compatibility with transport vessels and handling/storing equipment, handle-ability, cleanliness, assembly/disassembly time, and overall ergonomics.

2.5.2 Protection Function

The protection function of packaging is its ability to protect a product throughout a logistical system, from the point of origin to the final point of use. Protection is an extremely important packaging function. In-transit damage can destroy all of the value added to a product during the previous processes along the supply chain. Thus, damage wastes production, logistics and environmental resources. Moreover, replacement orders add further costs and impose unnecessary (and repeated) environmental impacts. Any delays may result in lost customers and thus a long-term loss of opportunity.

2.5.3 Identification Function

The identification function of a package helps identify the material contained inside the package along with the origin of the package and destination. This process could be conducted through RFID (Radio Frequency Identification) transmitters, scanning barcodes or simple labels. Usually RFID systems are very costly, thus they are adopted for very expensive containers and in the case the number of containers lost along the supply chain is sufficiently high to justify this investment (benefit vs. costs analysis).

2.6 Packaging Supply Chain

Figure 2.5 illustrates the general scheme of the packaging production supply chain. This scheme can apply to every industry (not only automotive). Within the supply chain, packages go through a number of stages in order to provide logistical utility, but, at the same time, most of these stages are associated with logistical cost and environmental impacts.

The cost of packaging material is equal to its purchasing price. However, the total cost related to packaging is complex and usually requires substantial analysis. To measure the total cost and sustainability of a packaging solution, the system and processes in which the packaging is used should first be analyzed. To do this, the package would have to be followed from the point it enters the supply chain until the point it is disposed or recycled.

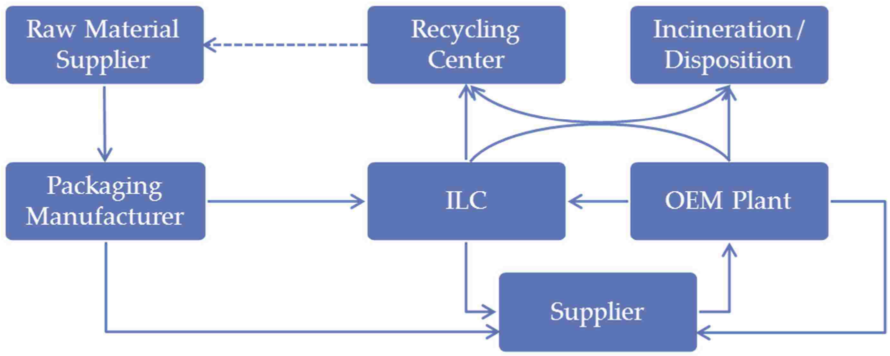


Figure 2.5 - Simplified view of package production and usage cycle.

2.7 Costs Affected by Packaging

Packaging cost is not simply related to its purchasing cost: it affects the total cost and efficiency of every logistical activity. Therefore, the impact on the productivity of logistical systems is significant. [14] In the following sections, some of the most important costs affected by packaging or their associated issues are presented. These costs will be considered in this research when developing the packaging selection model.

Handling cost related to packaging depends mainly on the number of turns (number of times a container is replaced by the operator at line side during a certain period of time, i.e., a shift or a working day), and thus on unit loading techniques and package density. Transportation and storage costs are directly related to package size and density (number of parts contained). In fact, the number of shipments to be carried out during a production program depends on the number of containers that can be loaded on the transport vessel as well as on the number of components contained in each packaging solution. Inventory control, which affects cost, depends on the accuracy of identification systems and on the complexity of the packaging system to be managed (higher complexity if there a lot of container types). Customer service depends mainly on the protection afforded to products. Finally, there are additional costs for managing a return system, such as for administration, warehousing, return transport and cleaning/maintenance.

2.7.1 Cost of Container Handling

The cost for container handling is depends on the number of turns needed during the production day, and on the possibility to handle more than one package at the same time. In other words, the number of parts that can be contained (package density) and stack-ability are two key factors heavily affecting the handling efficiency performances of a packaging solution. Furthermore, the act of re-packing adds significantly to the total cost from packaging handling. The repacking can be carried out for different reasons, including ergonomic issues and company policies (i.e. World Class Manufacturing principles do not allow the usage of cardboard or wood packaging at the assembly line side). Handling time is usually lower when eliminating expendable packaging, and, therefore, there will be operational benefits for the company. Usually, expendable packaging systems also require more space at the assembly plant than a returnable packaging system because specific areas are needed to collect the immense amount of cardboard to be disposed after the usage.

2.7.2 Cost of Transportation

Costs related to transportation (shipments) depend on how well the packaging is filled (packaging density) and how well it uses the space in the vessel transporting the packages. An extremely important aspect is the stack-ability of containers and their dimensional compatibility with transport vessel dimensions so that the loading unit can be used to its full potential, which would indicate high cubic *saturation*.

In general, the load efficiency for transportation is higher with expendable packaging if it is possible to stack them one over the other; sometimes wooden parts are inserted in the cardboard packaging to ensure the stack-ability. This is because expendable packages often are more weight/volume efficient than returnable packages which are built with a stronger and heavier structure in order to withstand more usages.

Volume efficiency is a measure of how well the space available is utilized and it is usually computed as the inner fill rate and transport vessel saturation. Inner fill rate is defined as the relation between the volume occupied by the contained components and packaging outer volume

Transport vessel saturation, instead, is defined as the ratio between the volume of packaging loaded in the loading unit and loading unit dimensions. This parameter depends on packaging outer dimensions and their compatibility with transport vessel loading unit dimensions.

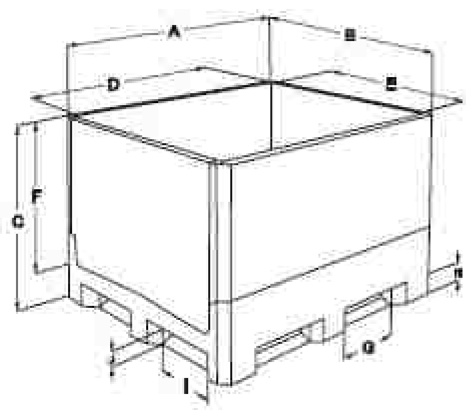


Figure 2.6 - External package dimensions. *[15]*

Weight efficiency is defined as the ratio between the weight of parts contained and total weight given by the sum of parts and package weight. A general requirement on the packaging is that it should be light in weight as possible. In fact, heavy goods, instead of volume, often have the weight as a limiting factor: if this happens, it would be possible to load more goods if the packaging is lighter. On the other hand, low volume and weight efficiency results in an increase of handling, transportation and warehousing costs. Thus, both volume and weight efficiencies are key factors to reduce logistic costs related to packaging and transportation.

2.7.3 Cost of Quality

The total cost related to a packaging solution also depends on its ability to protect the contained parts and ensure their quality along each step of the supply chain. However, the cost of a package usually rises when enhancing its protection function because more material, improved materials, or an improved design and engineering are needed.

Furthermore, the rougher the mode of transport, the more a package needs to be designed to ensure protection. Less expensive transportation modes, such as rail and road, generally have more package shaking during the travel, and so more packaging resources are required to keep the damaged goods to acceptable levels. The type of transport with the highest amount of damaged goods are border-crossing transports, where there are up to three times more transport damages than a regional or national transport. [16]

The same considerations are valid also for material handling equipment. Damage is more likely to occur for parts that are manually handled and so more robust packaging is needed, compared to components which are moved by means of automatic handling equipment.

There are usually trade off points which allow balancing the cost of the packaging solution versus the cost of poor quality, transportation and material handling equipment. The general trends of these cost and their trade off points are shown conceptually in in Figure 2.7. The level of protection the packaging should provide is difficult to estimate: the packaging has to be neither too weak nor too strong. On one hand, packages that do not have sufficient protection will lead to a higher cost for the company because of more damages (waste of all the value of previous manufacturing and logistics processes), poor service, repair activities and delays. On the other hand, using too much material to produce the package will lead to higher packaging purchase and distribution costs. Between these two main factors there is often a midpoint (even if it is not easy to find), which provides the most economically efficient situation. Note that environmental considerations are not explicitly represented in Figure 2.7.

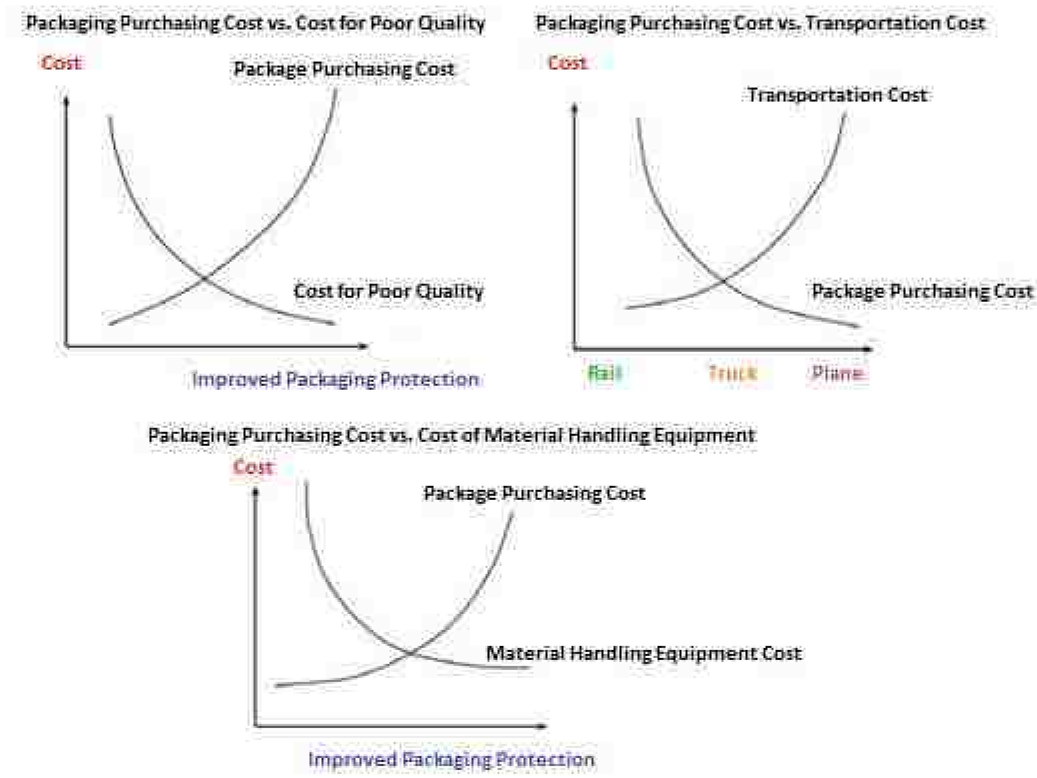


Figure 2.7 - Trade-off between packaging purchasing cost and cost of poor quality, transportation cost and material handling equipment cost. *[17]*

2.7.4 Cost of Packaging Disposal and Recycling

Packages at the end of the life cycle have to be disposed or recycled; this is not a negligible cost for the company. Therefore, accounting for the packaging end of life stages can be not only environmentally but also economically rewarding. All the packages that are disposed have been previously bought and have undergone many activities and steps through the supply chain (such as handling, transportation, etc.): disposal means the value of shipping is now gone, and at the very least, the container is no longer available for reuse. Reducing the amount of waste minimizes the use of expendable packaging, and should save costs for purchasing and disposal.

2.8 Environmental Considerations on Packaging

During the past few years, environmental issues have become increasing prominent. Directives have been created both by governments and organizations, to minimize as much as possible packaging waste and to emphasize more responsible methods of handling packaging materials, and to also reduce the emissions generated by logistics transportation. Packaging can clearly contribute to sustainability by limiting product waste and unnecessary over production due to damage or loss. At the same time, packaging requires the use of natural resources and has a direct impact on the environment.

Recycling and reusing materials are ways to reduce the amount of resources needed to produce packaging. Figure 2.8 [18] demonstrates that theoretically there is an optimum quantity of material usage in packaging that ensures the most sustainable trade-off between reducing product wastage (due to poor quality and damages) and reducing packaging material.

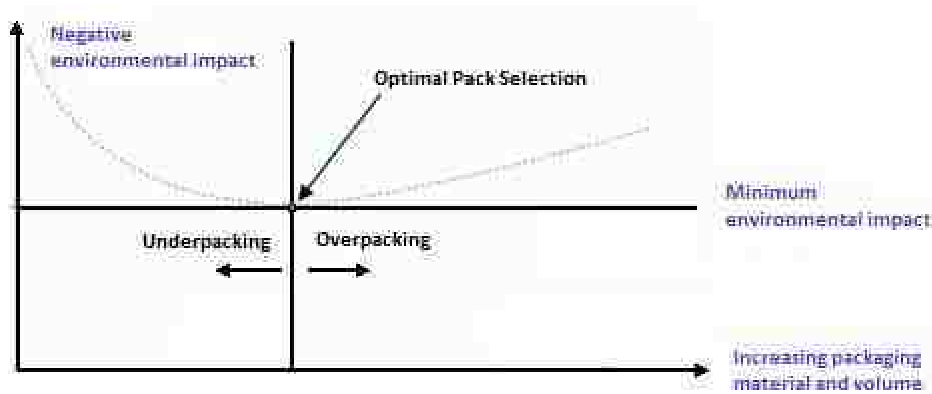


Figure 2.8 - Elements that determine the environmental impact equation in packaging. *[18]*

Most importantly, the figure shows that also under-packing has a greater negative environmental impact than over-packaging because it results in product loss and eventual waste of all the added value.

2.8.1 Returnable Packaging vs. Expendable Packaging from an Environmental Perspective

Both returnable and expendable packages have different environmental demands. [18] The amount of material and energy required to produce the packaging must be as low as possible to ensure the highest resource efficiency. Materials recycling should be adopted to reduce the need of new resources when producing new packages and returnable packaging should be used whenever possible. Pollutant and dangerous substances must be avoided or their usage minimized (e.g., within the percentage levels allowed by environmental regulations).

When selecting between returnable and expendable packaging, it is important to view comprehensively the overall supply chain and life cycle. For instance, it is necessary to weigh the environmental impacts of maintenance, and cleaning and returning empties against the reduction in material and waste obtained by implementing a returnable packaging system instead of an expendable one. In general, a returnable packaging can be more beneficial than expendable packaging if used a certain minimum number of times during its lifetime. The number of times it has to be used, in order to be more environmentally-friendly than expendable packaging would be based on key environmental measures, such as energy consumption, solid waste, pollution, water consumption and emission into the atmosphere. [19]

The environmental burden related to expendable packaging is mainly from the waste of material it generates and from the carbon dioxide emitted in the atmosphere when transporting the waste to disposal center and, eventually, by the incineration center. Companies which use returnable packaging can drastically reduce material waste. However, for a returnable packaging to be environmental friendly, the overall environmental burden generated along the supply chain and life cycle (assessed by LCAs) must be lower harmful than that generated by the expendable packaging system in its unique usage cycle. Unfortunately, the environmental impacts from packaging are difficult to estimate because the environmental impacts can be indirect and the effects not immediate. As a result, it is often easier to focus on CO_2 emissions which can be estimated or even calculated. It further represents a “global” concern, and therefore is a widely understood environmental parameter, and is particularly appropriate for transportation related activities.

2.9 Latest Research

In this section the latest research in the packaging field is summarized, highlighting good and weak points as well as the main differences of these works with respect to the research analysis performed in this thesis.

2.9.1 Comparison of Different Packaging Materials and Solutions on a Cost Basis for Volvo Logistic Corporation - Hamed Khademi Kord and Ali Pazirandeh

The outcome of the research made by Hamed Khademi Kord and Ali Pazirandeh in 2008 is a very general financial/comparative model, which should allow users to choose the packaging solution with the lowest possible cost. They focused their study on the Volvo Emballage Corporation, whose business concept is to provide packaging logistics services, to manufacturing industries, such as car and truck manufactures. The final conclusion, derived from the research carried out by Kord and Pazirandeh, was that there is no general optimal packaging solution. Customers have their own specific requirements, which lead to their own unique optimal packaging solution.

Various aspects (pros and cons) of different packaging solutions, available at the time of this research, have been described by them to help their customers make an optimal decision. In other words, Kord and Pazirandeh's study could be considered as a very general decision support system for managers to decide the best available packaging solution based on different weighting factors that can be assigned to each packaging function/cost as shown in Figure 2.9.

The total score can be calculated by the summation of the multiplication of each customer weighting factor by the packaging score within each corresponding category. This could be formulated as follows:

$$\text{Total Packaging Score} = \sum(\text{Customer weighting factor for each packaging factor} * \text{value corresponding to the packaging score})$$

The packaging solution with a higher total score would better suit customer requirements.

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

* CWF: Customer Weighting Factor

Figure 2.9 - The Financial Model based on different logistical and environmental factors for the selected packaging solutions. *[9]*

While instructive, this procedure is likely too general and significant number of customer driven evaluations and studies would be needed in order to assign the values of the scores and weighting factors (inputs of the model). Significant time and resources would have to be spent in order to obtain any insight into packaging solutions. This methodology could be affected by a high level of subjectivity, which could make the results unreliable. Finally, only people with extensive experience could assign weighting factors to each function of the investigated packaging solution.

2.9.2 Volvo Logistics Corporation Returnable Packaging System - Jacob Beselin Hallberg

The objectives of the work carried out by Jacob Beselin Hallberg in 2008 were to:

- Provide guidelines for calculating possible cost savings of using returnable packaging system;
- Search for relevant costs in a production plant that are measurable and affected by packaging; and
- Calculate and present different costs affected by packaging in a pre and post scenario.

The main concern with this work is that it does not investigate possible environmental effects when changing from expendable packaging to returnable packaging. In order to make a complete analysis, addressing life cycle assessments issues would have been helpful to understand what could be the best solution (returnable or expendable) from an environmental perspective. Moreover, this work does not address which is the preferred solution to be adopted from certain input parameters characterizing the investigated situation: it focuses on giving guidelines to make economic evaluations.

2.9.3 Automotive Supply Chain: Unlocking Potential Cost Savings in Automotive Packaging - Deloitte

Through an extensive analysis carried out in 2012, Deloitte concluded that significant amount of capital is often locked in automotive parts packaging. As previously stated, in the automotive industry, packaging for inbound parts usually costs 2%–4% of the total part value. Thus, the value of packaging for 2012 annual North American part flows alone was estimated to be $5B–$10B, with approximately 30%–40% of that in standard returnable plastic containers.

In both the OEM-owned and the supplier-owned packaging scenarios, the Deloitte study revealed significant issues for the parties involved, including:

- OEMs and suppliers surveyed maintain multiple closed loop systems (too many types of standard containers) limiting the ability to share idle containers. This can lead to 20%–25% more containers in the system than needed (requiring excess capital investments in idle containers). Despite excess containers in the system, a lack of efficient tracking and limited visibility make it difficult to get the appropriate container to the needed place at the right time.

- OEMs and suppliers are also affected by a lack of transparency in the total cost components since it is challenging for them to quantify and track all packaging-related costs. Moreover, limited tracking also results in a significant percent of packaging lost during the life of the program.
- Return logistics loops are not effectively utilized with many point-to-point returns. There are approximately 10%–15% empty miles (as an average estimated by Deloitte) on the return loop. In addition, clean and not-clean containers are often mixed together and create excess costs for the suppliers.
- Suppliers are also affected by container system complexity, having to expend significant effort in managing the different OEM requirements and container types.

Container pooling can be a very good solution to address these issues, as well as to reduce annual costs for standard returnable packaging. In container pooling, the pooler owns the fleet of standard returnable containers and manages the whole process (container shipping, preparing, cleaning, tracking, etc.). If the pooler is able to manage a sufficiently large number of programs, it can generate high efficiencies through reduced variability and economies of scale, thus reducing the system-wide cost of packaging services. This would be a significant advantage for both the suppliers that own their containers and for OEMs that own their packaging. Furthermore, in pooling, the containers can travel shorter distances. Moreover, pooling can facilitate OEMs and suppliers to ship more parts with fewer containers by reducing the safety stock (due to reduced system variability) and improving container utilization. Container losses can be reduced thanks to more efficient tracking as well as ease of transfer same containers from program to program can reduce expenditures on containers. Finally, pooling usually requires an improved and centralized tracking and management system which can reduce the headcount needs both for suppliers and OEMs, resulting in an additional economic saving in the long-run (after paying-back the initial investment for the new centralized information system).

The smaller the number of container types used by the company, the greater will be the possibility to share these containers between different production programs implementing a container pooling. This highlights the importance of the activities for reducing the number of standard container types as will be later explained in this research.

This study conducted by Deloitte indicates that pooling could reduce annual packaging costs of a company by 15%–25% annually. Thus, extending these savings to a medium-sized production program would translate to approximately $1B in additional profit for the OEM over the course of a typical automotive production program (with duration of 5 years). The same reasoning can be applied to Tier-1 suppliers which can realize similar savings with their Tier-2 suppliers. In the following the most important potential savings are presented.

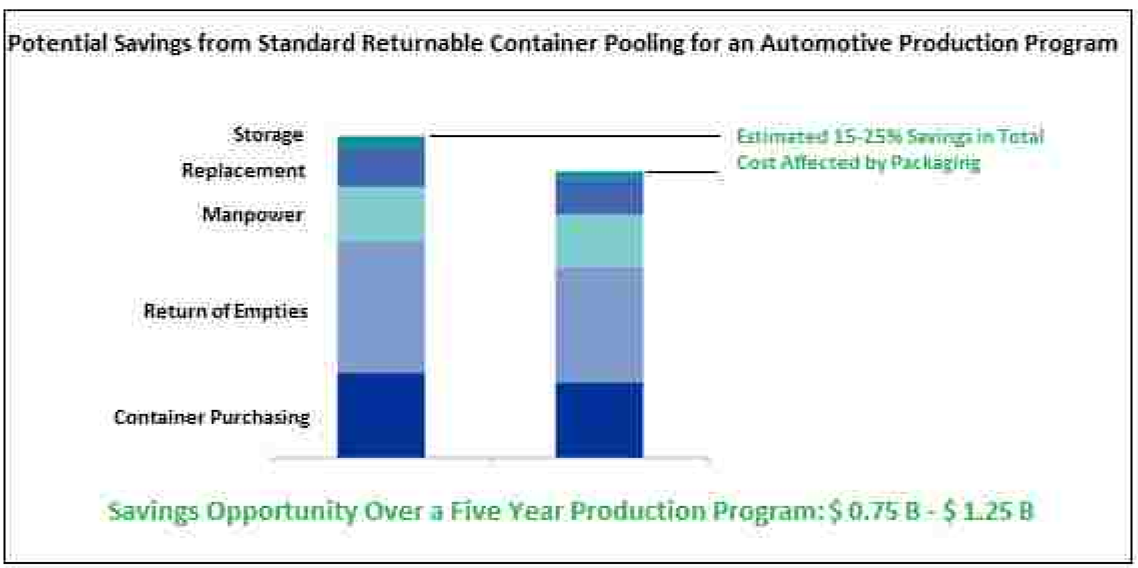


Figure 2.10 - Savings estimates based on Deloitte analysis of a mid-to-large sized vehicle program. *[1]*

CHAPTER 3

ANALYSIS OF PACKAGING SOLUTIONS

This chapter reviews the current packaging solutions used by Fiat and Chrysler. The information was collected through various documents and interviews that described the practical experiences in both companies. This overview serves as a basis for understanding the types of packages that can be used, and how the packages may be handled.

3.1 Expendable Cardboard Container

The selection of a corrugated container usually depends upon the specific part or material, the method of transportation, and the method of handling required by the supplier and the receiver. However, certain basic factors need to be carefully considered. Packages which are to be manually handled are subject to rougher handling than those handled mechanically, and consequently require more protection. Package size, strength and type must be selected to fit the method of transportation and the applicable carrier regulations, extent of protection from the elements, number of transfer points in the supply chain, distance of travel, and the roughness of route.

Other factors of equal importance that must receive high consideration are the packaging direct cost and indirect costs affected by the packaging. In finalizing the selection, the following factors must usually be considered:

- handling labor;
- handling equipment;
- transportation cost;
- cube utilization of the transport vessel;
- floor space occupied;
- manpower labor needed; and
- material recyclability.

The specific method used should be chosen to best fulfill the prerequisites of good packaging practice existing in each company or obtained by benchmarking processes.

All expendable containers are loaded to maintain the highest possible load density and package integrity, and to obtain optimum freight rates. However, containers usually cannot be stacked on top of each other, unless they are containers of the exact same type.
In addition, each shipping unit has to be properly palletized in level layers to allow for stacking and proper utilization of transportation.
It is mandatory that when a supplier ships in sufficient volume to warrant palletization that the parts or materials be packaged as a unit load (composed by a certain number of cardboard boxes packed together on a pallet).
Moreover, as already stated in the previous chapter, regulations require that all cardboard containers, trays and caps must have a manufacturer's certificate with bursting, puncture, or edge crush test (ECT) visible on the assembled container, as depicted in Figure 3.1.
Shipments from US or Canada to Europe and Mexico may require more robust packaging than materials shipped within US and Canada, to ensure good parts protection for the long travel. Moreover, shipments to Europe require the use of specially designed, stackable containers to fully cube out the ISO container. Shipping cost via ship or plane are very high; in this case, the low saturation of the mean of transport will result in an excessive transportation cost per piece which cannot be accepted. In fact, high shipping costs per piece often result in higher prices for the product (and subsequent reduced marketability of the product), or low profitability for the company.

Figure 3.1 – Certificate of box maker. *[20]*

3.1.1 Corrugated Pallet Boxes

All corrugated pallet boxes have to be of sufficient strength to withstand triple stacking under a full load when shipping within North America (with high limit of 110”, equal to 2794 mm); for international shipments, the stacking height requirements is 88”. If attached to a wooden pallet, cardboard packages must also be of “breakaway design” (the pallet should be easily detached from the bottom part of the cardboard package) with minimal staple usage to allow easy disassembly, as shown in Figure 3.2. In order to easily detach the carboard box from the pallet, the breakaway design usually requires perforations on the top and bottom flanges. Staples are usually placed inside the perforated area to secure the box to the pallet. Boxes must always contain also cutting guides to prevent part damage during opening activities.

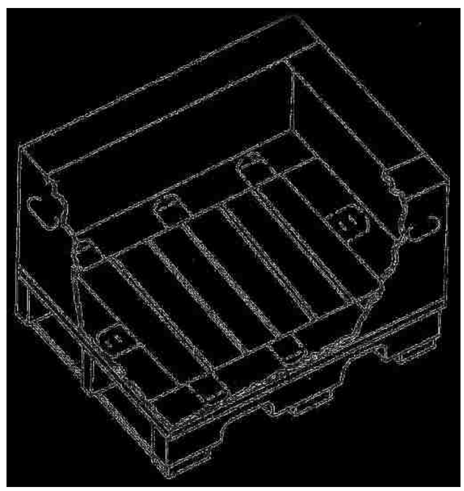


Figure 3.2 - Breakaway pallet box with perforations on the bottom. *[21]*

3.1.2 Corner Supports

When corner posts are required to ensure adequate stacking strength, a good option can be to use corrugated posts glued into place. Usually wooden corner supports require plant approval (since they need additional manpower to separate them to the reminder part of the structure) and must not be stapled to the boxes; because of that they are usually held in place using die cut folded inserts with the flaps stapled over them, as depicted in Figure 3.3.

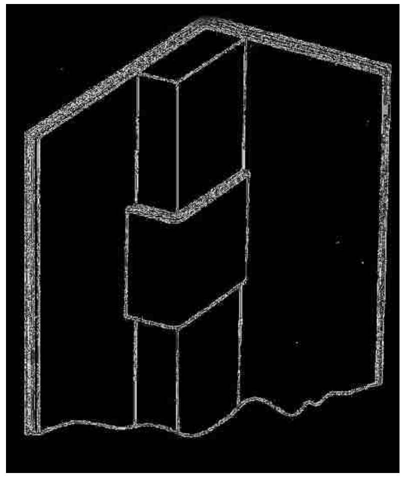


Figure 3.3 – Example of wood corner support. *[20]*

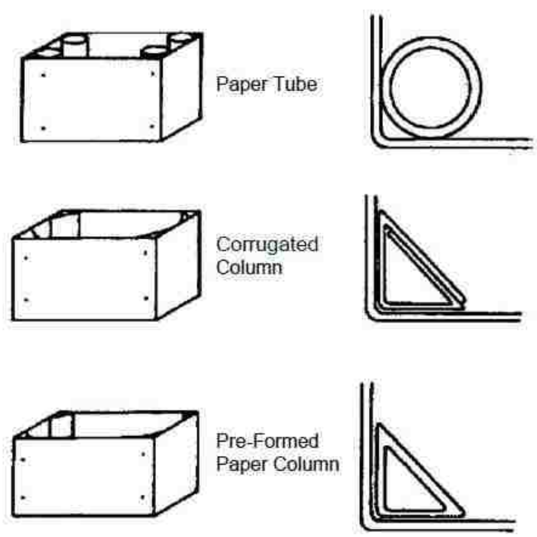


Figure 3.4 – Example of possible corner support options. *[20]*

3.1.3 Corrugated Cartons

Two basic types of corrugated cartons are allowed in the market and both are used by the two companies: single-face and double-face. Within the double-face category there are sub-categories such as single, double and triple walled construction.

Single-face consists of one layer of corrugated medium bonded to single layer of the liner and provides cushioning function for products wrapped in it, as represented in Figure 3.5.

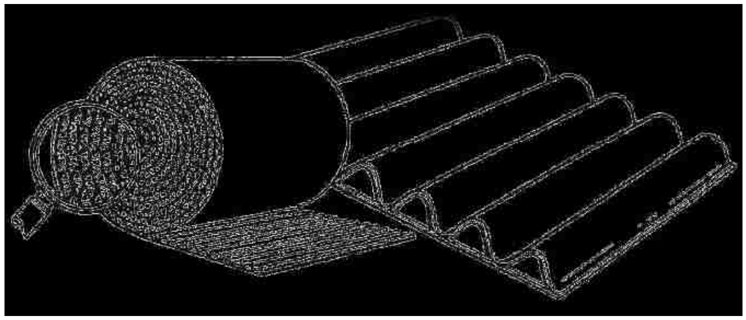


Figure 3.5 – Single-face cardboard. *[21]*

Single wall has a second face glued to the other side of the fluting medium, resulting in a more rigid structure compared to the single face.

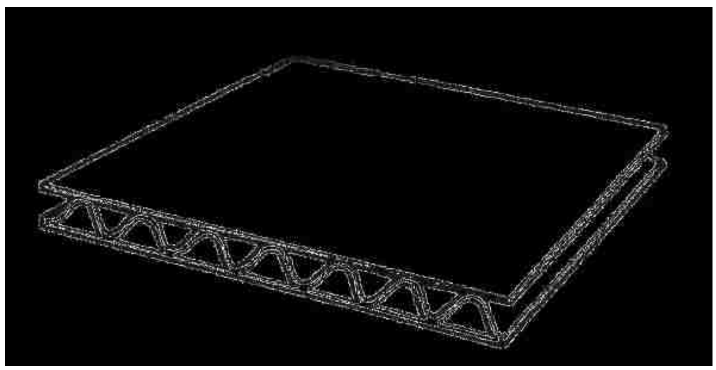


Figure 3.6 – Double face single wall cardboard. *[21]*

Double wall cardboard adds another corrugated medium and another sheet of liner for greater strength. It has three faces with two corrugated medium sheets between them. It has a high stacking strength and it is usually a good application for heavy products.

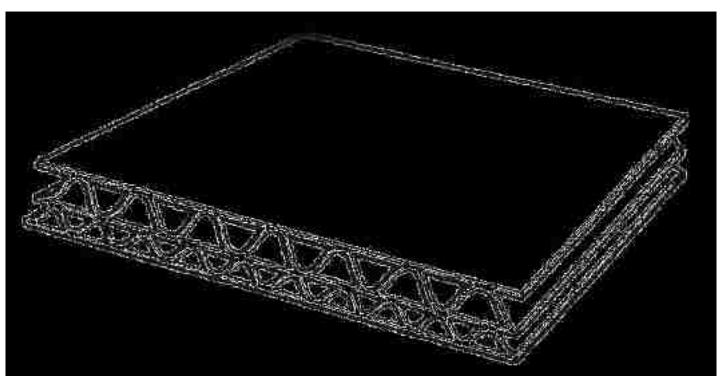


Figure 3.7 – Double face double wall cardboard. *[21]*

Triple wall consists of four faces with three fluting corrugated medium sheets between them and offers very high strength for packaging very large or very heavy products.

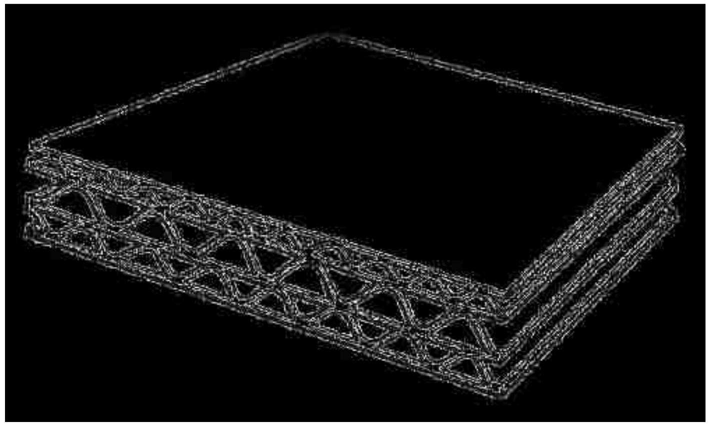


Figure 3.8 – Double face triple wall cardboard. *[21]*

The only acceptable methods of sealing manually handled cartons are strippable tape or spot gluing, while asphalt-based or plastic tapes are usually not allowed by the two companies. Staples can be accepted only with prior approval from the receiving plants.

Cartons cannot overhang the pallet or weigh more than maximum allowed by local plant or company regulations, or exceed ergonomic limits or governmental regulations. Within Chrysler, carton sizes must be equivalent in dimensions and density to existing standard returnable containers used in assembly and manufacturing locations.

All cartons shipped on a pallet must be properly palletized, as shown in Figure 3.9.

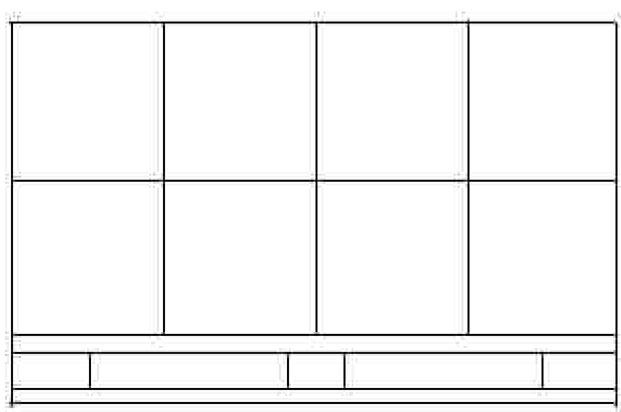


Figure 3.9 – Properly palletized unit load (side view).

Mixed loads must be properly labeled and the following criteria must be observed when shipping to a manufacturing plant to ease manufacturing and logistics processes:

- right and left hand parts cannot to be mixed on the same pallet;
- cartons must be uniform in size to maintain load stability;
- only packaging directed to one single plant per unit load are allowed (it is not possible to create a unit load made of smaller packages directed to different plants);
- containers with less than a full layer should not to be shipped.

3.1.4 Interior Dunnage

The timely delivery of high-quality parts at the designated destination is critical to an efficient operation. Custom interior dunnage, or "protective interior packaging", is available in both reusable and expendable (one-time use) styles to protect the product during assembly, work-in-process, and transportation activities. This packaging is custom designed and fabricated to provide a reliable packaging solution that offers continuous protection and support. This dunnage can be inserted into totes or bulk containers, used on pallets or used with racks.

Mixed materials are usually not acceptable (dunnage should always be made out of the same material, even if different from that of the packaging which contains it, in order not to create confusion or waste too much time when collecting materials to recycle after the usage), and plastic materials must be recyclable and marked with the standard symbol and meet any local governmental regulations which may apply. Dunnage generally should be designed to minimal levels (as little as possible) while still protecting the part.

3.1.5 Containment of Cardboard Boxes in Unit Loads

The preferred method of containment of cardboard boxes in unit loads is to use a plastic, heat sealed strap of polyester. The use of unitizing adhesives stripes (to bind together containers in unit loads on a pallet) for cartons is also very used. It can is usually the supplier's responsibility to secure all material unit loads with adequate banding.

Metal banding and seals are allowed on an exceptional basis only when PVC stretch films (plastic wrap) are not allowed for specific reasons. Also shrink film is acceptable only if any labels used and adhered to the film are of the same material.

3.2 Returnable Containers

Returnable containers are obviously intended to be used repeatedly and frequently. Their success as cost effective packaging depends highly on how well the returnable system is managed and controlled. Most returnable containers are constructed from plastic, and the decision makers are from many different areas of the plant: purchasing, operations, warehouse, materials, distribution, supply chain, logistics and quality managers, as well as packaging engineering and finance.

Selected key indicators highlighted by ORBIS Corporation help indicate if it could be convenient to implement a returnable system; these include:

- relatively short logistical cycle (time and distances);
- high product damage rates;
- high inventory velocity;
- well managed supply chain;
- concern about clean environment or part cleanliness;
- tightly controlled closed-loop or a well-managed open-loop shipping system;
- multiple component parts;
- expensive expendable packaging;
- high part-usage rates;
- high waste disposal costs;
- need to optimize line space;
- worker safety or ergonomic issues;
- product shipped to/from regional distribution centers; and
- facility/equipment constraints.

Moreover, some of the following indices may be used to measure packaging success over time and calculate the return on investment:

- expendable packaging costs;
- expendable set-up costs;
- disposal of expendable packaging;

- investment for returnable containers;
- attrition rate;
- logistics and freight costs;
- handling costs;
- system days and return ratio;
- product quality and cost due to product damage;
- ergonomics and safety issues;
- space savings in warehouse and line side;
- cleaning costs;
- container control (tracking and administrative costs);
- repair costs;
- re-packing costs; and
- cycle time.

There are a number of factors influencing the above scenarios, and as a result, using rs, returnable containers are not always the most cost effective choice for packaging.

3.2.1 Plastic Returnable Containers

Currently, plastic returnable packaging is the container solution most used both by Chrysler and Fiat to move, store and distribute products within their supply chain. Plastic reusable packaging replaces single-use corrugated containers and boxes as well as wood pallets along the supply chain. Moreover, the initial investment is usually high but the pay-back can be generally within 6-18 months.

Plastic packaging performs very well for multiple trip applications in a closed loop environment, or in a well-managed supply chain. It can also be used effectively in a managed open loop system, with reverse logistics in place to return empty containers or pallets for re-use or replenishment.

The design of plastic reusable packaging offers durable construction along with high levels of recyclability in most situations. These containers are easy to handle and can interface with multiple types of automated handling equipment. In fact, some containers are solely handled by automated equipment and conveyors in both Fiat and Chrysler plants. Moreover, plastic packaging has no nails or loose corrugated flaps which can stop a manufacturing system. This is an important point to be highlighted, since in high-volume industries a lot of money is lost when an automated system or production line will eventually stop.

Usually, the OEM in cooperation with reusable packaging providers analyzes a single operation or even the entire supply chain, conducts a financial assessment (analysis benefits vs costs). They finally select a solution and implement a packaging program for sustained cost reduction and supply chain efficiency. Supply chain systems are dynamic and the packaging programs that support them usually evolve. In fact, quality improvements, new production programs launches, changing production processes and new labor practices may require new demands that must be covered by the standard returnable packaging system in order to reach a high efficiency over several years. Replacing the returnable containers too soon due to damage or wear-and-tear can be costly since the investment would not be re-paid.

Packaging manufacturers like ORBIS (Chrysler's returnable packaging supplier) have proved that implementing a returnable packaging systems may result in significant optimization and total cost reduction in different ways such as:

- ***Reduced cost for disposal***: the disposal of cardboard and wood waste is a not-negligible cost in terms of disposal fees and non-value added activity. The long service life of returnable packaging allows it to be used many times in place of one-time usage of expendable packaging.

- ***Decreased overall purchasing costs***: returnable containers have an average life in the range from 5 to 10 years, so it is possible to reduce packaging material costs by allocating the initial investment over their useful life (usually the purchasing cost for expendable packaging computed for the entire program duration is higher than when compared to the initial investment for returnable packaging) This way, recurrent costs for single use expendable packaging are avoided and waste is reduced significantly compared with expendable packaging reducing the environmental impact.

- ***Container pooling***: the more robust design of reusable packaging allows it to be used many times, and many times, and to share the container among different production programs and plants.

- ***Increased product protection and reduction of damage rates***: Fragile components are usually much safer in durable and robust plastic containers with customized dunnage that protects delicate assemblies from damage. Moreover, these container solutions are also able to prevent part damage from nails and rust which can be often found in cardboard or wood packaging.

- ***Better compatibility with lean manufacturing processes***: returnable packaging is fundamental for implementing a lean manufacturing system, characterized by frequent parts deliveries, standardized package sizes and efficient packaging processes improve the flow of product/material. This reduces the need for extra storage or warehouse space for collecting used cardboard or wood packages that have to be eventually disposed.

- ***Optimized inventory levels***: shipping in smaller quantities, on a more frequent basis, and delivering parts closer to the time of usage reduces the number of days of parts inventory and therefore limits the capital tied up in inventory. Also combining supplier pick-ups or deliveries to plants into smaller and more frequent routes, such as "milk runs" can reduce the capital in inventory.

- ***Reduced transportation costs***: standardized sizes of returnable containers can increase the cube saturation of the transport vessel, and can also enable easier logistics and transportation planning. Stacking containers to the maximum transport vessel capacity reduces transportation costs per piece. Furthermore, to minimize return transportation costs, returnable packaging is often designed to nest (to be able to be inserted one inside the other) or collapses when empty.

- ***Reduced manpower costs for handling activities***: multiple layers of paper, plastic bags and other expendable packing materials in many cases can be eliminated. This reduction, in turn, requires fewer labor steps in the packaging process (less manpower cost for the handling), as well as no recurrent container disposal costs.

- ***Decreased space occupied in the storage areas***: reusable packaging can make better use of line-side and warehouse floor space, and material handling equipment. In fact, plastic or steel containers can stack higher than expendable ones and nest or collapse to occupy less floor storage space in each location of the supply chain.

- ***Improved process speed through reduced cycle times for handling activities***: using reusable packaging, companies can also speed the production processes. Workers spend less time handling, collecting and disposing expendable packaging. Furthermore, reusable packaging enables just-in-time deliveries to optimize productivity and reduce handling and space utilization at assembly plant location.

- ***Improved ergonomics and worker safety***: plant managers have reported fewer incidents related to packaging handling because of improved stack-ability, easier handling and better tracking of materials in storage areas. Compensation and health care costs cannot be neglected for large companies like Fiat and Chrysler: ergonomically designed containers improving worker safety can also result in significant economic savings. For example, standard containers with handles or access doors make packaging more user friendly, resulting in fewer strains and musculoskeletal disorders for the operators.

Returnable packaging offered by packaging suppliers is manufactured in a variety of styles. The packaging style selection is based on many factors of the company business: volume of product, supply chain network, product life cycle, shipment frequency, inventory velocity, storage and handling equipment, and product protection. For example, a small aesthetic component like a part of the car dashboard being shipped for assembly into a vehicle usually requires standardized packaging with dunnage to prevent part damage and reduce poor quality costs. Standard plastic small lot totes can be very helpful to optimize material flow with production quantities. Generally, they are available in the following styles:

- straight-wall/stack-only: for maximum container utilization, resulting in more parts per container (higher density);
- stack-and-nest: containers nest when empty and stack when full;
- nest-only: containers nest for efficient storage and return transport of empties;
- collapsible: containers collapse after use for efficient return transport of empties;
- attached-lid: for secure storage and shipment (specially to avoid dust depositions on parts).

Chrysler uses only straight-wall/stack only plastic totes and plastic totes with attached lid for its operations while Fiat uses three types of nest-able plastic totes (usually for long distances). Currently, also Fiat is using only straight-wall/stack only totes, while the nest-able ones have been returned to IVECO (which had the property on them).

Bulk containers, instead, offer greater strength, load capability and durability demanded in material handling systems for heavy or bulky big components. Bulk containers are available in many standard footprints and types:

- collapsible: containers collapse after use for efficient return transport of empties;
- straight-wall: for maximum container utilization and secure static storage; and
- nest-able: containers nest for efficient storage and return transport of empties.

Almost all the standard bulk plastic containers used by Chrysler are collapsible, but some straight-wall ones are still used. Fiat is only using collapsible standard bulk plastic containers.

Both the companies have converted from wood to plastic pallets for their work-in-process, storage and distribution applications because of the perceived economic, ergonomic and environmental benefits of plastic pallets. Wood pallets can be still used for oversea shipments (to avoid high cost of return transport).

3.2.2 Basic Information on Plastic Returnable Container Manufacturing

Plastic returnable packaging provided by ORBIS to Chrysler is manufactured in high-density polyethylene or polypropylene plastic using the following forming processes. A comprehensive range of manufacturing processes and high quality materials are necessary to achieve the desired performance characteristics needed for the container applications considered in this thesis. For the sake of completeness, the most important manufacturing processes are briefly presented in the following. [22]

Injection Molding

Plastic is injected, under pressure, into a closed cavity mold and cooled to ensure it maintains the exact shape of the mold. This process produces a solid wall and solid core product which is characterized by:

- high strength;
- high impact resistance;
- light weight structure;
- accurate tolerances.

Thermoforming

In single sheet thermoforming, a sheet of plastic is heated and drawn by vacuum over a mold to reproduce the shape of the final product. In twin sheet thermoforming, two sheets of plastic are heated and drawn by vacuum over separate molds and fused together through pressure to form a more structural double wall. These processes result in:

- impact resistance;
- high static load capacity;
- light weight structure.

Structural Foam Molding

Plastic and nitrogen gas are injected into a closed cavity mold and cooled to reproduce the exact shape of the mold. The combined use of these materials creates a cellular core that forms a solid layer and is characterized by:

- high strength/weight ratio;
- high static load capacity;
- accurate tolerances.

General Fabrication

A variety of materials are used in the fabrication and assembly of custom interior dunnage to ensure:

- improved part protection and better part separation;
- high surface protection for esthetic parts.

3.2.3 Custom Racks and Standard Containers

Chrysler uses a wide variety of custom racks and metal and plastic standard returnable containers. Standard containers have to be utilized to achieve optimal results in terms of standardization of the handling and line display equipment, high cubic utilization and transportation efficiency, reduce the container management complexity, decrease the obsolescence risk and eliminate the packaging design cost and time when a new program is launched. Nevertheless, there are some cases in which standard containers cannot be used and so a specific design of the packaging is needed. Custom racks are required for example for the containment, handling and shipment of large components such as body parts, engines and other powertrain components and subsystems.

3.2.3.1 Custom Steel Racks

Custom racks are usually of tubular steel construction and are specifically designed to hold a particular part. The design of these racks still has to consider the dimensions of the carrier and the possibility to stack one over another in order to optimize the cubic utilization as much as possible. For this reason, external dimension are usually standardized despite the rest of the container is specifically design taking into account each part number characteristics and quality requirements. Furthermore, they bear an identifying part number and description. Ergonomic devices are incorporated into the rack, such as swing arm dunnage bars and hands clear locking mechanisms.

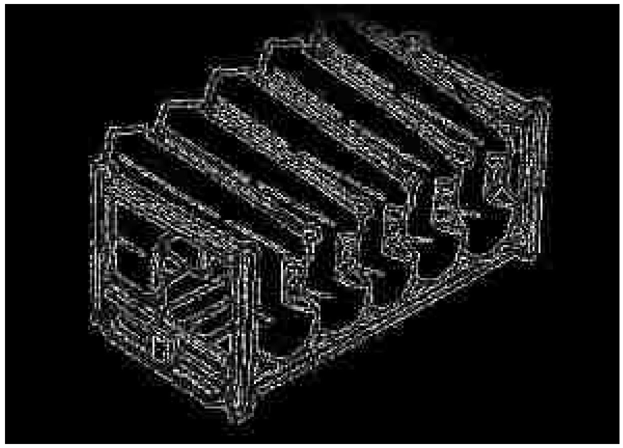


Figure 3.10 – Sketch of a rack**.** *[20]*

3.2.3.2 Standard Containers

A wide variety of standard containers are available: metal and plastic, collapsible, non-collapsible, and nest-able. Within Chrysler, plastic containers larger than 4 cu. ft. (2500 cu. mm) have a maximum weight capacity of 2500 lbs. (1136 kg); collapsible metal containers have a maximum weight capacity of 4000 lbs. (1800 kg); and non-collapsible containters cannot exceed 6000 lbs. (2700 kg). It is very important to take into account the maximum weight capacity because the maximum number of parts that can be efficiently loaded in a container is often constrained by weight, not volume. Examples of the most common containers of each type used by Chrysler are shown in the following.

3.2.3.3 Non-Collapsible Metal Bins

CC8	CC3A
	
0CS02341	**0CS02343**
	
0CS00699 and 0CS00701	**0CS02342**
	

Table 3.1 – Some examples of standard non-collapsible metal bins.

When a high capacity container is needed, usually because of the weight and dimension of the parts to be contained, a metal bulk container may be a good solution to meet the requirements. Metal bulk boxes are available in several standard sizes in collapsible and non-collapsible versions. However, non-collapsible metal bins need less maintenance and have higher durability because they need fewer features.

3.2.3.4 Collapsible Metal Bins

0CS00120	0CC0071
	

Table 3.2 – Some examples of standard collapsible metal bins.

Collapsible metal bins usually require higher maintenance and have lower durability with respect to non-collapsible ones, but they can guarantee higher efficiency for transportation, due to the higher number of containers that can be loaded in a trailer. They are usually more expensive than non-collapsible and so a case study is needed in order to evaluate when it is convenient to use them. Both the distance between supplier and the plant, and the production volume forecasted for a new program, greatly influence the selection of the bin.

Due to their high volume and high weight, these containers are used when it is not possible to use a plastic container, which is preferred for the lower transportation and handling costs.

3.2.3.5 Metal Baskets

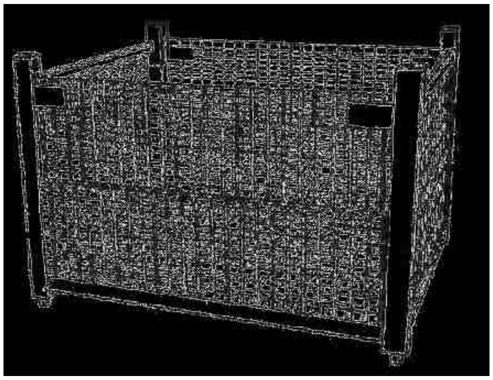


Figure 3.11 – Sketch of a standard non-collapsible metal basket. *[20]*

Metal baskets are used especially to contain smaller cardboard boxes, in order to reach a higher efficiency for the handling, reducing the time needed to move them. There are both collapsible and non-collapsible metal baskets and this solution (metal basket with smaller cardboard cartons inside) is quite often used for shipping fasteners overseas.

3.2.3.6 Non-Collapsible Plastic Bins

0CC00030	0CC00050	0CC00058
		

Table 3.3 – Examples of standard non-collapsible plastic bins.

Non-collapsible plastic bins are smaller than plastic containers (showed in the next paragraph), but are larger than plastic totes (small lot plastic containers).

They are designed to have a higher weight capacity with respect to plastic totes and they can contain components which are not very large, but still quite heavy.

Plastic totes can also be handled with the fork-lift. It may be possible then to reach a good density inside the container without reaching the weight limit given both from the container capacity and ergonomic requirements.

3.2.3.7 Collapsible Plastic Containers

0CC00031	0CC00032	0CC00038	0CC00041
			
0CC00042	**0CC00044**	**0CC00046**	**0CC00047**
			
0CC00048	**0CC00052**	**0CC00074**	**0CC00075**
			

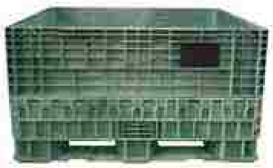
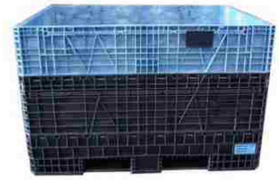
0CC00076	0CC00091	0CC00094	0CC00095
			
0CC00096	0CC00097	0CC00098	0CC00152
			
0CC01032	0CC01033	0CC01036	0CC01071
			

Table 3.4 – Some examples of standard collapsible plastic containers.

Almost all the plastic containers used by Chrysler are supplied by ORBIS Corporation, which offers a largest selection of bulk containers measuring from 32" x 30" to 78" x 48". These containers protect products during picking, assembly, processing, storage and distribution application. Bulk containers are available in light-duty, medium-duty and heavy-duty designs for multiple applicaitons. There are both collapsible and straight-wall styles for these containers and they guarantee high strength and durability demanded in automotive industry material handling and distribution systems. It is also possible to add custom designed dunnage for the safe and efficient protection of parts and components throughout the supply chain. Nearly all the plastic bulk containers used by Chrysler are collapsible in order to reduce the shipping cost for the empty containers and save room occupied in the warehouses and storage areas. Plastic containers offer greater reuse potential when compared to corrugated cardboard containers.

3.2.3.8 Small Lot Returnable Containers

A wide variety of small lot containers of different sizes are available. All of these containers fit on pallets (for unit loading) and are supported by top caps.

CT12075	CT121505	CT121507	CT121509
			
CT241109	CT241505	CT241507	CT241509
			
CT241514	CT242207	CT242209	CT242211
			
CT242214	CT321507	CT481507	CT481511
			

Table 3.5 – Examples of standard totes.

Plastic totes are available in a variety of dimensions and there is also the possibility to use standard totes with the lid, mainly used to contain components used in powertrain processes to prevent the deposition of dirt and dust.

CTA121507	CTA121509	CTA241109	CTA241509	CTA241514
				

Table 3.6 – Examples of standard totes with lid.

3.3 Expendable Back-Up

Suppliers must maintain a sufficient supply of suitable expendable packaging to be used for expedited shipments, production pilot programs (when the right returnable container has not been selected or validate yet), alleviating container shortages, service orders, and/or plants not participating in the returnable container program, for example “Completely Knocked Down” (CKD) ones (which will be explained later in this thesis). This backup packaging must be dimensionally (interior) the same and maintain the identical density as the returnable container it is replacing. Each backup expendable container must accommodate the identical interior dunnage, where required, as the corresponding returnable container.

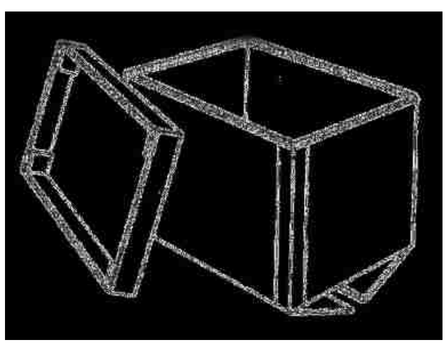


Figure 3.12 – Half slotted box with cover. *[15]*

The usage of a lid allows for a safer work environment by eliminating the use of cutting instruments; in fact, the use of re-closable boxes with flaps is generally prohibited, unless authorization is granted by the receiving plants material handling engineering departments.

In most cases the expendable backup container, especially if triple walled, can be used as an international shipping container. Special dimensions and footprints are designed and have to be used for sea container cube high utilization, unless the part dictates a new size (exceptions). If the part is outside the dimensional specifications for international shipments, it is necessary to work with the corrugated supplier and obtain the approval prior to proceed with shipping. Finally, the supplier is generally responsible for the packaging design, prototype, and purchase of all corrugated packaging.

3.4 Ownership

Returnable containers can be either OEM or supplier-owned and be made of either metal or plastic; the use of wooden pallets as returnables is usually discouraged due to the confusion they might generate with the recyclable pallets. Moreover, Chrysler does not pay deposits on returnables. For all supplier-owned returnables, suppliers must complete and submit a “Unit Load Data Sheet” for written approval to the Corporate Material Handling Engineering department or to the appropriate receiving plant prior to use of these returnables.

3.5 Labels

Suppliers must insure that all materials shipped to the plants are correctly labeled and that the labels are properly attached or inserted into the holders on the racks or containers. To minimize misdirection of packaged parts and materials, it is essential that the exact shipping address of the receiving plant be shown in a manner that can be easily read and understood.

There are label specifications to be followed related to the color, size, quality, reflectivity, and readability. Labels must be scan-able from the exterior of the shipping unit and so not covered by banding, cardboard, or shrink wrap. A label that identifies the receiver of a shipping pack, especially when the package is routed through a consolidation point (ILC), has to contain the plant and dock destination code, ship date, plant address and bar code symbol of the destination. Other information that has to be added in the label is part number, part description, quantity and date manufactured. A "dock specific" destination label must be on every unit load routed through a consolidation center and no mixing of parts directed to different plants or plant dock locations is allowed on a single pallet.

For multiple common item packs, a master label is required to be used to identify the total contents of a multiple single pack load of the same part number. On the other hand, in the case mixed item loads are considered, a mixed load label must be used to identify a load of multiple single packs of different part numbers.

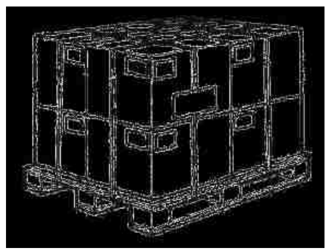


Figure 3.13 – Example of unit load with multiple packs.

Label protection against moisture, weathering, abrasion, etc., may be required to ensure that it does not detach even in harsh environments. Finally, care must be taken to assure that labels meet light reflectivity and contrast requirements and can be scanned with contact and non-contact devices along the supply chain.

3.6 Cleaning, Damage and Repair of Returnable Containers

The supplier ensures that all returnable containers are free of debris that would impact the quality of the material being packaged prior to loading with parts, as well as inspecting all containers prior to loading to ensure that damaged equipment which could cause damage to parts or injury to operators is removed from the system for subsequent repair or disposition.

At Chrysler plants, the Production Control department usually makes arrangements with Corporate Material Handling Engineering department to conduct or arrange on-site inspection and disposition (repair or scrap) of this damaged equipment when sufficient quantities have been accumulated to cost-justify such actions.

3.7 Implementation of Returnable/Expendable Programs

3.7.1 Pre-Concept Meetings and Analysis

The pre-concept meetings are needed to discuss packaging alternatives, packaging materials, particular part characteristics, load/unload scenarios, and timing. Suppliers have to send a sample part or math data to the latest change level and a supplier representative qualified to address their concerns, must be available in person (or for a conference call).

If the vehicle production line that uses components is located oversea, international packaging requirements must be discussed. International packaging requirements will depend on if the goods are supplied to a Free Flow Country or Complete Knocked Down (CKD) Country. A complete knock-down scenario is when a complete kit needed to assemble a product. It is also a method of supplying parts to a market, particularly when shipping to foreign nations, and serves as a way of counting or pricing. CKD is a common practice within the automotive industry, bus and heavy truck industry, and trail vehicle industry, as well as electronics, furniture, and in other business fields. A company sells knocked down kits to their foreign affiliates or licensees for various reasons, including to avoid import taxes, to receive tax preferences for providing local manufacturing jobs, or even in public transit projects with "buy national" rules that would exclude a foreign company. In a CKD country, it is usually the responsibility of the supplier (not of the OEM) to submit samples and costs associated with packaging solutions in lots of specific quantity (which can be different from domestic packaging). In a free flow (not CKD) scenario, it is possible that domestic packaging may be adequate for international shipments.

3.7.2 Proposed Packaging Solution Review and Final Testing

Suppliers must usually loan or release a minimum of three sample parts for testing different solutions of package. If required, parts will be returned upon the successful testing and approval of the package to be used. Once a packaging solution is proposed a review is scheduled with all parties concerned to assess the package fulfillment of requirements as set at the pre-concept meetings, and validate the choice.

If a new packaging solution has been approved, testing for all returnable programs is required to be performed via test shipments to the receiving location. Full package quantities (enough to reach the established density inside the container) must be released for this purpose. Once testing is completed parts can be eventually returned if requested.

3.7.3 Containers Allocations

Normally the Company (in this case, Fiat and Chrysler) have to assess and define a quantity of returnables to cover published transit times, in-plant floats and operational stock reserves. Variations to this allocation must be approved every time by the Corporate Material Handling Engineering department. This department and the Logistics Department usually work with the suppliers to identify quantities that will be sufficient to cover all the operational needs.

3.7.4 Unit Loading Information in the Information System

Once this process is completed, a new part number for the container solution selected with related data information is loaded directly on-line into the “CRATES” (Container Repository and Tracking System) by the Tier-1 supplier, and the unit load information for any new released part is periodically updated by the Corporate Material Handling Engineering department.

3.8 Combination Returnable and Expendable

Complexity and economics can force a new program to use returnable containers with expendable dunnage. Parts not meeting the economic criteria for total returnable systems can be containerized with the cooperation of the supplier. In this program, the OEM supplies the container and the supplier is responsible for the design, testing, and replacement of the interior dunnage. Costs attributable to the dunnage are included in the purchase order by the supplier on a piece price basis. Moreover, all cardboard must be uncoated to permit recycling, and suppliers can also contact the plant recycling teams if they want to purchase quantities of their recyclable dunnage back.

CHAPTER 4

ANALYSIS OF MATERIAL FLOW TYPES, BENCHMARKING FIAT-CHRYSLER AND ANALYSIS FOR REDUCTION OF STANDARD CONTAINER COMPLEXITY

4.1 Review of Material Flow Types and Their Requirements in the Automotive Industry (Chrysler - Fiat Case Study)

This section examines the main material flow types used in the automotive industry. The information presented has been gathered thanks to meetings and cooperation with the Chrysler Material Flow team and Fiat Logistics Engineering team as well as with direct visits of Chrysler and Fiat plants And Integrated Logistics Centers (ILCs) both in U.S.A. and Italy. The visits in Italy include: Officine Maserati Grugliasco (OMG), where the new Maserati Quattroporte is assembled, and Villanova S.p.A. Logistics Consolidation Center. The visits in the USA include: the Jefferson North Assembly Plant, Sterling Heights Assembly Plant, and Linc Integrated Logistics Center. These activities have been very helpful to determine from a practical and operational points of view the different material flow types with which the production line can be fed.

According to World Class Logistics principles, there are three main material flow types for moving materials and components through the supply chain:

- Just in Sequence (JIS)
- Just in Time (JIT)
- Indirect (IND)

The optimal material flow will depend on many parameters such as distance between supplier and OEM plant, production volume, product complexity, dimensions and cost of the components. More importantly, choosing one type of material flow rather than another will affect the selection of the best packaging solution. For example, because of the system days required and the subsequent number of containers needed, material handling costs (number of container turns during the program duration) and shipping costs will vary, as well as differing environmental impacts.

4.1.1 Just in Sequence

With this material flow, parts are delivered to the line in sequence, according to the sequence of assembly orders launched by production scheduling (“pull system”). A small buffer (small sequenced storage area) is required as close as possible to the point of use in the production line. This buffer is not larger than the quantity of sequenced containers contained by a single transportation mode. The line feeding is arranged by parts of the same logistic family (sequencing) or sets of parts of different logistic families in sequence (kitting). There are different sub-kinds of *Just in Sequence* flows:

- Build to Sequence
- External Ship to Sequence
- Internal Ship to Sequence
- Internal Pick to Sequence

4.1.1.1 Build to Sequence

This type of flow is an external build to sequence process at the supplier plant. The assembly process sequence drives the supplier production process and so the part is not manufactured until the vehicle reaches the assembly point. Moreover, there is no stock in the plant and so it is the “leanest” flow type with the least amount of inventory.

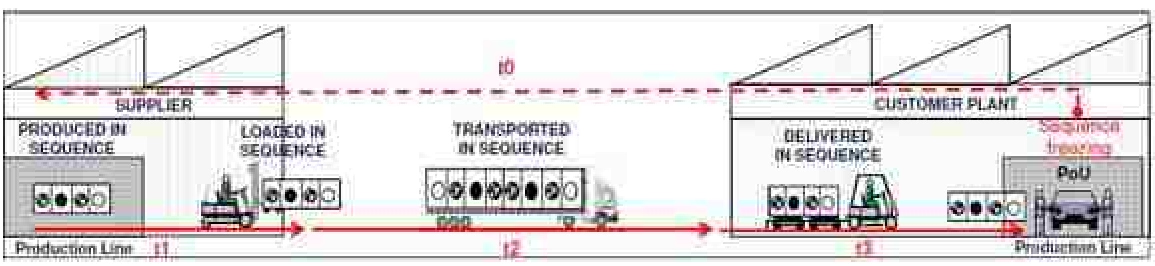


Figure 4.1 – Build to Sequence. *[23]*

The supply chain inventory condition is given by the sum of inventory of supplier production, in transit inventory, and in house inventory (handling and point of use buffer). The available lead time must always be greater than the whole logistics process lead time to avoid stopping the OEM assembly process. A safety factor, defined according to supplier and supply chain reliability and key performance indicators (KPIs), is usually taken into account to further increase the value of the process lead time and decrease the risk of stopping the assembly line. The available lead time is the time difference between the sending of the assembly process sequence and the arrival of the product at the point of use.

$$\text{Lead Time}_{BtS} = \mathrm{t}_0 + \mathrm{t}_1 + \mathrm{t}_2 + \mathrm{t}_3 \tag{4.1}$$

t_0 is the time required for information transmission, t_1 is the supplier process lead time including truck load, t_2 is the transport lead time and t_3 is the material handling delivery lead time.

As far as this material flow type is concerned, the supply chain inventory, handling costs and lead time can be considered low while the stock turn (number of times the stock is renewed in a certain time period) is very high.

4.1.1.2 External Ship to Sequence

This is an external ship to sequence process at the supplier plant from a finished goods buffer (that depends on production mix) in its plant or in its advanced warehouse. It takes place after the production process at the supplier. The assembly process sequence drives the picking and loading process at supplier plant and the consequent transport and delivery schedule to the customer.

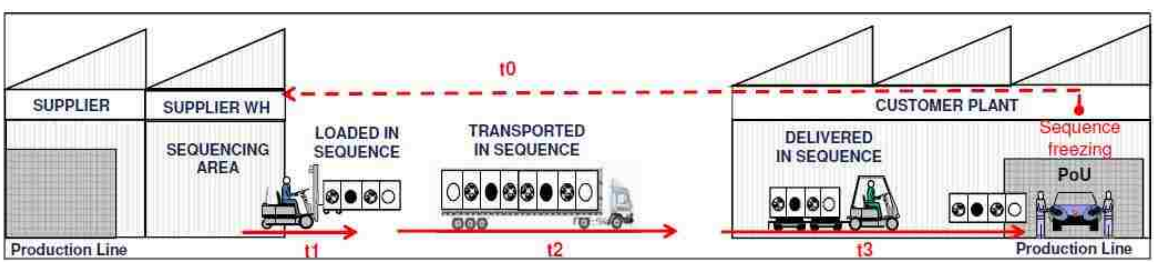


Figure 4.2 – External Ship to Sequence**.** *[23]*

The supply chain inventory is similar to the *Build to Sequence* plus the supplier stock.

$$\text{Lead Time}_{EStS} = \mathrm{t}_0 + \mathrm{t}_1 + \mathrm{t}_2 + \mathrm{t}_3 \tag{4.2}$$

t_0 is the time required for information transmission, t_1 is the supplier process lead time including truck load, t_2 is the transport lead time and t_3 is the material handling delivery lead time. As in the previous case, the supply chain inventory, handling costs and lead time can be considered low while the stock turn is usually very high.

4.1.1.3 Internal Ship to Sequence

Internal ship to sequence can be considered an indirect flow since the supplier sends materials and components but not in sequence. The assembly process sequence drives the picking and loading process at the warehouse area using a kitting or picking area. The supply chain inventory condition is given by the sum of inventory of supplier production, supplier stock, in transit inventory, warehouse stock and in house inventory of handling and point of use buffer.

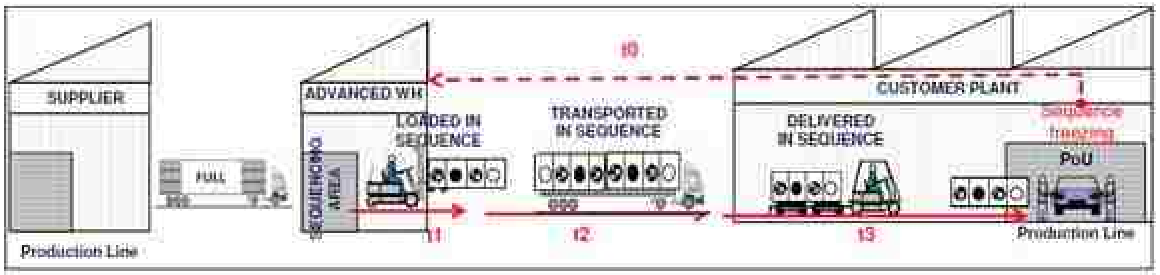


Figure 4.3 – Internal Ship to Sequence. *[23]*

The process lead time for Internal Ship to Sequence flow type is given by:

$$\text{Lead Time}_{IStS} = t_{-1} + t_0 + t_1 + t_2 + t_3 \tag{4.3}$$

t_{-1} is the supplier process lead time including truckload and transport from the supplier to the warehouse, t_0 is the time required for information transmission, t_1 is the process lead time for sequencing the components in the warehouse area, t_2 is the transport lead time and t_3 is the material handling delivery lead time.

In an *Internal Ship to Sequence* flow, the supply chain inventory, handling costs and lead time are usually higher compared to *Build to Sequence* and *External Ship to Sequence*; however, the stock turn is lower.

4.1.1.4 Internal Pick to Sequence

Internal pick to sequence is a sequencing activity that can be performed in production area by either internal people or an external service provider with material delivered from plant warehouse or temporary storage.

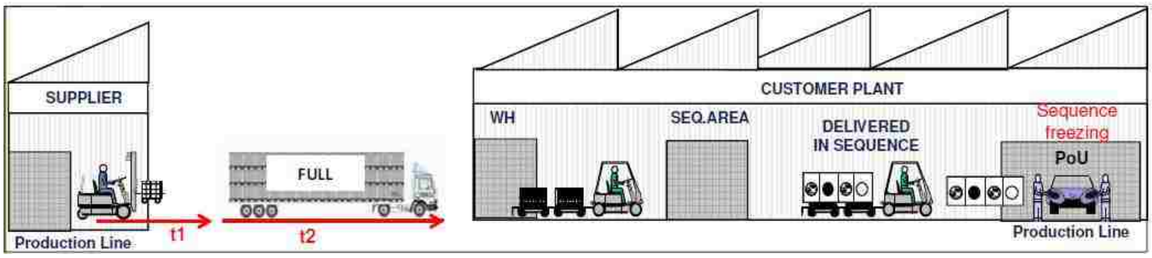


Figure 4.4 – Internal Pick to Sequence. *[23]*

This process may also be preceded by a Just in Time or Indirect material flow. The supply chain inventory condition is given by the sum of inventory of supplier production, in transit inventory, supplier stock, warehouse stock, inventory of the sequencing area and inventory of handling and point of use buffer. For this material flow type, the lead time is given by:

$$\text{Lead Time}_{IPtS} = \mathrm{t}_1 + \mathrm{t}_2 + \mathrm{t}_3 + \mathrm{t}_4 + \mathrm{t}_5 \tag{4.4}$$

t_1 is the supplier process lead time including truckload for transport, t_2 is the transport lead time, t_3 is the material handling lead time in the warehouse area, t_4 is lead time for preparing the right sequence in the sequencing area, t_5 is the material handling delivery lead time.

The supply chain inventory, handling costs and lead times are even higher than Internal Ship to Sequence, and the stock turnover is lower.

4.1.2 Just in Time

Just in Time (Direct External Delivery) is a material flow used to deliver parts in the exact quantity according to the consumption ("pull system"). Parts are delivered into specific docks and placed in temporary storage areas close to usage point: there is no permanent storage of the parts at the plant. It is a direct flow from supplier finished product stock to usage point and for this reason the total supply chain inventory is very low.

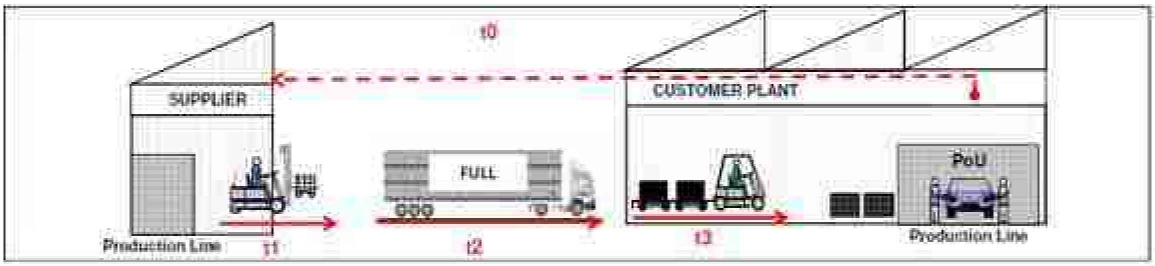


Figure 4.5 – Just in Time. *[23]*

The supply chain inventory condition is given by the sum of inventory of supplier production, supplier stock, in transit inventory and inventory of handling and point of use buffer.

$$\text{Lead Time}_{JIT} = t_0 + t_1 + t_2 + t_3 \tag{4.5}$$

t_0 is the time required for information transmission, t_1 is the supplier process lead time including truck load, t_2 is the transport lead time and t_3 is the material handling delivery lead time at the OEM plant.

Implementing a Just in Time flow, it is possible to obtain a very low lead time, handling cost and supply chain inventory. The stock turnover is very high and this, in turn, helps reduce the value tied up in inventory.

4.1.3 Indirect Material Flows

These parts are delivered to the plant according to a “push” material schedule. There is no synchronization between the supplier production process and the OEM assembly process. Furthermore, the quantity shipped is not related to the consumption of parts of the final customer (the assembly plant) and the components are sequenced neither by the supplier nor by the final plant.

4.1.3.1 Indirect Material Flow through Plant Buffer

Parts are received in a temporary storage area (buffer) and then delivered to the line. This material flow uses to be from temporary storage area close to point of use and applied to single-item containers (not kit-containers with different items inside). From the buffer area close to the line the parts are delivered to the line side with a pre-settled frequency.

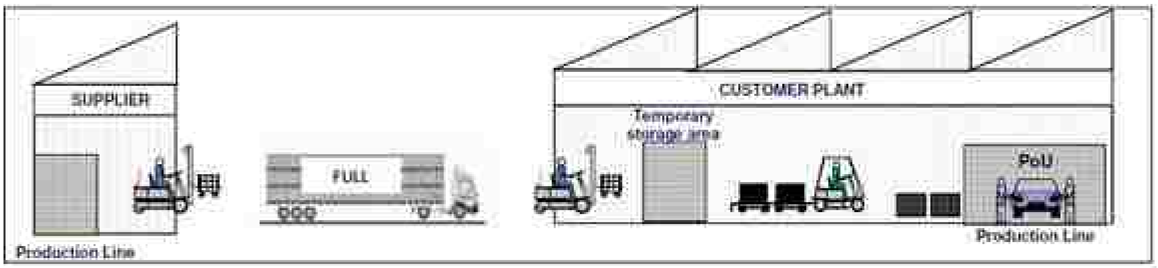


Figure 4.6 – Indirect flow through plant buffer. *[23]*

This material flow type is characterized by a high lead time, high handling costs, high supply chain inventory, and low stock turnover.

Indirect Flow with a plant buffer is usually recommended for bulky items with high stock turnover level.

4.1.3.2 Indirect Material Flow through Plant Warehouse

Parts are received and stored in a warehouse, within the plant area, and then prepared and delivered to the line. Material flows in single item containers, not delivered in sequence to the assembly line.

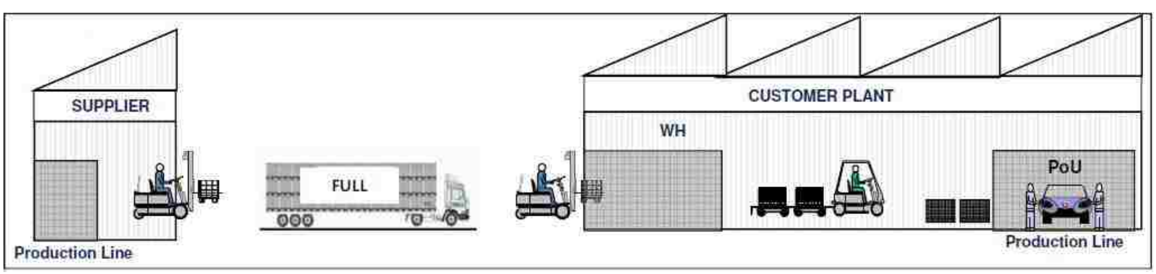


Figure 4.7 – Indirect flow through plant warehouse. *[23]*

The supply chain inventory is far higher than the supply chain inventory for Just in Sequence and Just in Time material flow, and it is also higher than the supply chain inventory for Indirect Flow through Plant Buffer. Lead time and handling cost are high, and stock turn is very low.

4.1.3.3 Indirect Material Flow from Consolidation Center or Advanced Warehouse

Parts are shipped from the supplier according to a "push" material schedule, received and stored in an external warehouse, which can be a consolidation center or warehouse out of the plant area, then prepared and delivered to the line not in sequence. These activities can be performed either by internal people (OEM employees) or by third party logistics services providers.

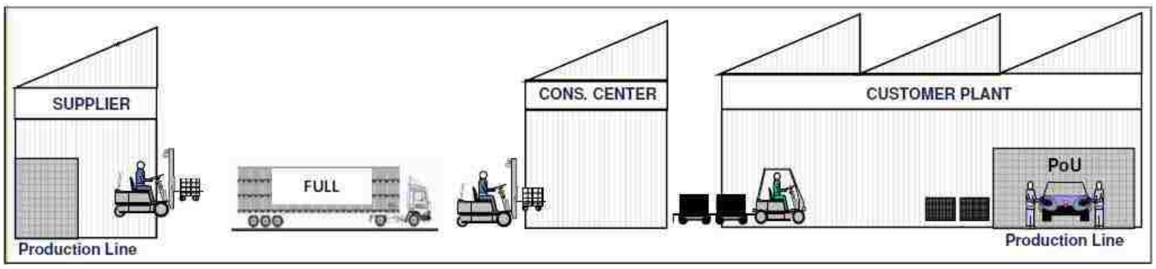


Figure 4.8 – Indirect flow from consolidation center or advanced warehouse. *[23]*

When this type of material flow is implemented, the stock turn is very low, and supply chain inventory, lead time and handling costs reach their highest levels.

4.2 Benchmarking Analysis Fiat - Chrysler

In this section, the benchmarking analyses of the solutions adopted by Fiat and Chrysler are assessed to compare how the two Companies differ in the management of the logistic processes, with a special focus on the container management.

The first significant difference is that Chrysler manages directly the standard returnable container system, while a separate group, i-FAST, carries out this activity for Fiat. Contracts are negotiated and signed with all suppliers to use i-FAST as a condition of dealing with Fiat. Fiat suppliers book empty containers from the i-FAST system and they have a specific number of days for the container utilization free of charge. There are Container Service Centers (CSC) which clean and provide "ready for use" containers to the suppliers based on their orders.

Chrysler provides container delivery to suppliers prior to a vehicle program start. Standard containers will be provided from container fabricators or from available excess located at ILC's (Integrated Logistics Centers) or from previous suppliers. A calculated float quantity of containers is provided to each supplier based on part volume, plant work days, container density, and supplier system days. The container float for each supplier is contained in the Container Management System.

The container relationship is established in the CRATES System for every part/supplier/plant combination. The CRATES system stores information about the container part density (number of parts contained), unit load part density, container tare weight, pallet/lid/dunnage requirements, supplier system days, and other key information.

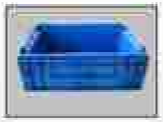
i-FAST account managers and staff are responsible for monitoring containers at supplier locations and ensuring suppliers book and receive container needed for their correct operation. Conversely, Chrysler container management analysts and manager are responsible for assisting a supplier in maintaining container inventory records and container shipment transactions, ensuring supplier receive required containers for their shipments, tracking container excess in the network, and analyzing the root causes for which a supplier ships with the expandable back-up container instead of the returnable one. Notably, Chrysler pays the supplier for the cardboard, thus this is a cost to carefully control to reach high efficiencies in the container management.

Fiat suppliers and plants can rent additional containers that are over target (thus, more containers with respect to planned quantities based on forecasted production volume, system days and service levels) from i-FAST. Chrysler does not provide additional containers to work-in-progress to its suppliers. However, Fiat is responsible for paying the supplier for the expendable back-up container if returnable containers are not available for part shipment. Similarly, Chrysler is responsible for paying the supplier for the expendable back-up container if returnable containers are not available for parts shipment. However, a careful analysis is made by Chrysler analysts to confirm that the standard container shortage and the shipment with expendable backup is actually Chrysler’s responsibility.

Fiat suppliers notify their i-FAST account managers if they receive damaged empty containers, while Chrysler suppliers have to submit container repair requests directly to Chrysler Container Management team, which then organize the pick-up of the damaged containers for repair and returning the containers back to the suppliers or to the ILC.
Fiat is using a considerably smaller number of container types when compared to the list of standard containers used by Chrysler. This reduced number simplifies the management complexity and improves the overall level of standardization of all the equipment both on the line side and in storage areas along the supply chain. In particular, Fiat is using nine standard plastic tote types, six straight wall and three nest-able, four standard plastic bulk bins and three standard steel bulk bins.

In contrast, Chrysler is using twenty-six standard plastic tote types, thirty-seven standard plastic bulk bins and fourteen standard steel bulk bins, as shown in Table 4.2. All the standard containers types used by Chrysler in its operations and supply chain have been described in the first section of Chapter 3 (Analysis of Packaging Solutions) while all the standard totes used by Fiat are shown in the following along with their main technical characteristics. The plastic standard totes are presented in Figure 4.9 and Figure 4.14 (nest-able, currently used only by IVECO), the plastic bulk standard containers are depicted in Figure 4.10 and Figure 4.11 and the standard steel bulk containers in Figure 4.12 and Figure 4.13.

Code	3147		
Loading capacity	15 Kg	Volume capacity	5 l
External dimensions	298x198x147	Internal dimensions	243x162x130
Packaging on pallets 1200 x 1000 mm	4 layers of 20 racks	Tara	0.60 Kg

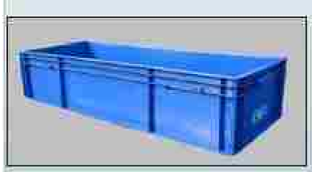


Code	4147		
Loading capacity	17 Kg	Volume capacity	12 l
External dimensions	395x295x147	Internal dimensions	345x260x130
Packaging on pallets 1200 x 1000 mm	6 layers of 10 racks	Tara	1.08 Kg

Code	4280		
Loading capacity	17 Kg	Volume capacity	24 l
External dimensions	395x295x280	Internal dimensions	345x260x262
Packaging on pallets 1200 x 1000 mm	3 layers of 10 racks	Tara	1.70 Kg

Code	6147		
Loading capacity	17 Kg	Volume capacity	25 l
External dimensions	592x395x147	Internal dimensions	544x369x130
Packaging on pallets 1200 x 1000 mm	6 layers of 5 racks	Tara	2.00 Kg

Code	6280		
Loading capacity	17 Kg	Volume capacity	52 l
External dimensions	592x395x280	Internal dimensions	544x369x262
Packaging on pallets 1200 x 1000 mm	3 layers of 5 racks	Tara	2.67 Kg



Code	4961		
Loading capacity	17 Kg	Volume capacity	67 l
External dimensions	994x397x214	Internal dimensions	947x350x198
Packaging on pallets 1200 x 1000 mm	4 layers of 3 racks	Tara	3.40 Kg

Figure 4.9 – Fiat plastic standard totes (measurement unit: mm and kg).

Code	4202			
Loading capacity	250 Kg	Volume capacity		878 l
External dimensions	1200x1000x990	Internal dimensions		1140x945x815
		Folded height		220
Stackability (dynamic) Stackability (static)	1+2 1+4		Tara	39 Kg

Code	4203			
Loading capacity	250 Kg	Volume capacity		405 l
External dimensions	1000x800x750	Internal dimensions		945x745x575
		Folded height		220
Stackability (dynamic) Stackability (static)	1+3 1+4		Tara	28 Kg

Code	4995			
Loading capacity	250 Kg	Volume capacity		647 l
External dimensions	1230x825x925	Internal dimensions		1150x745x755
		Folded height		250
Stackability (dynamic) Stackability (static)	1+2 1+3		Tara	30 kg

Code	4204			
Loading capacity	300 Kg	Volume capacity		927 l
External dimensions	1600x1200x750	Internal dimensions		1535x1135x532
		Folded height		325
Stackability (dynamic) Stackability (static)	1+3 1+4		Tara	46.5 Kg

Figure 4.10 – Fiat plastic bulk standard containers (measurement unit: mm and kg).

Code	4201		
Loading capacity	500 Kg	Volume capacity	790 l
External dimensions	1200x1000x975	Internal dimensions	1120x920x767
		Folded height	406
Stackability (dynamic) Stackability (static)	1+2 1+4	Tara	51 Kg

Figure 4.11 – Fiat plastic bulk standard container, high load capacity (measurement unit: mm and kg).

Code	4700		
Loading capacity	500 Kg	Volume capacity	105 l
External dimensions	800x600x475	Internal dimensions	712x510x 290
		Folded height	n.a.
Stackability (dynamic) Stackability (static)	6	Tara	58 Kg

Code	4710		
Loading capacity	1500 Kg	Volume capacity	460 l
External dimensions	1200x800x750	Internal dimensions	1120x720x570
		Folded height	n.a.
Stackability (dynamic) Stackability (static)	6	Tara	125 Kg

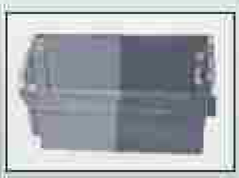
Figure 4.12 – Fiat steel bulk standard containers (measurement unit: mm and kg).

Code	4730		
Loading capacity	2000 Kg	Volume capacity	970 l
External dimensions	1600x1200x750	Internal dimensions	1520x1120x570
		Folded height	n.a.
Stackability (dynamic) Stackability (static)	 5	Tara	218 Kg

Figure 4.13 – Fiat steel bulk standard container (measurement unit: mm and kg).

Code	4990		
Loading capacity	50 Kg	Volume capacity	58 l
External dimensions	600x400x400	Internal dimensions	460x340x370
		Tara	3.06 Kg

Code	4991		
Loading capacity	50 Kg	Volume capacity	47 l
External dimensions	600x400x300	Internal dimensions	460x340x270
		Tara	2.3 Kg



Code	4992		
Loading capacity	32 Kg	Volume capacity	29 l
External dimensions	600x400x200	Internal dimensions	475x338x177
		Tara	1.84 Kg

Figure 4.14 – Fiat nest-able plastic standard totes (measurement unit: mm and kg).

Gathering all the technical information about the standard containers used by Chrysler and Fiat is critical to this research for several reasons.

1. This activity has been necessary to complete the benchmarking study and compare the solutions adopted by the two companies.
2. The data has been used in the analysis aimed at reducing Chrysler's standard container types to be used starting with new programs and for the new packaging selection model: these activities will be described in details in the following sections.

	Package ID.	L	W	H	IL	IW	IH (Fill Line)	Weight (lbs)	Loading Capacity
PLASTIC BULK BINS	0CC01034	32	30	18	29.2	27.3	11.5	50	2000
	0000CC30	32	30	21.5	28	26	13	43	2500
	0CC00032	32	30	25	29.2	27.3	18.3	65	2000
	0CC00034	32	30	25	29.2	27.3	18.3	65	2000
	0CC00031	32	30	34	29.2	27.3	27.3	81	2000
	0CC00050	45	32	21.5	40	27	12.75	50	2500
	0CC00058	45	32	27	40	27	18.25	71	2500
	0CC01035	48	45	17	44.3	41.3	10.3	102	2000
	0CC10411	48	45	19	44.3	41.3	12.3	102	2000
	0CC00076	48	45	25	44.2	41.2	18.5	119	2000
	0CC00077	48	45	25	44.2	41.2	18.5	119	2000
	0CC00091	48	45	34	44.2	41.2	27.5	145	2000
	0CC00074	48	45	34	44.2	41.2	27.5	145	2000
	0CC00038	48	45	39	44.2	41.2	32.3	166	2000
	0CC00075	48	45	42	44.2	41.2	35.4	175	1700
	0CC00052	48	45	48	44.2	41.2	41.3	188	1700
	0CC00044	48	45	50	44.2	41.2	43.3	199	1700
	0CC01032	56	48	25	53.3	44.8	18	166	2000
	0CC01071	56	48	34	53.3	44.8	26.9	201	2000
	0CC01033	56	48	42	53.3	44.8	34.9	220	2000
	0CC00098	64	48	25	61.3	44.8	17.9	170	2000
	0CC00097	64	48	34	61.3	44.8	26.8	192	1000
	0CC00094	64	48	34	61.3	44.8	26.8	209	2000
	0CC00152	64	48	34	61.3	44.8	26.8	209	2000
	0CC00095	64	48	42	61.3	44.8	34	250	2000
	0CC00096	64	48	50	61.3	44.8	43	279	2000
	0CC00041	70	48	25	66.4	44.5	17.9	173	2000
	0CC00042	70	48	34	66.4	44.5	26.7	206	1000
	0CC00048	70	48	34	66.4	44.5	26.7	228	2000
	0CC00046	70	48	50	66.4	44.5	42.9	259	1000
	0CC00053	70	48	50	66.4	44.5	42.9	281	1700
	0CC00047	70	48	50	66.4	44.5	42.9	303	1500
	0CC01037	78	48	25	74.5	44.5	17.9	173	1500
	0CC01036	78	48	34	74.5	44.5	26.7	230	1500
	0CC00084	80	48	25	75.6	43.6	18.6	208	2000
	0CC00081	90	48	25	86.5	44	18.6	255	2000
	0CC00082	90	48	34	86.5	44	27.5	287	2000

STEEL BULK BINS	0CC01041	48	36	21.5	45.7	33.7	13.25	189	4000
	0CC01040	48	36	26	45.7	33.7	17.8	185	4000
	0CC00071	48	45	33	45.5	42	24	300	4000
	0000CC3A	53	42	38.1	51	40	28	300	4000
	0CS00120	64	48	34	59	45	28	500	4000
	0CS00699	72	47.6	34	71.4	47	23.5	400	4000
	0CS00701	72	47.6	34	71.4	47	23.5	580	4000
	0WS0001	75	48	34	72	44.5	25	520	4000
	0CS02344	96	48	28	93	45	18	638	4000
	0CS02341	96	48	33	92	45	23	750	4000
	0CS02345	120	48	28	117	45	18	740	4000
	0CS02342	120	48	33	116	45	23	850	4000
	0CS02346	144	48	28	141	45	18	842	4000
	0CS02343	144	48	33	141	25	23	800	4000
PLASTIC SMALL LOT TOTES	0AIAG003	14.0	7.5	6.6	11.3	5.7	5.7	2.0	40
	0AIAG001	15.0	9.0	8.0	12.8	6.4	6.1	3.0	40
	CT120705	12.0	7.4	5.0	9.4	5.5	4.5	1.1	40
	CT121505	12.0	15.0	5.0	9.4	13.0	4.4	1.6	40
	CT121507	12.0	15.0	7.5	9.4	13.0	6.8	2.2	40
	0CTA121507	12.0	15.0	7.5	9.4	13.0	6.6	2.9	40
	CT121509	12.0	15.0	9.5	9.4	13.0	8.8	2.5	40
	0CTA121509	12.0	15.0	9.5	9.4	13.0	8.6	3.2	40
	CT241109	24.0	11.2	9.5	21.4	9.3	8.7	4.3	40
	0CTA241109	24.0	11.2	9.5	21.4	9.3	8.5	5.6	40
	CT241505	24.0	15.0	5.0	21.4	13.0	4.4	3.0	40
	CT241507	24.0	15.0	7.5	21.4	13.0	6.8	3.6	40
	CT241509	24.0	15.0	9.5	21.4	13.0	8.8	4.4	40
	0CTA241509	24.0	15.0	9.5	21.4	13.0	8.6	5.6	40
	CT241514	24.0	15.0	14.5	21.4	13.0	13.8	5.7	40
	0CTA241514	24.0	15.0	14.6	21.4	13.0	13.8	7.3	40
	CT242207	24.0	22.5	7.5	21.4	20.5	6.8	4.8	40
	CT242209	24.0	22.5	8.7	21.4	20.5	8.1	4.9	40
	CT242211	24.0	22.5	10.9	21.4	20.5	10.4	6.3	40
	CT242214	24.0	22.5	14.5	21.4	20.5	13.8	7.1	40
	CT321507	32.0	15.0	7.5	29.4	13.0	6.7	5.8	40
	CT481507	48.0	15.0	7.5	45.4	13.0	6.3	8.3	40
	CT481511	48.0	15.0	10.8	45.4	13.0	9.6	10.1	40
	CT482207	48.0	22.5	7.3	45.4	20.5	6.3	9.8	40

Table 4.1 – Chrysler standard containers list with dimensions (measurement unit: inches, lbs.).

In Table 4.1 all standard containers used by Chrysler and its suppliers are listed with their dimensions expressed in inches.

Both Fiat and Chrysler are using small plastic totes, plastic bulk containers and steel bulk containers. As far as the packaging typology is concerned, the only difference is that Fiat is also using nest-able small plastic totes (which are not i-FAST property), while Chrysler is only using straight wall, small lot totes. Fiat is using three different dimensions of these nest-able totes only when the business case justifies the convenience of this choice because nest-able totes are more expensive than straight wall ones. Usually these containers are used for long distance shipments.

	Std. Plastic Totes	**Std. Plastic Bulks**	**Std. Steel Bulks**
Fiat	6	5	3
CHRYSLER	26	37	14

Table 4.2 – Fiat/Chrysler standard container comparison.

Table 4.3 shows Chrysler plastic totes similar in dimensions to Fiat ones. However, making comparison on the basis of the dimensions of the standard containers can be misleading since vehicles produced for North American market are very different from vehicles produced for European market, and in turn, the components used for their assembly can be very different in weight and overall dimensions, which will affect packaging dimensions. The strategy used for reducing the standard containers types and obtaining the related economic and environmental benefits presented in the introduction of this thesis (such as the increased possibility to implement the container pooling, reduce container obsolescence risk when a production program ends and a new one is launched, increase handling and storage equipment standardization, reduce the stock and room occupied by each standard container type) will be described in the next section.

Similar CG Container	Desc	Length		Width		Height	
		mm	in.	mm	in.	mm	in.
CT120705	3147	300	11.81102	200	7.874016	147	5.787402
CT121509	4280	400	15.74803	300	11.81102	280	11.02362
CT121507	4147	400	15.74803	300	11.81102	147	5.787402
CT241514	6280	600	23.62205	400	15.74803	280	11.02362
CT241505/7	6147	600	23.62205	400	15.74803	147	5.787402
CT321507	4961	1000	39.37008	400	15.74803	147	5.787402

Table 4.3 – Chrysler plastic totes similar in dimensions to Fiat plastic totes.

4.3 Analysis for Reducing Standard Container Types

Starting from the benchmarking analysis, it has been possible to highlight the difference in the quantity of standard container typologies utilized by the two companies in their supply chain. One objective of this study has been to check the possibility of reducing the number of standard container types used by Chrysler, and subsequently, to develop a strategy for reducing or deleting standard containers from future programs, as well as assessing which ones should be maintained. Such reductions and improvements tie in well with the overall environmental objectives of this research.

4.3.1 Benefits achievable with standard container types reduction

Reducing or deleting some types of standard containers for new programs usage will reduce the number of standard containers types to be managed along the supply chain over the years. This can lead to a higher level of standardization of handling equipment, rather than having many different equipment which increases complexity. Examples of typical equipment used in the warehouse and for line side display are shown in Figure 4.15 and Figure 4.16 respectively.

Increasing the container and equipment level of standardization, in turn, will increase the possibility to obtain important savings through an economy of scale when purchasing new items given that more of the *same* container is purchased or being maintained. Being able to order larger quantities of standard containers and equipment provides purchasing leverage for the buyer and cost advantages for the seller.

Figure 4.15 – Example of warehouse equipment for standard totes. *[24]*

Figure 4.16 – Example of line side equipment for standard totes. *[23]*

These improved economies of scale can be considered first as cost advantages that standard containers and equipment manufacturers obtain because of size, with cost per unit of output generally decreasing with increasing scale as fixed costs are spread out over more units of output. Often operational efficiency is also greater with increasing scale, leading to lower variable cost as well. Because of this cost reduction, standard container and equipment providers can lower the prices of their products, and ideally, pass on their benefits to the car maker and thereby increasing their competitiveness.

Having a reduced number of standard containers to manage in the supply chain will also enhance the possibility to implement an effective and efficient container pooling. This addresses weaknesses and reduces costs typical of car makers with a very complex standard container system. Many of these OEMs and suppliers maintain their own separate, multiple closed loop systems with different containers types: such inconsistency between the OEM and its partners limits any ability to share idle containers. This typically leads to having more containers in the system than needed, meaning significant investments are tied up in idle containers.

Moreover, difficulties in tracking and limited visibility mean a container might not make it to the right place at the right time: this often results in extra-costs for expendable back-up containers (e.g., cardboard) to be paid to suppliers. There is a greater environmental impact due to the cardboard to be disposed after the usage. The loss rate is also high, and a significant percentage (15%–20%) of packaging is lost during the life of the program due to the complexity in tracking. Overall, suppliers have to expend significant effort in managing different OEM requirements and container types which reduces their efficiency and, in turn, reduces the overall efficiency of the supply chain.

Alternatively, in the *pooling solution*, a third party or the OEM itself owns the fleet of standard returnable containers and manages the entire process: shipping, cleaning, preparing, and tracking of the containers, but only if the pooler is able to serve a sufficiently large number of programs. If so, it can generate efficiencies through reduced variability and economies of scale to lower the system-wide cost of packaging services. Pooling can reduce the overall logistics costs and environmental impact because the containers can travel shorter distances to the service centers.

OEMs and suppliers can ship more parts with fewer containers by reducing the safety stock, due to reduced system variability, and improving container utilization. Fewer losses through easier tracking as well as easier transfer of containers from one vehicle program to program can also reduce expenditures on containers.

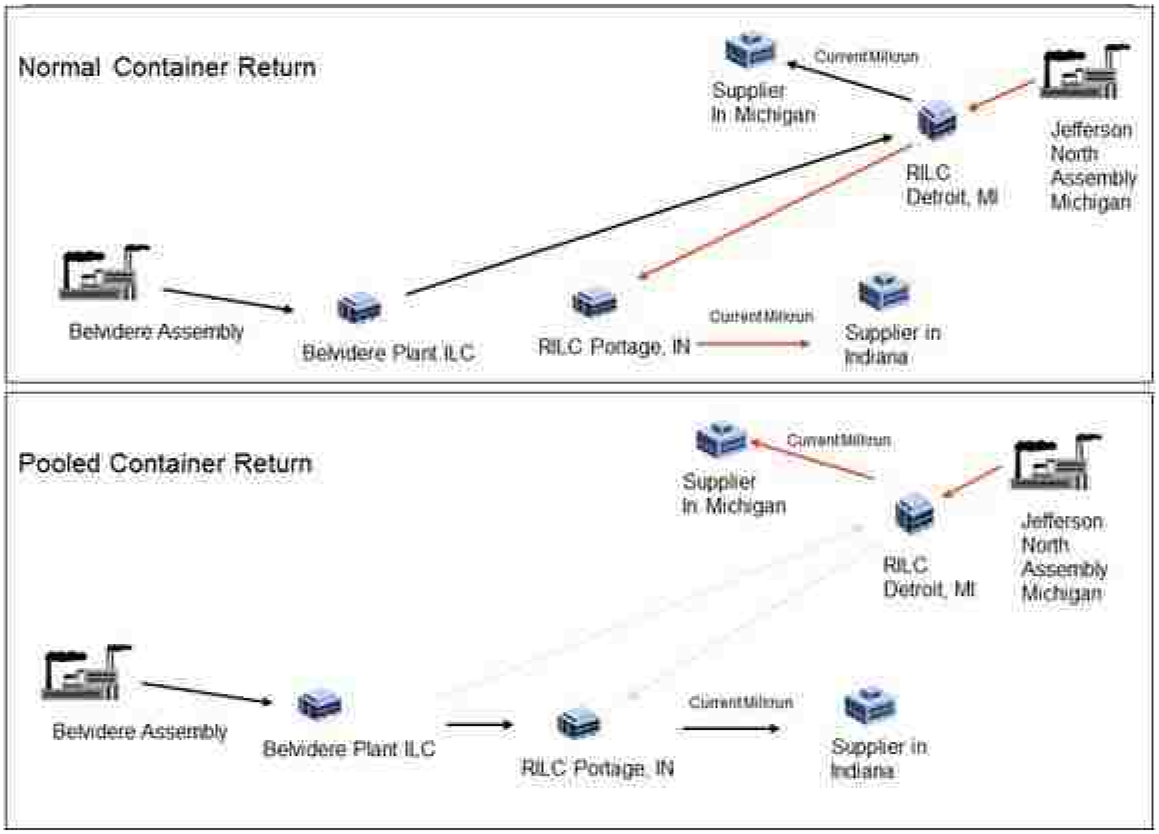


Figure 4.17 – Example of return of empty containers used by two different suppliers**.**

A streamlined container management can also reduce the staffing requirements at both suppliers and OEMs. Furthermore, reducing the number of standard container types will reduce the risk of obsolescence because a smaller number of standard container types shared between many programs has to meet the requirements given by many different components to be contained. Because of this, there will be a higher possibility that containers from a program being phased out can then be used in the launch of a new one.

Another aspect to be considered is that, reducing the number of standard container types will reduce the space required for the storage in the warehouses and buffers of OEM plants, integrated logistics centers, and suppliers. Space saving is due both to the reduction of the types of standard containers itself - different types of containers cannot be stacked over each other - and to the reduced "safety" stock of containers for each typology in case extras are needed. Saving space is very important for a company since the space that is not occupied can be used for other operations. Finally, reducing the number of standard container types will decrease environmental impacts overall due to reduced material handling and resource consumption.

Figure 4.18 – Standard containers storage area.

4.3.2 Chrysler Plants Analysis for Standard Container Types Reduction

All Chrysler assembly plants in Canada, United States of America and Mexico have been analyzed using the CRATES software to assess how the number of standard container types might be reduced or deleted from new vehicle production programs.

Figure 4.19 – Chrysler locations in Canada, U.S.A. and Mexico.

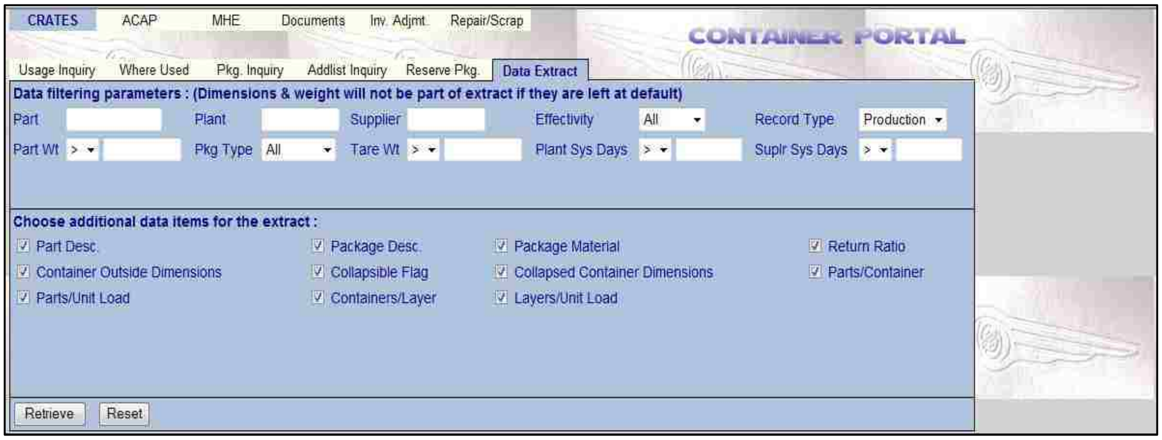


Figure 4.20 – CRATES software user interface.

As depicted in Figure 4.20, it is possible to investigate the data using the part number, the supplier number, or the plant number. Each supplier and plant is identified by a unique code. Furthermore, it is possible to consider all the part numbers used by a plant or produced by a supplier, or to select only the part numbers used by current production programs or by upcoming, future production programs. Some data filtering parameters can be including to isolate part weight, packaging type, packaging weight, plant system days and supplier system days. As a reference, the software allows obtaining information related to:

- part description: part number and part name;
- container outside dimensions;
- parts per unit load;
- package description (macro-family and identification number);
- collapsible flag;
- containers per layer;
- package material;
- collapsed container dimensions;
- layers per unit load;
- return ratio;
- parts per container.

The previous information are loaded in the system during the packaging selection phase of a new program and are reviewed weekly to guarantee their consistency in case of changes during the program life cycle. The engineering department, container management department, suppliers, and Ghafari - Chrysler's tier-1 in charge of the selection process of the container for each part number of a production program - have access to a program, Data Manager, in which it is possible to load and modify these data, and automatically update the CRATES software on a weekly basis. The information can be extracted from CRATES and loaded into Microsoft Excel® for further analysis to carry out operational activities and for management review.

With respect to the previous objective of reducing the number of standard containers, all Chrysler assembly plants have been analyzed to develop a complete scenario of the current situation. The following Chrysler plants analyzed are reported.

Canada

- Windsor Assembly Plant
- Brampton Assembly Plant

United States of America

- Warren Truck Assembly Plant
- Toledo North Assembly Plant
- Toledo South Assembly Plant
- Jefferson North Assembly Plant
- Belvidere Assembly Plant
- Sterling Heights Assembly Plant
- Conner Avenue Assembly Plant

Mexico

- Saltillo Truck Assembly Plant
- Toluca Assembly Plant
- Saltillo Truck/Van Assembly Plant

Furthermore, two Chrysler powertrain plants have been added in the analysis also to consider specific needs of powertrain operations: the Trenton Plant, and the Indiana Transmission Plant.

To develop the analysis, all the part numbers used in the assembly operations of each plant have been considered. All the part numbers used by each plant were not grouped by production program because logistics and production activities are frequently shared between the different programs assigned to a plant. All the containers in fact have to be managed, handled and stored by the plant independently from the production program. For this reason, all programs assigned to each plant have been considered for the analysis as part of an entire standard container system.

The strength of this methodology is to bring together the commonalities between *multiple, different programs* assigned to one plant and to develop improvements that are immediately useful for plant operations. Conversely, it would have been difficult from an operational point of view to focus on a single program as a basis for overall improvement.

Once all the part numbers used for assembly operations of each plant have been collected, the next step is to remove from the list all the part numbers no longer used in the assembly because of engineering changes to the components. However, it was not possible to make the software to do this filtering option automatically. Instead, a filtering function was implemented in Excel to accomplish this selection and to account only for the part numbers actually used in the plant at the moment of the analysis.

Each part number is defined by ten digits: the first eight are numerical, while the last two are letters. The letters are used to define the release of the component: if there two part numbers have the same first eight digits, the last two letters indicate which part is the latest version. For example, a part number ending with AB indicates it is a newer release than a part number with the same eight digits but ending with AA.

After compiling the list of all the part numbers used in a plant, a standard packaging number is associated with each part number of the list. Because thousands of components are used to assembly a vehicle, it is necessary to use Excel® software to sort and evaluate the data.

A function has been used to extrapolate the first eight digits of the part number array in order not to count more than once the same part number.

Part ID. Number	Package ID. Number
04560152AC	CT321507
04560221AA	CT121507
04560232AB	CT241507
04578779AB	CT241507
04578779AC	CT241507
04578782AA	CT241507
04578782AB	CT241507
04581512AA	CT121505
04581657AA	CT242209
04581657AB	CT242209
04581665AA	CT242209
04581666AA	CT242209
04581666AB	CT242209
04581667AA	CT242209
04581667AB	CT242209
04581668AA	CT242209
04581668AB	CT242209
04589050AA	CT121507
04589131AF	CT241514
04589408AA	CT241509
04589533AB	CT241509
04589656AB	CT241514
04589688AD	CT241507
04589689AA	CT121509
04589770AC	CT481507
04589781AA	CT121507
04589881AH	CT241514

Table 4.4– Example of a small portion of the list part number/associated standard packaging for Jefferson North Assembly Plant.

To compute how many part numbers are assigned to each type of standard container, another function has been used to calculate how many times a certain value or array of letters is repeated.

Table 4.5 shows an example from the Jefferson North Assembly Plant Analysis. In the second column, all the standard tote types used by the plant are listed. In the third column the corresponding number of part numbers used by the plant assigned to each standard container type and computed by this function is reported. This methodology has been followed to start the analysis for each plant. Moreover, each analysis by plant, in turn, has been divided in sub-analyses for each standard container macro-family (plastic totes, plastic bulks, steel bulks).

Ranking	Package ID. Number	Counts of Part Numbers Assigned to the Container Type
1	CT241509	243
2	CT121507	188
3	CT241507	157
4	CT241514	132
5	CT242209	97
6	CT321507	92
7	CT242214	90
8	CT242211	78
9	CT481511	44
10	CT481507	42
11	CT242207	27
12	CT121509	17
13	CT121505	10
14	CT482207	10
15	CT241505	4
16	CT241509XL	2

Table 4.5 – Number of part numbers assigned to each standard tote type, Jefferson North Assembly Plant.

After calculating the number of part numbers assigned to each standard container type, the data has been further assessed to suggest how container types can be reduced or deleted in new production program launches.

The percentages of part numbers (components used for car assembly with the same ID number) assigned to each standard container type (containers with the same container ID) over the total amount of part numbers (components) used by the investigated plant has been calculated; an example from Jefferson North Assembly Plant analysis is shown in Table 4.6. This percentage is computed over the total number of part numbers used by the investigated plant assigned to the considered container macro-family (plastic totes/plastic bulk containers/steel bulk containers). Then, a Pareto chart has been developed to evaluate what were the standard container types in which the greatest majority of the part numbers assigned to that container macro family were going into. For example, referring to Table 4.6 we would like to find out what are the container IDs (container types) that can contain the majority of part numbers (components with the same ID number) assigned to the macro-family of the "plastic totes" and used by Jefferson North Assembly Plant.

Pareto analysis is a statistical technique in decision making for selecting a limited number of tasks that produce a significant overall effect. It is based on the Pareto principle that a large majority of factors are produced by a few key causes. Pareto analysis is a formal technique useful in situations in which many possible courses of action are competing for attention. In essence, the problem solver estimates the benefit delivered by each action, then selects several of the most effective actions that deliver an overall benefit that can be expected to be reasonably close to the maximum benefit possible.

Ranking	Package ID. Number (Container Type)	Percentage of Part Numbers Assigned to the Container Type	Cumulative Percentage
1	CT241509	19.7%	19.7%
2	CT121507	15.2%	35.0%
3	CT241507	12.7%	47.7%
4	CT241514	10.7%	58.4%
5	CT242209	7.9%	66.3%
6	CT321507	7.5%	73.7%
7	CT242214	7.3%	81.0%
8	CT242211	6.3%	87.3%
9	CT481511	3.6%	90.9%
10	CT481507	3.4%	94.3%
11	CT242207	2.2%	96.5%
12	CT121509	1.4%	97.9%
13	CT121505	0.8%	98.7%
14	CT482207	0.8%	99.5%
15	CT241505	0.3%	99.8%
16	CT241509XL	0.2%	100.0%

Table 4.6 – Percentage of part numbers assigned to each standard tote type, Jefferson North Assembly Plant

Generally speaking, this technique helps identify the predominant factors that need to be considered to capture the majority of the issues addressed.

A Pareto analysis has been adapted and applied in this container management application to find out the standard container types (of a selected macro family and for the investigated plant) into which the majority of the part numbers used by the plant are going into, and to also highlight the ones used just for a very small number of part numbers.

A Pareto chart in which individual values are represented in descending order by bars, and the line represents the cumulative total, has been created for each standard container macro family and plant to show the outcomes of Pareto analysis.

Figure 4.21 shows an example of Pareto chart taken from the analysis for standard totes used at Jefferson North Assembly Plant (the Pareto Analysis has been developed using data from Table 4.6 and Table 4.5). The vertical axis is the cumulative percentage of the total number of occurrences. Because the number of occurrences is in decreasing order, the cumulative function is a concave function. The Pareto charts were developed using the following steps:

- Step 1: creation of an explicit table listing the standard container types used by the plant (for each container macro family) and their usage frequency as number of part numbers assigned to each of them.
- Step 2: creation of an explicit table listing the standard container types used by the plant (for each container macro family) and their usage frequency as a percentage of part numbers assigned over the total amount of part numbers used by the plant and assigned to the investigated macro family.
- Step 3: arrangement of the rows in the decreasing order of occurrence frequency (i.e., the most used container type first).
- Step 4: insertion of a cumulative percentage column to the table.
- Step 5: creation of a bar graph with container IDs on x- and percent frequency on y-axis.

- Step 6: plot creation with container IDs on x- and cumulative percentage on y-axis.
- Step 7: linkage of the above points to form a curve.
- Step 8: placing a threshold line at a certain value that incorporates the most of the addressed factors on y-axis parallel to x-axis. Then drop the line at the point of intersection with the curve on x-axis. This point on the x-axis separates the most used container types to the least used ones. Based on the literature, 80% is often accepted as a reasonable threshold value.
- Step 9: explicitly review of the chart to check the consistency.

Equation 4.1 shows the formula used to find each point P_i of the interpolating cumulative line of Pareto chart.

$$P_i = \frac{\sum_i^n F_i}{\sum F} \tag{4.1}$$

In equation 4.1, F_i is the frequency of occurrence for each container type or, in other words, the number of part numbers assigned to each standard container type of the table created at step 1. The container types are ordered in the table in decreasing order of occurrence frequency. 80% of the total amount of part numbers assigned to standard totes and used by the investigated plant were packaged into just seven standard totes types, while the remaining twenty per cent were packaged into a further nine standard tote types. Jefferson North Assembly Plant was, at the time of this analysis, using sixteen different standard totes for its assembly operations.

This preliminary assessment helps assess the possibility to reduce the number of standard container types, and determines what standard containers are most used by the plant. These containers – particularly the most commonly used ones (the ones to which the majority of the part numbers are assigned) - can then be checked for their potential to meet the majority of the requirements imposed by different components.

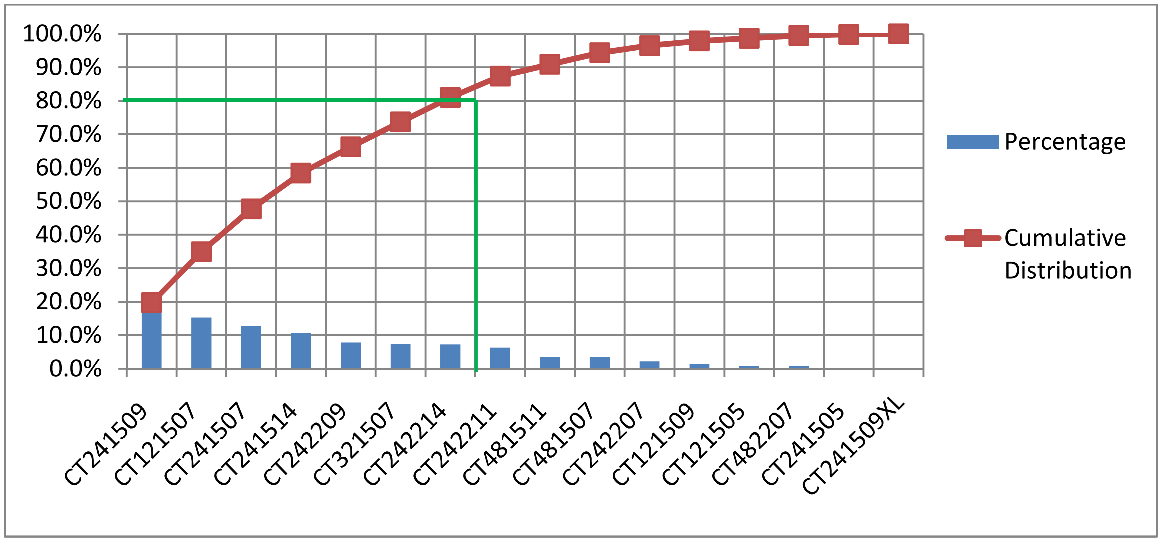


Figure 4.21 – Pareto chart, example from standard totes analysis, Jefferson North Assembly Plant

Afterwards, the focus changes to the container types in the "low usage area" of the graph. To save resources, could the part number contained in these lesser-used containers be re-assigned to the most used containers?

This is a quite complex process since many aspects have to be considered. The most important ones are related to the dimension compatibility, new filling percentages (in turn given by dimensions, weight limit requirements, etc.), the balance between potential arising and decreasing costs, and environmental impacts. In terms of dimensional compatibility, components can often fit in other standard containers with dimensions similar (but not the same) to the dimensions of the currently assigned container. For this reason, a further analysis considering similar container dimensions has been developed.

Technical data related to the dimensions of each standard container type have been gathered from the Chrysler Container Management department and standard container manufacturer. For standard totes, the procedure has been easier since the identification number of the container indicates the dimension. For instance, the standard tote code CT241509 identifies a standard tote of 24 inches length, 15 inches width and 9 inches height. Additional tables have been created, listing footprints and heights of each standard container type.

Package ID Number	Footprint	Height	Number of Assigned Part Numbers	Percentage
CT121505	12x15	05	10	0.8%
CT121507	12x15	07	188	15.2%
CT121509	12x15	09	17	1.4%
CT241505	24x15	05	4	0.3%
CT241507	24x15	07	157	12.7%
CT241509	24x15	09	243	19.7%
CT241509XL	24x15	09	2	0.2%
CT241514	24x15	14	132	10.7%
CT242207	24x22	07	27	2.2%
CT242209	24x22	09	97	7.9%
CT242211	24x22	11	78	6.3%
CT242214	24x22	14	90	7.3%
CT321507	32x15	07	92	7.5%
CT481507	48x15	07	42	3.4%
CT481511	48x15	11	44	3.6%
CT482207	48x22	07	10	0.8%

Table 4.7 – Example of standard tote dimension analysis, Jefferson North Assembly Plant.

After creating these tables, the data have been analyzed to produce further graphical output.

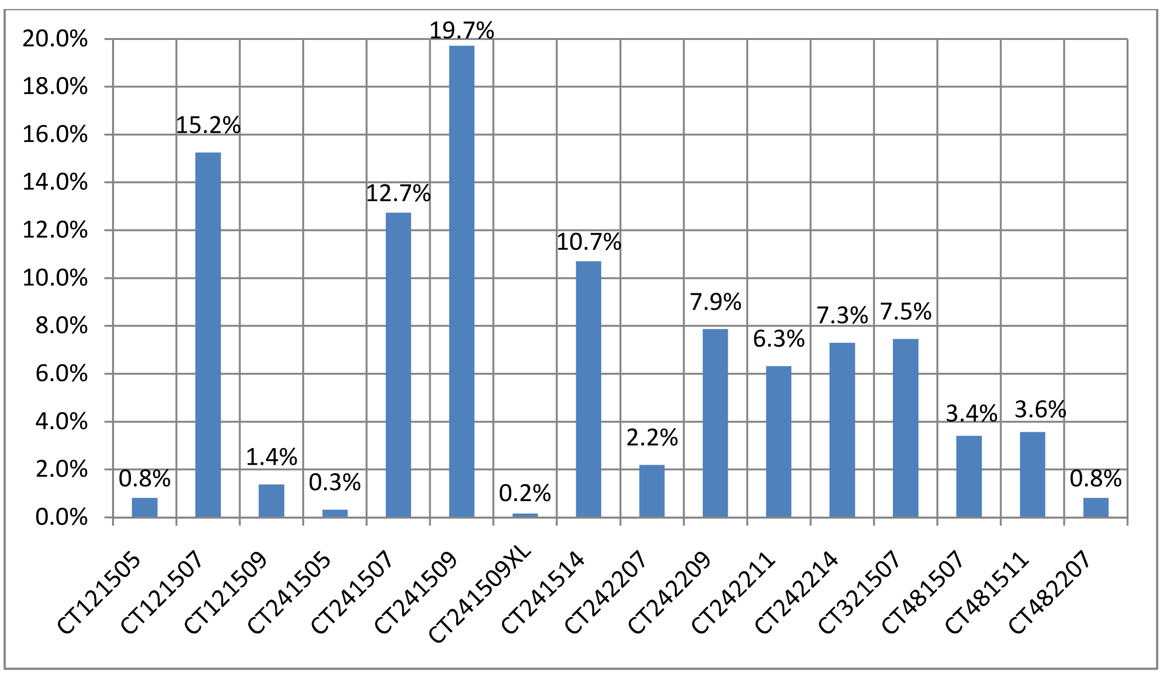


Figure 4.22 – Dimension analysis, example from standard totes reduction study, Jefferson North Assembly Plant.

Finally, all the analyses made on a single plant basis (Canada, U.S.A. and Mexico) have been incorporated in an overall study to obtain company-wide insights that could prove valuable at an overall corporate level. For example, deleting some containers from not only an individual plant list but from the overall container list of containers used by the company means that no Chrysler plant will be able to use them. If such containers are shown to be redundant or not needed, then even higher benefits could be obtained for the company overall throughout its supply chain as these less efficient containers will no longer be used. The outcomes of these analyses and studies will be presented in Chapter 6

CHAPTER 5

PACKAGING SELECTION MODEL CREATION

Creating a model for selecting rapidly and consistently the best packaging solution from economic and environmental perspectives has been one of the key objectives of this research. For the model, the research activities focused on two new production programs: 1) the 2014 KL Program (Jeep Cherokee) launched at Toledo North Assembly Plant; and 2) the 2015 UF Program, which will be launched at the Sterling Heights Assembly Plant. Many meetings were held with experts of Chrysler Material Logistics Management team as well as Ghafari and Ryder Logistics managers to document and analyze the actual decision making process and the main operational and technical constraints and issues. As shown in Figure 5.1, there are a number of stakeholders and aspects that influence this model development.

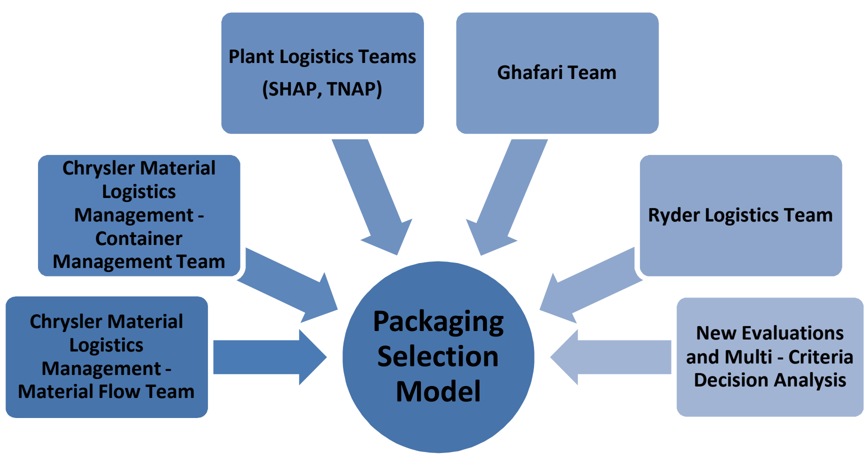


Figure 5.1 – Data gathering and cooperation from many company departments and Chrysler tier-1s, packaging selection model creation.

5.1 Technical, Ergonomics and Quality Requirements

Ghafari is a Tier-1 supplier which provides process engineers who work closely with Chrysler's Material Logistics Management team to carry out the packaging selection process for each part number from the Bill of Materials (BOM) of a new production program. Normally, there is no standard procedure for selecting the packaging solution for each part number of the BOM. Instead, each time a new production program is launched, the selection process for packaging is “re-created” and involves extensive meetings between Ghafari employees, members of the Chrysler Material Logistics Management team, plant Logistics teams, Material Flow teams and other suppliers to propose solutions, develop them, and then validate them. Because this process is resource intensive and time consuming, selecting the packaging solution usually involves:

1. If a part number is a carry-over part (a part re-used from previous or current production program), the previous packaging solution is adopted for the new program.
2. If a part number is not a carry-over part but is similar to part numbers used by previous or current production programs, the previous solution is also adopted for the new program.
3. If a part number is brand new, very different in shape or dimensions from previous ones, then extensive meetings between personnel take place to assess and decide how to select the best packaging solution.

The procedure followed in the first two instances discourages exploring alternative solutions which might be superior from an operational, economic and/or environmental perspective. In fact, all the evaluations in selecting for the *first time* the packaging solution for a part number were made on the basis of specific operation characteristics describing the production program investigated at that time. As a result, they would likely not be optimized for other new operations (new production programs) characterized by different locations, assembly processes, material handling equipment, suppliers, and other factors. Furthermore, in the third instance, economic and environmental evaluations are not considered. Only technical, operational, quality and material flow requirements are taken into account during the decision making process.

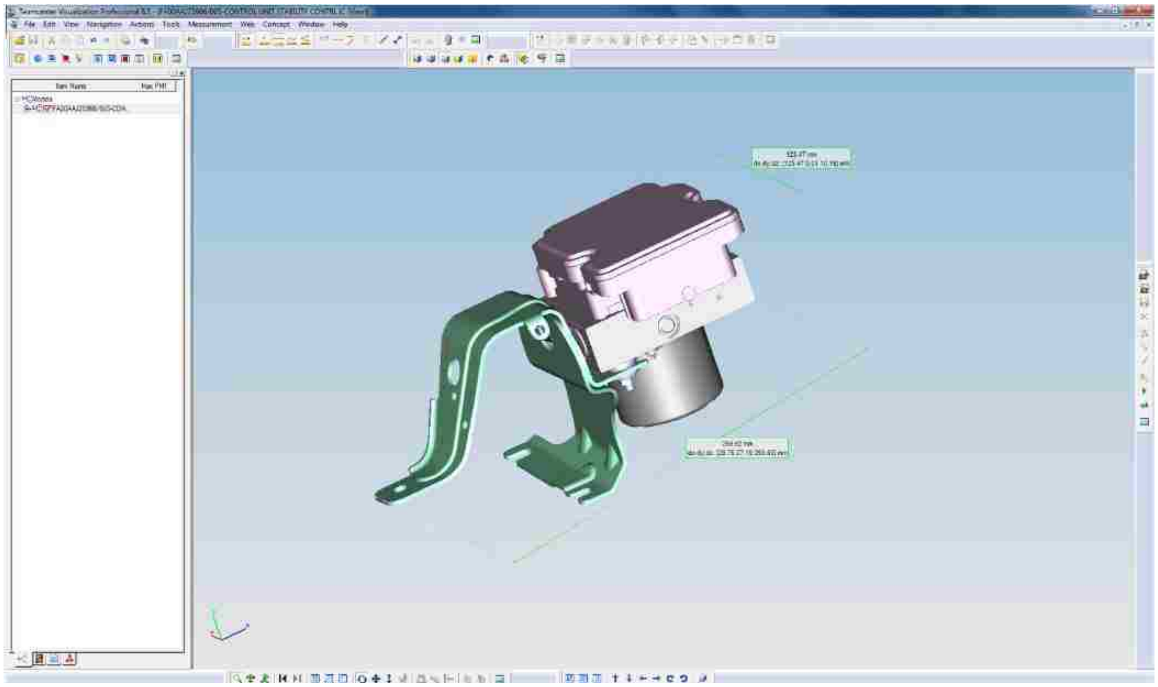


Figure 5.2 – Component dimension evaluation by means of Teamcenter Visualization Professional® software.

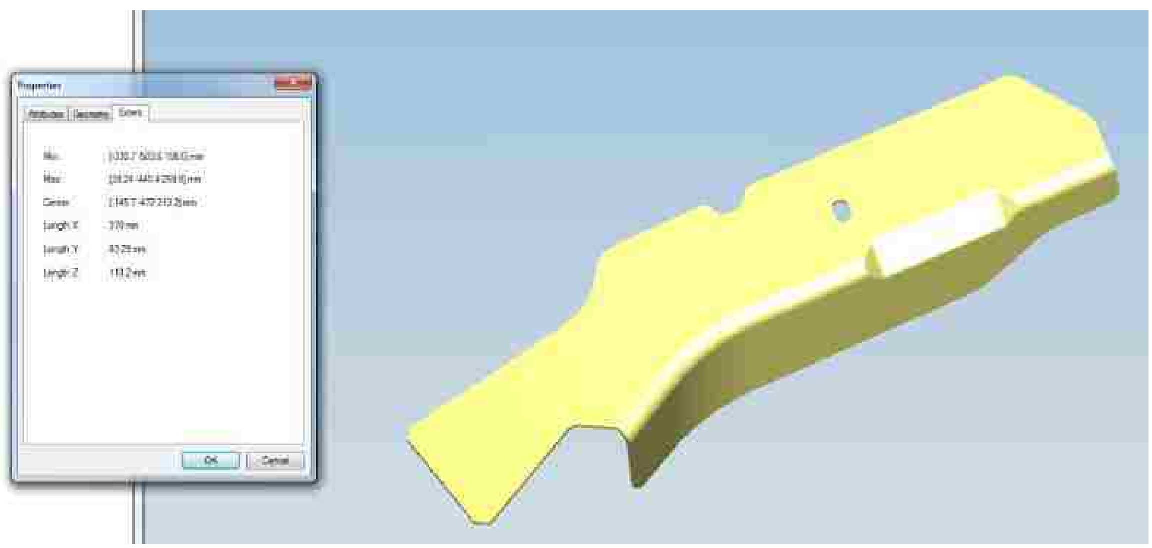


Figure 5.3 – Dimension property panel, Teamcenter Visualization Professional® software.

The decision process begins with evaluating the dimensions of the component using the Teamcenter Visualization Professional® software, as depicted in Figure 5.2 and Figure 5.3. This evaluates the overall dimensions along the x, y and z directions as well as other geometrical properties using the CAD information of the considered component. After evaluating the geometrical dimensions, it is possible to evaluate into what containers the part can be fitted. To evaluate how many parts can fit in the container, or the density, CADs of the part and of the container can be used or else physically tested for fit. Finally, there are some general heuristics that are generally followed:

1. Selecte standard containers whenever possible.
2. Use the smallest possible plastic tote first.
3. If it is not possible to use a plastic tote, try using the smallest possible plastic standard bulk container.
4. Use steel containers only for heavy components in order to achieve acceptable density inside the container due to the higher load capacity with respect to plastic containers.

The part weight can be obtained from the vehicle weights system as represented in Figure 5.4. By filling in the part number it is possible to get part weight both in pounds and kilograms measurement unit and its release date (date of the last update of the information inserted in the system)

Figure 5.4 – Vehicle weights system, example of weight inquiry for a part number.

However, there are limitations and constraints when selecting the container solution for a part number.

With respect to weight, there are limits dictated by the strength of the container and by ergonomic requirements (e.g., when being lifted by a worker). Because small lot plastic totes are often handled manually by the operators, ergonomic requirements regarding the maximum total weight must be met. The total weight is given by the sum of partial weights: container weight, parts weight, dunnage weight (in case of container with dunnage inside). As shown in Table 5.1 there are two different limits for standard totes, depending on the type of motion made by the operator. If the container has to be moved in the vertical direction (lift), the ergonomic limit will be more stringent than compared to the horizontal motion criteria.

	Horizontal Motion	Lift
Weight Limit Requirement for Std. Totes	30.0	20.0
Weight Limit Requirement for Std. Bulks	1500.0	

Table 5.1 – Ergonomic weight limit requirements, lbs.

In addition, there is also an ergonomic weight limit requirement of 1500 lbs. for bulk containers (total weight given by the sum of dolly weight, container weight, parts weight and dunnage weight) should the dolly have to be moved manually.

Quality requirements also have to be considered. The Quality Department can require to use protective dunnage inside the container (small tote or bulk container). As previously mentioned, interior dunnage protects valuable or aesthetic parts from damage during transport, assembly and storage. Dunnage is custom designed and constructed with expendable or returnable materials. Popular dunnage designs include custom cardboard or die-cut plastic corrugated divider sets, saw-cut foam inserts, pigeon hole dunnage, custom thermorformed trays, sewn fabric bags, foam rails and molded foam inserts.

Each time dunnage is required, a certain percentage of the volume inside the container is lost and, in turn, the container density (number of parts contained) will be lower.

Figure 5.5 – Example of dunnage use for external mirrors.

Finally, there are *stages* in the decision making process for assigning a container to a part number. These are defined as:

- *baseline*: total guess provided by the decision making team;
- *proposed*: the supplier team agrees with the solution suggested;
- *actual*: the plant logistics team and material flow team agree with the solution suggested;
- *validated*: Material Logistics Management team representatives control the adopted solution during the assembly operations (usually in pilot or pre-production trials, but sometimes also later) and should every requirement be approved, the solution is adopted.

5.2 Logistics Information and Requirements

Logistical information is key to successfully choosing and implementing a packaging solution. For this research, this information has been gathered thanks to Ryder Logistics managers in charge of developing logistics services for Chrysler's new production programs.

Packaging design specifications such as size, weight, and stack-ability drastically impact the cost of transportation. Facility constraints, volume, density, and ship frequency are factored to develop a shipping mode. Each supplier of production parts and materials must have supplier routing instructions from the OEM Logistics Department listing the "Primary Carrier". The primary carrier is the preferred carrier (which usually has been assessed as providing the most efficient solution) and using a carrier other than the primary carrier must be approved by Corporate Logistics. Routing instructions should include information regarding supplier routing for premium shipments. The "Expedite" mode of shipping, for example, is utilized for unforeseen circumstances mean the primary carrier cannot be used, and therefore a different mode of transportation and a different appropriate packaging could be required. This deviation usually must be approved by Production Control team and the emergency method specified governs the type of packaging to be employed. Finally, Chrysler's primary modes of shipping are by railroad car, truckload direct carrier, intermodal, truckload "geographic shipping/receiving", scheduled delivery programs, dedicated logistics centers, common carrier less than truckload, supplier delivery/private carrier, and parcel delivery.

5.2.1 Railroad Boxcar

Railroad boxcars are a carload shipment to a single destination. Rail transportation tends to be more economical than road transportation when large volumes of material are shipped, when racks sizes exceed standard over the road trailer dimensions, or long distances exist between origin and destination.

Standard boxcar dimensions are 50', 60' and 86' in length. Fifty feet cars have been phased out of most rail fleets, sixty feet cars are used primarily for engines and transmissions, while eighty-six feet cars are mainly used for stampings and miscellaneous commodities. On all cars void spaces should be minimized, and usually spaces in cars greater than five inches need to be braced by wood or bulkheads to avoid damage in transit. Rail shipments utilize either 'consist' or 'common' boxcars. As far as consist boxcars are concerned, the shipment is authorized and developed in conjunction with receiving activity and boxcars are in assigned service at the origin plant. Moreover, material is shipped in uniform quantities in a repetitive manner throughout the model-year using pre-engineered loading patterns and dunnage arrangements. Special returnable dunnage or equipment may be required to contain and protect material. However, if common cars are used, any material is not loaded in set quantities and boxcars are not assigned to a specific activity.

5.2.2 Truckload Direct Carrier

Truckload shipments are highly desirable because of pick-up and delivery flexibility, and the relatively short travel time between shipping and destination points. Chrysler's standard truckload trailers are 53 feet long (see Figure 5.6), 102 inches wide and 110 inches tall.

As with railroad boxcars, on all truckload shipments dead spaces must be minimized. The general rule requires that spaces in truckloads greater than three inches must be braced by wood or bulkheads to avoid shifting and damage during transit.

Figure 5.6 – 53' standard truckload trailer.

5.2.3 Intermodal

Material is shipped between two points by a road-and-rail combination. Intermodal routings can be a trailer on a flat car, a roadrailer, or a stack container (see Figure 5.7 for examples). Using roadrailers, due to their construction, the trailers can be pulled directly behind other freight equipment without the use of trailer flatcars.

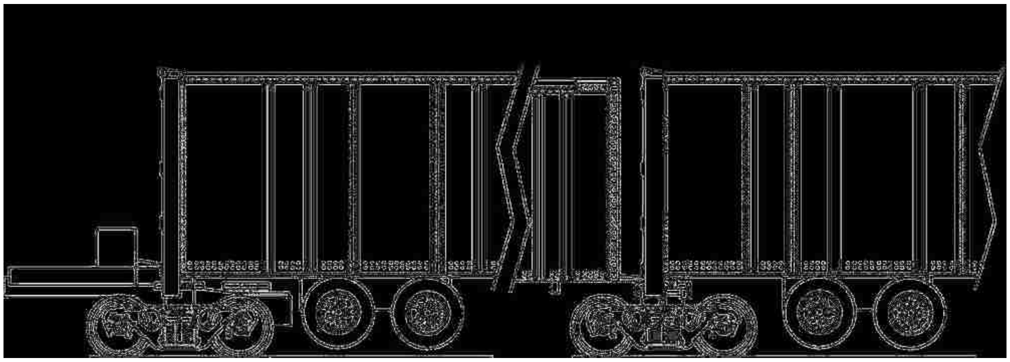


Figure 5.7 – Sketch of a roadrailer. *[25]*

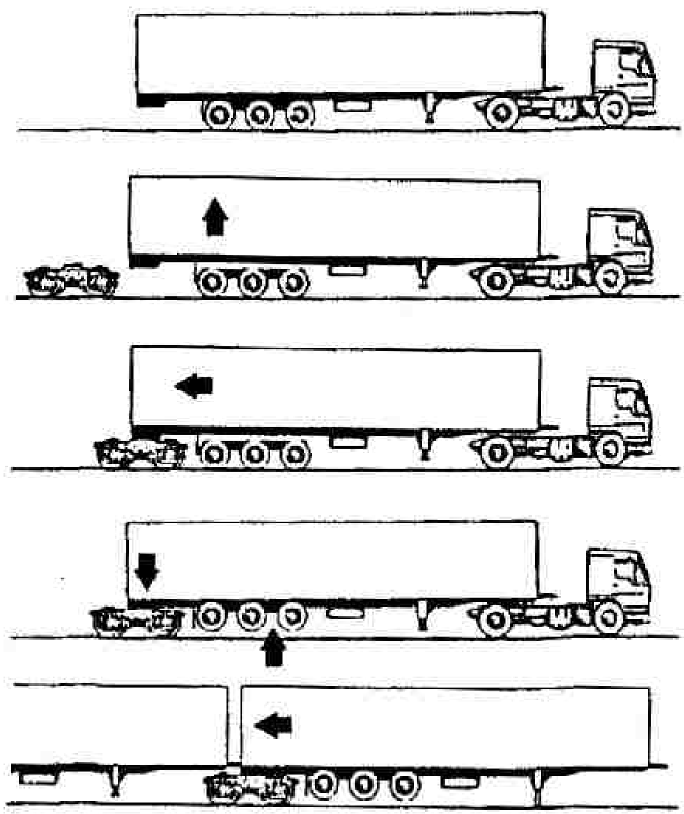


Figure 5.8 – Roadrailer setup. *[26]*

Figure 5.9 – Stack containers. *[27]*

5.2.4 Truckload Geographic Shipping/Receiving (GEO)

This shipping mode relates to shipments containing two or more suppliers on one truck and shipments containing supplies for two or more plants. The percentage of goods shipped in this way depends also on production volumes and thus can vary from one day to another. This is one of the purpose of this mode: transport variable percentages for different plants in order to try to saturate as much as possible the trailer volume even if there are fluctuations in production volumes (by shipping to various plants it may be possible to balance lower volumes with higher volumes).

Figure 5.10 – Milk run. *[28]*

5.2.5 Scheduled Delivery Program

Less than truckload shipments (the trailer is not fully saturated in volume) are picked up for a specific destination, with a dedicated carrier, based on a *Just in Time* schedule.

5.2.6 Dedicated Logistics Centers

Less than truckload shipments are picked up for multiple Chrysler destinations, with a dedicated carrier, into a cross-dock, based on a *Just in Time* schedule. Cross-docking is the practice of unloading materials from an incoming semi-trailer truck or railroad car and loading these materials directly into outbound trucks, trailers, or rail cars, with little or no storage in between (Figure 5.11). This may be done to change the type of conveyance, to sort material intended for different destinations, or to combine material from different origins into transport vehicles or containers with the same, or similar destination.

5.2.7 Common Carrier LTL

Less than truckload (LTL) direct with a common carrier is utilized in certain circumstances when it has been deemed the most efficient means of transport, usually due to the geographic location of the ship point.

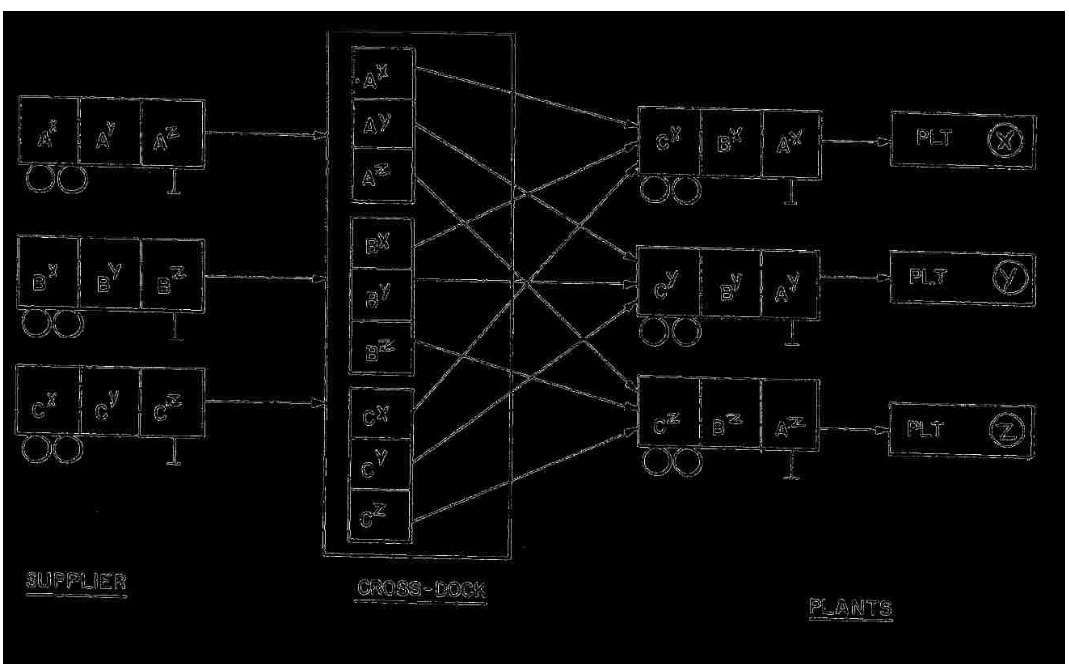


Figure 5.11 – Cross dock functioning scheme. *[29]*

5.2.8 Supplier Delivery/Private Carrier

In some instances suppliers provide regular parts delivery service on their own trucks, leased trucks or contract carriers. Return loads of materials, containers, pallets, and so on can make such moves even more beneficial to both parties.

5.2.9 Parcel Delivery (PD)

All shipments weighing 70 pounds or less are usually routed via United Parcel Service.

5.2.10 Emergency Methods

Chrysler's emergency methods of shipping are via Expedited truck, "full" truckload, air express, and air charter. All emergency shipments must have prior approval of the Production Control Releasing Activity. The shipper must receive an AETC, (Authorization Excess Transportation Charge) number which is to be included on the bill of lading and the responsibility for correctly packaging, identifying and addressing parts and materials remains with the supplier.

5.2.11 Indications and Guidelines for Mode Determination

Table 5.2 and 5.3 shows some key values helpful when trying to decide the best shipping mode and transportation mode to be used for the shipment. Further analyses, studies and business cases are needed each time to validate the first indication provided by this general guideline, but it could be helpful to start with a first suggestion based on past experience when addressing a new situation. The indicative values have been decided on the basis of logistics studies and from past program experiences.

Daily Ship Volume	Ship Mode
0 to 20 %	RILC or LTL/PD
20 to 60 %	GEO or Low Frequency Direct Ship
> 60 %	Direct Ship

Table 5.2 – Daily ship volume – suggested ship mode.

Distance to the Plant	Truck or Rail/Intermodal
< 500	Truck
> 500	Rail or Intermodal where available

Table 5.3 – Distance to the plant – suggested mean of transport.

5.2.12 Bill of Lading

Packing slips and bills of lading (BOL) must be submitted with every shipment whether they be for direct shipments or shipments moving through a consolidation point. A BOL represents an agreement between the supplier and carrier that the freight pallet quantity is correct and that the material is damage-free for pickup. There is a distinction: a signed BOL represents the carrier's liability for pallet quantity and that the material was in good shipping condition when received; however, the supplier is liable that the individual part quantity is correct and the material is in good shipping condition. The supplier is responsible for sealing the package and to note it as such on the BOL. As a result, if a seal is broken at the arrival at the plant, the carrier is responsible for any missing pallet material. If the seal is intact at the plant, the supplier is responsible for content. In the case where the carrier is not allowed on the suppliers dock, the carrier is to mark on all of the BOLs "Shipper Load & Count" and the supplier is responsible for the entire load (shortage and damage due to staging the material). The supplier is responsible to properly secure all material on the trailer.

5.2.13 Equipment Types and Dimensions

There are many possible equipment types that can be used for shipping components from one location to another along the supply chain. Table 5.4 shows all the equipment types used by Chrysler Group with related dimensions and maximum allowed weight.

As far as truck shipping mode is concerned, the most used types are 53 Ft. Drop Deck, 53 Ft. Standard and 53 Ft. Tri-Axle U.S. are the most used for road shipments in North America. The dimensions of 53 Ft. Standard and of 53 Ft. Tri-Axle U.S. are identical but the Tri-Axle allows a weight load 20,000 lbs. higher than the standard one.

The most used equipment type for Mexico is the 53 Ft. Cama Baja, while the 86 Ft. Rail Platform is the one of the most used equipment types for rail transportation, with 950” x 122” x 200” dimensions and 140000 lbs. maximum weight.

Equipment Type	*Desc.*	*Max Weight (lbs.)*	*L In.*	*W in.*	*H in.*
53 FT. STANDARD	Truck	45000	626	99	104
53 FT. Heavy duty	Truck	44000	626	99	104
48 FT. STANDARD	Truck	45000	566	99	104
53 FT. DROP DECK	Truck	45000	509	99	120
53 FT. STACK TRAIN	Intermodal	41500	626	99	102
53 FT TRI-AXLE U.S.	Truck	65000	626	99	104
86 FT. RAIL CAR HIGH CUBE	Rail Boxcar	140000	1032	109	147
60 FT. RAIL CAR HIGH CUBE	Rail Boxcar	200000	720	109	147
60 FT. RAIL CAR LOW CUBE	Rail Boxcar	200000	720	109	126
40 FT. TWIN TRAILERS	Truck - MX	80000	940	96	104
53 FT CAMA BAJA	Truck - MX	42000	575	99	126
53 FT. MEXICAN	Truck - MX	45000	625	99	106
20 FT. ST SEA CAN	Ocean	42000	232	92	90
40 FT. HIGH SEA CAN	Ocean	42000	474	92	102
40 FT. ST SEA CAN	Ocean	42000	474	92	90
53 FT. ST- CANADIAN	Truck - CAN	52000	626	99	104
89 FT. FLAT BED	Rail Flatbed	140000	1068	123	206
86 FT RAIL PLATFORM	Rail Flatbed	140000	950	122	200

Table 5.4 – Equipment types and dimensions, America.

5.3 Material Flow, Material Handling and Operational Requirements

Along with technical, quality and logistics requirements, material flow and operational requirements and information are needed to develop a consistent packaging selection model.

5.3.1 Material Classification

Each component of the bill of material needs to be classified to guide the shipping logistics from time, cost and quality perspectives. For each different type of classified material, expectations of productivity set by Fiat and Chrysler Workplace Organization and World Class Logistics principles have to be met.

Establishing a common methodology based on material characteristics to classify parts helps identify the priority of action in planning supply chain logistics. This also helps assess new program logistic processes and evaluates existing processes for improvement actions planning. To classify components, following World Class Logistics principles, different criteria are considered to incorporate all the part characteristics affecting logistics processes. The primary focus is on the physical characteristics (e.g., size), parts' cost and parts' variants. Table 5.5 presents all the possible, current classifications.

Production process constraints have also to be considered; for instance, a multi-vehicle/model assembly line could increase the number of variations. The same components used to assemble different vehicles or models can fall into different logistic families, which are group of parts with the same logistic flow from supplier to point of use. Even if the part is the same from one production to another, they can have different flows depending on the complexity of each model.

Material classification is usually utilized just for parts received by the assembly plant and to be assembled in the line production process or in other areas inside the plant ,such as smaller areas for sub-systems and modules assembly. It is critical to note that parts integrated in modules, systems or sub-systems are not part of the material classification because these modules and systems are later considered to be a a "single part". Because of the dynamic current between a supplier and an OEM, the material classification of module components generally is within the supplier's scope.

An "A" parts is one identified as expensive, bulky (large dimensions), or characterized by many variants. The logistics of these parts have to be managed very carefully in order not to have significant expenses and losses in assembly processes. Within the “A” class, there are further sub-classifications; for example, “expensive” parts are identified with the letters “AA”. To identify expensive parts the following procedure is applied.

- The total value of the “tracked vehicle” (most commonly produced version of the vehicle) should be considered starting from the bill of materials and adding the value of each component.
- The components are sorted by decreasing value and a threshold chosen. The threshold is the value of the component above which the cumulative value is approximately fifty percent of the whole “tracked vehicle” value.
- In the case of multi-model production line, the threshold should be the minimum threshold among the different models.

Class		Type	Sub Class	
A	A	EXPENSIVE	*AA.1*	*many variants and bulky*
			AA.2	*bulky*
			AA.3	*many variants*
			AA.4	*other expensive*
	B	BULKY (Big Components)	*AB.1*	*many variants*
			AB.2	*other bulky*
	C	MANY VARIANTS	*AC*	
B		NORMAL	*B*	
C		SMALL COMPONENTS (Fasteners)	*C*	

Table 5.5 – Material classification.

The “AB” class identifies components which have large, bulky dimensions. A component is usually considered bulky if its volume is greater than 60 L, in which it will be assigned to a standard container. If the component is at or exceeds 1200 L, it will be assigned to a specific container.

The “AC” class indicates parts characterized by many variants. Generally components which have three or more variations (e.g., different colours) are considered in this category. Three variations is a standard reference quantity but if any space issues or other constraints at the plant arise, a lower quantity can be used. Another case in which a quantity lower than three can be chosen is when the process is characterized by the high possibility of mistake during picking operations (i.e., activities of picking up parts in the storage area before proceeding to the assembly line).

The “C” class identifies components with very small dimensions such as “fasteners” (e.g., nuts, screw, bolts, springs) and all small parts with a volume usually lower than 0.015 L.

The “B” class is assigned to all the “normal” components which have not been assigned to classes “A” or “C” during the classification process. Essentially, these are components that do not fall into either size extreme, nor are they particularly valuable or cumbersome to handle.

Finally, within “AA” class there are additional sub-classifications such as “AA.1” for parts that are expensive, with many variants, and are bulky; “AA.2” for parts which are both expensive and bulky; “AA.3” for parts which are both expensive and many variants; and “AA.4” for other expensive parts which are not assigned to one of the previous group. Within the “AB” class, the “AB.1” sub-classification includes parts which are both bulky and many variants, while “AB.2” sub-class identifies other bulky parts not assigned to the other categories.

5.3.2 Material Classification, Maximum Inventory Level and Material Flow Type

Table 5.6 highlights the maximum inventory level for each material class. It is important to maintain a low inventory level especially for “A” and “B” class parts in order to decrease as much as possible the value tied up in the warehouse and buffers, while at the same time ensuring the requested service level. Starting from the material classification of the investigated part, the matrix provides the user with the maximum inventory level suggested by World Class Logistics principles. The matrix does not provide unique values for the maximum inventory level but three possible alternatives (choice 1, choice 2, choice 3) since the maximum inventory level also depends on the efficiency of the logistics and production activities.

Class		Type	Sub Class	Inventory Level Requirements		
				Choice 3	Choice 2	Choice 1
A	A	EXPENSIVE	*AA.1*	*< 2 hours*	*< 1 hour*	*< 30 minutes*
			AA.2			
			AA.3			
			AA.4			
	B	BULKY (Big Components)	*AB.1*	*< 2 hours*	*< 1 hour*	*< 30 minutes*
			AB.2			
	C	MANY VARIATIONS	*AC*	*< 2 days*	*< 1 day*	*< 0,5 days*
B		NORMAL	*B*	*< 2 days*	*< 1 day*	*< 0,5 days*
C		SMALL COMPONENTS (Fasteners)	*C*	*< 7 days*	*< 5 days*	*< 2 or 3 days*

Table 5.6– Material classification and related maximum inventory requirement.

Whenever possible the user should select choice 1 to decrease the capital tied up in inventory, but if there are constraints because of efficiency and operations issues, a higher inventory level can be selected (choice 2 or choice 3). It is important to reduce as much as possible especially the inventory level (ensuring at the same time high service level) of expensive components in order to reduce the value of the capital tied up in inventory, as well as of bulky parts to reduce the space needed for storage areas.

Essentially, a trade-off is constantly being evaluated between the capital tied up in inventory and the cost of shipments (affected by shipping frequency) when selecting the preferred inventory level. However, the values as shown are suggested ones: the maximum inventory level requirement of the input sheet can also be filled in with different values according to company needs. Furthermore, the maximum inventory level is a very important requirement to consider in selecting the packaging solution because some containers might be potentially filled with more parts than allowed (i.e., the physical capacity may not be exceeded, but the specified capacity for quality purposes may be exceeded).

An indicator is provided (following World Class Logistics principles) about the suggested material flow types to be adopted for each material class. Table 5.7 represents the different material flow types recommended for each material class. There is the possibility to select one of the different suggested material flow types depending on company operations needs and constraints. Whenever operationally possible, material flow types are selected in this colour-order of preference: green, yellow, orange, red. White cells indicate flow types which are usually inappropriate for the considered material classification. In this way, higher benefits through reducing total costs for logistic operations can be achieved.

Each material flow type has been described in details in Chapter 4. (Material Flow Types and Their Requirements in the Automotive Industry) of this thesis. Just in Sequence material flow types are required for parts characterized by many variants (high logistics complexity); the objective is to reduce as much as possible material handling operations (with related time and costs) and the space needed to store all the components in the warehouse or buffers.

For AA.1, AA.3, and AB.1 class components, Built to Sequence and External Ship to Sequence flows are usually preferred for these components to reduce the manpower cost for handling and space needed for preparing activities at OEM location (all the activities are carried out at supplier location).

Parts characterized by many variants but which are not expensive or bulky can be sequenced at the OEM location, since they have less impact on the capital tied up and space needed for handling and storing operations. This is usually the case of AC parts (pick to sequence flow).

Bulky components which are not characterized also by many variants are preferably shipped from supplier to assembly plant with a Just in Time flow, since the main objective is to reduce the space required in the OEM warehouse However, for bulky components, sometimes benefits/cost analyses do not validate the selection of the JIT flow; therefore, an indirect flow can be implemented also for this material class. In this case, using a buffer or advanced warehouse is usually preferred with respect to a conventional warehouse (if the economic convenience is proved), to reduce the amount of components stored at the plant location. The same reasoning can still be applied to normal components (B class).

If a component is both characterized by large dimensions (bulky) and many variants, the latter characteristic usually drives the selection of the material flow type (in this case there is usually preferred ratio benefits/costs). Finally, very small parts (such as fasteners) can be always assigned to indirect flows, since their impact on capital tied up and handling activities is usually very small. Increasing the shipping frequency for these parts is usually not economically convenient.

Using World Class Logistics principles, the material flow types selected will affect the system days and, in turn, the number of containers needed for a production program. The implementation of another material flow (within the same material flow macro-class) as well as the switch to higher levels of material flow (i.e., from indirect to JIT, from JIT to JIS) must always be validated through benefit/cost analysis. The material flow type will also influence the selection of the best container solution since the number of system days is directly affected by the type of flow adopted. System days are the number of days (expressed in terms of daily production volume) needed to move the containers from one location to another, usually from supplier to the plant and eventually also through ILCs, and the number of days during which the containers are used at supplier and plant location. In other words, the average number of days that passes for a container to complete a loop in the system and then return to the starting point is referred to as *system days*. System days are used to calculate the number of container needed for each part number when a new production program is launched. The investment for new containers also depends on this number.

	Built to Sequence	External Ship to Sequence	Internal Ship to Sequence	Pick to Sequence (Make)	Pick to Sequence (Buy)	Direct External Shipment	Through Plant Buffer	From Warehouse	From ILC / Advanced Warehouse
Sub Class	**JIS1**	**JIS2**	**JIS3**	**JIS4**	**JIS5**	**JIT1**	**Ind1**	**Ind2**	**Ind3**
AA.1									
AA.2									
AA.3									
AA.4									
AB.1									
AB.2									
AC									
B									
C									

Table 5.7 – Material classification and suggested material flow types.

When selecting a container for a part number it is also important to consider constraints of material handling equipment, such as line display equipment and dolly dimensions and load capacity (an example of dolly is shown in Figure 5.13), warehouse equipment such as shelves of the rack (an example of flow rack is depicted in Figure 5.12) or any other handling equipment for moving the containers from one location to another during the process.

Figure 5.12 – Example of storage equipment for standard plastic totes.

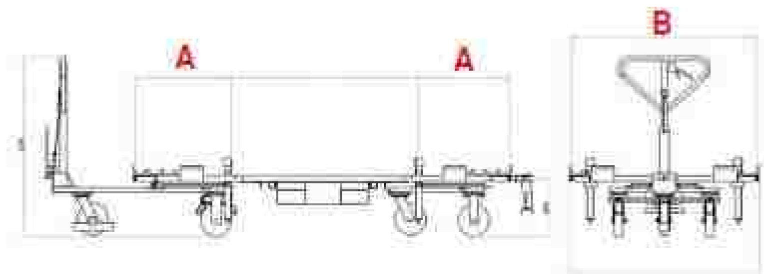


Figure 5.13 – Example of dolly used for container handling inside the plant, dimension constraints. *[23]*

When ending one production program and launching a new one, there will be an effort to reuse some of these equipment in order to lower as much as possible the new investment requried. Thus, part numbers used in the segment of the assembly line or stored in a storage area already equipped with this equipment have to be assigned to containers which are able to fit the dimensions. In this case, material handling and operational constraints of the plant in which the new production program is launched will strongly impact the selection of the packaging solution for the investigated part number.

5.3.3 Container Handling Activities

The main activities required for container handling at plant location affect the total cost of different packaging solutions. All the handling activities need a certain time to be performed and the time can be associated to a cost using the manpower cost rate. The main activities for bulk and tote container handling are:

Bulk Container Activities

- Trailer unloading and container storing in the warehouse/buffer.

- Container pickup from storage area and delivery to the assembly line/kitting area.
- Empty container pickup from the assembly line/kitting area and storing in the storage area.
- Container pick up from the storage area and loading in the trailer.

Small Lot Totes Activities

- Trailer unloading and unit load storing in the warehouse (or storage area).
- Container pickup from the unit load and positioning on the shelves of the rack in the warehouse/buffer.
- Container pickup from the shelves in the warehouse/buffer and positioning on the dolly for delivery to the line / kitting area.
- Container delivering to the assembly line / kitting area.
- Container pickup from the dolly and line feeding.
- Empty container pickup from the line / kitting area and positioning on the dolly.
- Empty container delivery to the storage area.
- Empty container pickup from the dolly and positioning in the storage area.
- Unit load of empty container pickup from storage area and truck loading.

The average times for these activities are usually available to the Company; thus, a cost for container handling can be computed. For a single container, it is important to allocate the time of moving more than one container at the same time (for example for small totes delivery to the assembly line) to each investigated container. Depending on the number of parts with which each container type can be filled, these handling activities will be carried out by the operators more or less frequently, resulting in a higher or lower manpower cost allocated to the production program. Reducing these activities as much as possible preserves the effectiveness of the process because they are considered as *Not Value Added Activities* (NVAA) because they do not add a direct value to the final product for the customer.

5.4 Creation of the Packaging Selection Macro Model

A first packaging selection macro model has been created (by me) to outline the main steps and requirements to be followed in the decision making process. This flowchart of this macro model is depicted in Figure 5.14 and the main steps described in the following sub-sections.

5.4.1 Regional or Oversea Shipment

The process starts with the investigated part number and with the indication about the shipping type. Depending on the locations of the supplier and receiving plant, the shipment will be classified as regional or overseas. Regional shipment is usually carried out by trucks or trains since parts are moved within the same country or between adjacent, land countries. In the case of an overseas shipment, there are specific containers dimensions used to fill up as much as possible the volume of the mode of transport. Oversea shipments are very costly: it is even more important to reach an optimal "saturation" to reduce the shipping cost per piece. Furthermore, there are specific qualitative requirements that have to be followed for oversea shipments by ship to protect the products from moisture and corrosion. Plastic bags and wraps with chemical agents inside are common solutions to preserve part quality when an oversea shipment has to be performed.

5.4.2 Selection between Expendable and Returnable Containers and Choice of the Material

After knowing if the shipment is regional or overseas, the next step is to select between an expendable or returnable packaging solution. At the moment, both Chrysler and Fiat are following the general rule by which regional shipments are performed implementing returnable packaging systems, while oversea shipments are usually performed using expendable packaging to eliminate the costs of the return of empty containers. To accurately assess if a returnable or expendable packaging system is preferred, the significant costs generated by the two solutions and their environmental impacts have to be addressed and compared. This analysis helps determine what is the best solution in terms of material to be used for the container.

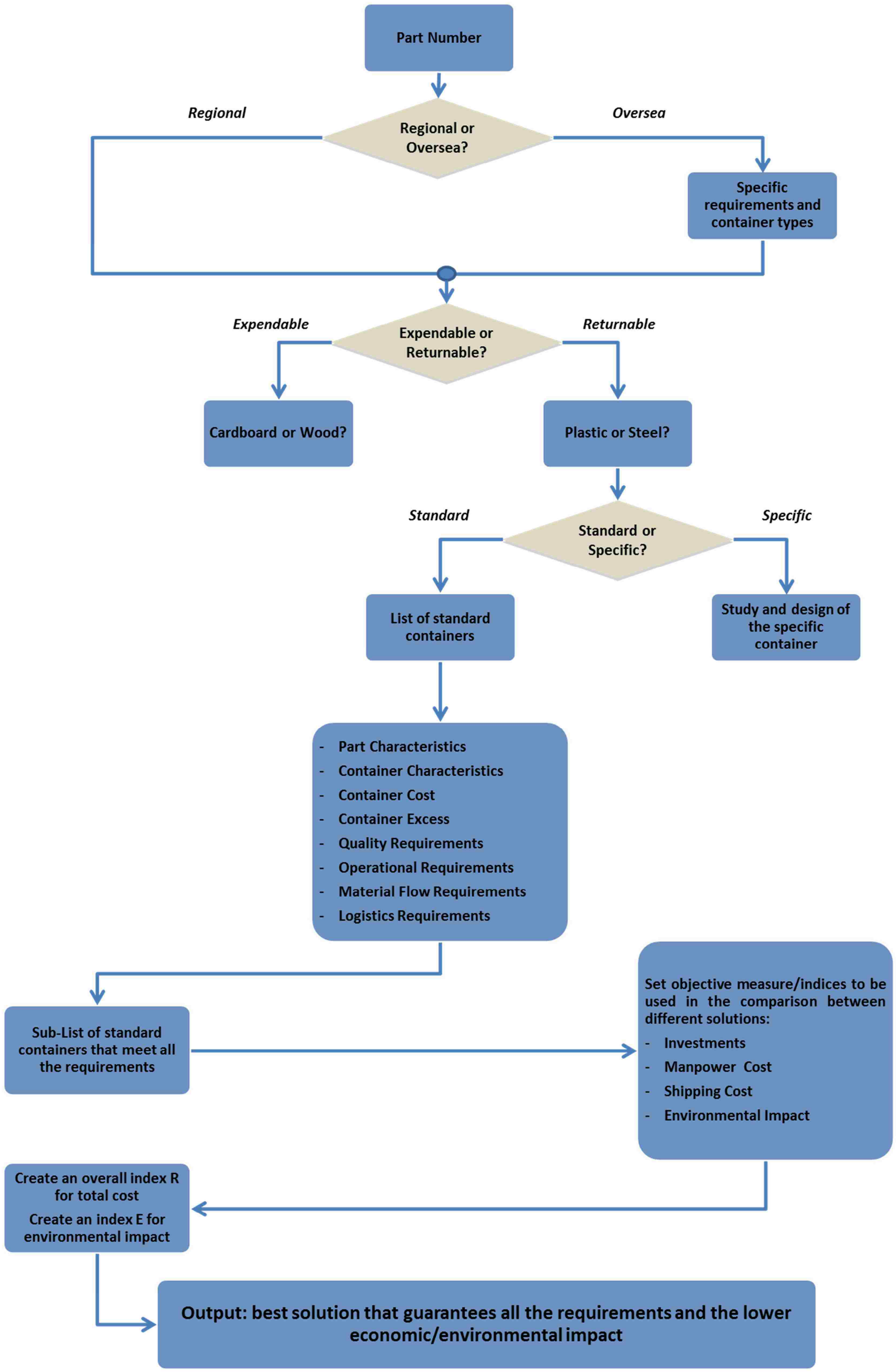


Figure 5.14 – Flowchart of the macro model for packaging selection.

Usually in North America and Europe cardboard and wood are materials used for expendable packaging, while plastic and steel for returnable ones. Exceptions exists in other geographical areas: for example, some Fiat suppliers located in Korea ship containers with expendable pallets made with steel sheets. This way, they can avoid all costs related to the fumigation process required by European countries (in which assembly plants are located) compared to shipping with expendable wood pallets or containers; the steel solution results overall less expensive in this case. This is actually a good example that highlights how the "general rule" is not necessarily actually the most efficient, and emphasizes that all the costs and environmental impacts associated to each step of the process have to be carefully analyzed and considered.

A life cycle costing approach is fundamental to perform these analyses. For expendable packaging systems, the costs to be included are:

- cardboard container cost
- shipping cost
- handling cost (unloading, sorting and delivery to the line)
- re-packing cost (often cardboard containers are not allowed at the side of the assembly line because of World Class Manufacturing and operational requirements)
- average cost due to transport related damages
- average cost due to handling related damages
- disposal cost (including used cardboard handling and transportation to disposal / recycling center).

As far as returnable containers are concerned, the principal costs to be considered are:

- investment for new containers
- shipping cost including the return of empty containers
- handling cost (unloading, sorting, delivery to the line and back to empty storage area)
- cost for container cleaning processes
- administration and informative systems costs for container management and tracking
- average cost due to transport related damages
- average cost due to handling related damages

- disposal cost (end of life).

For each situation, production volumes and shipping distances will be two of the most influential parameters when selecting between expendable and returnable containers.

Expendable and returnable packaging environmental impacts depend on the specific characteristics of transported products, packaging format and material, supply chain conditions and detailed logistics processes in a given situation. It is usually not possible to state outright that one packaging format and material is environmentally preferable to the other as it may vary according to key factors that will be discussed in Chapter 6 (Analysis of Results).

5.4.3 Selection between Standard and Specific Container

After deciding to use an expendable or returnable packaging solution, a choice has to be made between standard or specific (custom) packaging. Standard containers (totes or bulks) should to be used whenever possible because custom or specific containers require significant time and cost for their design, manufacturing, and also greater investment in corresponding appropriate handling equipment. Nevertheless, part characteristics, such as shape and dimensions, and quality requirements may result in adopting a specific container solution.

5.4.4 Standard Container Type Selection

If a standard container can be adopted, the selection is made from the standard container list of either Chrysler (or in the latter part of this analysis, Fiat). Starting from the whole list, the number of sub-lists is reduced based on the dimensional compatibility of the component within the container dimensions, technical requirements, operational requirements, quality requirements, material handling requirements and logistics requirements. Moreover, container costs and container excess (stock of containers of each type not used) available in the system are input data useful for further evaluations. After creating the final sub-list of standard containers that meet all the requirements, measures are then set to compare the different possible solutions from a total cost and environmental impact perspective.

The economic aspect, investment for new containers, manpower handling costs and logistics shipping cost will be evaluated by the model for each potentially adoptable packaging solution.

5.4.5 Carbon Dioxide Emissions as Environmental Performance Measure

There are a number of environmental key performance measures that can be selected. In the automotive sector, carbon dioxide (CO_2) is one of the most widely used and accepted. It is not without controversy; however, given that CO_2 is closely associated with transportation because of fuel consumption and emissions, it is a reasonable parameter to adopt as an environmental indicator for assessing the different packaging solutions.

Carbon dioxide is the primary greenhouse gas emitted through human activities. Research from the United State Environmental Protection Agency (U.S. EPA) states that CO_2 accounted for about 84% of all U.S. greenhouse gas emissions from human activities during 2011. While CO_2 emissions come from a variety of natural sources, human-related emissions are responsible for the abnormal and dangerous increase that has occurred in the atmosphere since the industrial revolution.

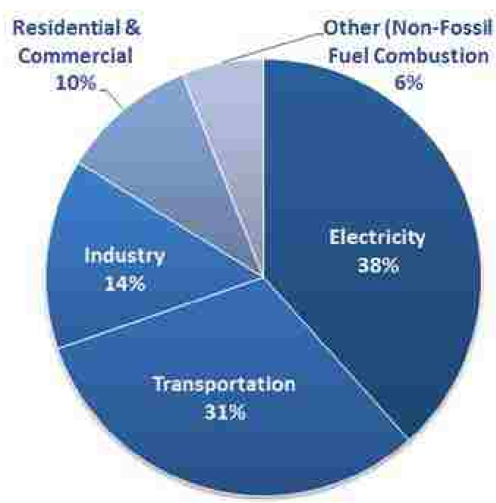


Figure 5.15 – Percentage of emission of carbon dioxide in the atmosphere for each human activity. *[30]*

The main human activity that emits carbon dioxide is the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation as depicted in Figure 5.15. The transport people and goods is the second largest source of CO_2 emissions, accounting for about 31% of total U.S. CO_2 emissions and 26% of total U.S. greenhouse gas emissions in 2011 (U.S. EPA data). This category includes transportation sources such as highway vehicles, air travel, marine transportation, and rail. Clearly, reducing the number of round trip travels for shipping components through the supply chain can significantly reduce the amount of carbon dioxide and the environmental burden of logistic processes.

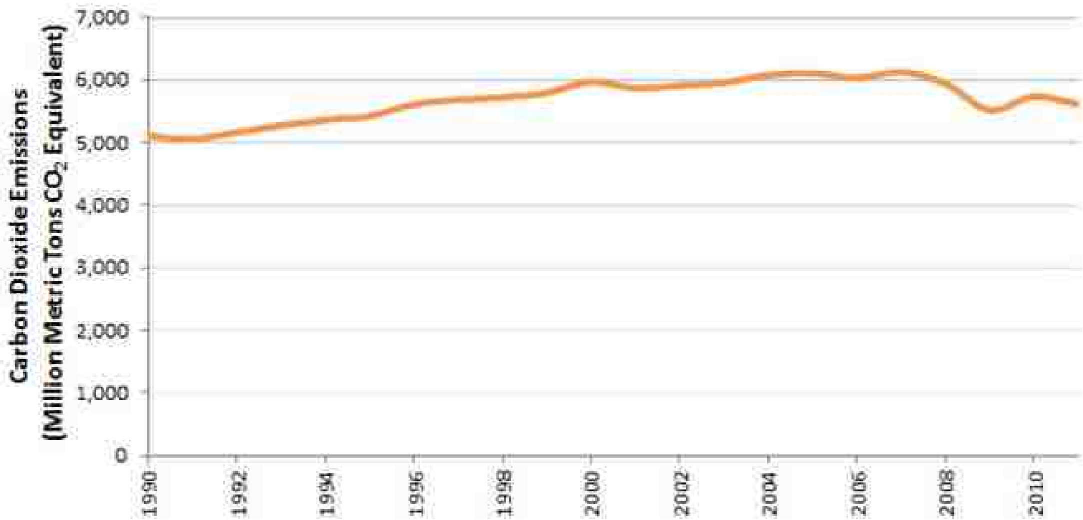


Figure 5.16 – Carbon dioxide emissions in the U.S. from 1990 to 2011. *[30]*

Finally, an overall index R for rapid total cost comparison between different possible standard container solutions and an overall E index for their environmental performance evaluation were set. This way, the output of the model is the best packaging solution (within the investigated set) able to meet all the requirements and to guarantee the lowest possible economic and environmental impact. These aspects, related to the selection of the best standard packaging solution,will be discussed more in details in the following sections of this work.

5.5 Multi Criteria Decision Making and Decision Theory

Multi Criteria Decision Making (MCDM) and Decision Theory principles have been used to treat and balance all the requirements and aspects of the packaging selection model.

5.5.1 Decision Theory

Decision Theory deals with methods for determining the optimal course of action when a number of alternatives are available and the preferred one cannot be easily forecast. An optimal decision is a decision such that no other available decision options will lead to a better outcome. In order to compare the different decision outcomes, a relative utility has to be assigned to each of them. "Utility" is a term for quantifying the desirability or effects of a particular decision outcome and not necessarily related to "usefulness". If there is uncertainty in what the outcome will be, the optimal decision maximizes the expected utility (utility averaged over all possible outcomes of a decision). Sometimes, the equivalent problem of minimizing some measures is considered, particularly in financial situations, where the utility is defined as economic gain. This is for modeling the selection of the optimal packaging solution that results in the lowest cost and environmental burden.

A formal approach may be used when the decision is important enough to motivate the time it takes to analyze it, or when it is too complex to solve with more simple intuitive approaches. [31] Thus, the problem of finding the optimal decision can often be outlined mathematically and then optimized. The formal mathematical description of a general decision problem is presented as follows:

Each decision d in a set D of available decision options will lead to a certain outcome $o = f(d)$. All the possible outcomes form the set O. Assigning a utility $U_O(o)$ to every outcome, it is possible to define the utility of a particular decision d as

$$U_D(d) = U_O[f(d)] \tag{5.1}$$

After formulating the mathematical expression of the problem it is possible to define an optimal decision d_{opt} as the one that minimizes, as in the case of the packaging selection model, or maximize $U_D(d)$:

$$d_{opt} = \arg \substack{min \\ max} \; U_D(d) \;\; with \;\; d \in D \tag{5.2}$$

Where arg $\substack{min \\ max}$ stands for the argument of the minimum or maximum (depending on the type of decision problem), or the set of points of the given argument for which the given function attains its minimum or maximum value.

Thus, solving the problem can generally be divided in three steps:

1. predicting the outcome o for every decision d
2. assigning a utility $U_O(o)$ to every outcome o
3. finding the decision d that minimize or minimize or maximize $U_D(d)$

Many parameters, requirements and various demands have to be considered for the selection of the optimal packaging solution: Multi Criteria Decision Making principles and approaches will inform this decision making model.

5.5.2 Multi Criteria Decision Making (MCDM)

MCDM is a sub-discipline of operations research that explicitly considers multiple criteria in decision-making environments. In professional settings (and also in our daily life), there are usually multiple conflicting criteria that have to be evaluated when making decisions. [32] Multi Criteria Decision Making is concerned with structuring and solving decision and selection problems involving multiple criteria. The objective is to support decision makers facing such problems. Usually, a unique optimal solution for such problems does not exist and it is necessary to use decision maker's preferences to differentiate between solutions.

Solving the packaging challenge can be interpreted in different ways. It could correspond to choosing the best alternative from a set of available alternatives, where "best" can be interpreted as the most preferred alternative between the ones available; this is the final objective of the packaging selection model developed and presented in this thesis work. Another interpretation of solving could be choosing a small set of “good” alternatives, or grouping alternatives into different preference sets: this is the procedure followed in the first part of the model, when creating increasingly reduced lists of standard containers able to meet the imposed requirements.

Thus, the packaging selection model presented in this thesis can be classified in the frame of multiple-criteria evaluation problems, consisting of a finite number of alternatives, explicitly known at the beginning of the solution process. The first problem is to find the set of good alternatives (able to meet all the requirements) and then select the best alternative among them. It can also classify and sort alternatives, as it has been done in the packaging selection tool that has been created on the basis of the model. Classifying refers to assigning alternatives to non-ordered sets, such as dividing the set of possible solutions in packaging families; for example, standard plastic bulk containers, standard steel bulk containers, standard plastic totes. Sorting refers to placing alternatives in a preference-ordered set depending on measures or indices to help the decision maker focus the attention on the best ones.

Some of the alternatives may be “dominated” or “non-dominated". Generally, many solutions are influenced by some of the considered criteria. In the packaging selection model, all the possible final solutions compared from economic and environmental criteria are dominated by technical, quality, material flow, material handling and operational requirements because none of the packaging solutions adopted can neglect these requisites. Finally, tradeoffs between varying economic and environmental criteria may have to be made.

5.6 Container Selection Model Outline and Procedure

This section outlines the model for selecting the optimal packaging as well as the main steps of the decision procedure. This decision making model incorporates all the technical, quality, operational, material flow, material handling, logistics requirements and specifications presented in the previous sections of this thesis. Economic and environmental considerations not considered by Fiat, Chrysler, and Ghafari previously have been incorporated in the model in order to forecast and account since the early stages of a new production program for total costs and environmental burdens of each possible standard container solution. Many Chrysler and Fiat company departments, as well as Ghafari and Ryder Logistics teams and managers, contributed to the understanding of the information and parameters, as well as, ensuring the consistency also from an industrial point of view.

The following is the step-by-step procedure used to obtain the relevant data for the model development. It includes: input data requests, measures and variables computations, requirement checks, creation of sub-lists of standard containers compatible with the requirements established, economic and environmental evaluations, indices setting, and final comparison required for selecting the preferred solution. The procedure may seem unusually explicit: however, given the immense complexity of transport logistics and the many different data points needed, a detailed listing also acts as a checklist to ensure no critical aspects are missed.

5.6.1 Packaging Selection Model Procedure

1. Obtain the Bill of Materials and select a part number
    a. Obtain part characteristics
        i. Part dimensions
        ii. Part weight; W_p
        iii. Material classification.

2. Obtain the shipping type: regional or oversea.

3. If oversea shipping, obtain specific quality and shipment requirements and the list of specific container and packaging types that can be used.

4. Evaluate the convenience and sustainability (economically and environmentally) of using an expendable or returnable packaging system.

5. Evaluate the convenience of using plastic or steel (if a returnable packaging system has been chosen at point 4), cardboard or wood packaging (if an expendable packaging system has been chosen at point 4).

6. Evaluate if part characteristics and quality specifications require adopting a standard packaging or a specific (custom) packaging.

7. If standard container typology has been selected at point 6, obtain the list of standard containers available.
    a. Obtain standard container characteristics and technical specifications
        i. Internal dimensions
        ii. External dimensions
        iii. Weight; W_c
        iv. Empty / full dimensions ratio
        v. Cost; C_c
        vi. Container rental cost, C_{c_r}
        vii. Load Capacity; W_{lc_c}

8. Evaluate if operational or material flow requirements (i.e., delivery frequency, etc.) necessitate the use of a small lot tote or bulk container. In the case this preliminary requirement exist, do not take into account the other container family type in the following steps.

9. Obtain room limit requirements at line side, if existing.

10. Obtain dimensions limit requirements given by line side display or warehouse / buffer equipment (that have to be used), if existing.

11. Create a sub-list of standard containers that meet line side room and equipment dimensions requirements.

12. Evaluate if the investigated part can fit in a standard container of the sub-list created at point 11.

13. Create the sub-list of standard containers compatible with part dimensions.

14. Compute the available volume inside each standard container of the last sub-list.

15. Evaluate if quality requirements make it necessary to insert dunnage inside the container.

16. If dunnage is required, obtain the CAD or the estimated percentage of the total container volume occupied by the dunnage.

17. Obtain dunnage weight; W_{du}

18. Compute (or estimate, in case the dunnage is required and its CAD is not available) the actual available space inside the container (with a first approximation, in case accurate date are not available in the early stages, it can be taken into account as a percentage of the available space without dunnage).

19. Compute overall part volume (given by the overall dimensions of the part).

20. Evaluate how many parts can fit in each container type of the last sub-list (container density); D_c. If the part has a simple geometry and shape, it can be evaluated as the ratio between internal volume of the container and volume of the part as a first approximation, and then checked; on the contrary, if the part has a very complex shape and geometry, it has to be evaluated by means of the CAD design of the part and of the container or by physical tests.

21. In case a Golden Batch Quantity (quantity multiple of the shift or daily production volume which is able to optimize all the handling activities so that there are not half

empty containers to be handled when switching form the production of one batch to another) is required, correct the density of each container type of the last sub-list with the new density equal to the multiple of the Golden Batch Quantity closest to the previous density.

22. Compute the weight of the parts inside each container of the last sub-list, based on container density:

$$W_{parts} = D_c \cdot W_p \tag{5.3}$$

23. Compute the total weight, given by the sum of container weight, dunnage weight, parts weight; W_{tot_t}

24. Evaluate if a dolly is needed to move the container (usually this requirement exists for bulk containers).

25. If a dolly is needed, obtain dolly weight; W_{do}

26. Obtain dolly load capacity; W_{lc_d}

27. Compute the new total weight given by the sum of dolly weight, container weight, dunnage weight and parts weight; W_{tot_b}

28. Obtain ergonomic weight limit requirements for standard totes and standard bulk containers. Weight limit requirements for standard totes are expressed as the maximum allowed total weight given by the sum of container, dunnage and part weights; $W_{e_{l_t}}$. Weight limit requirements for standard bulk containers are made by the maximum total weight given by the sum of dolly, container, dunnage and parts weight; $W_{e_{l_b}}$.

29. Evaluate the most stringent weight limit requirement among technical specifications of the container, of the dolly and ergonomic limit requirements.

$$W_{limit} = \min\left[\left(W_{e_{l_t}} or\ W_{e_{l_t}}\right), W_{lc_c}, W_{lc_d}\right] \tag{5.4}$$

30. If the total weight exceeds the weight limit (W_{limit}), evaluate the new corrected density inside each container of the last sub-list:

$$D_{c_c} = \frac{(W_{limit} - W_c - W_{du})}{W_p} \tag{5.5}$$

31. Obtain the maximum inventory level requirement based on material classification. This value is usually expressed in hours of production coverage; I_{l_max}.

32. For each year, from $i = 1$ to $i = n$, of the production program, obtain the number of vehicle produced per hour, $N_{v_{p_{h_i}}}$

33. Obtain the number of parts used per vehicle, N_{p_v}

34. For each container of the last sub-list, evaluate the inventory level expressed as hours of production coverage:

$$I_l = \frac{D_{c_c}}{\min_i(N_{p_v} \cdot N_{v_{p_{h_i}}})} \tag{5.6}$$

35. Create the new sub-list of standard containers that meet the maximum inventory level requirement:

$$I_l \leq I_{l\_max} \tag{5.7}$$

36. For each year of the production program, from $i = 1$ to $i = n$, obtain the daily production volume, $V_{d_{p_i}}$.

37. Obtain the number of working days per year; N_{wd_y}.

38. Obtain total system days, $S_{d_{tot}}$. Total system days are given by the sum of "days of containers", expressed in terms of production days depending on the production volume, that have to be guaranteed in each location of the supply chain and the days needed for transportation.

39. Obtain Reapair Factor, F_r. This statistical factor has to be considered since an additional percentage of containters are needed for the production program because of damages and wear that take place during the years.

40. Obtain Service Factor, F_s. This factor can usually be provided by the Supply Chain Department and represents the "efficiency" of the overall supply chain. A service factor greater than "1" implies a poorer performing chain. For example, if the supply chain performance is considered "low", a multiplier of greater than "1" would result in additional containers in order to prevent container shortages (and related issues) in any location.

41. Obtain Volume Mix (or Part Usage per Job); V_m. This parameter is used to evaluate on what percentage of the total production volume the investigated part number is assembled.

42. For each container type of the last sub-list, evaluate the number of containers needed, N_{c_n}

$$N_{c_n} = \left\{ \left[\left(\frac{V_{d_{p_i}} \cdot N_{p_v} \cdot V_m}{D_{c_c}} \right) \cdot S_{d_{tot}} \right] \cdot F_r \right\} \cdot F_s \tag{5.8}$$

43. Obtain the number of available excess standard containers for each container type. Excess containers can be located in any location along the supply chain. This value is usually obtained from the container information and management system, E_c.

44. Evaluate the quantity of containers to purchase, N_{c_p}:

$$N_{c_p} = N_{c_n} - E_c \tag{5.9}$$

45. If containers are purchased, evaluate the investment needed for each standard container type, I_C

$$I_C = N_{c_p} \cdot C_c \tag{5.10}$$

46. If containers are rented, evaluate the container rental cost for each standard container type for the entire duration of the program, C_{CR}:

$$C_{CR} = \left\{\left[\left(\frac{V_{d_{p_i}} \cdot N_{p_v} \cdot V_m}{D_{c_c}}\right) \cdot S_{d_p}\right] \cdot F_r \cdot F_s\right\} \cdot C_{c_r} \tag{5.11}$$

47. For each year, from $i = 1$ to $i = n$, evaluate the number of container turns, $N_{t_{y_i}}$:

$$N_{t_{y_i}} = \frac{V_{d_{p_i}} \cdot N_{p_v} \cdot V_m \cdot N_{wd_y}}{D_{c_c}} \tag{5.12}$$

48. Obtain the manpower cost rate, R_{c_m}.

49. Obtain the estimated time for unloading the container or unit load (of small lot totes) from the truck and storing it in the warehouse / buffer; T_1.

50. Obtain the number of containers handled at the same time for truck unloading; $N_{h_{c_f}}$.

51. For each container of the last sub-list, evaluate the manpower cost for unloading the container or unit load from the truck and storing it in the warehouse / buffer for the whole program's duration; C_{m_1}:

$$C_{m_1} = \sum_{i=1}^{n} \frac{V_{d_{p_i}} \cdot N_{p_v} \cdot V_m \cdot N_{wd_y}}{D_{c_c} \cdot N_{h_{c_f}}} \cdot T_1 \cdot R_{c_m} = \sum_{i=1}^{n} \frac{N_{t_{y_i}}}{N_{h_{c_f}}} \cdot T_1 \cdot R_{c_m} \tag{5.13}$$

52. Obtain the estimated time for picking up the container from the rack in the storage area and placing it on the dolly for line delivery; T_2.

53. For each small lot tote of the last sub-list, evaluate the manpower cost for picking up the container from the rack in the storage area and placing it on the dolly; C_{m_2}:

$$C_{m_2} = \sum_{i=1}^{n} N_{t_{y_i}} \cdot T_2 \cdot R_{c_m} \tag{5.14}$$

54. Obtain the estimated time for delivering the container from the warehouse / buffer to the line or kitting / re-packing area. In case multiple containers are delivered at the same time, allocate the total time to each of them; T_3.

55. For each container of the last sub-list, in the case an Automated Guided Vehicle (AGV) is not used, evaluate the manpower cost for container delivering from the warehouse / buffer to the line or kitting / re-packing area; C_{m_3}:

$$C_{m_3} = \sum_{i=1}^{n} N_{t_{y_i}} \cdot T_3 \cdot R_{c_m} \tag{5.15}$$

56. Obtain the estimated time for picking up the empty container from the line and delivering it to the storage area. Also in this case, if more than one empty container is handled at the same time, allocate the total time to each container; T_4.

57. For each container of the last sub-list, evaluate the manpower cost for picking up the empty container from the line and delivering it to the storage area; C_{m_4}:

$$C_{m_4} = \sum_{i=1}^{n} N_{t_{y_i}} \cdot T_4 \cdot R_{c_m} \tag{5.16}$$

58. Obtain the estimated time for picking up the empty container or unit load (of empty totes) and load the truck, T_5.

59. Obtain the number of empty containers handled at the same time; $N_{h_{c_e}}$.

60. For each container of the last sub-list, evaluate the manpower cost for picking up the empty container or unit load (of empty totes) and load the truck; C_{m_5}:

$$C_{m_5} = \sum_{i=1}^{n} \frac{N_{t_{y_i}}}{N_{h_{c_e}}} T_5 \cdot R_{c_m} \tag{5.17}$$

61. For each container type of the last sub-list, compute the estimated total handling manpower cost for all the program's duration; $C_{m_{tot}}$:

$$C_{m_{tot}} = C_{m_1} + C_{m_2} + C_{m_3} + C_{m_4} + C_{m_5} \tag{5.18}$$

62. Obtain unit load standard dimensions.

63. Obtain the Daily Ship Volume.

64. Evaluate the Ship Mode. A first suggestion can be given by the following range of values for the Daily Ship Volume:

    a. 0 to 20 %: ILC
    b. 20 to 60 %: GEO or low frequency direct ship

c. > 60 % Direct Ship.

65. Obtain the distance from the supplier to the assembly plant; D_{s_p}.

66. Evaluate the means of transport to be used for the shipment. A first indication might be given by the distance from the supplier to the assembly plant:

   a. < 500 miles: Truckload
   b. > 500 miles: Rail or Intermodal where available.

67. Obtain the available loading space for the selected mode of transport:

   a. Overall dimensions of the mode of transport in which the containers will be loaded:
      i. Length; $\mathrm{L_t}$
      ii. Width; $\mathrm{W_t}$
      iii. Height; $\mathrm{H_t}$

68. Evaluate the number of containers or unit loads that can be loaded in the selected mode of transport depending on the dimensions of the container or unit load and of the transport vessel; $N_{c_{mt}}$:

$$N_{c_{mt}} = \left\{ max \left[\left(\mathrm{INT}\frac{\mathrm{L_t}}{\mathrm{L_c}} \cdot \mathrm{INT}\frac{\mathrm{W_t}}{\mathrm{W_c}} \cdot \mathrm{INT}\frac{\mathrm{H_t}}{\mathrm{H_c}} \right), \left(\mathrm{INT}\frac{\mathrm{L_t}}{\mathrm{W_c}} \cdot \mathrm{INT}\frac{\mathrm{W_t}}{\mathrm{L_c}} \cdot \mathrm{INT}\frac{\mathrm{H_t}}{\mathrm{H_c}} \right) \right] \right\} \tag{5.19}$$

69. Evaluate the number of transport vessels of full containers that has to be shipped during the whole program duration; $\mathrm{N_{tv_f}}$:

$$\mathrm{N_{tv_f}} = \sum_{i=1}^{n} \frac{V_{d_{p_i}} \cdot N_{p_v} \cdot V_m \cdot N_{wd_y}}{\left\{ \mathrm{MAX} \left[\left(\mathrm{INT}\frac{\mathrm{L_t}}{\mathrm{L_c}} \cdot \mathrm{INT}\frac{\mathrm{W_t}}{\mathrm{W_c}} \cdot \mathrm{INT}\frac{\mathrm{H_t}}{\mathrm{H_c}} \right), \left(\mathrm{INT}\frac{\mathrm{L_t}}{\mathrm{W_c}} \cdot \mathrm{INT}\frac{\mathrm{W_t}}{\mathrm{L_c}} \cdot \mathrm{INT}\frac{\mathrm{H_t}}{\mathrm{H_c}} \right) \right] \right\} \cdot D_{c_c}} \tag{5.20}$$

70. Obtain the full/empty volume ratio for each container type; $\mathrm{R_{e_f}}$.

71. Evaluate the number of transport vessels that has to be shipped for the return of empty containers during the whole program duration, $\mathrm{N}_{\mathrm{tv}_\mathrm{e}}$:

$$\mathrm{N}_{\mathrm{tv}_\mathrm{e}} = \frac{\mathrm{N}_{\mathrm{tv}_\mathrm{f}}}{\mathrm{R}_{\mathrm{e}_\mathrm{f}}} \tag{5.21}$$

72. Evaluate the total number of transport vessels (full and empty) that has to be shipped during the whole program duration; $\mathrm{N}_{\mathrm{tv}_\mathrm{tot}}$:

$$\mathrm{N}_{\mathrm{tv}_\mathrm{tot}} = \mathrm{N}_{\mathrm{tv}_\mathrm{f}} + \mathrm{N}_{\mathrm{tv}_\mathrm{e}} \tag{5.22}$$

73. Obtain the (average) shipping cost for the selected mode of transport; C_{p_m};

    a. Cost/mile – truck
    b. Cost/mile – train
    c. Cost/mile – ship
    d. Cost/mile – plane

74. For each container of the last sub-list, evaluate the total shipping cost for the entire duration of the production program; C_S:

$$C_S = \mathrm{N}_{\mathrm{tv}_\mathrm{tot}} \cdot D_{s_p} \cdot C_{p_m} \tag{5.23}$$

75. Obtain kg of CO_2 per gallon (or liter) of fuel consumed for the selected mode of transport $K_{CO2_{g/l}}$ or $\frac{K_{CO2}}{Mile \cdot Ton}$ and compute the overall weight W_o.

76. Obtain average mileage per gallon (or liter) for the selected mode of transport; $M_{g/l}$.

77. Evaluate the kg of CO_2 due to shipping for the whole program duration, $K_{CO2_{tot}}$:

$$K_{CO2_{tot}} = \mathrm{N_{tv_{tot}}} \cdot D_{s_p} \cdot \frac{K_{CO2_{g/l}}}{M_{g/l}} \text{ or } \mathrm{N_{tv_{tot}}} \cdot D_{s_p} \cdot \frac{Kg_{CO2}}{Mile \cdot Ton} \cdot W_o \tag{5.24}$$

78. For each container type that has passed all the previous requirements checks (all containers of the last sub-list), evaluate the total cost index R:

$$R = \frac{I_C \; or \; C_{CR} + C_s + C_{m_{tot}}}{max(I_C + C_s + C_{m_{tot}})} \tag{5.25}$$

Where:

$$I_C = \left\{\left[\left(\frac{V_{d_{p_i}} \cdot N_{p_v} \cdot V_m}{D_{c_c}}\right) \cdot S_{d_{tot}} \cdot F_r \cdot F_s\right] - E_c\right\} \cdot C_c \tag{5.26}$$

$$C_S = \left(\sum_{i=1}^{n} \frac{V_{d_{p_i}} \cdot N_{p_v} \cdot V_m \cdot N_{wd_y}}{\left\{\mathrm{MAX}\left[\left(\mathrm{INT}\frac{\mathrm{L_t}}{\mathrm{L_c}} \cdot \mathrm{INT}\frac{\mathrm{W_t}}{\mathrm{W_c}} \cdot \mathrm{INT}\frac{\mathrm{H_t}}{\mathrm{H_c}}\right), \left(\mathrm{INT}\frac{\mathrm{L_t}}{\mathrm{W_c}} \cdot \mathrm{INT}\frac{\mathrm{W_t}}{\mathrm{L_c}} \cdot \mathrm{INT}\frac{\mathrm{H_t}}{\mathrm{H_c}}\right)\right]\right\} \cdot D_{c_c}}\right)\left(1 + \frac{1}{\mathrm{R_{e_f}}}\right) \cdot D_{s_p} \cdot C_{p_m} \tag{5.27}$$

$$C_{m_{tot}} = \left[\sum_{i=1}^{n} \frac{V_{d_{p_i}} \cdot N_{p_v} \cdot V_m}{D_{c_c} \cdot N_{h_{c_f}}} \cdot T_1 + \sum_{i=1}^{n} \frac{V_{d_{p_i}} \cdot N_{p_v} \cdot V_m}{D_{c_c}} \cdot (T_2 + T_3 + T_4) + \sum_{i=1}^{n} \frac{V_{d_{p_i}} \cdot N_{p_v} \cdot V_m}{D_{c_c} \cdot N_{h_{c_e}}} \cdot T_5\right] \cdot R_{c_m} \tag{5.28}$$

79. For each container type that has passed all the previous requirements checks (all containers of the last sub-list), evaluate the environmental performance index E:

$$E = \frac{\mathrm{N_{tv_{tot}}} \cdot D_{s_p} \cdot \frac{K_{CO2_{\frac{g}{l}}}}{M_{\frac{g}{l}}} \; or \; \mathrm{N_{tv_{tot}}} \cdot D_{s_p} \cdot \frac{Kg_{CO2}}{Mile \cdot Ton} \cdot W_o}{max\left(\mathrm{N_{tv_{tot}}} \cdot D_{s_p} \cdot \frac{K_{CO2_{\frac{g}{l}}}}{M_{\frac{g}{l}}}\right) \; or \; max\left(\mathrm{N_{tv_{tot}}} \cdot D_{s_p} \cdot \frac{Kg_{CO2}}{Mile \cdot Ton} \cdot W_o\right)} \tag{5.29}$$

The R index, whose compact formula is shown in Equation 5.25 is given by the ratio of all the main cost related to each standard packaging solution able to meet all the requirements, compared to the maximum value of the cost reached by one of the possible solutions. The R index can assume values in the range between 0 and 1 and this allows for quick comparisons among different solutions. The preferred solutions from a total cost perspective will be the one with the value of the R index closest to 0 because it meets all the requirements set and provides the lowest possible cost among the investigated packaging types.

The same procedure has been implemented to create an index helpful to investigate the environmental performances of each solution. The E index is based on the kilograms of CO_2 emitted in the atmosphere during the whole duration of the production program and it takes into account that, depending on different packaging and transport characteristics, there will be the need to make more or less shipments, each having a different environmental burden on the environment.

Starting from the list of all the standard containers, a sequence of checks are carried out in order to create increasingly reduced sub-lists of standard container types able to meet all the requirements given by material flow, material handling, ergonomics, quality, technical specifications, etc. At the end, a reduced list of containers that has passed all the previous checks is used to perform all the economic and environmental evaluations.

The R and E indices will be associated to each standard container type of the last reduced sub-list. The best packaging solution should be the one with the smallest R index and lowest possible E index: this solution meets all the requirements, guarantees the smallest cost reaching the highest efficiency, and ensures a reduced environmental impact.

This procedure has been implemented creating a decision making tool in order to automate all the process. The steps followed in the creation of the decision making tool will be presented in the following section.

5.7 Creation of the Decision Making Tool for Selection of the Optimal Standard Packaging Solution

The packaging selection model outlined in the previous section as a list of procedural steps has been implemented into a decision making tool for the rapid and consistent selection of the best packaging solution able to ensure the lowest possible economic and environmental impact. The huge number of parameters to take into account and computations required by the model would have resulted in a time consuming activity for the Chrysler and Fiat.

To make this model successful and relevant not only from an academic but also an industrial point of view, a tool able to automate all the data processes also had to be developed. Because of Company needs and consistency with the other World Class Manufacturing tools, Excel Software has been used for the implementation. The tool is composed of fourteen named spreadsheets:

- Macro Model Flow Chart;
- Input Sheet;
- Matrix Class-Inventory Level;
- Number of Containers per Transport Vessel Computation;
- Computations and Requirements Check;
- Graphs (for each container macro-family);
- Overall Graphs;
- Total Cost Evaluations;
- Environmental Evaluations;
- R-Index vs. E-Index;
- Overall R-Index;
- Overall E-Index;
- Overall R-Index vs. Overall E-Index;
- Cost Sensitivity Analysis.

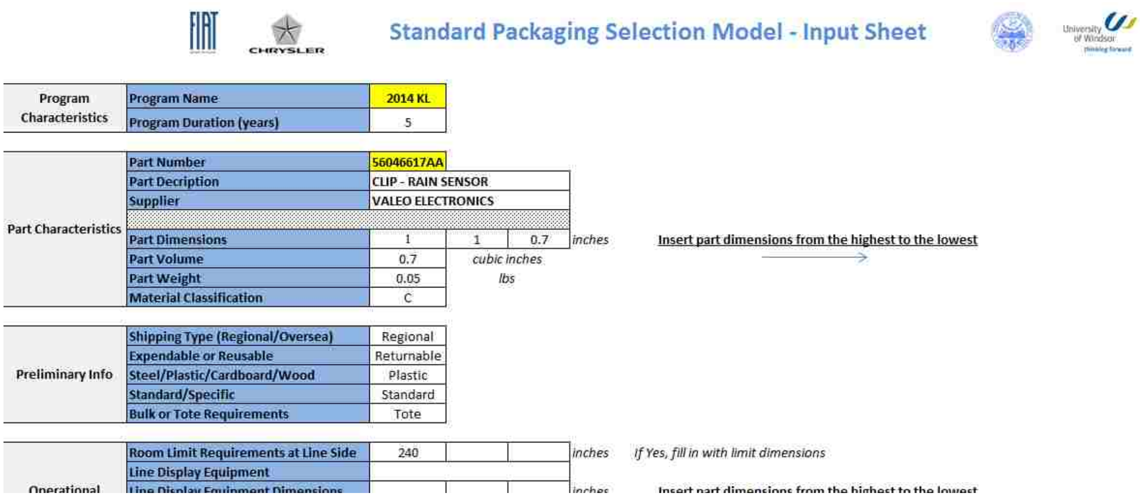
5.7.1 Macro Model Flow Chart

The first spreadsheet shows the macro model flow chart depicted in Figure 5.14 and explained in paragraph 5.1.4. The flowchart of the macro model has been inserted in the tool to provide the user with a general background and knowledge about the functioning of the decision making tool since all the equation, computations and checks are automatically performed by the software.

5.7.2 Input Sheet

An Input Sheet to be filled in by the user with all the parameters and data required for the computations and evaluations have been created.

All the information required by the model has been grouped in different blocks depending on the information typology. The measurement unit of all the input parameters required by the model can be changed by the user depending on Company location.


Standard Packaging Selection Model - Input Sheet

Program Characteristics	Program Name	2014 KL				
	Program Duration (years)	5				
Part Characteristics	Part Number	56046617AA				
	Part Decription	CLIP - RAIN SENSOR				
	Supplier	VALEO ELECTRONICS				
	Part Dimensions	1	1	0.7	inches	Insert part dimensions from the highest to the lowest
	Part Volume	0.7	cubic inches			
	Part Weight	0.05	lbs			
	Material Classification	C				
Preliminary Info	Shipping Type (Regional/Oversea)	Regional				
	Expendable or Reusable	Returnable				
	Steel/Plastic/Cardboard/Wood	Plastic				
	Standard/Specific	Standard				
	Bulk or Tote Requirements	Tote				
Operational	Room Limit Requirements at Line Side	240			inches	If Yes, fill in with limit dimensions
	Line Display Equipment					
	Line Display Equipment Dimensions				inches	Insert part dimensions from the highest to the lowest

Figure 5.17 – Screenshot of a part of the Input Sheet of the Standard Packaging Selection Tool.

The first block refers to the production program characteristics such as program name and duration. In the second block information about part characteristics are contained. The data required are:

- part number;
- part description;
- supplier name;
- part dimensions;
- part weight;
- material classification.

Part dimensions and weights will be used to evaluate dimension and load compatibility with each standard container type, as well as the ergonomic weight requirements which would limit the density (number of parts) of each container type.

In the third block all the preliminary information are grouped. The preliminary information includes:

- shipping type (regional or oversea);
- choice between expendable or returnable packaging;
- choice of the material (if previously established);
- choice between standard or specific;
- bulk or tote requirement (if previously established).

The fourth block refers to operational requirements. If specific operational requirements do not exist for the production program and part number at the moment of the packaging selection, this block can be left blank. The model will work with the computations and evaluations without considering these constraints. On the contrary, if operational requirements already exist at the moment of packaging selection because - for example, some equipment for material handling, line display and storage can be re-used from previous production programs - this will reduce the investment for new equipment. In this case the following data are needed to select a container which is compatible with equipment taken from previous production programs:

- room limit requirements at line side;
- line display/handling/storage equipment description;
- line display/handling/storage equipment dimension;
- dolly required (yes/no);
- dolly weight (if dolly needed);
- dolly load capacity (if dolly needed).

These parameters will be necessary to select from the list of standard containers which ones are the ones technically compatible with the equipment to be used.

Quality requirements are included in the fifth block. Sometimes, because of quality specifications, dunnage is required to increase protection inside the container for safeguard a delicate part. If so, a reduced volume would be available inside the container, reducing the number of parts that can be filled in. Inputs required in this block are:

- dunnage required (yes/no);
- percentage of volume occupied by the dunnage;
- dunnage weight.

The percentage of volume occupied by the dunnage is only needed to estimate the available volume in the container to be filled with the parts. This value can be useful to estimate the density inside the container in the case the part and the dunnage has a simple geometry. If the geometries are complex, the appropriate number of components has to be evaluated with CAD software and completed manually in the "Computation and Requirements Check" spreadsheet.

The sixth block incorporates ergonomics requirements needed to evaluate the maximum number of parts that can be contained in each packaging type because of its weight limit. As far as small lot totes are concerned, different limit values exist for horizontal or lift motion for manual handling operations: the model allows for two different values. Usually, both horizontal and lift motions are performed by the operator: in this case, the tool selects the smallest value between the two. Inputs required are:

- ergonomic weight limit requirements for standard totes;
- ergonomic weight limit requirements for standard bulks.

The seventh block relates to production data needed to compute many variables used by the model. These are the inputs required for each year of the production program as they relate to the investigated part number (i.e., in the input sheet there is one column for each program year):

- number of working days per year;
- daily production volume;
- vehicle produced per hour;

- option take rate;
- parts per vehicle;
- maximum inventory level;
- number of parts used per day (automatically computed on the basis of the previous parameters give as input).

It is also possible to insert also information related to the need to take into account a Golden Batch Quantity.

Times (actual or estimated) of each handling operation - and already reported in the packaging selection procedure - are inputs in the eighth block “Material Flow Information” along with the value of the manpower cost rate for the plant to which the production program is assigned.

“Logistics Information” is inputted into the ninth block. Parameters about the mode of transportation and transport mode to be used (ILC, geographic or less than truck load, direct shipment, etc.) are also outputs from this block depending on the input parameters. Parameters to be inputted include:

- logistics system days (transportation);
- system days at supplier/ILC/plant location;
- total system days (automatically computed);
- repair factor;
- service factor;
- daily ship volume (percentage over the total);
- distance from supplier to the plant.

Furthermore, in this block, all the data about the dimensions of the different mean of transport that can be used are collected and used in the “Number of Container per Transport Vessel Computation” spreadsheet. Finally, average values of the cost per mile for direct shipment or shipment through an Integrated Logistics Center and for the different mean of transport can be included. This way, estimates for the shipping cost can be obtained automatically as outputs from this block and used in the “Computation and Requirements Check” spreadsheet for further analysis.

Finally, the tenth block collects the parameters needed for environmental performance evaluation such as:

- Kg of CO_2 per gallon of fuel (or ,kg of CO_2 per litre of fuel);
- Miles traveled per gallon of fuel (or km per litre of fuel).

These parameters are used by the tool to compute the total kilograms of carbon dioxide emitted in the atmosphere from the container shipping solution and for the entire duration of the program.

5.7.3 Matrix Class-Inventory Level

The spreadsheet “Matrix Class-Inventory Level” provides the user with the matrix represented in Table 3.20. By starting from the material classification of the investigated part number, it is possible to set the maximum inventory level allowed by World Class Manufacturing principles, and to fill in the Input Sheet with this value.

5.7.4 Number of Containers per Transport Vessel Computation

As depicted in Figure 5.18, this spreadsheet automatically calculates the number of containers of each type that can be loaded on the selected mode of transportation and the corresponding percentage of saturation of the available volume. Equipment type, dimensions and maximum weight are the input parameters to be filled in by the user along with container codes and dimensions. For small lot totes, because they are handled in unit loads (made of a certain number of small lot totes on a pallet) for transportation, unit loads dimensions (rather than single container dimensions), and additional information such as number of containers per layer of the unit load, layers per unit load, number of totes per unit load (automatically computed by the tool) are required to compute the actual quantity of containers that can be loaded in the transportation mode selected.

Number of Containers per Transport Vessel

Equipment Type	TRAILER			
	Length	Width	Height	
Equipment Dimensions	13600	2440	2600	mm
Equipment Volume	86278400000			cubic millimeters
Max Weight	24000			Kg

								Unit Load Dimensions					
	Container Code	L	W	H	Cntrs/Layer	Layers/UL	UL Qty	L	W	H	Containers per Transport Vessel	Volume Occupied by Containers	Transport Vessel Saturation
PLASTIC BULK BINS	4202	1200	1000	990							52	61776000000	71.6%
	4203	1000	800	750							117	70200000000	81.4%
	4995	1230	825	925							44	41300325000	47.9%
	4201	1200	1000	975							52	60840000000	70.5%
	4204	1600	1200	750							48	69120000000	80.1%
STEEL BULK BINS	4700	800	600	475							340	77520000000	89.8%
	4710	1200	800	750							102	73440000000	85.1%
	4730	1600	1200	750							48	69120000000	80.1%
PLASTIC SMALL LOT TOTES	3147	298	198	147	20	4	80	1200	1000	798	6240	74692800000	86.6%
	4147	395	295	147	10	6	60	1200	1000	1092	3120	68140800000	79.0%
	4280	395	295	280	10	3	30	1200	1000	1050	1560	65520000000	75.9%
	6147	592	395	147	5	6	30	1200	1000	1092	1560	68140800000	79.0%
	6280	592	395	280	5	3	15	1200	1000	1050	780	65520000000	75.9%
	4961	994	397	214	3	4	12	1200	1000	1066	624	66518400000	77.1%

Figure 5.18 – Screenshot of the Number of Containers per Transport Vessel Computation spreadsheet (example with Fiat data).

The outputs from this spreadsheet are the:

- number of containers per transport vessel;
- volume occupied by containers; and
- transport vessel saturation.

The model calculates these variables for each standard container on the Company's list (e.g., plastic small lot totes, steel bulk bins, plastic bulk bins). New container types can be added with their characteristics or old ones can be deleted by the user. Finally, the outputs from this spreadsheet are used by the "Computations and Requirements Check" spreadsheet, or they can also be used directly by the user for other purposes (such as to directly assess the transportation mode saturation and number of containers that can be loaded for transportation efficiency evaluation).

5.7.5 Computations and Requirements Check

This is the most complex spreadsheet of the packaging selection tool because the majority of the calculations and requirements checks are performed here. To give an idea of the complexity, ninety-eight columns are assigned to each container type on the list. The first eighteen columns are related to container characteristics (i.e. dimensions, costs, weight, etc.); the remaining ninety columns are needed for the analysis. Because of this complexity and immense amount of data, in this thesis only the most important information and measures calculated by the model will be discussed, and only selected parts of the spreadsheet will be included.

	FIAT Code	L	W	H	IL	IW	IH (Fill Line)	Tare Wt	Container Capacity (Weight - Kg)	Empty/Full Ratio	Container Cost	Container Daily Rental Cost	Number of Available Excess Containers
PLASTIC BULK BINS	4202	1200	1000	990	1140	945	815	39	250	4.5	€ 99.00	€ 0.2775	0
	4203	1000	800	750	945	745	575	28	250	3.4	€ 66.00	€ 0.1887	0
	4995	1230	825	925	1150.0	745.0	755.0	30.0	250	3.7	€ 120.00	€ 0.2800	0
	4201	1200	1000	975	1120.0	920.0	767.0	58.0	500	2.3	€ 165.00	€ 0.4000	0
	4204	1600	1200	750	1535	1135	532	46.5	300	2.4	€ 220.00	€ 0.4440	0
STEEL BULK BINS	4700	800	600	475.0	712.0	510.0	290	58	500	1.0	€ 100.00	€ 0.2700	0
	4710	1200	800	750	1120.0	720.0	570.0	125	1500	1.0	€ 200.00	€ 0.4500	0
	4730	1600	1200	750	1520	1120	570	218	2000	1.0	€ 275.00	€ 0.8000	0
PLASTIC SMALL LOT TOTES	3147	298.0	198.0	147.0	243.0	162.0	130.0	0.6	15	1.0	€ 1.60	€ 0.0111	0
	4147	395.0	295.0	147.0	345.0	260.0	130.0	1.1	17	1.0	€ 2.60	€ 0.0111	0
	4280	395.0	295.0	280.0	345.0	260.0	262.0	1.7	17	1.0	€ 4.00	€ 0.0222	0
	6147	592.0	395.0	147.0	544.0	369.0	130.0	2.0	17	1.0	€ 4.30	€ 0.0222	0
	6280	592.0	395.0	280.0	544.0	369.0	262.0	2.7	17	1.0	€ 7.00	€ 0.0333	0
	4961	994.0	397.0	214.0	947.0	350.0	198.0	3.4	17	1.0	€ 12.50	€ 0.0444	0

	Inner Volume	Inner Volume, with Dunnage Volume Correction	Dim 1	Dim 2	Dim 3	Dim 1 Container > Dim 1 Part	Dim 2 Container > Dim 2 Part	Dim 3 Container > Dim 3 Part
PLASTIC BULK BINS	877999500	864829508	1140.0	945.0	815.0	TRUE	TRUE	TRUE
	404814375	398742159	945.0	745.0	575.0	TRUE	TRUE	TRUE
	646846250	637143556	1150.0	745.0	755.0	TRUE	TRUE	TRUE
	790316800	778462048	1120.0	920.0	767.0	TRUE	TRUE	TRUE
	926863700	912960745	1535.0	1135.0	532.0	TRUE	TRUE	TRUE
STEEL BULK BINS	105304800	103725228	712.0	510.0	290.0	TRUE	TRUE	TRUE
	459648000	452753280	1120.0	720.0	570.0	TRUE	TRUE	TRUE
	9.7E+08	955812480	1520.0	1120.0	570.0	TRUE	TRUE	TRUE
PLASTIC SMALL LOT TOTES	5117580	5040816.3	243.0	162.0	130.0	FALSE	FALSE	FALSE
	11661000	11486085	345.0	260.0	130.0	FALSE	TRUE	FALSE
	23501400	23148879	345.0	260.0	262.0	FALSE	TRUE	TRUE
	26095680	25704244.8	544.0	369.0	130.0	TRUE	TRUE	FALSE
	52592832	51803939.5	544.0	369.0	262.0	TRUE	TRUE	TRUE
	65627100	64642693.5	947.0	350.0	198.0	TRUE	TRUE	FALSE

Figure 5.19 – Screenshot of part of Computations and Requirements Check spreadsheet (example with Fiat data).

As depicted in Figure 5.19, in the first part of this spreadsheet, external and internal dimensions of each standard container have to be inserted along with container weight, load capacity, full/empty ratio, container cost, and container excess in the system.

Taking into account inner dimensions, the tool automatically calculates the inner volume considering the reduction of the available volume if dunnage is required. Then, a dimension compatibility check is performed. The dimensions of the component and of the containers have to be filled in decreasing order (from the greatest to the smallest). In this way, comparing each inner container dimension with part dimension (in the described order), and evaluating if the former are all greater than the latter, it can be determined if the part is compatible in dimension with each container being considered. Each cell then assumes the value “true” if the container dimension is greater than part dimension, “false” in the other case. A conditional formatting has been applied to the cells, so that when assuming the value “false’ their colour becomes red to be easily seen by the user.

Only if each of the three ordered container dimensions is greater than each corresponding ordered part dimensions, is the component then considered dimensionally compatible with the container.

The same procedure has been implemented to check the compatibility of each container with handling and storage equipment.

Once dimensional compatibility has been checked, a first estimate of the density (number of parts inside the container) is made by the tool by considering the overall volume occupied by the component and the available inner volume inside the container.

Estimated Density	Estimated Volume Occupied by the Parts	Estimated Parts' Weight	Estimated Total Weight	Est. Weight < Weight Limit	Density Correction	Corrected Total Weight	Estimated Volume Occupied by the Parts (With Weight Limit)	Volume Filling Percentage	Inventory Level at Line Side (Hours)	Inventory Level at Line Side < Max Inventory Level	Computation of Number of Container Needed	Number of Container Needed	Number of Container to Purchase	**Investment for New Containers**	**Investment Comparison Index**	**Percentage of the Investment Over the Total Cost**
48	851558400	100.8	140.01	TRUE	48	140.01	851558400	97.0%	1.9	TRUE	145.0848438	146	146	€ 9,033.75	0.20	30.99%
22	390297600	46.2	74.41	TRUE	22	74.41	390297600	96.4%	0.9	TRUE	316.54875	317	317	€ 13,076.25	0.29	28.61%
35	620928000	73.5	103.71	TRUE	35	103.71	620928000	96.0%	1.4	TRUE	198.9735	199	199	€ 14,925.00	0.33	32.88%
43	762854400	90.3	148.51	TRUE	43	148.51	762854400	96.5%	1.7	TRUE	161.9551744	162	162	€ 16,706.25	0.37	41.16%
51	904780800	107.1	153.81	TRUE	51	153.81	904780800	97.6%	2.0	TRUE	136.5504412	137	137	€ 18,837.50	0.42	47.42%
5	88704000	10.5	68.71	TRUE	5	68.71	88704000	84.2%	0.2	TRUE	1339.7549	1340	1340	€ 44,666.67	1.00	26.85%
25	443520000	52.5	177.71	TRUE	25	177.71	443520000	96.5%	1.0	TRUE	267.95098	268	268	€ 17,866.67	0.40	34.33%
53	940262400	111.3	329.51	TRUE	53	329.51	940262400	96.9%	2.1	TRUE	126.3919717	127	127	€ 11,641.67	0.26	33.06%
0	0	0	0.81	TRUE												
0	0	0	1.29	TRUE												
1	17740800	2.1	4.01	TRUE												
1	17740800	2.1	4.31	TRUE												
2	35481600	4.2	7.08	TRUE	2	7.08	35481600	67.5%	0.1	TRUE	3931.33125	3932	3932	€ 17,202.50	0.39	19.24%
3	53222400	6.3	9.91	TRUE												

Figure 5.20 – Screenshot of part of Computations and Requirements Check spreadsheet (example with Fiat data).

As previously explained, this estimation is usually very accurate in case of parts with simple geometry. While evaluating dimensions are more accurate via CAD software, physical tests would be helpful if shapes and geometries of the parts are complex. In this case, the software derived value can be manually overwritten and used by the model for further computation. Regardless, a reasonable estimation can be made if precise data are not available in the early stages of analysis.

When using the tool for complex part shape without knowing the actual evaluated density, the density computed with the procedure and used by the tool is conservative. However, the first objective of this tool is to compare the relative performance of different solutions; assuming all solutions are conservatively estimated, the key is to evaluate the relative performances, not the absolute performances, among alternatives.

Part weights are estimated by the tool starting from container density and part weight, and the total weight is computed adding the weight of container and of dunnage (if required). If a dolly is used for bulk containers handling, the weight of the dolly is taken into account in the total weight. The total weight is then compared with weight limit requirements. Within this weight, the tool selects the smallest possible container load capacity and ergonomic requirements. If the total weight is smaller than the weight limit the corresponding cell assumes the value “true”; if it exceeds, it assumes “false”. Using the “IF” function, the density of the container types with the weight limit check equal to “false” is adjusted using Equation 5.5, and the corrected density is used by the model for further calculations. Using the corrected density, the volume occupied by the parts inside the container is calculated and the volume filled percentage, given by the ratio between inner container volume and volume occupied by the parts, is evaluated for each container solution.

The inventory level is evaluated in the tool with Equation 5.6, and its compatibility with World Class Logistics requirements is checked with Equation 5.7. Container solutions that produce a value of “false” will not be considered in the final economic and environmental evaluations.

At this point, the number of container needed for the production program can be calculated by the tool using Equation 5.8. Obviously an integer value is needed so the function “ROUNDUP” has been also used to keep the closest integer value.

In the next column, the number of available containers excess in the supply chain can be inputted and these values are used to decrease the number of container to purchase. Finally, the investment needed for new containers is computed by the tool and given as output for each container type able to meet all the requirements. A complex function (composed of multiple “IF” cycles to check against criteria) has been implemented in the tool to leave blank the main outputs of the model for containers which are not able to meet even just one requirement.

The number of turns per day (number of times a container has to be replaced at line side), times for each handling operation, and related costs for each year of the production program are automatically computed and utilized for evaluating the total manpower cost for the all container handling activities over each year, and over the entire program duration. These values are calculated and assigned to each standard packaging solution which has successfully passed the previous checks.

Full containers per transport vessel already computed in the “Container per Transport Vessel Computation” spreadsheet are also reported here. Furthermore, the same information for empty containers, which have to be returned, is calculated using the full/empty ratio. Finally, the number of parts shipped per transport vessel is evaluated using the corrected container density and this value is used, in turn, to compute the number of transport vessels of full and empty containers to be shipped during the entire duration of the production program. All these computed variables finally converge in the evaluation of the total shipping cost for the production program related to each container type fulfilling all the requirements and allocated to the single considered part number, using Equation 5.27.

In the last part of the spreadsheet, the main variables used for quick comparison between different solutions are evaluated. The total cost for each requirements-compatible standard container type and kilograms of CO_2 emitted in the atmosphere are computed first. Then, the R index and E index are calculated separately for each container of each macro-family (small lot totes, steel bulk bin and plastic bulk bin) to compare similar solutions. Overall indices are also calculated to compare all the different requirements-compatible container types without considering their macro-family.

Total Kg of CO_2 Emission - Train - Year 2	Total Kg of CO_2 Emission - Train - Year 3	Total Kg of CO_2 Emission - Train - Year 4	Total Kg of CO_2 Emission - Train - Year 5	Total Kg of CO_2 Emission - Truck - For All the Program Duration
3585.0	3585.0	3585.0	3585.0	17924.9
4474.8	4474.8	4474.8	4474.8	22373.8
3672.4	3672.4	3672.4	3672.4	18361.8
4616.6	4616.6	4616.6	4616.6	23083.0
3775.6	3775.6	3775.6	3775.6	18877.9
24360.8	24360.8	24360.8	24360.8	121803.9
11639.6	11639.6	11639.6	11639.6	58197.9
9930.4	9930.4	9930.4	9930.4	49652.0
4686.2	4686.2	4686.2	4686.2	23431.2

Total Cost Comparative Analysis					
If Considering Investment for Containers			*If Considering Containers Rental Cost*		
Total Cost	***R Index (For Each Container Macro-Family)***	***Overall R Index***	***Total Cost***	***R Index (For Each Container Macro-Family)***	***Overall R Index***
€ 29,150.15	0.64	0.18	€ 20,149.70	0.62	0.17
€ 45,707.17	1.00	0.27	€ 32,679.98	1.00	0.27
€ 45,387.49	0.99	0.27	€ 30,508.69	0.93	0.25
€ 40,590.30	0.89	0.24	€ 23,938.05	0.73	0.20
€ 39,726.41	0.87	0.24	€ 20,939.97	0.64	0.17
€ 166,366.22	1.00	1.00	€ 122,003.31	1.00	1.00
€ 52,037.94	0.31	0.31	€ 34,272.53	0.28	0.28
€ 35,213.22	0.21	0.21	€ 23,659.55	0.19	0.19
€ 89,408.48	1.00	0.54	€ 72,299.55	1.00	0.59

Environmental Performance Comparative Analysis		
Kg of CO_2 Emitted During the Entire Duration of the Program	***Environmental Index***	***Overall Environmental Index***
35250.27	0.75	0.22
39867.88	0.84	0.25
47225.89	1.00	0.30
44793.71	0.95	0.28
38534.78	0.82	0.24
158729.65	1.00	1.00
82815.04	0.52	0.52
74327.20	0.47	0.47
63670.84	1.00	0.40

Figure 5.21 – Screenshot of part of Computations and Requirements Check spreadsheet (example with Fiat data).

As shown in Figure 5.21, these final measures and indices are computed by the tool only for containers that meet all the imposed requirements. For the other containers, the cell is purposely left blank by the tool to help the user focus only on the containers that can be actually used in the logistic and production processes being considered. The tool is able to compute the total cost both in the case containers to be purchased (investment) or rented (rental cost) by the Company.

5.7.6 Graphs and Overall Graphs

The “Graphs” spreadsheet has been created in the tool to permit the user to immediately view the different variables characterizing each standard container solution. The tool creates the graph considering only the container types that have met all the requirements in the “Computations and Requirements Check” spreadsheet. The values of the variables are presented to the user by means of bar graphs in order to provide a rapid comparison. The variables considered are represented by the tool in this spreadsheet are:

- filling percentage;
- investment for new containers and rental cost for containers (the user of the tool has to consider just one of the two graph: the first one if containers are purchased while the second one if containers are rented);
- handling manpower cost (entire program duration);
- shipping cost (entire program duration);
- kilograms of CO_2 emitted (entire program duration).

All these variables are compared both within each container macro-family in the Graphs spreadsheet, while at the same time, they are grouped together without considering the standard container classification to compare between solutions that are very different (and also if a pre-requisites for the container macro family has not been set). In fact, it can happen that there is no specific need to use a small lot tote or plastic bulk bin or steel bulk bin. In this situation, potentially all the container types can be assigned to the investigated part number so that the tool can then compare differences among the macro-family. Examples of these graphs and comparisons will be presented and discussed in Chapter 6 (Analysis of Results).

5.7.7 Total Cost Evaluations

The "Total Cost Evaluations" spreadsheet provides the user with an immediate comparison on a total-cost basis of the different container solutions potentially usable for the investigated part number. As for the graphs described in the previous paragraph, the tool, after implementing a certain number of integrated "IF cycles", calculates the R-Index only for container types fulfilling all the pre-established requirements. The value of the R-Index for the other containers is forced to zero. A line graph has been created and is used by the tool for representing the trend of the R-Index for each container type, grouped by macro-families. One graph is created for plastic bulk bins, one for steel bulk bins and, finally, one for small lot totes.

The graphs have the container codes on the x-axis and the value assumed by the corresponding R-Index on the y-axis. R-index can assume values between 0 and 1. Values closest to 0, but, at the same time, different from 0, indicate a good container solution from a total cost perspective. When the graph goes to zero, it indicates that the corresponding container solution is not applicable because it does not fulfill all the requirements. Practical examples will be introduced and discussed in Chapter 6.

5.7.8 Environmental Evaluations

The "Environmental Evaluations" spreadsheet has been created with the same procedure followed for the "Total Cost Evaluations" spreadsheet but it refers to the environmental impact of each container solution potentially applicable. The number of transport vessels needed for the shipment of full and empty containers during the entire duration of the program are taken from the "Computations and Requirements Check Spreadsheet" and reported here for each container solution along with the kilograms of CO_2 emitted in the atmosphere.

The E-Index is plotted in each graph referring to a container macro-family. As for R-Index, container codes are reported on the x-axis, while the value of the E-Index, assuming values from 0 to 1, is represented on the y-axis. Also in this case, values equal to 0 stand for non-applicable container solutions, whilst values closest to zero (and different from 0) highlight solutions which are environmentally friendlier with respect to solutions with E-Index closest to 1.

5.7.9 R-Index vs. E-Index

This spreadsheet allows the user to rapidly compare different possible solutions grouped for a container macro-family, both from a total cost and environmental perspective. If in a certain macro-family has to be used because of specific pre-requisites imposed, the user can examine the graph referring to the desired container macro-family and select the best container, namely the one that guarantees the smallest total cost and environmental burden (sometimes making a trade-off between the two outputs).

5.7.10 Overall R-Index

The "Overall R-Index" spreadsheet presents an overall comparison from a total cost point of view over all the potentially applicable container solutions, without grouping them in different graphs depending on their container macro-family. A unique graph showing the trend and values of the R-Index for all the container types is presented and it is helpful to compare different solutions when there are no pre-requisites for the container category to be used.

5.7.10.1 Overall E-Index

The "Overall E-Index" spreadsheet is created with the same procedure and objectives of the spreadsheet described in the previous paragraph but refers to the compared environmental performances attributed to each applicable standard container type. The procedure and tool are very helpful for focusing the user on the environmental aspects of the process.

5.7.11 Overall R-Index vs. Overall E-Index

When both economic and environmental impacts need to considered, the "Overall R-Index vs. Overall E-Index" comparison provides a rapid output of the different total cost and environmental performances of each potentially applicable solution, with a broad view on every container type "behaving" independently from its macro-family.

This is a very powerful output provided by the tool since all the possible solutions have been evaluated automatically using input parameters elaborated by different equations and algorithms in the previous spreadsheets, and are presented and assessed both from a total cost and environmental perspective simultaneously.

5.7.12 Cost Sensitivity Analysis

The Cost Sensitivity Analysis spreadsheet provides the weighting of each cost component within the total cost, for each standard container solution. This analysis can be used by the user to determine if all the costs are almost equally influential for the economic performance of the container solution, or if it is possible to focus just on select priorities to address the costs of impacts.

CHAPTER 6

ANALYSIS OF RESULTS

This chapter reviews the results of the research and their analysis. It is divided into three main sections, relating to the three main research topics. In the first part, the outcomes of the analysis for the reduction of the standard container types are presented and discussed.

The second section identifies the key factors that influence the environmental performances of one-way and returnable packaging systems as well as the selection of the right packaging material from a sustainability perspective.

In the third section, the results of the packaging selection model are shown and analyzed, and the consistency of the model is tested and validated using real data from both Chrysler and Fiat production programs.

6.1 Outcomes of the Analysis for the Reduction of Standard Container Complexity

The outcomes provided by the analysis for the reduction of the standard container types described in Chapter 4 are discussed in this section. In the ***overall study***, all Chrysler plants have been analyzed, but, for brevity, only one specific case of a plant-base analysis will be shown in detail as an example, and then compared to the results from the overall study, or corporate wide assessment.

6.1.1 Results from Plant-Based Analyses

The analysis made for the Sterling Heights Assembly Plant (SHAP) has been chosen to represent the methodology used to read and interpret the results provided as output from a plant-based study as well as the strategies defined to take executive actions. Sterling Heights Assembly Plant has been assigned the production program for the new model 2015 UF (New Chrysler 200); therefore, the results from this research have already been incorporated into the decision making process for the actual, upcoming selection of the container solutions for each part number of this new program.

6.1.1.1 Standard Tote Analysis

Studies for reducing the standard container types used in plant operations can start from a Pareto analysis. This statistical tool provides a first broad indication about the possibility for reducing the complexity of the container system by reducing the number of typologies to be managed in each assembly and logistic step. In fact, generally the greater the number of container types outside the range of the 80 % of total part number assigned (or equally the slope of the curve), the greater the potential to reduce the complexity of the standard container system investigated.

Ranking	Packaging ID. Number	Cumulative Percentage of Part Numbers Assigned to the Container Type
1	CT121507	20.8%
2	CT242214	37.2%
3	CT241509	50.6%
4	CT241507	63.5%
5	CT321507	71.9%
6	CT242209	78.8%
7	CT481507	84.3%
8	CT121505	87.7%
9	CT242211	90.9%
10	CT121509	93.6%
11	CT242207	96.3%
12	CT241505	97.6%
13	CT241514	98.6%
14	CT481511	99.3%
15	0CTA121509	99.6%
16	CT120705	99.7%
17	CT482207	99.9%
18	CT241109	100.0%

Table 6.1 – Cumulative percentage of part numbers assigned to each standard tote type, Sterling Heights Assembly Plant.

As far as standard totes are concerned, Table 6.1 shows the cumulative percentage for each container. Approximately 85 % of the part numbers used by this plant and going into standard totes are assigned to 7 tote types, while the remaining 15 % is assigned to 11 tote types. This is graphically represented also in the Pareto chart of Figure 6.1. The outcome of this analysis does not suggest that these 11 totes which see comparatively less use must be eliminated, but it does strongly suggest there is significant potential to improve the standardization level and decrease the container management complexity.

Thus, in this particular plant situation, it seems appropriate to continue the container analysis to improve on the container utilization.

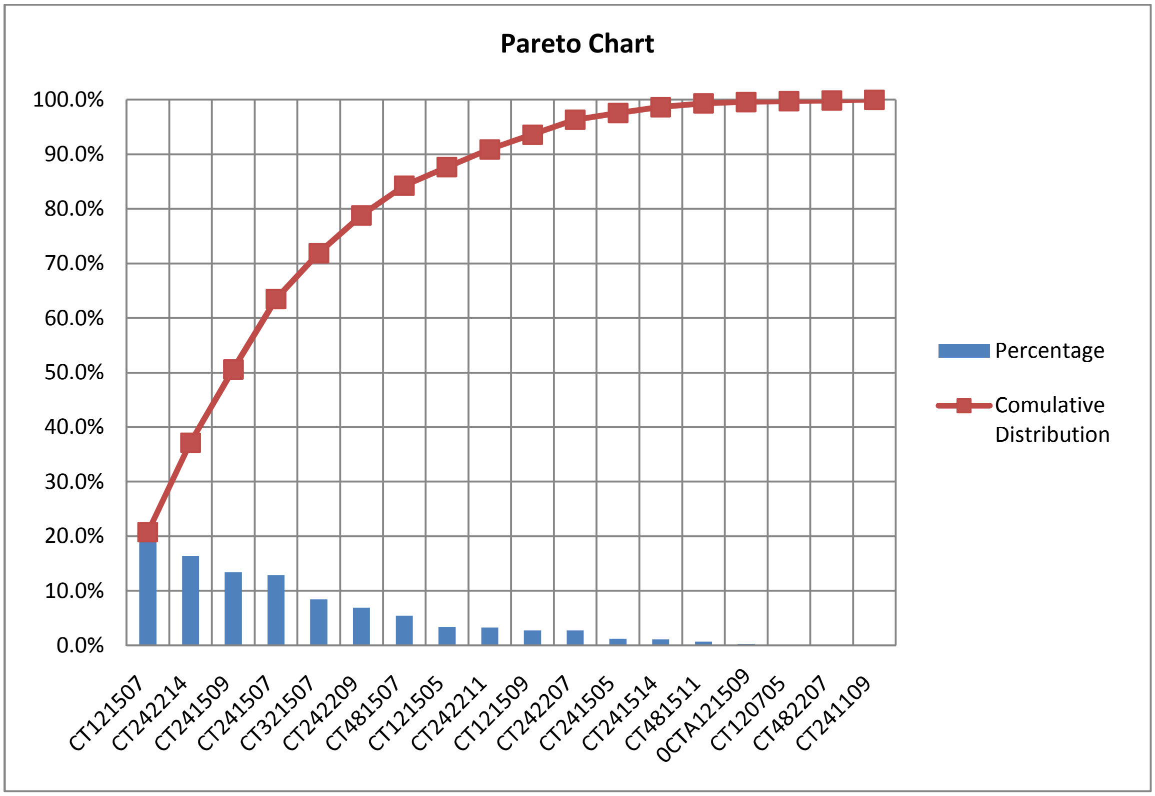


Figure 6.1 – Pareto chart for standard totes, Sterling Heights Assembly Plant.

To develop a more detailed view about the standard totes to which a small number of part numbers (components IDs) are assigned, Table 6.2, showing the number of part numbers assigned to each container type, can be used. The different solutions have been ordered in the table from the most used solution the least used one, and a ranking value have been assigned to each of them.

The standard tote 0CTA121509 is assigned just to two part numbers and totes CT120705, CT 482207 and CT241109 are assigned to only one part number each. Thus, it might be worth to check if these part numbers can be re-assigned to different tote types (probably with similar dimensions) which have already been assigned and will be used with a higher number of part numbers. Figure 6.2 represents the graph created from the data of Table 6.2 and provides a more immediate view about what explained.

Ranking	Package ID. Number	Counts
1	CT121507	153
2	CT242214	121
3	CT241509	99
4	CT241507	95
5	CT321507	62
6	CT242209	51
7	CT481507	40
8	CT121505	25
9	CT242211	24
10	CT121509	20
11	CT242207	20
12	CT241505	9
13	CT241514	8
14	CT481511	5
15	0CTA121509	2
16	CT120705	1
17	CT482207	1
18	CT241109	1

Table 6.2 – Number of part numbers assigned to each standard tote type, Sterling Heights Assembly Plant.

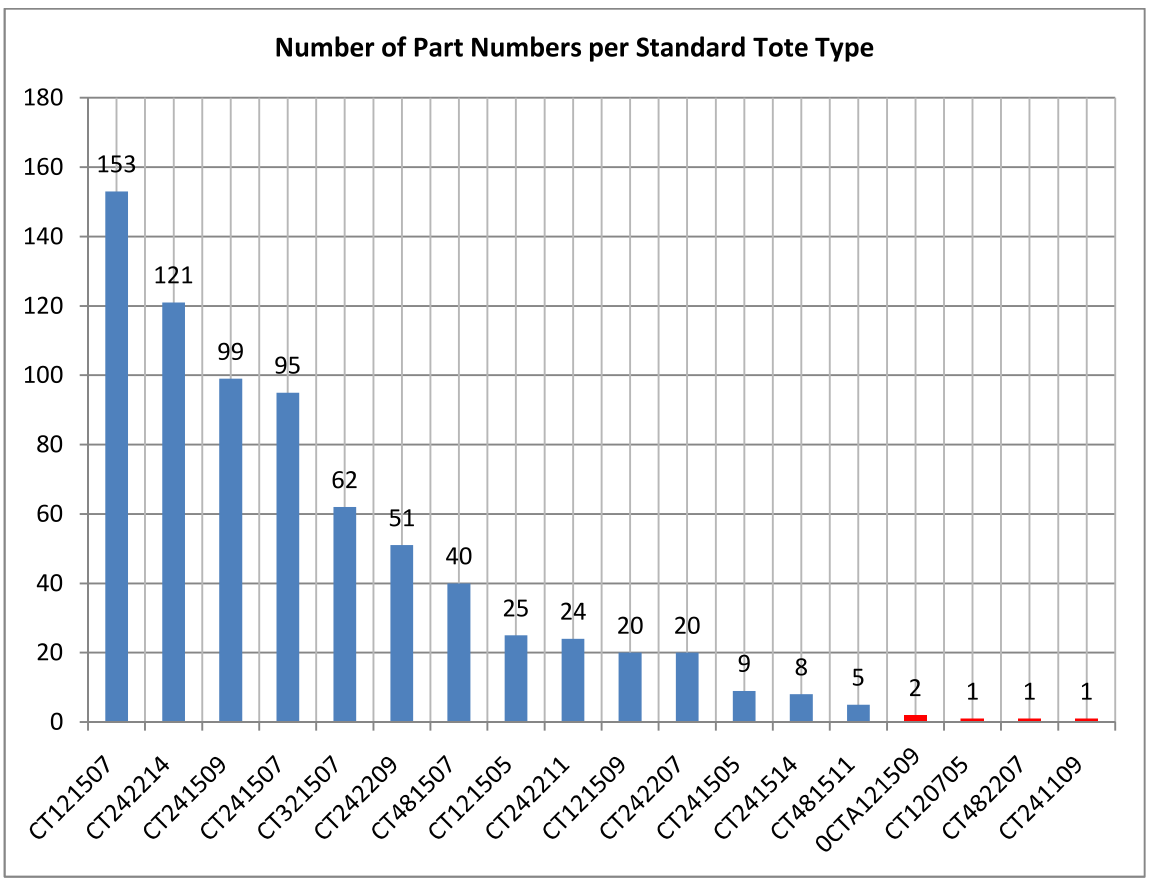


Figure 6.2 – Number of part numbers assigned to each standard tote type, Sterling Heights Assembly Plant**.**

Data contained in Table 6.2 have been further analyzed and percentages of part numbers assigned to each standard tote type have been calculated and listed in Table 6.3. There are many container types with a very low percentage of part number assigned and, in particular, 7 tote types have a percentage of part number assigned which is lower than 2 %. Percentages are computed over the total number of part number used by this plant going into standard totes.

In addition, three more tote types have been highlighted and added to the previous list of investigated containers to be potentially eliminated from the usage in this plant checking the possibility to assign their part numbers to other similar containers. These totes are CT241505, CT241514 and CT481511 (ranks 12, 13, and 14) and are highlighted in Table 6.3 with light red colour.

Ranking	Package ID. Number	Percentage
1	CT121507	20.8%
2	CT242214	16.4%
3	CT241509	13.4%
4	CT241507	12.9%
5	CT321507	8.4%
6	CT242209	6.9%
7	CT481507	5.4%
8	CT121505	3.4%
9	CT242211	3.3%
10	CT121509	2.7%
11	CT242207	2.7%
12	CT241505	1.2%
13	CT241514	1.1%
14	CT481511	0.7%
15	0CTA121509	0.3%
16	CT120705	0.1%
17	CT482207	0.1%
18	CT241109	0.1%

Table 6.3 – Percentage of part numbers assigned to each standard tote type, Sterling Heights Assembly Plant.

Finally, dimensional analysis – arguably the most important analysis, - should be able to provide more precise and helpful indications about the actual containers that could be eliminated. This analysis is presented in Table 6.4 and Figure 6.4. Tote types have been grouped by footprint and then further divided by different heights. Within each footprint the class, number, and percentages of part number assigned to each height have been assessed. This assessment should provide valuable information about containers similar in dimensions to other containers (e.g., same footprint and similar height) which are assigned to few part numbers and might therefore be deleted from new vehicle program lists, and then replacing them with the others.

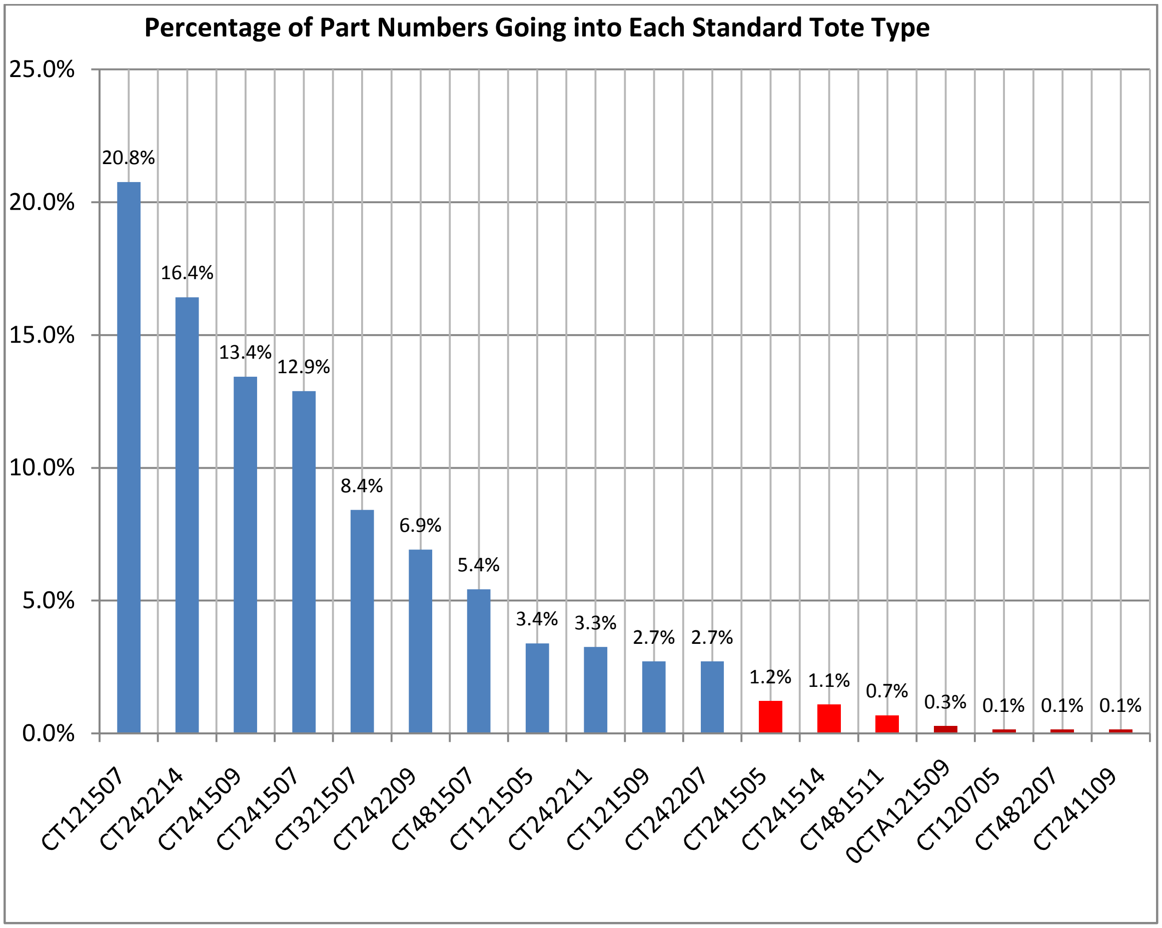


Figure 6.3 – Percentage of part numbers assigned to each standard tote type, Sterling Heights Assembly Plant.

Following this strategy, tote CT120705 should be kept since it is the only one with footprint of 12x07 inches; in other words, it is possibly fulfilling a unique niche that can also represent a difficult packaging scenario. On the other hand, from Table 6.4, tote CT120705 is clearly assigned only to one part number: it could possibly be deleted from the standard list and used only for exceptional cases.

Within 12x15 inches footprint, tote CT121507 should be kept since it has an overall percentage of 20.8% and 76.5% within its footprint category.

Tote CT241109, with footprint 24x11 inches, faces the same considerations of CT120705. CT241507 and CT241509 should be maintained since they are both assigned to a large number of part numbers with percentages of 45% and 47% respectively within their container footprint class.

Package ID. Number	Footprint (inches)	Height (inches)	Counts per Plant	Percentage per Plant	Percentage per Footprint Class
CT120705	12x07	05	1	0.1%	100%
CT121505	12x15	05	25	3.4%	12.5%
CT121507	**12x15**	**07**	**153**	**20.8%**	**76.5%**
CT121509	12x15	09	20	2.7%	10%
0CTA121509	12x15	09	2	0.3%	1%
CT241109	24x11	09	1	0.1%	100%
CT241505	24x15	05	9	1.2%	4.3%
CT241507	**24x15**	**07**	**95**	**12.9%**	**45%**
CT241509	**24x15**	**09**	**99**	**13.4%**	**47%**
CT241514	24x15	14	8	1.1%	3.7%
CT242207	24x22	07	20	2.7%	9.3%
CT242209	**24x22**	**09**	**51**	**6.9%**	**23.6%**
CT242211	24x22	11	24	3.3%	11.1%
CT242214	**24x22**	**14**	**121**	**16.4%**	**56%**
CT321507	**32x15**	**07**	**62**	**8.4%**	**100%**
CT481507	**48x15**	**07**	**40**	**5.4%**	**88.9%**
CT481511	48x15	11	5	0.7%	11.1%
CT482207	48x22	07	1	0.1%	100%

Table 6.4 – Standard totes dimensional analysis, Sterling Heights Assembly Plant.

As far as the 24x22 inches group is concerned, totes CT242214 and CT242209, should be both kept in the standard list because they are both assigned to several part numbers. CT321507, assigned to 62 part numbers, but as only tote with footprint 32x15 inches should be kept in the standard list.

Between the two totes with footprint 48x15 inches, totes CT481507, with 40 parts assigned, an overall percentage equal to 5.4% and percentage per footprint equal to 88.9%, should be kept in the standard list. Finally, for tote CT482207 the same considerations as for totes CT120705 and CT241109 are valid.

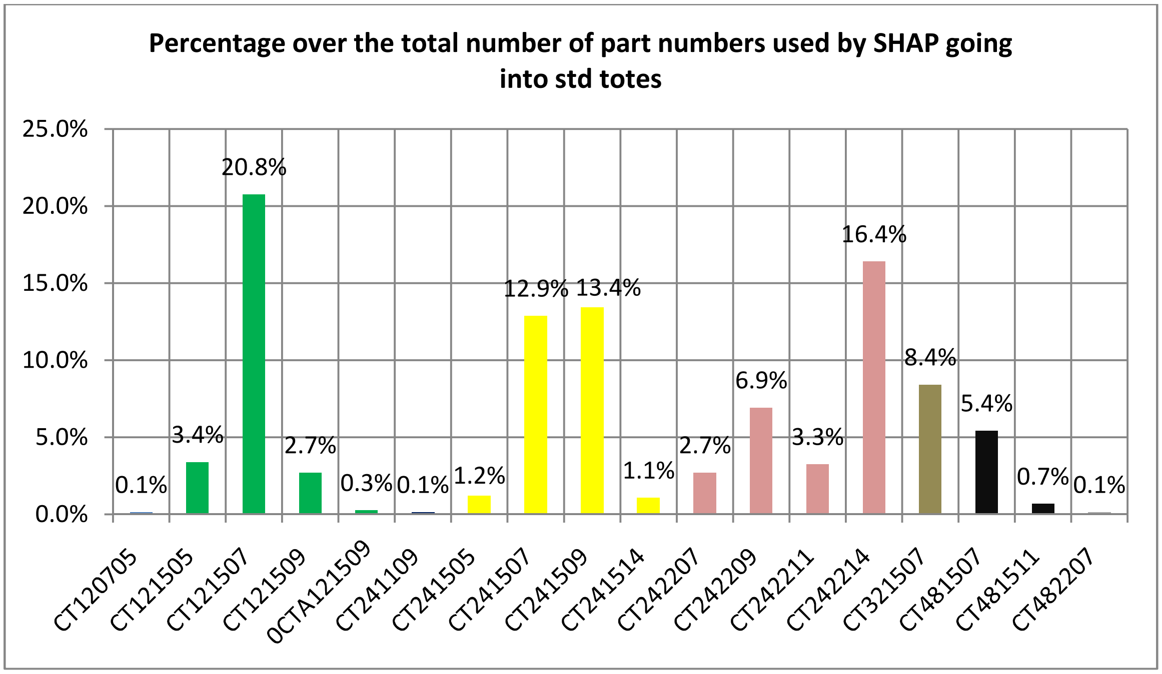


Figure 6.4 – Percentage of part numbers assigned to each standard tote type, Sterling Heights Assembly Plant.

Package ID. Number	Footprint (inches)	Height (inches)	Counts per Plant	Percentage per Plant
CT121507	**12x15**	**07**		
CT241507	**24x15**	**07**		
CT241509	**24x15**	**09**		
CT242209	**24x22**	**09**	**621**	**84.3%**
CT242214	**24x22**	**14**		
CT321507	**32x15**	**07**		
CT481507	**48x15**	**07**		
CT120705	12x07	05		
CT121505	12x15	05		
CT121509	12x15	09		
0CTA121509	12x15	09		
CT241109	24x11	09		
CT241505	24x15	05	116	15.7%
CT241514	24x15	14		
CT242207	24x22	07		
CT242211	24x22	11		
CT481511	48x15	11		
CT482207	48x22	07		

Table 6.5 – Standard totes to be kept in the standard list and to be used only as exceptions, Sterling Heights Assembly Plant.

Overall, one strategy is to exclusively use seven tote types up to CT120705 in Table 6.5 which incorporate the 84.3% of the total amount of part numbers assigned to standard totes in Sterling Heights Assembly Plant, representing, 621 part numbers out of 737. This is only one of the possible strategies that can be followed to reduce the standard list of standard containers and that the packaging types not included in the new reduced standard list can still be used as exceptions if one of the seven standard totes are not applicable in the specific case considered.

Having a large availability of different containers types might increase the possibility to achieve higher filling percentages but as discussed in Chapter 4, it may not be possible to capture economic and environmental benefits if the complexity of the packaging system is not reduced.

As previously explained, usually containers were selected by Fiat and Chrysler to increase the fill percentage as much as possible. Instead, the strength of this newly proposed strategy in this research is to keep the containers which incorporate the most of the part numbers assigned and meets plant operations needs (thus ensuring the highest fill percentage) and, at the same time, guaranteeing the availability of different dimensions (footprint and heights) in the standard list. Trying to use as much as possible standard containers from the reduced list for new production programs will reduce the container complexity through the years and it possible to achieve the related benefits presented in Chapter 4.3.1.

6.1.1.2 Standard Bulk Containers Analysis

This subsection shows the results from the analysis for reducing the standard bulk container types. Sterling Heights Assembly Plant has again been chosen as the example. For the sake of brevity, only the most important graphs and tables will be reported and the final results briefly discussed.

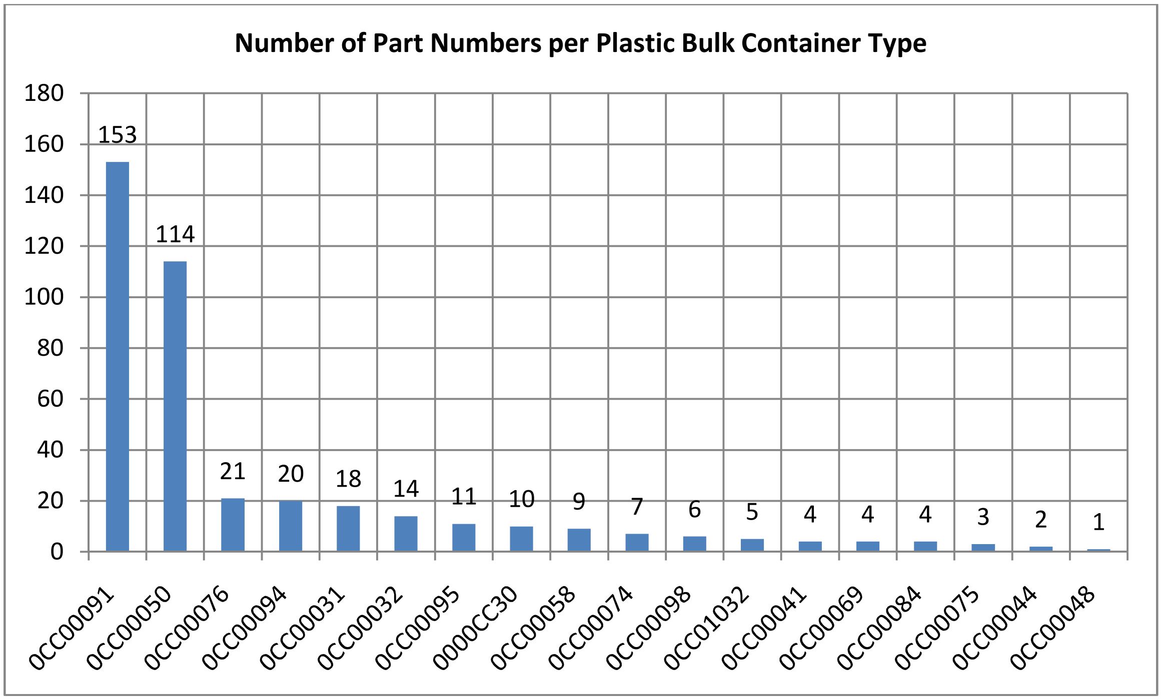


Figure 6.5 – Number of part numbers assigned to each standard bulk type, Sterling Heights Assembly Plant.

As presented in Figure 6.5, a large number of standard bulk containers are assigned to very few part numbers: there are ten container types to which less than 10 part numbers are assigned. Figure 6.6 shows the percentages of part numbers assigned to each standard bulk container type, grouped by different colours depending on the footprint class. Table 6.6 shows the dimensional analysis.

The strategy followed is the same as for standard totes, and 6 bulk container types out of 17 have been kept in the standard list incorporating 77.3% of the total part numbers assigned to standard bulk containers in this plant. In other words, container 0CC00084 with a footprint of 80”X48” should be kept because it is the largest sized needed, but can also accept parts that would have otherwise used the slightly smaller 0CC00041/48.

The same reasoning applied to the case of standard totes can be considered also in this case.

Package ID. Number	Footprint (inches)	Height (inches)	Counts per Plant	Percentage per Plant	Percentage per Footprint Class
0000CC30	32x30	22	10	2.5%	23.8%
0CC00032	32x30	25	14	3.4%	33.3%
0CC00031	**32x30**	**34**	**18**	**4.4%**	**42.9%**
0CC00050	**45x32**	**22**	**114**	**28.1%**	**92.7%**
0CC00058	45x32	27	9	2.2%	7.3%
0CC00076	48x45	25	21	5.2%	11.3%
0CC00091	**48x45**	**34**	**153**	**37.7%**	**82.3%**
0CC00074	48x45	34	7	1.7%	3.8%
0CC00075	48x45	42	3	0.7%	1.6%
0CC00044	48x45	50	2	0.5%	1%
0CC01032	**56x48**	**25**	**5**	**1.2%**	**100%**
0CC00098	64x48	25	6	1.5%	16.2%
0CC00094	**64x48**	**34**	**20**	**4.9%**	**54.1%**
0CC00095	64x48	42	11	2.7%	29.7%
0CC00041	70x48	25	4	1.0%	80%
0CC00048	70x48	34	1	0.2%	20%
0CC00084	**80x48**	**25**	**4**	**1.0%**	**100%**

Table 6.6 – Standard bulk containers dimensional analysis, Sterling Heights Assembly Plant.

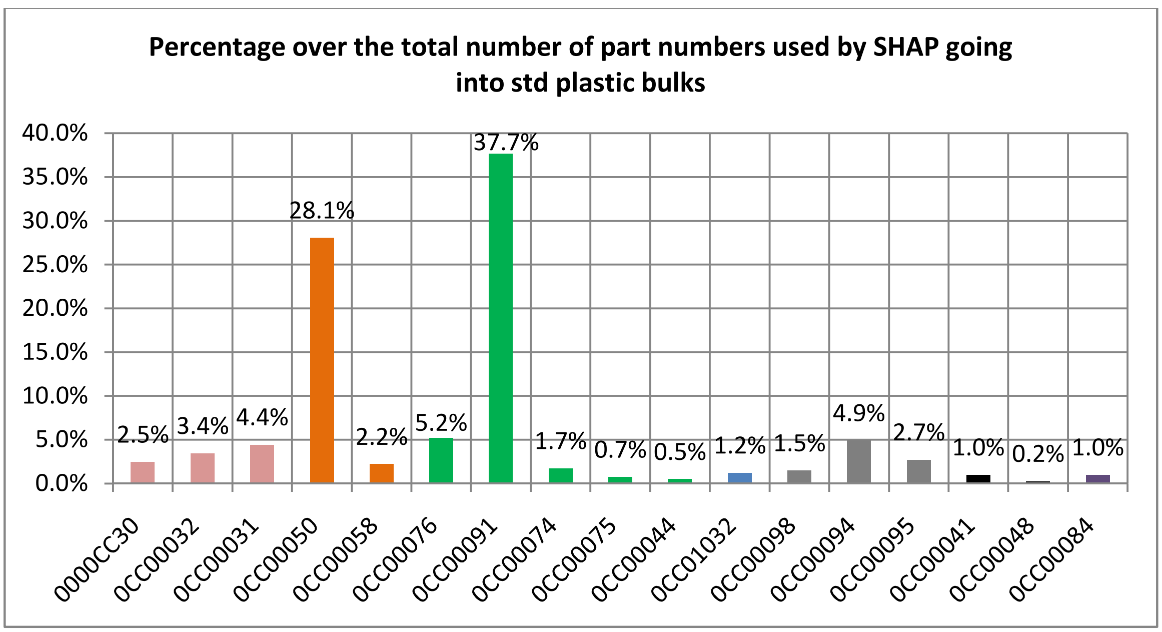


Figure 6.6 – Percentage of part numbers assigned to each standard bulk type, Sterling Heights Assembly Plant.

6.1.2 Results from Overall Analysis – All Chrysler Plants

Analyses like the one presented for Sterling Heights Assembly Plant have been performed for all Chrysler assembly plants in Canada, U.S.A. and Mexico. Moreover, two powertrain plants have been considered to take into account eventual specific needs of their operations. The results of all these analyses have been used in an overall analysis at the corporate level.

6.1.2.1 Standard Tote Overall Analysis

The trend observed for standard totes at a plant basis is reflected also in the overall analysis. In fact, several container types have been assigned to a very small percentage of part numbers, as shown in Figure 6.7.

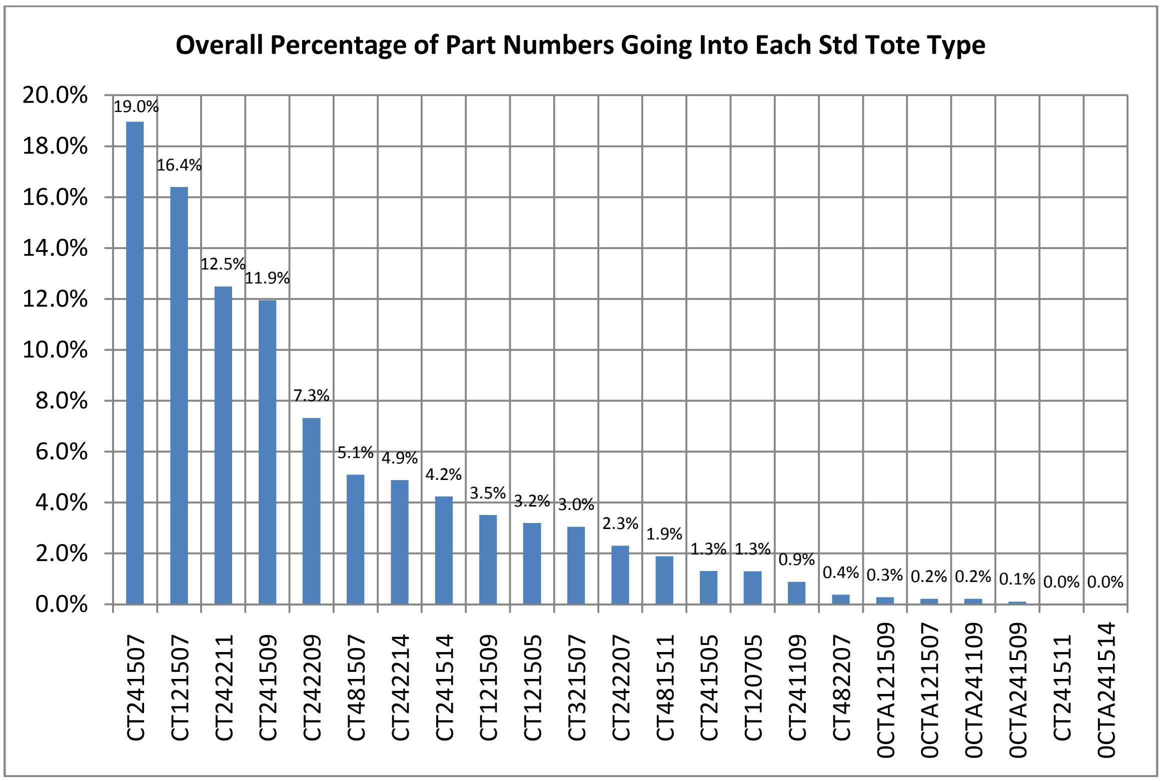


Figure 6.7 – Percentage of part numbers assigned to each standard tote type, overall analysis.

From the dimensional analysis presented in Table 6.7, Figure 6.8 and Figure 6.9, information about the tote types that can be kept in the reduced standard list of Chrysler and the ones that might be used as exceptions can be obtained.

Figure 6.8 shows container's usage percentages grouped by footprint class and divided by heights. The percentages have been computed over the total number of part numbers assigned to standard totes, while in Figure 6.9 they are calculated over the total number of part numbers assigned to the footprint class. The first column refers to the tote type characterized by a footprint equal to 12x07 inches and height equal to 5 inches.

Also in this case, the objective has been to keep packaging types able to incorporate most of the part numbers assigned to standard totes, ensuring high filling percentages for parts already assigned to those tote types, while at the same time maintain a sufficient variability of dimensions in order to reach reasonable filling percentages for the other components.

Package ID. Number	Footprint (inches)	Height (inches)	Overall Percentage	Percentage per Footprint Class
CT120705	12x07	05	1.3%	100.0%
CT121505	12x15	05	3.2%	13.5%
CT121507		**07**	**16.6%**	**70.4%**
CT121509		09	3.8%	16.1%
CT241109	24x11	09	1.1%	100.0%
CT241505	24x15	05	1.3%	3.6%
CT241507		**07**	**18.9%**	**51.7%**
CT241509		**09**	**12.1%**	**33.1%**
CT241511		11	0.0%	0.0%
CT241514		**14**	**4.2%**	**11.6%**
CT242207	24x22	07	2.3%	8.7%
CT242209		**09**	**7.3%**	**27.1%**
CT242211		**11**	**12.5%**	**46.2%**
CT242214		**14**	**4.9%**	**18.0%**
CT321507	32x15	**07**	**3.0%**	**100.0%**
CT481507	48x15	**07**	**5.1%**	**72.9%**
CT481511		11	1.9%	27.1%
CT482207	48x22	07	0.4%	100.0%

Table 6.7 – Standard totes dimensional analysis, overall analysis.

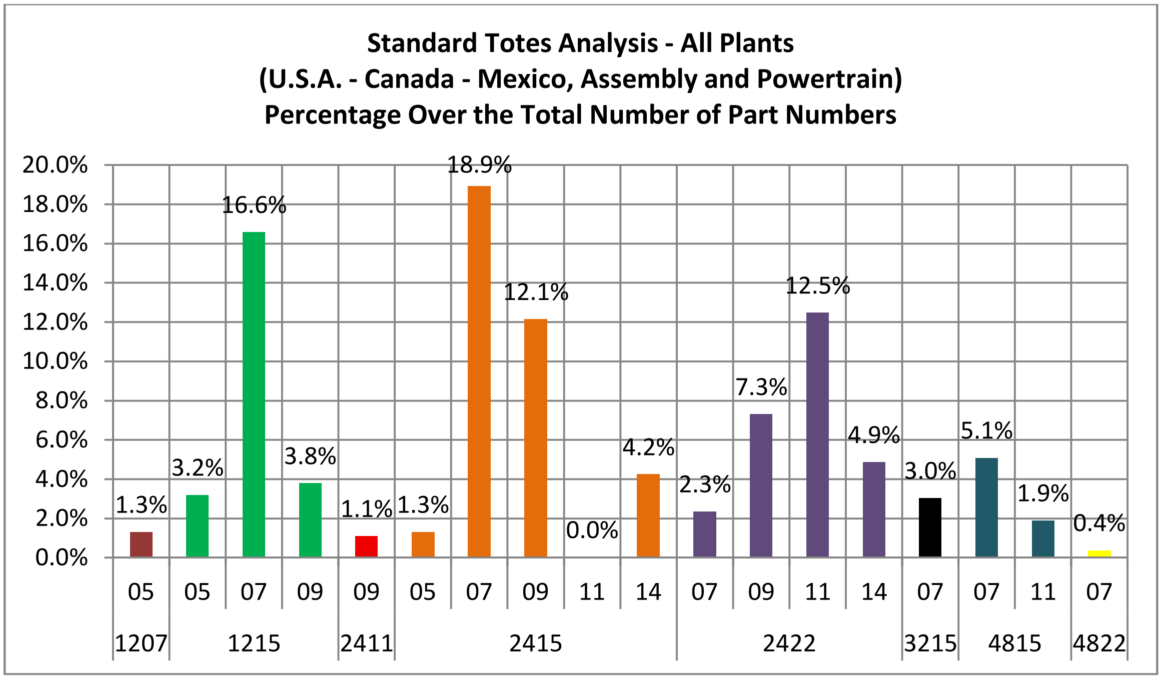


Figure 6.8 – Percentage over total number of part numbers assigned to standard totes, overall dimensional analysis.

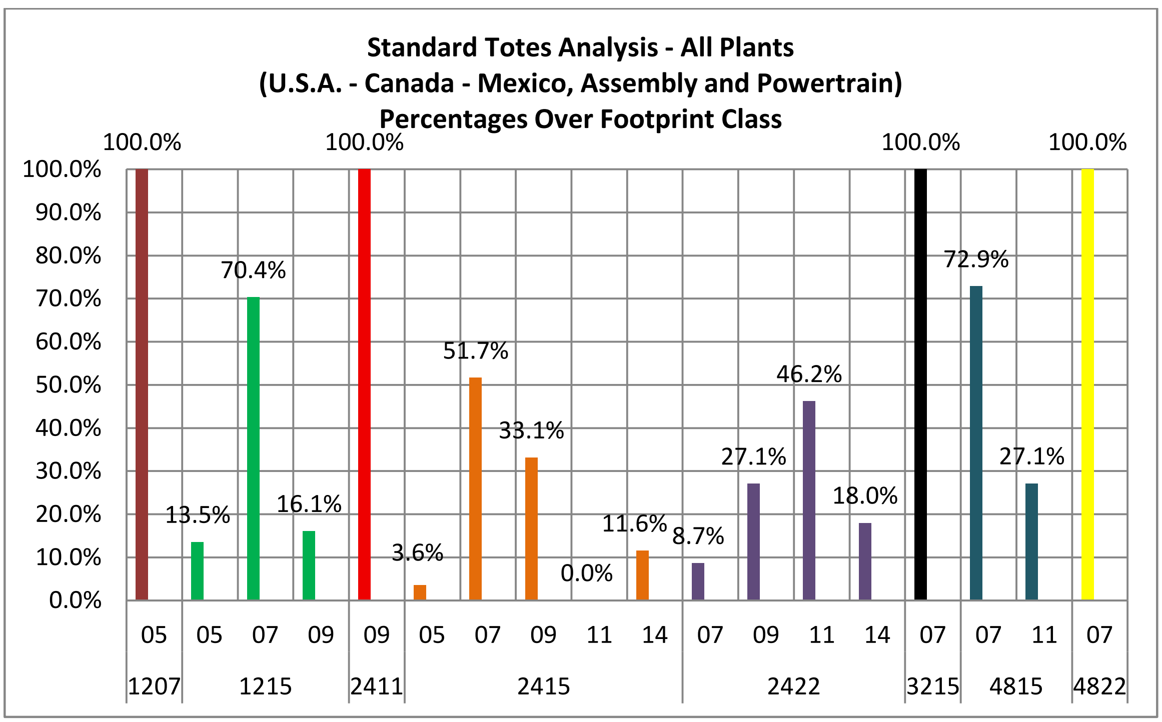


Figure 6.9 – Percentages per height over total number of part numbers assigned to footprint class, standard totes dimensional analysis.

Nine tote types over a total of eighteen have been kept in the standard list, incorporating 84.6% of the part numbers assigned to standard totes. All the tote types which have been selected to be kept in the reduced standard list of Sterling Heights Assembly Plants are also present in the reduced standard list resulted from the overall analysis at the overall company level for Chrysler. This strongly suggests that container strategy improvements in one plant are indicative of what can be accomplished at all plants.

6.1.2.2 Standard Bulk Containers Overall Analysis

The outcomes from the overall analysis of the standard bulk containers used are in some respects even more impressive than those attained with standard tote analysis. From the graph depicted in Figure 6.10, the majority of the standard bulk container types are assigned to a very small percentage of part numbers (percentage computed over the total number of part numbers going into standard bulk containers). There are 26 bulk container types to which less than 1% of the part numbers are assigned, while 82% of the part numbers are assigned just to 4 types.

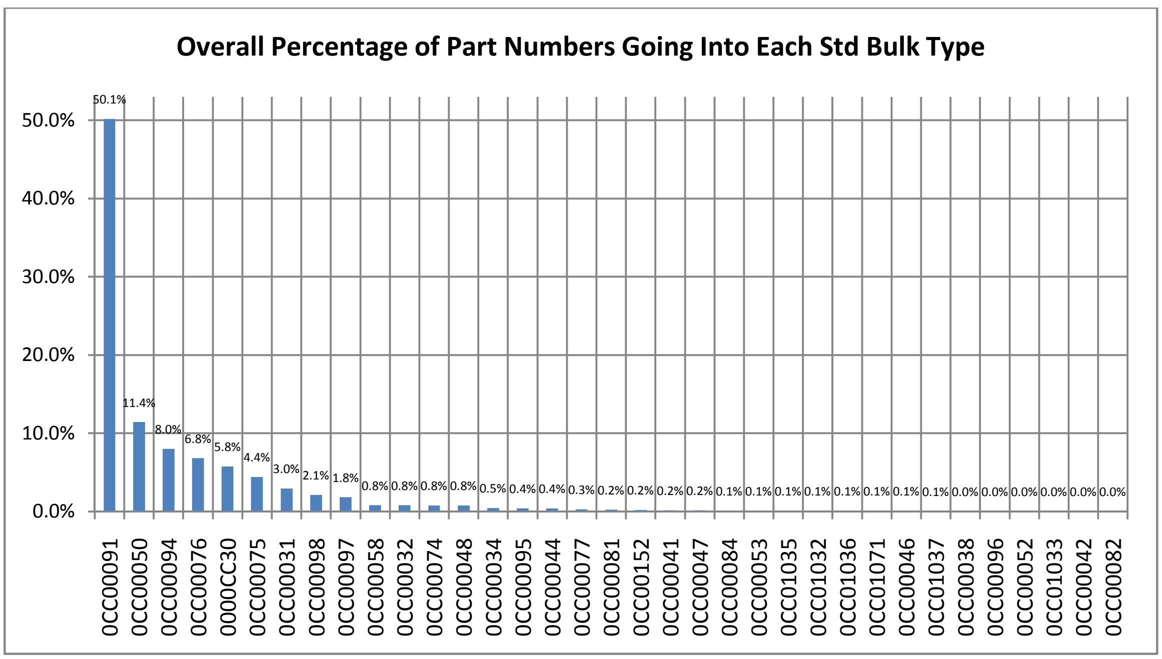


Figure 6.10 – Percentage of part numbers assigned to each standard tote type, overall analysis.

The dimensional analysis presented in Table 6.8, Figure 6.11 and Figure 6.12, has been used to select the bulk container types in different ranges of dimensions.

Package ID. Number	Footprint (inches)	Height (inches)	Overall Percentage	Percentage per Footprint Class
0000CC30	32x30	**22**	**5.8%**	**57.8%**
0CC00032		25	0.8%	8.1%
0CC00034		25	0.5%	4.5%
0CC00031		**34**	**3.0%**	**29.6%**
0CC00050	45x32	**22**	**11.4%**	**93.2%**
0CC00058		27	0.8%	6.8%
0CC01035	48x45	17	0.1%	0.2%
0CC00076		**25**	**6.8%**	**10.9%**
0CC00077		25	0.3%	0.4%
0CC00091		**34**	**50.1%**	**79.5%**
0CC00074		34	0.8%	1.2%
0CC00038		39	0.0%	0.1%
0CC00075		**42**	**4.4%**	**7.0%**
0CC00052		48	0.0%	0.0%
0CC00044		50	0.4%	0.6%
0CC01032	56x48	25	0.1%	46.2%
0CC01071		34	0.1%	38.5%
0CC01033		42	0.0%	15.4%
0CC00098	64x48	25	2.1%	16.9%
0CC00094		**34**	**8.0%**	**63.4%**
0CC00097		34	0.2%	1.5%
0CC00152		34	1.8%	14.5%
0CC00095		42	0.4%	3.3%
0CC00096		50	0.0%	0.3%
0CC00041	70x48	25	0.2%	12.0%
0CC00048		34	0.0%	2.2%
0CC00042		**34**	**0.8%**	**58.7%**
0CC00046		50	0.1%	9.8%
0CC00047		50	0.1%	5.4%
0CC00053		50	0.2%	12.0%
0CC01037	78x48	25	0.1%	40.0%
0CC01036		34	0.1%	60.0%
0CC00084	80x48	25	0.1%	100.0%
0CC00081	90x48	**25**	**0.2%**	**88.9%**
0CC00082		34	0.0%	11.1%

Table 6.8 – Standard bulk containers dimensional analysis, overall analysis.

The list of the standard bulk containers is excessive – there are 35 different types. However, upon further analysis, some container types have exactly the same dimensions (footprint and height), and they differ one from another because of a simple configuration variation (i.e., fold-able, not fold-able). Using the strategy used in the previous cases, 9 types have been selected out of the total of 35 bulk containers, and these 9 will be kept in the reduced standard list. All the other containers may still be used, but only in special cases as exceptions. Finally, it should be noticed that 90.5% of the total part numbers assigned to standard bulk containers are assigned to these 9 bulk container types.

There is significant consistency between the results obtained from the single plant-based analysis at Sterling Heights Assembly Plant (SHAP) and the overall analysis. There are just two containers which have been kept in the reduced standard list for SHAP and are not in the overall one; however, it should be possible to replace these two with two other, more common container types similar in dimensions when implementing the overall list.

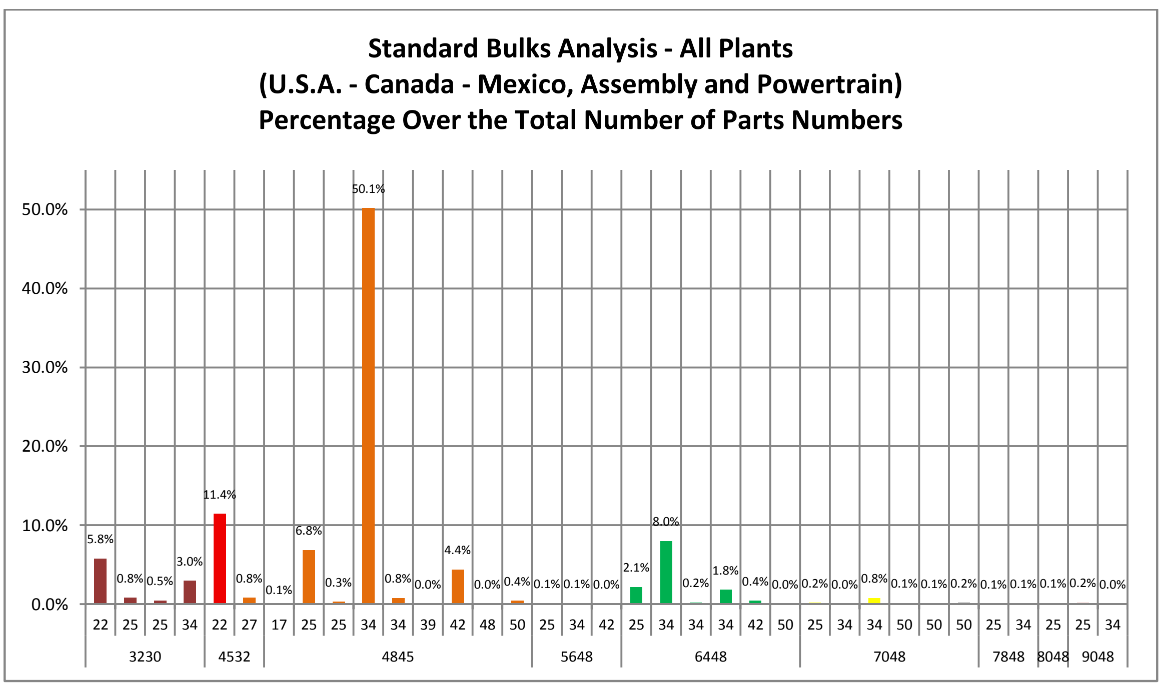


Figure 6.11 – Percentage over total number of part numbers assigned to standard bulks, overall dimensional analysis.

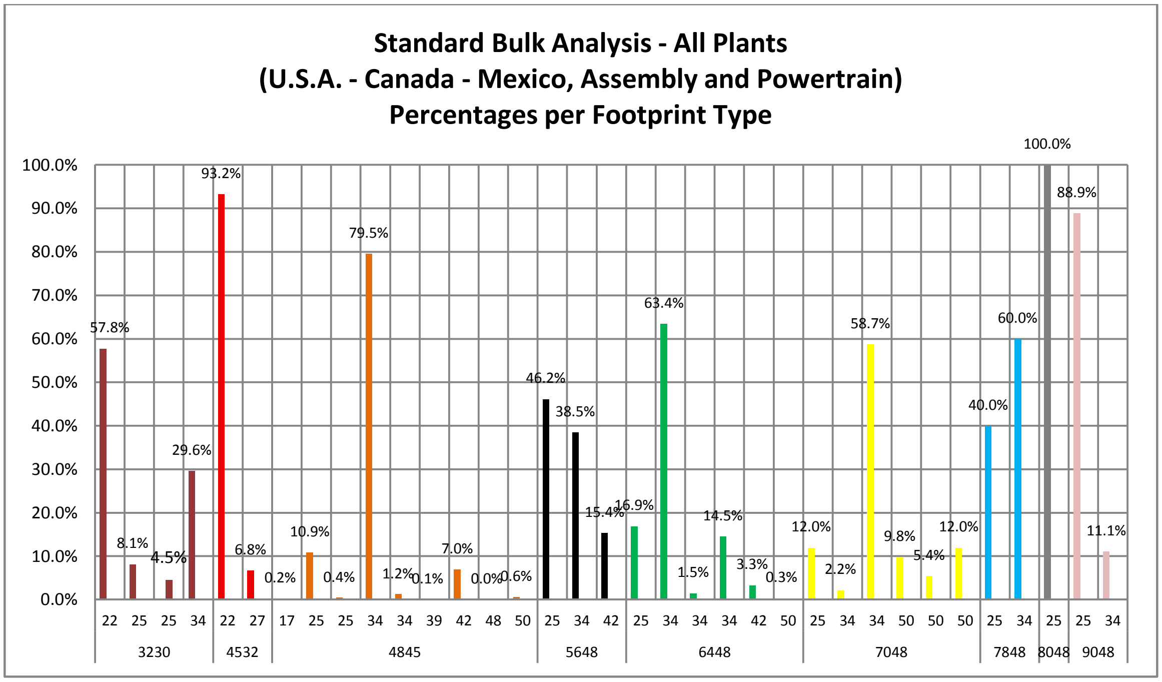


Figure 6.12 – Percentages per height over total number of part numbers assigned to footprint class, standard bulks dimensional analysis.

6.2 Key Factors for Environmental Performance Evaluation in the Selection between Expendable / Returnable Packaging and in the Choice of the Material

This section identifies the key factors that influence the environmental performances of expendable and reusable packaging systems when selecting between the two categories. This section also evaluates the most sustainable packaging material to be used.

These outcomes have been obtained from a review of life cycle assessments of companies operating in different business areas outside the automotive sector. From the study it have been possible to understand that the relative merits of one-way and returnable packaging depend on the specific characteristics of transported products, packaging format, supply chain conditions and detailed logistics processes in a given situation. Thus, it is usually not possible to state outright that one packaging format is generically environmentally preferable to another. Finally, these key factors can be used to develop guidelines in the first part of the packaging selection macro model (flow chart depicted in Figure 5.14).

6.2.1 Primary Key Factors

6.2.1.1 Energy Used and Raw Material Used in Manufacturing Process

The total environmental impact of expendable packaging systems usually depends more on the raw material type and energy effort used in packaging manufacturing than returnable packaging. This is because significant environmental impacts are incurred to make the package or container but it is then used for only a single trip. With returnable packaging, the immediate environmental impacts from production, for example, could be even greater if the package is made more robust, but the impacts are then distributed over a longer period of time and multiple uses over the lifetime of the package.

6.2.1.2 Number of Trips for Returnables

The number of trips made by returnable packaging during its lifetime is fundamental because it determines the allocation of the most significant environmental burden (package manufacturing) to each trip made by the returnable packaging. The more trips a returnable packaging unit makes, the lower the proportion the burden becomes. However, it is also worth to observe that, after a certain threshold, as the number of trips increases, the proportional decrease in environmental impact slows; in other words, there are diminishing benefits after this threshold point.

In general, lower trip rates favor expendable packaging, but higher trip rates favor returnable packaging due to the expected differences in manufacturing burdens discussed above. The number of trips that a returnable packaging will make in its lifetime depends on a number of interconnected factors such as:

- return rates;
- design characteristics of the returnable package (which highly influence its durability)
- frequency of shipments;
- time to return to point of filling from point usage;
- life of the product in the market;
- losses due to theft or damage;
- inspection, cleaning and repair activities.

6.2.1.3 Distances from Originating Point to Final Point

Longer journey distances tend to favor expendable packaging while shorter journey distances tend to favor returnable packaging. When distances are long, the return trip for empty containers becomes a highly relevant factor. The return trip for reusable packaging increases the number of truck kilometers required for the system to operate and, in turn, the kilograms of CO_2 emitted in the atmosphere. For primary returnable packaging or returnable distribution packaging that cannot be nested, the journey distance is doubled for these containers: the reusable packaging will occupy just as much space when empty on its return journey as it did on its journey full of products. Conversely, for returnable distribution packaging designed to nest (one tote sitting inside another when empty) or to be foldable/collapsible, although the journey distance will be doubled, the volume for the return journey is considerably reduced since more empty containers can be loaded on the transport vessel.

6.2.1.4 Pool Size for Returnables

The number of packaging units required to support a returnable packaging system is significantly higher than the number of packaging units required for the current parts supply needs at any one point in time. This is to allow for the time taken for return logistics, the cleaning of reusable containers, peaks in volumes, and buffer units for damages and losses in the system. Therefore, when comparing expendable packaging with returnable packaging, the full burdens of this packaging pool must be considered. The number of returnables required in the distribution system at any one time depends on several factors, including:

- dispersal of the supply chain locations;
- average time taken for the returnable to go through the whole distribution cycle;
- degree of statistical spread in the distribution of journey distances in the supply chain;
- sales volumes and seasonality;
- level of stock held in each part of the supply chain;
- efficiency of packaging collection systems;
- asset visibility in the supply chain; and

- losses and damages.

6.2.1.5 Cube Transport Vessel Utilization

Reusable packaging is usually (although not always) heavier and often occupies greater volume by design in order to withstand multiple trips. In some scenarios, this affects the efficiency of product distribution because of the higher mass reaching the weight constraints or limits for palletization (exceeded pallet weight load capacity) and transportation, or more commonly, the volume, which then limits the amount of parts that can be stored and transported in a given capacity or transport vessel size. The effect of this space reduction is that more transport travels may be required to ship a certain amount of parts. Fuel and energy requirements therefore rise and environmental impact increases.

6.2.1.6 Recycled Content and Post Use Material Recycling Rates

In general, the higher the recycled content of the packaging the lower the environmental burden from manufacturing that package because several upsteam processes (e.g., raw material extraction) would have been avoided. This reduced environmental burden usually outweighs the environmental burdens associated with recycling activities and operations.

6.2.2 Secondary Key Factors

6.2.2.1 Location of the Recycling or Disposition Center

The distance between the location of waste packaging collection and point of recycling or disposal can affect the environmental impact of the system. Because this aspect is so dependent on specific geographies and is typically beyond a company's control, it will not be assessed any further in this research. However, locations of such recycling or waste facilities will need to be accounted for in any local analysis.

6.2.2.2 Transportation Mode

The energy consumed by different modes of transportation varies considerably, as shown in Table 6.9 (data gathered from US Department of Energy). Nevertheless, when comparing between one-way and returnable packaging systems, the transportation mode is usually assumed to be the same for both.

Mode of Transport	Cargo Ship	Air Cargo	Rail	Heavy Truck	Medium Truck
Energy Use $MJt^{-1}Km^{-1}$	0.37	15.9	0.23	3.5	6.8

Table 6.9 – Energy use for different transport modes from US. Department of Energy.

6.2.2.3 Energy Mix Used in the Overall System

Methods of energy generation vary and each method has different impacts. They can consist of mixes of fossil fuel (oil and gas), hydro-electric, nuclear, wind, and solar generation. Again, much of the energy related impacts will be beyond an individual company's control; however, it should be recognized that each method of generation has its own raw material depletion, water usage, and emissions footprint for each unit of energy produced. Energy generation is important as it can have a great impact on the overall sustainability impact of a packaging system.

6.2.2.4 Frequency of Repair of Returnable Packaging

Returnable containers have to be repaired so that they can continue to be used. These repairs can vary from minor refurbishment to major work; therefore, the associated environmental impacts will therefore vary.

6.2.2.5 Cleaning Activities of Returnable Packaging

The energy and resources used in cleaning processes for returnable packaging are part of the environmental burdens of the whole system and have to be taken into account in a detailed environmental analysis.

6.2.2.6 Ancillary Packaging

Examples of ancillary packaging items are labels, shrink-wrap, and dunnage. Generally, when used for a one-way shipment, these items represent only a small percentage of the overall packaging materials and contribute relatively less to the overall environmental impacts with respect when used for returnable packaging. However, it is important to take them into account for any detailed environmental analysis.

6.2.3 Additional Factors

6.2.3.1 Product Damage Rate

Product damage occurring during normal distribution and storage has a significant influence on the environmental impact. The type and level of damage sustained in a given part distribution may vary significantly from one-way and returnable packaging formats and materials.

Packaging solution should help deliver the product to the consumer in an undamaged condition. If a product is damaged in the distribution processes, that component must be scrapped, or sold at reduced price, recycled, or repaired. For the damaged items, all manufacturing, packaging and logistics processes have already occurred, and have been wasted as a consequence of the damage: their environmental burden can be significant. This is particularly important where the ratio of the environmental impact associated with the product manufacture versus the one of packaging and delivery is high, or where damage rates are significant. The burden of product damage may outweigh the combined impacts of all the factors relating to the packaging surrounding it. Therefore, the impact of product damage rates between different expendable and returnable packaging formats and materials is a significant economic and environmental factor when selecting the packaging solution.

6.2.3.2 Packaging Size and Volume Efficiency

When comparing packs of different sizes, larger pack sizes are likely to be preferred from an environmental perspective because smaller containers have a larger surface area for a given volume of components contained than larger containers. Consequently, there would be a higher number of smaller sized containers needed to ship the same amount of parts, and as a result, they will be heavier, more bulky and use more material. However, it is also important to consider that some packaging have dimensions that better saturate the transport vessel, reducing the number of shipments and ultimately fuel emissions. Therefore, packaging dimensions have to be carefully considered when selecting among different possible solutions because the tradeoffs of environmental burdens is not always obvious.

6.3 Results from Packaging Selection Model Testing with Fiat and Chrysler Data

This section addresses the testing of the standard packaging selection model and discusses the results. Fiat and Chrysler data have been used to run the tool to ensure the consistency of the model for both companies to select the best packaging solution within a predetermined set of possibilities. This approached can later be generalized to apply to other industries. Two completely different components (in shape, geometry and requirements) have been selected to assess the tool and its consistency in two different situations.

6.3.1 Model Testing with Fiat Data

As far as Fiat operations are concerned, the model has been tested focusing on a part number used in the assembly of an actual vehicle from the “330” program (Fiat 500 L). The main data given as input to the model will be presented and the results obtained as output will be analyzed and discussed. The cooperation by many Fiat Group departments has been fundamental to acquiring the data needed to run the tool and to review the final results.

6.3.1.1 Main Input Data

The component chosen for model testing is a complete air filter supplied by Mecaplast. Its overall dimensions are 352 mm x 252 mm x 200 mm and it weighs 2.1 kg. It is classified as a B material (see section 5.1.3). The supplier is located in Beinasco (a town near Turin, Italy) while the Fiat assembly plant is in Kragujevac (Serbia). This is a case of intermodal shipment, and represents a complex case selected for model testing that should test the models’ robustness and highlight any data handling or analysis deficiencies.

Because intermodal shipping is used, the logistics consolidation center (or Integrated Logistics Center) in Villanova (Asti, Italy) manages the changeover in the transportation mode. The first part of the shipment from Beinasco to Villanova (37 km) is made by truck (from point A to point B in Figure 6.13); the second part from Villanova to Kragujevac (1,290 km) is made by train (from point B to point C in Figure 6.13). Operational constraints related to warehouse and line display equipment have not been taken into account to reflect the real conditions at the moment of the selection of the packaging solution for this component. In fact at the moment of the selection of the solution of this part number, constraints of this type did not exist (equipment have been purchased and not re-used from previous production programs).

Dunnage (corrugated cardboard layers) is needed for protection because of quality requirements and the space occupied by the dunnage inside the container is about 1.5 % of the inner volume of the packaging. Ergonomics requirements set the maximum admissible total weight to 10 kg for standard totes. However, because bulk containers for this plant operation are not handled manually, ergonomic requirements do not apply for this particular container macro-family. The daily production volume used for equipment planning is 550 vehicles produced per day (25 vehicles produced per hour). One part per vehicle is used and the option “take rate” is 38.9 %: in other words, this component is only assembled on 38.9% of all vehicles produced.

Figure 6.13 – Route from supplier to ILC and finally to assembly plant.

The maximum inventory level required by the matrix class / maximum inventory level is 11 hours (thus, there cannot be a stock of components in the container higher than this value). The number of working days for this plant is 222. The manpower cost rate for this plant is 3.90 euro. Times for each container handling operation (both for full and empty containers) have been obtained from Fiat Manufacturing Planning and Control Department. The total systems days are 30 days for bulk containers (25 logistics system days in which the tote is in transit, and 5 system days at the plant) and 36 for small lot totes (26 logistic system days in which the container is in transit, and 10 system days at the plant).

A repair factor of 5% is included when calculating the number of plastic containers needed, while the repair factor for steel containers is 1%. As suggested by the Supply Chain Management Department, no additional correction factor has been considered to further increase the number of containers needed.

Depending on the distances, the tool suggests using intermodal shipping through ILC, as it currently does in reality. The average shipping cost for truck is 1.59 euro/km, while the cost for shipping a train with 32 train cars from Villanova to Kragujevac is 17,350.00 euro. The trailer dimensions are 13,600 mm (length) x 2,440 mm (width) x 2,600 mm (height) while train car dimensions are 13,600 mm (length) x 2,400 mm (width) x 2,600 mm (height).

With respect to environmental data, an emission factor equal to 0.893 kg of CO_2 per vehicle-km has been used for truck shipment (value given by Fiat database). The same factor for rail transportation instead has been obtained from "Climate Leaders Greenhouse Gas Inventory Protocol Core Module Guidance, Optional Emissions from Employee Commuting, Business Travel and Product Transport (US EPA, 2008)", because no value was available in the Fiat database. The emission factor for rail transportation suggested by U.S. Environmental Protection Agency (U.S. E.P.A.) is equal to 0.0252 kg of CO_2 per ton-km. The emission factors provided by U.S. E.P.A. are reported in Table 6.10.

Vehicle Type	**CO_2 Factor (Kg/Unit)**	**Unit**
Medium and Heavy-Duty Truck	1.726	vehicle-mile
Passenger Car	0.3640	vehicle-mile
Light-Duty Truck	0.519	vehicle-mile
Rail	0.0252	ton-mile
Waterborne Craft	0.048	ton-mile
Aircraft	1.527	ton-mile

Table 6.10 – Environmental Emission Factors (from U.S. E.P.A.).

6.3.1.2 Analysis and Discussion of the Outputs of the Model

After entering these parameters into the input sheet of the tool, it generates the following output to help select the best packaging solution for the user. Please refer back to Chapter 5 for a detailed explanation of the computations and procedures.

The tool provides two different kinds of output: 1) results applicable within a packaging macro-family; or 2) overall outputs in which the results are directly compared between different macro-family solutions. The former can be better for the user when boundary conditions impose the use of a predetermined macro-family (known before starting the decision making process). This way, the user can focus his attention only on the standard containers within the investigated macro-family. On the other hand, when all the standard containers macro-families (plastic totes, plastic bulk bins, steel bulk bins) are potentially suitable to contain the investigated part number, it may be more convenient for the user to analyze the outputs of the model in which all the possible standard containers solutions are directly compared.

Because there were not preliminary constraints for the packaging macro-family to be used for the complete air filter considered, the outputs presented will refer to all the possible standard containers solutions available for the company.

6.3.1.3 Container Filling Percentage, Container Density and Cost Comparative Analysis

The standard packaging selection tool provides as output: the volume filling percentages; container density; investment cost for containers (allocated to the production program); manpower cost for container handling (whole program duration); and shipping cost (whole program duration). Figure 6.14 shows the fill percentage for each standard container on the company list. Containers codes are presented on the x-axis, while percentages of filling on the y-axis. The bars of the graphs have different colours to distinguish between the different container macro families. Yellow is used by the tool for the plastic bulk bins, light blue for the steel bulk bins, and green for the small lot plastic totes

Some container codes do not have bars corresponding to their fill percentages because the tool has been created purposely to leave blank the space for containers which are not able to meet all the established requirements. In fact, those solutions cannot be applied and, therefore, the user of the packaging selection tool must focus only on solutions which are actually applicable in the investigated operational environment.

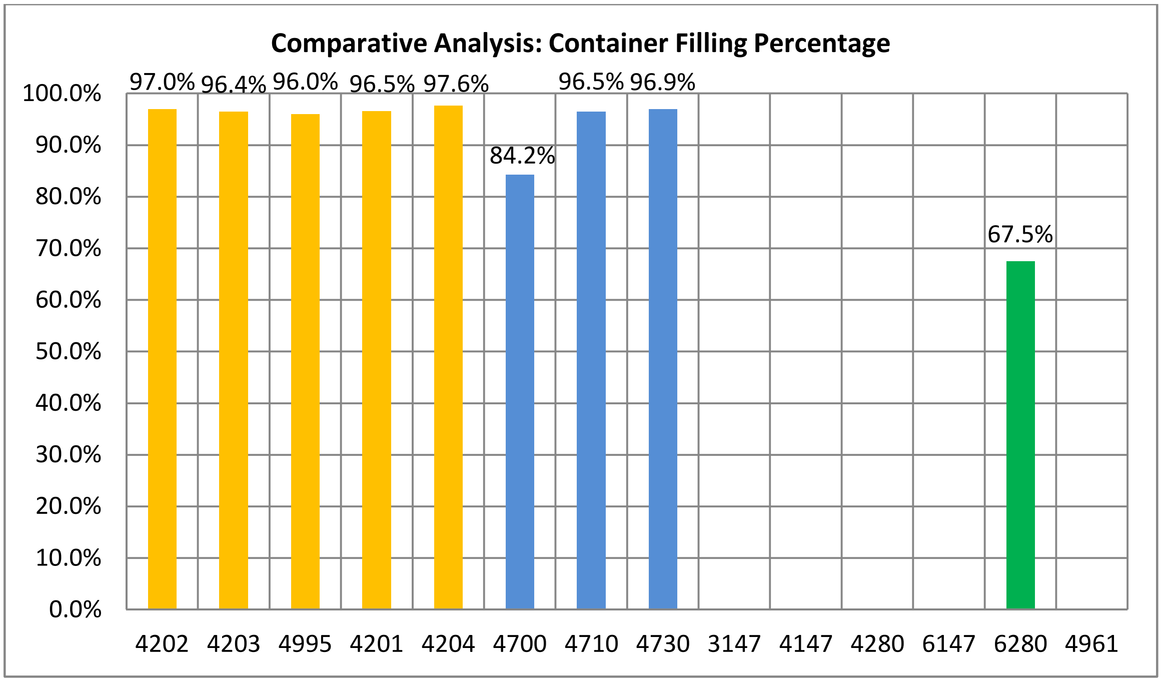


Figure 6.14 – Containers volume filling percentage.

All the plastic bulk bins have almost the same fill percentage. The same can be said for steel bulk bins, except for container 4700. Only one small lot tote is able to meet all the requirements but its filling percentage is significantly smaller with respect to bulk containers.

Figure 6.15 presents the container density for each possible solution. Comparing this graph to the previous one reveals significant differences between different solutions within each container macro-family, while the container fill percentage varies much less from one solution to the other. This is mainly due to the different dimensions and geometry of the various container solutions.

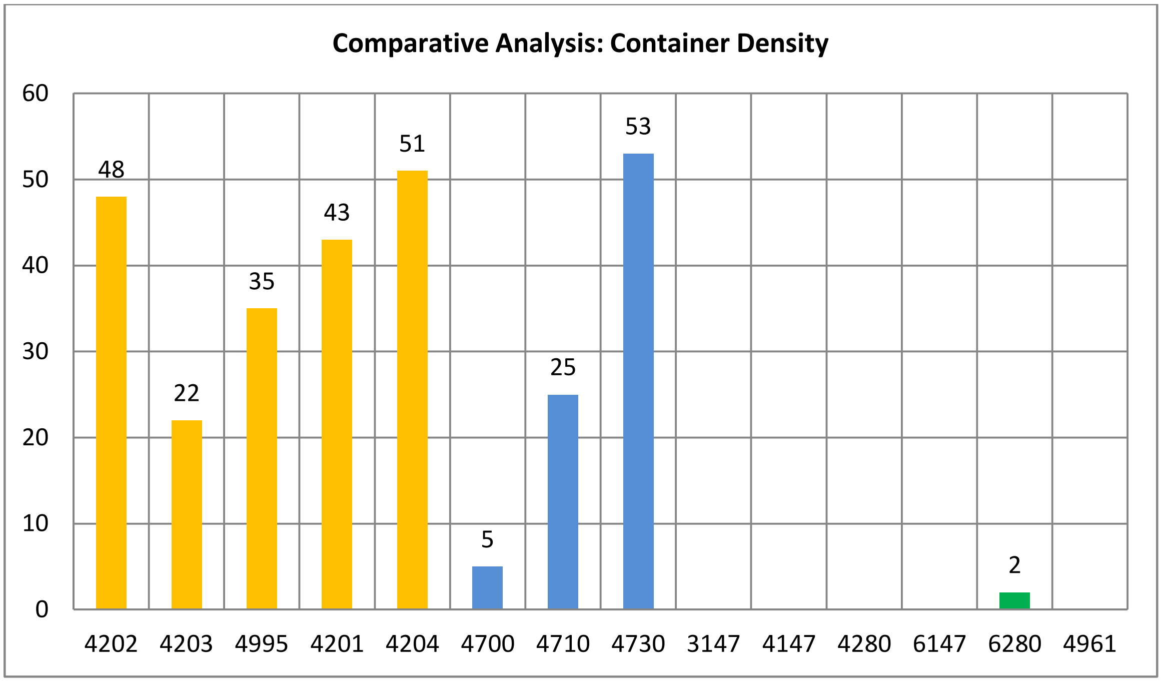


Figure 6.15 – Containers density: number of parts inside the container.

These two graphs provide important, overall information but they are insufficient by themselves to select the best container solution because the total economic and environmental impacts depend on many other parameters as explained in the section of this thesis dedicated to the model outline and procedure. These other, critical parameters are accounted for in the output graphs presented in the following.

The key factors affecting the total economic impact and performance of a packaging solution are the investment for new containers, total manpower cost for the handling and total shipping cost. These three main economic outputs are computed by the model for each container solution and presented as graphs to the user to compare. In Figure 6.16, the investments for new containers allocated to the production program are shown. The model allocates the investment on the basis of the average life of the containers and of the program duration. An average life of 8 years has been considered for plastic container and 15 years for steel containers. The production program duration has been considered of 5 years.

The graph shows both the values for the investments (bar graph) and an investment comparison index (black dots) helpful for rapidly comparing the different solutions without focusing on the actual investment values. The investment comparison index assumes values between 0 and 1. For each container solution the comparison index is computed as the ratio between the investment for each of the container solutions investigated (and allocated to the single component for which we want to select the best container solution) and the investment of the solution which, after the computation, is characterized by the highest investment. This also measures the percentage of investment saved by selecting one of the other container solutions with respect to the one that will result in the highest investment.

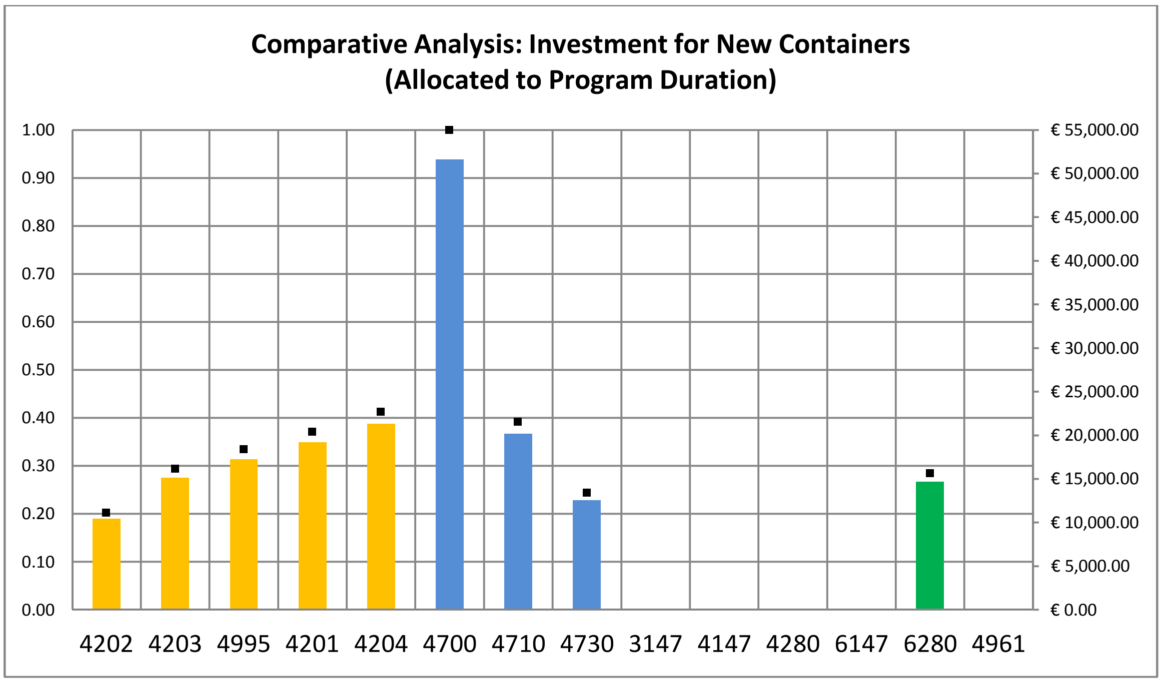


Figure 6.16 – Investment for new containers allocated to the production program.

There are two y-axes in this graph; the bar graph refers to the currency values while the black dots refer to the comparison index values between 0 and 1.

The value of the investment depends on many parameters as shown by Equations 5.8, 5.9, and 5.10. Generally steel containers are more expensive than plastic containers but their life is longer, and thus the investment allocated to the considered program will be a small portion of the total investment. As shown in the figure, the highest value for the investment is reached by steel bin 4700, characterized by a high cost and small number of parts contained.

Figure 6.17 depicts the forecasted values and comparison for the manpower cost for container handling. In this case, the container density is one of the main driving factors, but small lot totes are generally subjected to a higher number of handling operations with respect to bulk containers. In fact, when a unit load of standard totes arriving at the plant location has to be unloaded from the truck, delivered and unpack in the warehouse, the totes have to be sorted on the storing equipment (usually shelves of the racks), then they have to be picked up from the shelves and placed on the dolly for line delivery and finally placed on the line display equipment. These same operations are needed for the return of the empties. As far as bulk containers are concerned, since they are not grouped in higher level distribution packaging, the handling operations needed are less numerous and usually require less time. All or nearly all the handling operations are performed directly with a fork-lift.

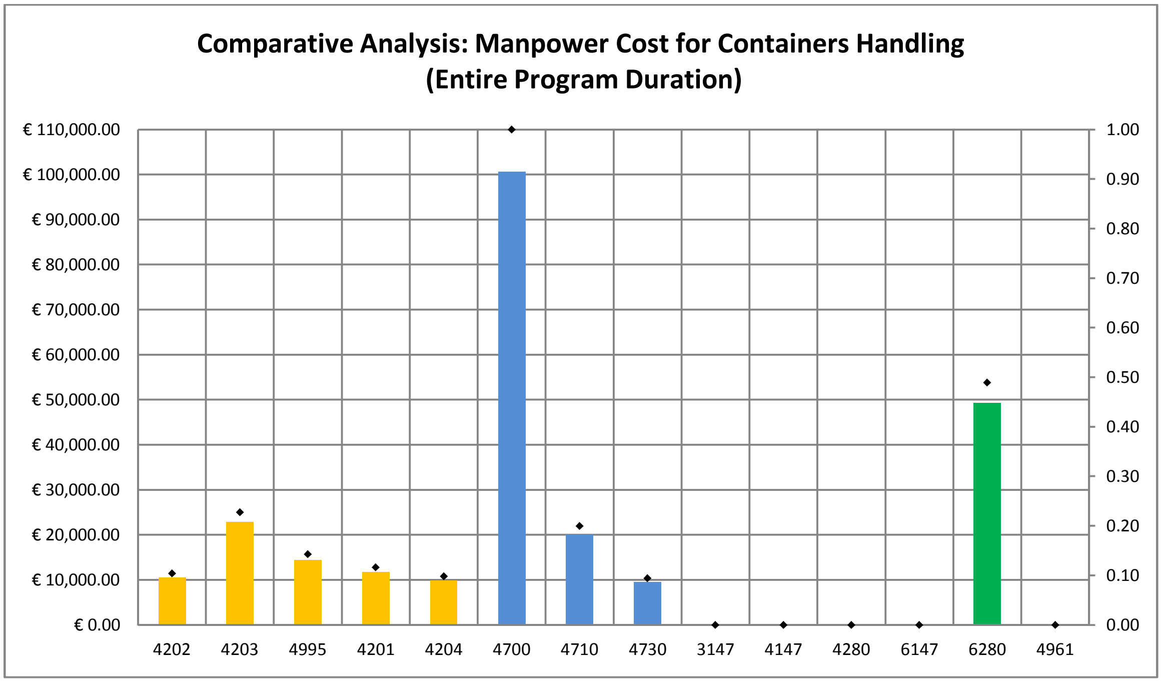


Figure 6.17 – Forecasted manpower cost for containers handling, entire duration of the program.

Figure 6.18 shows the total shipping cost for full and empty containers. The packaging selection tool estimates this cost for the entire duration of the program to be consistent with the other two main cost factors. The shipping cost depends on several parameters as pointed out in Equations 5.19, 5.20, 5.21, 5.22 and 5.23. The significant differences between the various packaging solutions are mainly due to container density, container dimensions and geometry (mean of transport volume saturation), and the container full/empty ratio.

When considering small lot totes, the tool refers to the unit load dimensions. As a matter of fact, small totes are grouped in distribution packaging (unit loads) for improving the efficiency of handling and transportation activities. Finally, considering that the investigated situation refers to an intermodal transportation, the shipping cost computed by the tool relates to the total cost given by the sum of truck shipping cost and train shipping cost.

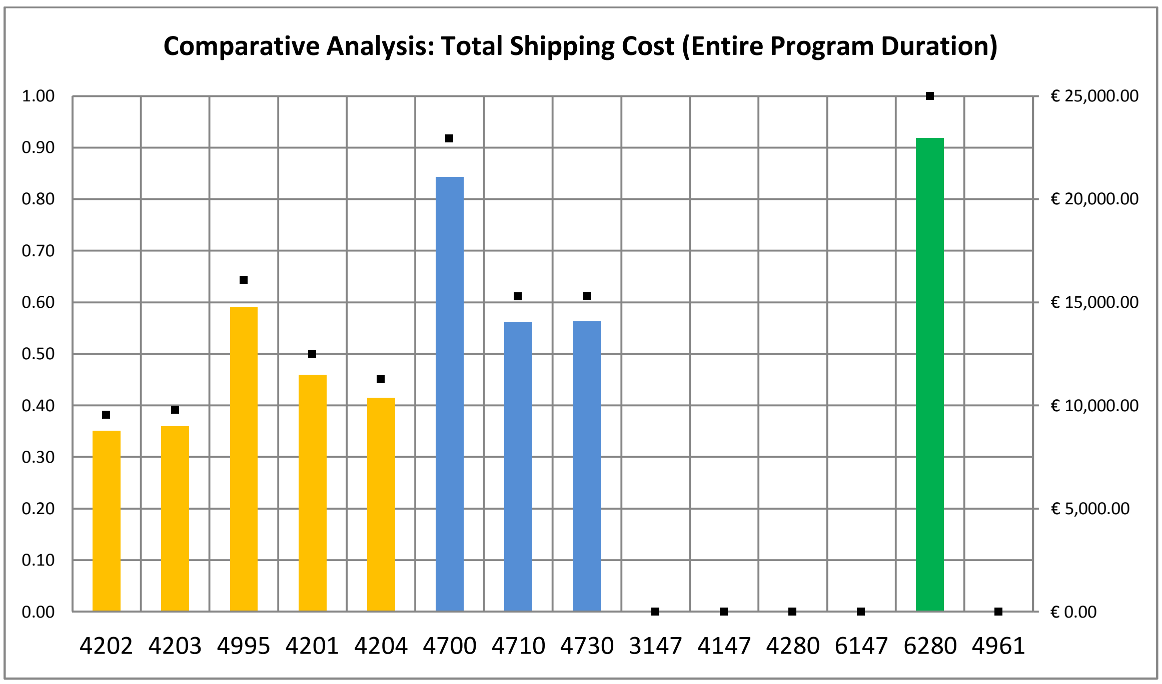


Figure 6.18 – Forecasted total shipping cost (full and empty containers), entire duration of the program.

The train shipping cost allocated to the part number is smaller than the truck cost, even if the distance traveled by the train is significantly longer than the distance traveled by the truck. This supports the argument that when shipping volume are enough to saturate the mean of transport, train shipment is more efficient with respect to truck shipment for long distances from supplier to assembly plant.

6.3.1.4 Sensitivity Analysis of Total Cost Components

In Figure 6.19, the total cost impact is not generally dominated by a single factor. In fact, each component influences the total cost impact and there is no common trend among the different packaging solutions (great differences exists also within the same macro-family). Investment, manpower handling cost or shipping cost can be greater or smaller, depending on each solution, but they have all a significant impact on the total cost.

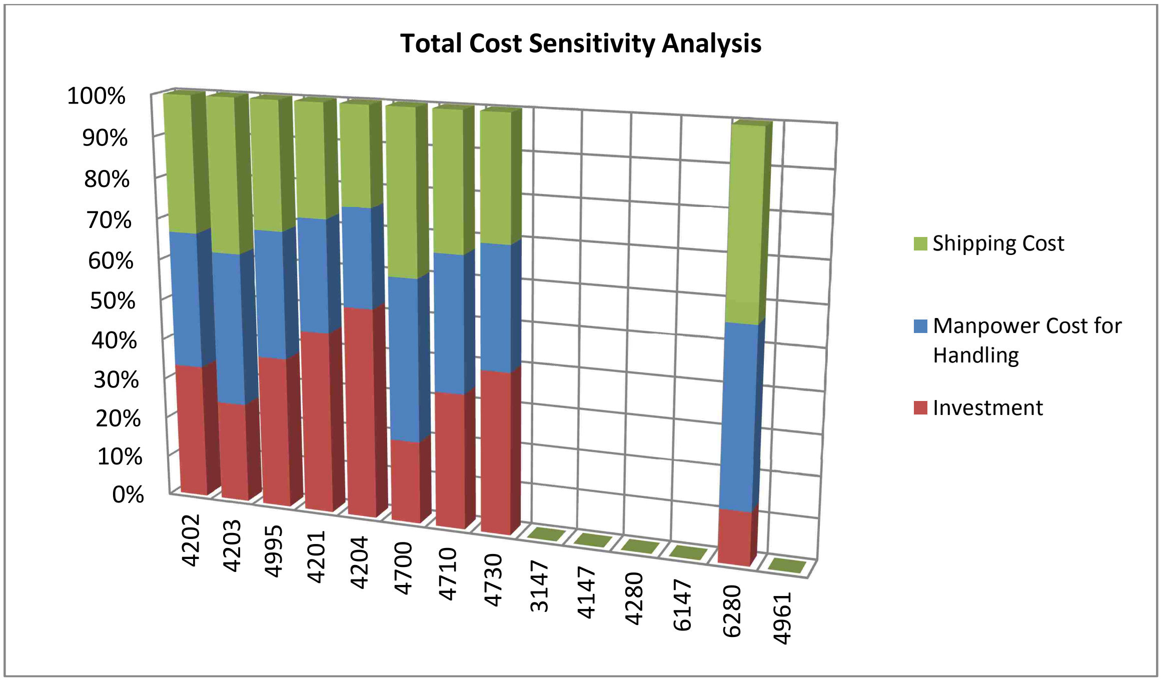


Figure 6.19 – Total cost components sensitivity analysis.

These issues demonstrate the importance of this multi criteria decision making model and tool for the selection of the best packaging solution. Because there is no dominant factor, without having a tool able to take into account all the different parameters, requirements and aspects, elaborating and combining them together in order to have a consistent forecast of the various possible scenarios, it is very difficult to choose a solution that provides the lowest, possible, overall impacts. One can focus on reducing the impact of one factor or another, but the overall impact may not be reduced. For example, when focusing on reducing the manpower cost for the handling, container 4730 might seem the best solution, but this solution will be not best from a total cost perspective and for the environmental impact. The same could be said for other containers when focusing on the other cost related factors. Moreover, the number of parts contained in each container is not the only driver in the final selection of the best solution.

These considerations highlight the importance of a comprehensive analysis like the one performed by this tool to account all the various aspects and parameters affecting the total economic and environmental impact of each investigated solution.

6.3.1.5 Comparative Analysis of the Environmental Impact

The tool analyzes the environmental burden associated with each container solution. As previously stated, the kilograms of CO_2 emitted in the atmosphere by shipping logistics processes has been chosen as key factor for evaluating the environmental performance of each container solution. Figure 6.20 presents the values of carbon dioxide emissions during the entire duration of the production program associated to each container solution. In this case, the plastic bulk containers ensure the lowest environmental burden, while the highest impact is generated by the steel bulk containers. This is mainly due to their dimensions, non-collaopsibility and to the heavy weight characterizing them. Because carbon dioxide emissions are directly related to the number of trips needed to ship the whole amount of components required for assembly operations during the production program, the container density (number of parts contained) is a significant factor affecting the environmental performance of each solution.

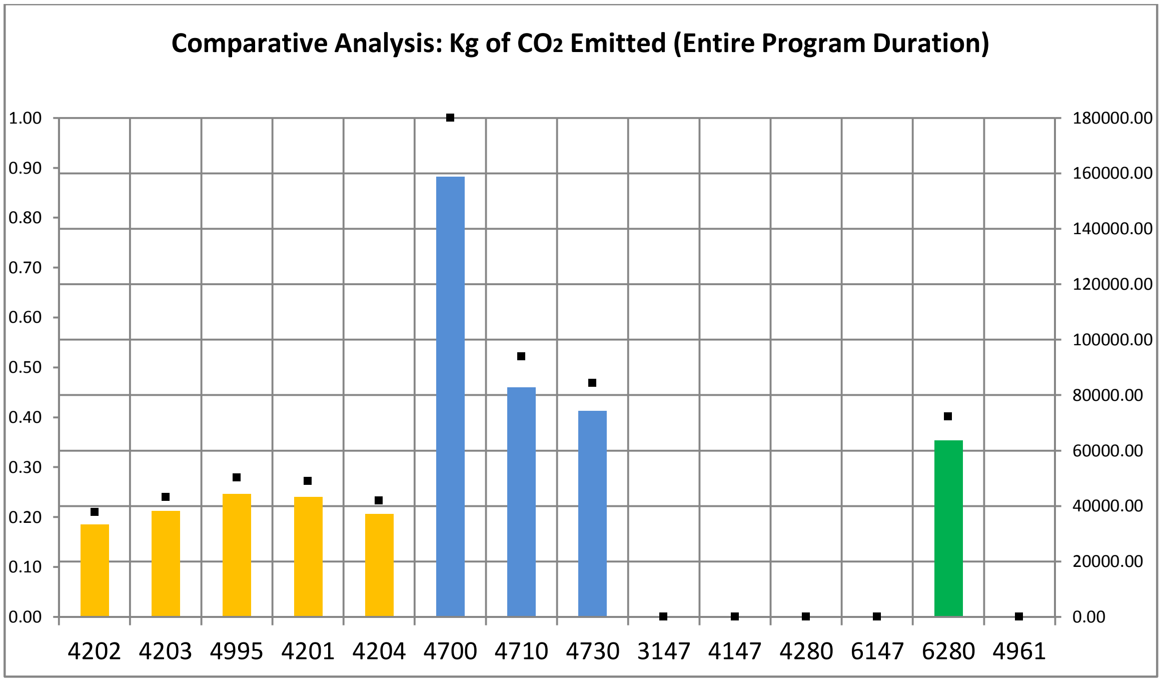


Figure 6.20 – Environmental impact, Kg of carbon dioxide emitted during the entire duration of the program.

6.3.1.6 Overall Comparison, R-Index and E-Index

The analyses presented in the previous sub-sections of this work can help assess more in depth the cost and environmental performances of each potential container solution. However, two indices have been created and are calculated by the tool to more quickly an comprehensively compare alternative solutions from a total cost and environmental perspective.

These indices are given as output by the model, and the user can immediately obtain a first indication about the best standard container solution. All the parameters and aspects considered are finally integrated in these two indices for final comparison. The formulas and development of these indices are shown from Equation 5.25 to Equation 5.29.

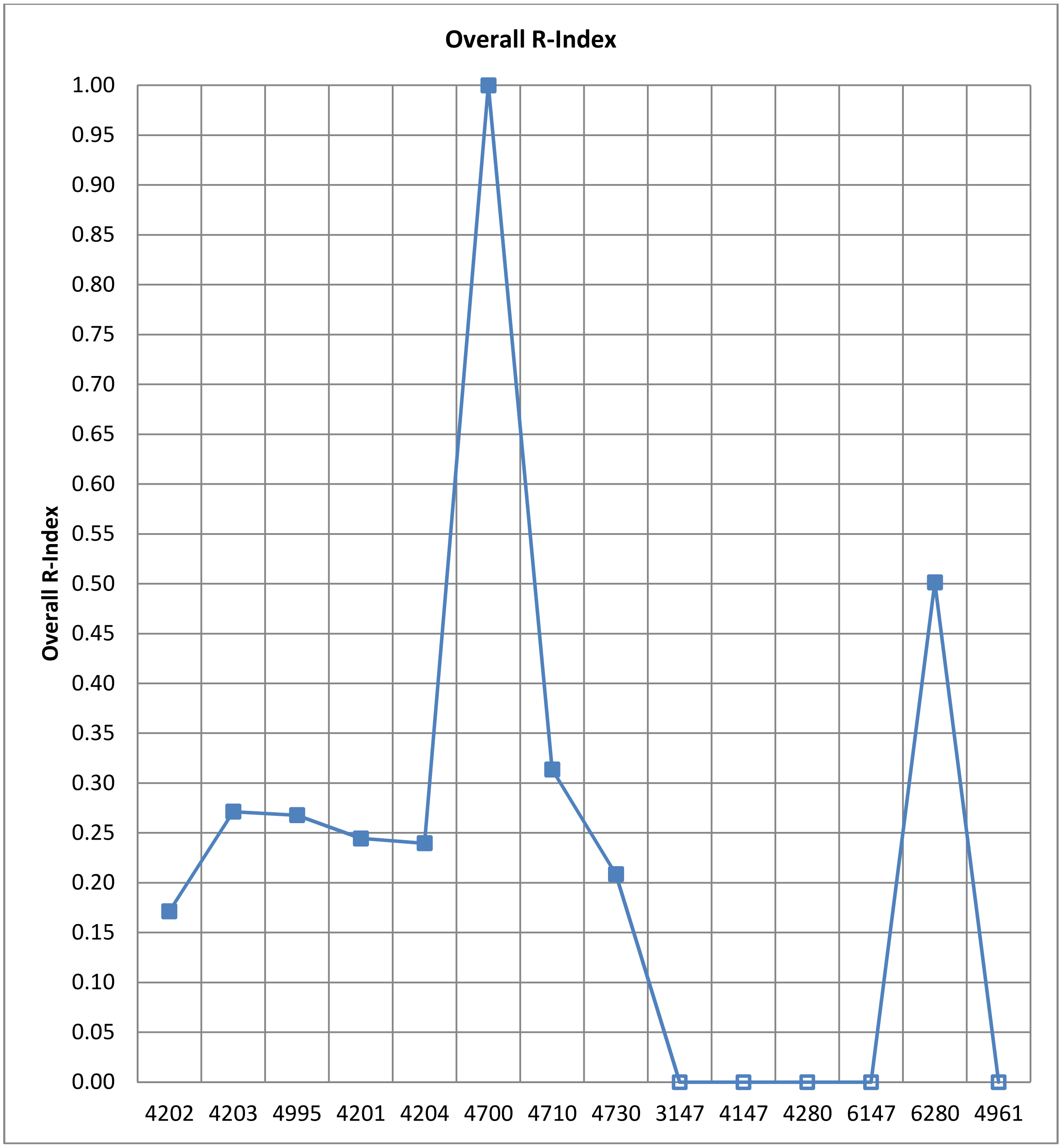


Figure 6.21 – Overall R-Index: total cost comparison index.

The total cost comparison is performed by the *R-Index*, which is shown as output of the decision making tool and depicted in Figure 6.21. The environmental impact comparison is highlighted by the *E-Index*, presented in Figure 6.22.

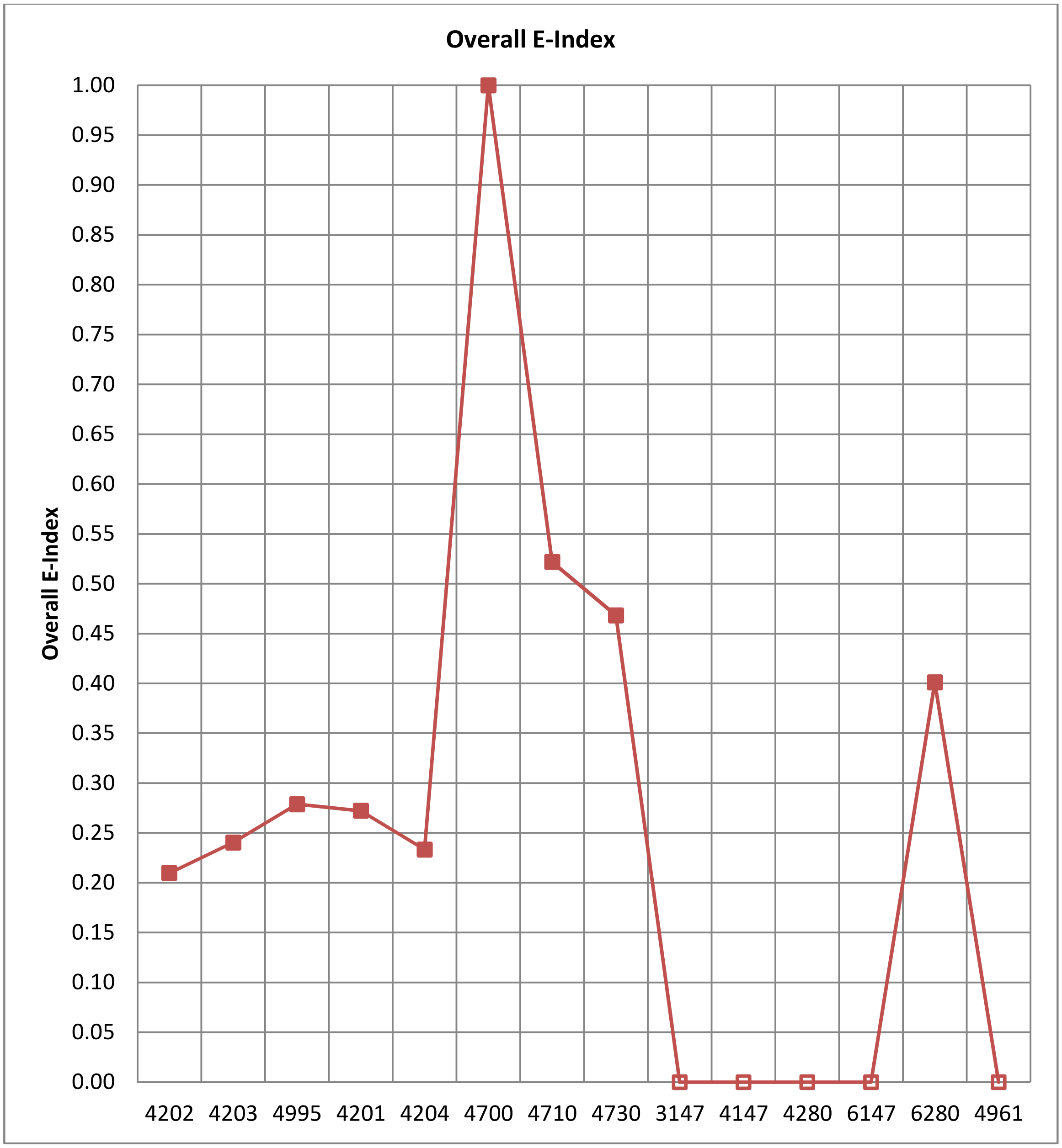


Figure 6.22 – Overall E-Index: environmental impact comparison index.

Finally, R-Index and E-Index are plotted together on the same graph in Figure 6.23. This graphical output compares the economic and environmental impacts simultaneously. The values of these indices are also listed in Table 6.11. As in the previous graphs, the values of these indices are shown only for the container solutions actually applicable (able to meet all the requirements).

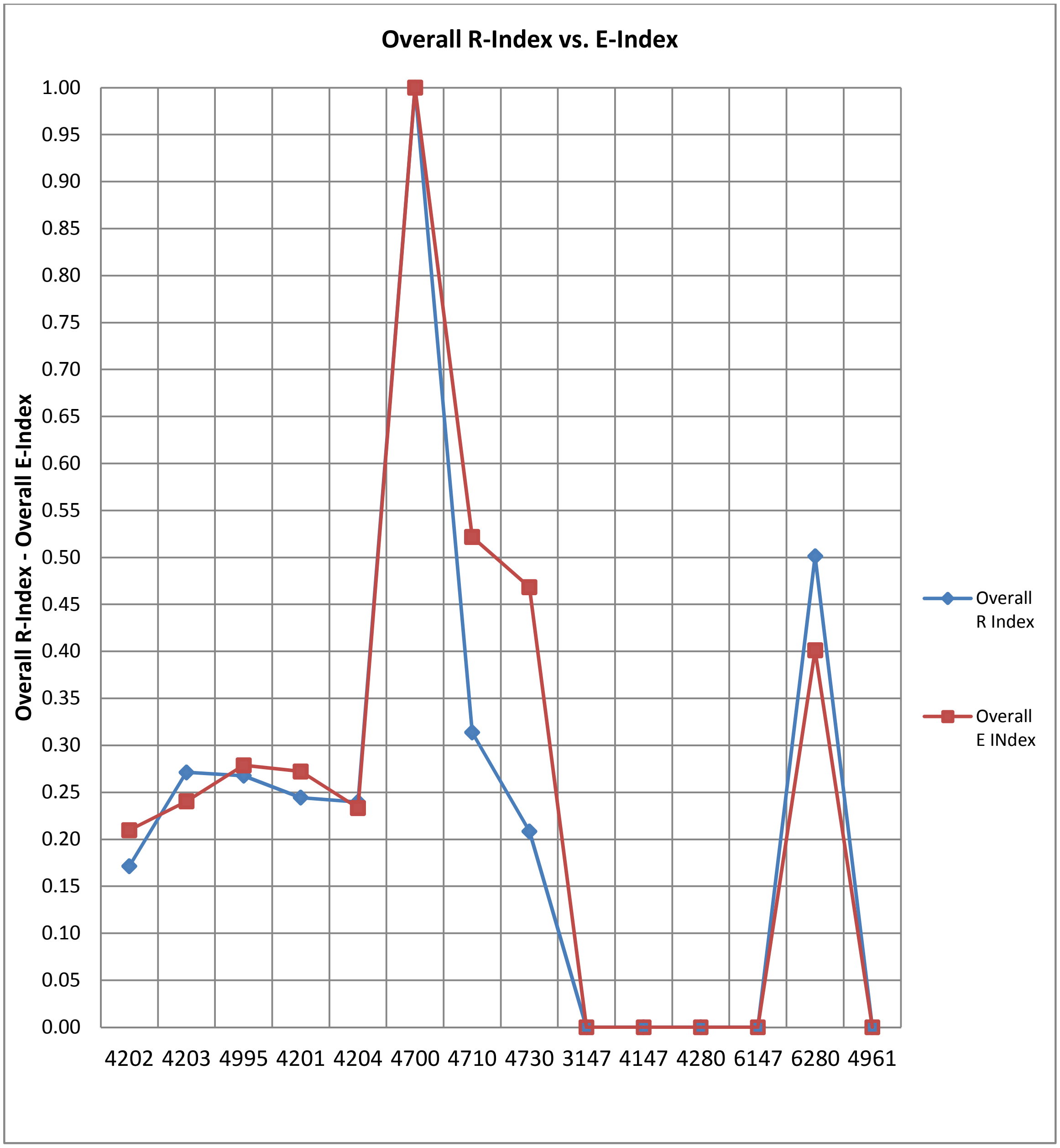


Figure 6.23 – Overall R-Index versus E-Index: final comparison for the selection of the optimal solution.

The tool assigns a zero value in the graph and a blank cell in the table to other containers which are not applicable in this case: there is no possibility for the user to select a solution which cannot be actually used. Note that in Figure 6.23 the total cost and environmental impact representations do not have to align. This difference is also apparent between the total cost ranking and environmental ranking shown in Table 6.11.

	Packaging ID. Number	Overall R Index	Overall E Index	Total Cost Ranking	Environmental Ranking
PLASTIC BULK BINS	4202	0.17	0.21	1	1
	4203	0.27	0.24	4	3
	4995	0.27	0.28	4	5
	4201	0.24	0.27	3	4
	4204	0.24	0.23	3	2
STEEL BULK BINS	4700	1.00	1.00	7	9
	4710	0.31	0.52	5	8
	4730	0.21	0.47	2	7
PLASTIC SMALL LOT TOTES	3147				
	4147				
	4280				
	6147				
	6280	0.50	0.40	6	6
	4961				

Table 6.11 – Overall R-Index and E-Index values, packaging ranking.

The highest discrepancy between the total cost and environmental performances exists for the steel bulk container macro-family because they can be quite cost efficient but, because of their greater weight and non-collapsibility, their emissions from use in shipping are also significantly greater. Should a shipping solution be preferred economically but not environmentally (or the other way around), the user can assess the trade-offs depending on the Company priorities.

As for the real case tested and presented, the model selected plastic bulk container 4202 as the preferred solution among the ones available for the company from both an economic and environmental perspective. In fact, this packaging solution is the one actually selected by the Company after a lengthy decision making process in which different solutions were analyzed by the Logistics Engineering team, supplier team and the Logistics team of Kragujevac plant, where the final assembly is performed.

PRODOTTO

Famiglia Materiale	Codice Disegno	Descrizione Disegno	Modello	Codice Fornitore	Ragione Sociale Fornitore	Cod. Stab. Cliente
1,6 L - 1,4 l	00518851370- 00519200960	FILTRO ARIA COMPLETO	330	42891	MECAPLAST	148

IMBALLO

N°	Codice Imballo	Descrizione	TIPO	Base	Lato	Altezza	Peso (Kg)	Q.tà componenti	Utilizzo
1	4202	CONTENITORE PLASTICO ABBATTIBILE	Grande	1210	1010	990	39	1	RENDERE

Sono previsti ulteriori elementi nella composizione dell'imballo? Se si, specificare di seguito:

N°	Elemento Imballo	SI / NO	Descrizione	Base	Lato	Altezza	Peso (Kg)	Q.tà componenti	Utilizzo
2	Termoformato	NO							
3	Separatore	SI	separatore cartone	1150	955	4	0,07	3	PERDERE
4	Busta	SI	Busta 600 x 700	600	700		0,01	48	PERDERE
5	Rivestimento								
518851370- 00519		330		234	273	221	2,1	48	
							Pezzi per Imballo		48
							Peso Imballo		140,49

Inserire foto o schemi relativi alla disposizione del materiale nell'imballo

Note:

COMPOSIZIONE UNITA DI CARICO

N°	Codice Contenitore	Descrizione	N° Layer per Pedana	N° Imballi per Layer	Base	Lato	Altezza	Peso (Kg)	Q.tà	Utilizzo
1	4202	ENITORE PLASTICO ABBAT	1	1	1210	1010	990	39	1	RENDERE
2									1	
3									1	
								Pezzi per UDC		48
								Peso UDC		140

Inserire foto o schemi relativi alla composizione dell' Unità di Carico

Note:

sign off

FGA								FGA Approval	
LOGISTICS		WO (Prod. Engineering)		SAFETY		QUALITY			
Name	C. [illegible]	Name	[illegible]	Name	[illegible]	Name	[illegible]		
Date	26/7/2012	Date	26.07.'12	Date	26.07.12	Date	26/07/12		
Supplier									
LOGISTICS		WO (Prod. Engineering)		SAFETY		QUALITY			
Name	Ribaudo V.	Name	Mina M.	Name	Pavoni M.	Name	La Micela M.	Revisione	Data Revisione
Date	23/04/2012	Date	23/04/2012	Date	23/04/2012	Date	23/04/2012	1	23/04/2012

Figure 6.24 – Official Unit Load Data Sheet, complete air filter.

Based on this analysis, the final result provided by the model is consistent with the operative solution actually selected and applied by Fiat. The latter is shown by the official Unit Load Data Sheet for this component in Figure 6.24. Moreover, even in this complex case, in which dunnage is needed because of quality requirements and the part geometry is not simple, the number of parts inside the container computed by the tool is equal to the number of parts actually contained (48 parts).

6.3.2 Model Testing with Chrysler Data

This section tests the packaging selection model using Chrysler data. This is a demonstration that the model and tool has been created with the first objective to be able to address capably different operational environment, packaging solutions and components. The various parameters characterizing Chrysler containers, the considered production program, and requirements were filled in the input sheet of the tool. A component with different physical, geometrical and dimensional characteristics compared to the complete air filter used in the previous case was selected for this test in order to check the consistency and credibility of the results provided as output by the model in two completely different situations.

6.3.2.1 Main Input Data

The production program considered for this test is the new Chrysler 2014 KL program (New Jeep Cherokee). This program has been assigned to Toledo North Assembly Plant. A rain clip sensor supplied by VALEO Electronics is the investigated part number for selecting the best packaging solution. Compared to the Fiat air filter trial, the component is very small with dimensions 1 in. x 1 in. x 0.7 in. and weighing 0.05 lbs.

The shipment from the supplier to the plant is regional and because of company policies and requirements, a standard returnable container had to be used. No constraints related to the storing, handling and line display equipment were present at the moment of the packaging selection. Moreover, dunnage presence was not required by Chyrsler’s Quality Department.

The total weight limits established by ergonomics are 30 lbs. for small lot totes, and 1,500 lbs. for bulk containers (including the weight of the dolly). The working days per year is assumed to be 260; the daily production volume forecasted and used for all the computations is 996 vehicles; and one part per vehicle is used with an option take rate of 14.2%. The maximum inventory level allowed by World Class Logistics principles (shown in material class – maximum inventory level matrix) is equal to 48 hours. All the main container handling operations times have been filled in the input sheet and a manpower cost rate equal to $23.82 have been taken into account.

The distance between the supplier and the assembly plant is equal to 1646.4 miles and a direct truckload shipment is planned. Standard truck dimensions (53 ft) and characteristics have been given as inputs to the model for the calculations related to logistics shipments and trailer saturation levels. The average cost equal to 1.65 dollars per mile have used by the tool, while environmental data from U.S. E.P.A. and GHG protocol have been used as inputs for estimating the kilograms of carbon dioxide emitted during the production program duration for each container solution. Finally the average life of plastic containers is assumed to be 8 years and 15 years for steel containers.

6.3.2.2 Container Filling Percentage, Container Density and Cost Comparative Analysis

After using the model, Figure 6.25 shows container fill percentages for each container of the standard list of the Company. Only standard totes values are depicted in the bar graph. After evaluating that bulk containers' (both plastic and steel) are not applicable because their inventory levels (stock inside the container solution) are greater than the maximum allowed by World Class Logistics requirements (for reducing the value tied up in inventory), the tool does not show these container solutions (bulk containers) in the output graphs for comparison between the different applicable solutions; again, the user can focus just on container solutions that actually apply to the circumstances.

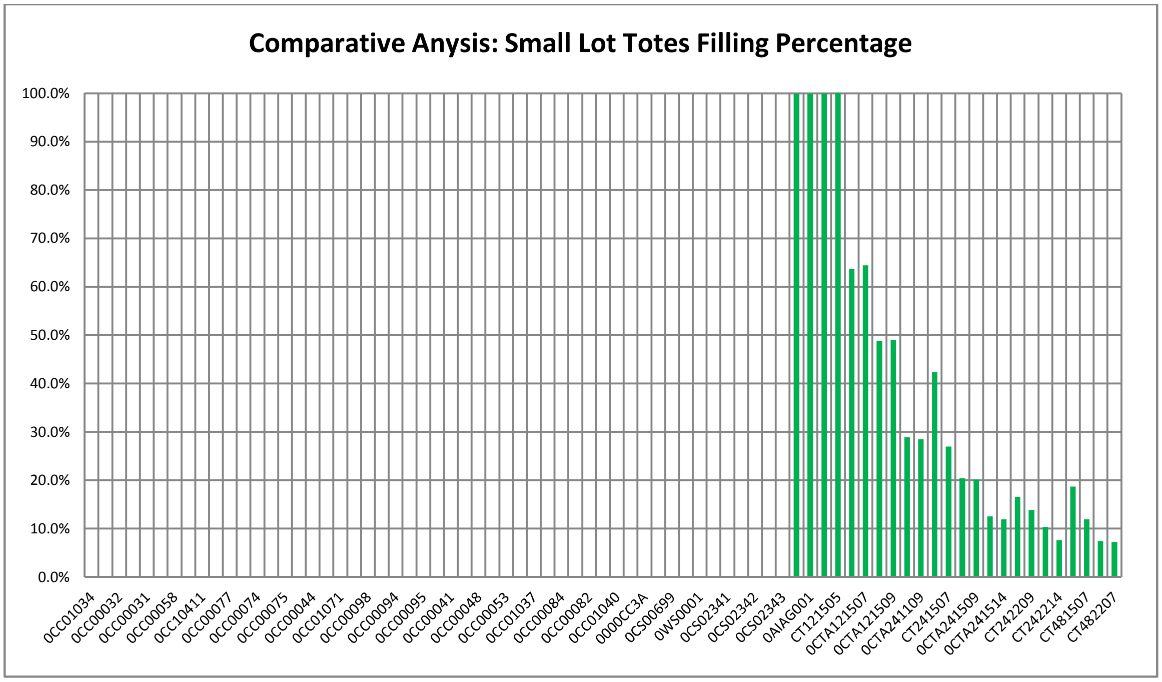


Figure 6.25 – Small lot totes fill percentage, comparative analysis.

The largest totes are characterized by a very low fill percentage because the maximum weight allowed by ergonomics requirements is reached prior to the point at which the totes can be completely filled.

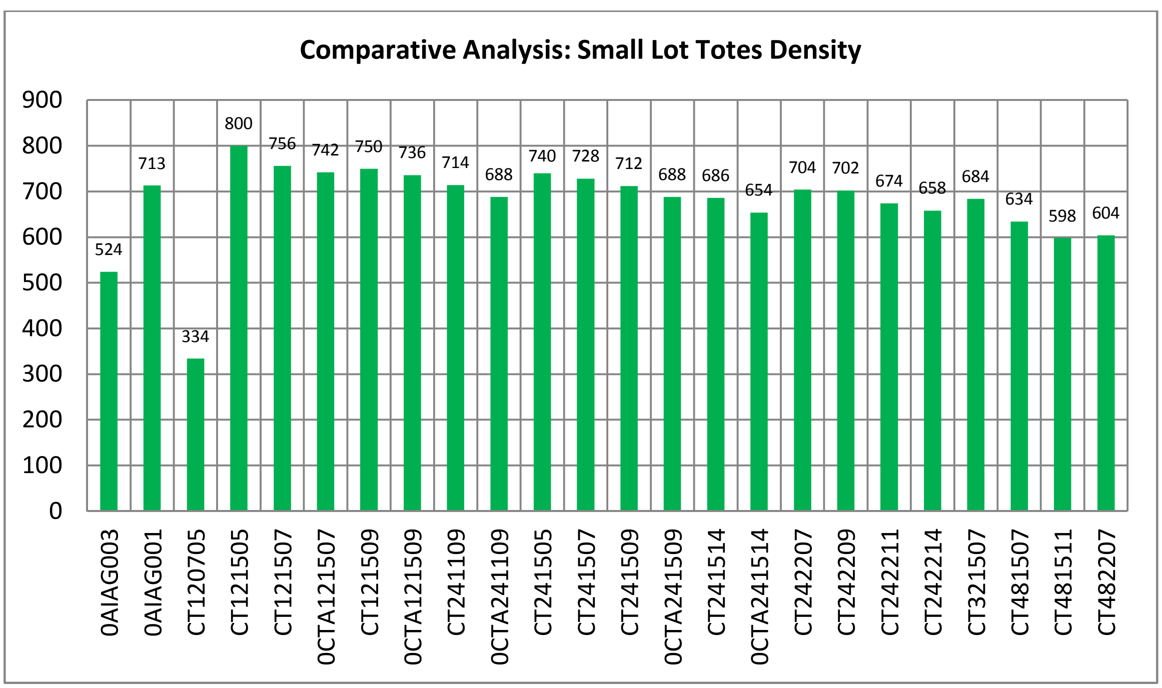


Figure 6.26 – Small lot tote density (number of parts contained), comparative analysis.

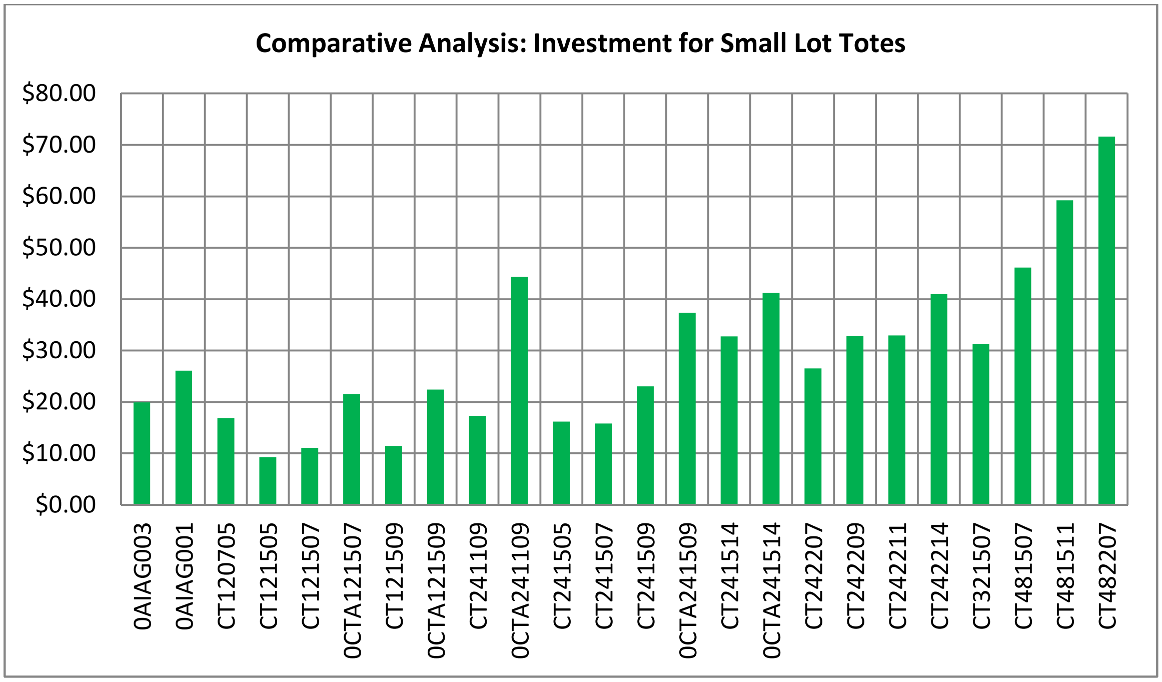


Figure 6.27 – Investment for small lot totes allocated to the production program and component considered, comparative analysis.

Container density is presented in Figure 6.26. Because the component used for model testing is very small, contrary to the complete air filter considered previously, these values basically depend on the ergonomic weight limit and container weight instead of the container dimensions and geometry.

The investment for new containers allocated to the production program and to the considered part number is depicted in the bar graph of Figure 6.27. In comparing different solutions, this value is strictly depended on container cost, container density and the amount of excess containers available in the systems which can be re-deployed and used for the new program. As far as manpower cost is concerned, given that we are considering container types within the same macro-family and thus all the handling operations required are almost the same, the different values obtained in the comparison are strictly affected by the number of parts contained in each container solution. The comparative analysis of manpower cost for handling is shown in Figure 6.28.

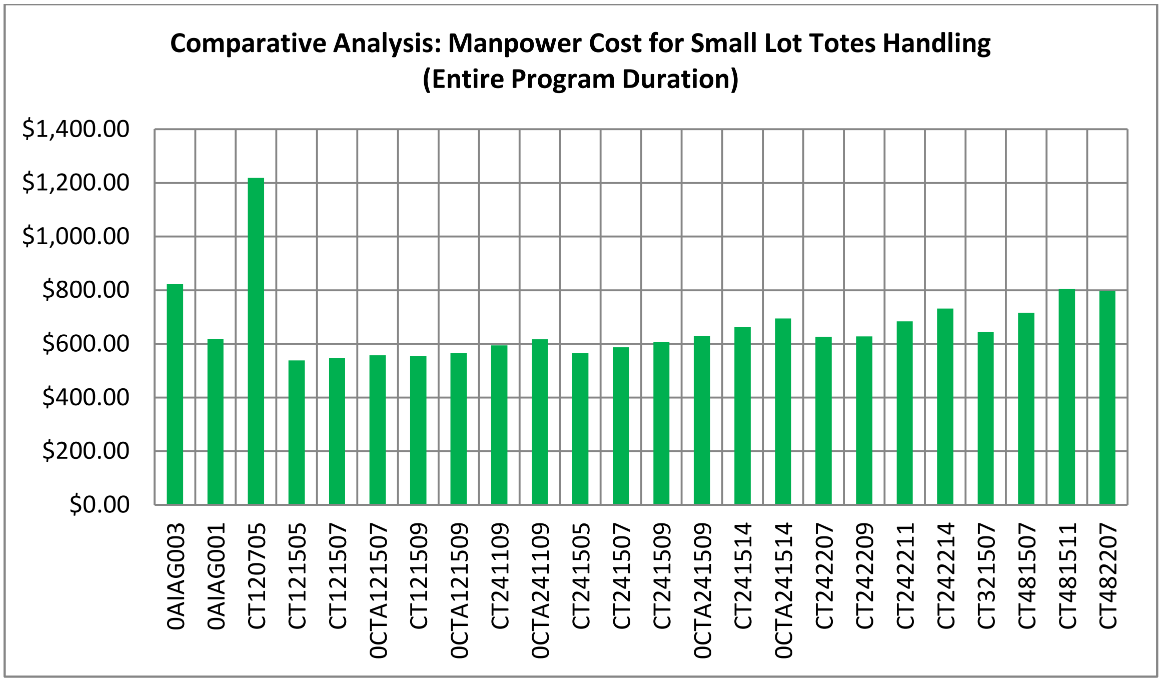


Figure 6.28 – Manpower cost for small lot totes handling, entire duration of the production program, comparative analysis.

Differences in the shipping cost for full containers and for the return of empties, also in this case depend on a large number of parameters and factors. However, the most critical ones are the dimensions of the unit load in which the standard totes are grouped (they have same footprint and different heights), the dimensions of the tote (they will affect the number of totes per unit load) and the number of parts contained in each tote. The full/empty ratio does not apply in this case because all the standard totes used by Chrysler are neither fold-able nor nest-able. The comparative analysis for shipping cost is presented in Figure 6.29. The total cost has been calculated by the model for the entire duration of the production program.

Comparing Figure 6.25 and Figure 6.29 reveals that totes characterized by a low fill percentage are also characterized by the highest shipping costs. This is because small lot totes are handled and shipped in unit loads (small lot totes on a pallet) with quite similar dimensions (same footprint as the base pallet), thus the external dimensions of the unit loads affect less the differences of shipping cost between the various standard tote types. Conversely, shipping cost for bulk containers, which are not handled in unit loads, are more affected by their external dimensional compatibility of each container solution with the selected mode of transportation selected. In the previous case of testing with Fiat data, the situation was quite different.

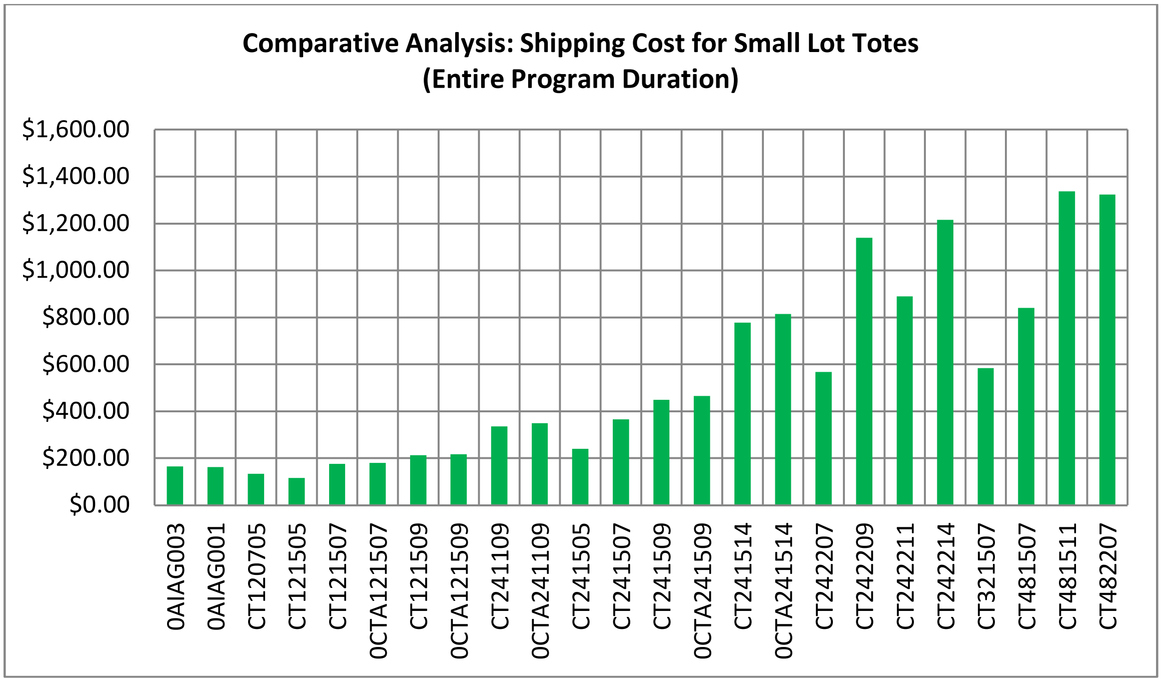


Figure 6.29 – Manpower cost for small lot totes handling, entire duration of the production program, comparative analysis.

Nearly all of the container types (from the Fiat test case) had high fill percentages (good volume saturation of the container) because the weight limits were not reached (thus it was possible to completely fill each container solution with the components to be contained), and the differences in external dimensions were much more significant with respect to this case tested with Chrysler data, and had a greater impact on the transport vessel cube utilization. Therefore, this outcome highlights that the output varies differently compared to the different input parameters: depending on each investigated situation, this variation cannot be easily predicted before running the model and analyzing the results.

6.3.2.3 Sensitivity and Variation Analysis of Total Cost Components

In Figure 6.30, the sensitivity analysis of the three main total cost components is shown. As with the Fiat case, the study highlights that there is not a cost component which dominates all others. Furthermore, there are differences in the weighting that each cost component has over the total cost even within the same container macro-family. The only commonality for this investigated situation is the investment cost of the containers: it is very small for all the small lot types.

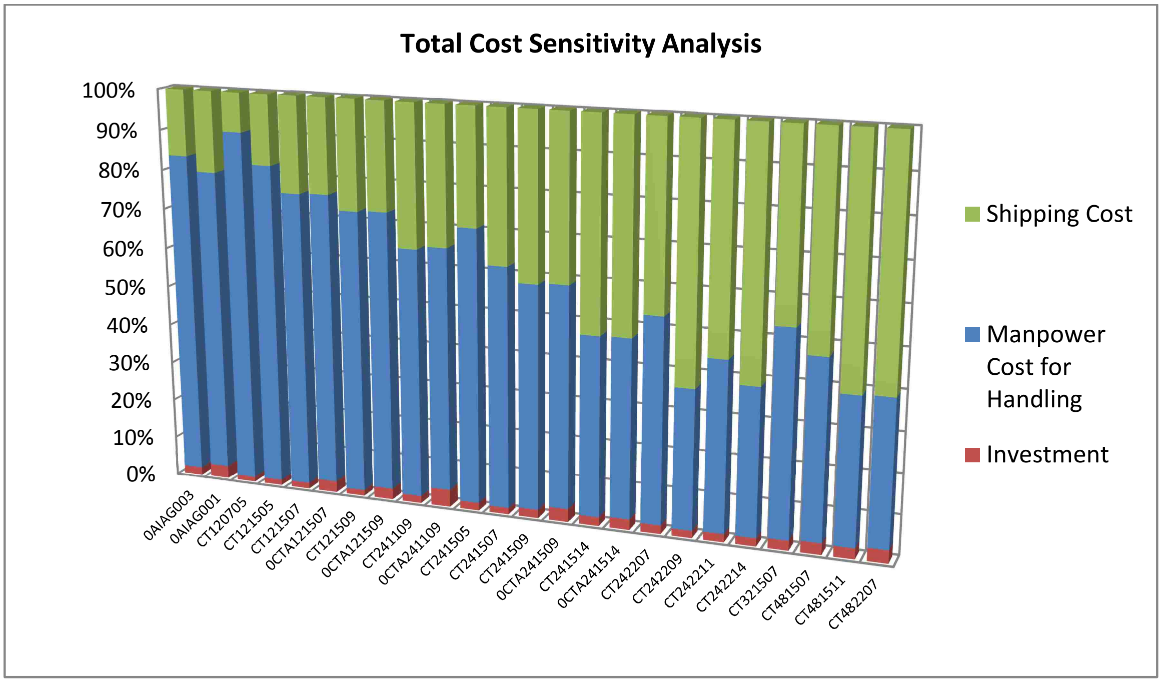


Figure 6.30 – Total cost components sensitivity analysis, small lot totes.

This is because the cost of small lot totes is quite low, and generally there are not significant differences between the different tote types used by the company. Moreover, the number of containers needed is small, since the number of parts that can be contained in each container is very high. As far as the investigated case is concerned, the investment for containers is always lower than 4% of the total cost.

There are significant sensitivity differences related to manpower cost for container handling and shipping cost. Manpower cost is characterized by weightings over the total cost in the range between 89% (tote CT120705) and 35% (tote CT242209). The same can be said for the shipping cost, which range between 63% (tote CT 242209) and 9% (tote CT120705).

The study shows that, for this specific case, generally the manpower cost for handling is more influential for totes with smaller dimensions - the number of handling operations required during the program duration will be higher. On the other hand, the shipping cost is becomes increasingly more influential with the increasing dimensions of the totes. Given that unit load dimensions are quite similar – there are only small differences in trailer saturation - and that the maximum weight allowable because of ergonomic limitations dictates the number of parts contained in each totes, the resulting packaging with a small fill percentage will be characterized by a higher shipping cost.

Finally, the significant differences highlighted in the outputs, even within the same macro-family, underline the potential value of using the model in assessing the optimal solution given the multiple variables.

6.3.2.4 R-Index and E-Index

The model provides the user with the output results in both the overall comparison form which cross over multiple container macro-families and within each macro-family. The model has discarded all the bulk containers solutions (plastic and steel) because they did not fulfill maximum inventory level requirements. Instead, the outputs relate to comparisons within the small lot tote macro-family.

Figure 6.31 presents the value of the total cost comparison R-Index for each tote type. The preferred solution is the one able to reduce as much as possible the total cost is tote CT121505. Totes with the largest dimensions are generally depicted as the least preferred solutions from a total cost point of view in this particular case.

The E-Index for the carbon dioxide emitted in the atmosphere for shipping using different tote solutions is shown in Figure 6.32. The container solution which will ensure the lowest emissions of CO_2 is CT121505. Interestingly, the tote solutions identified by an ID code starting with "0CTA" are identical in dimensions with some other containers starting with "CT" and with the same following ID numbers (representing the dimensions of the tote).

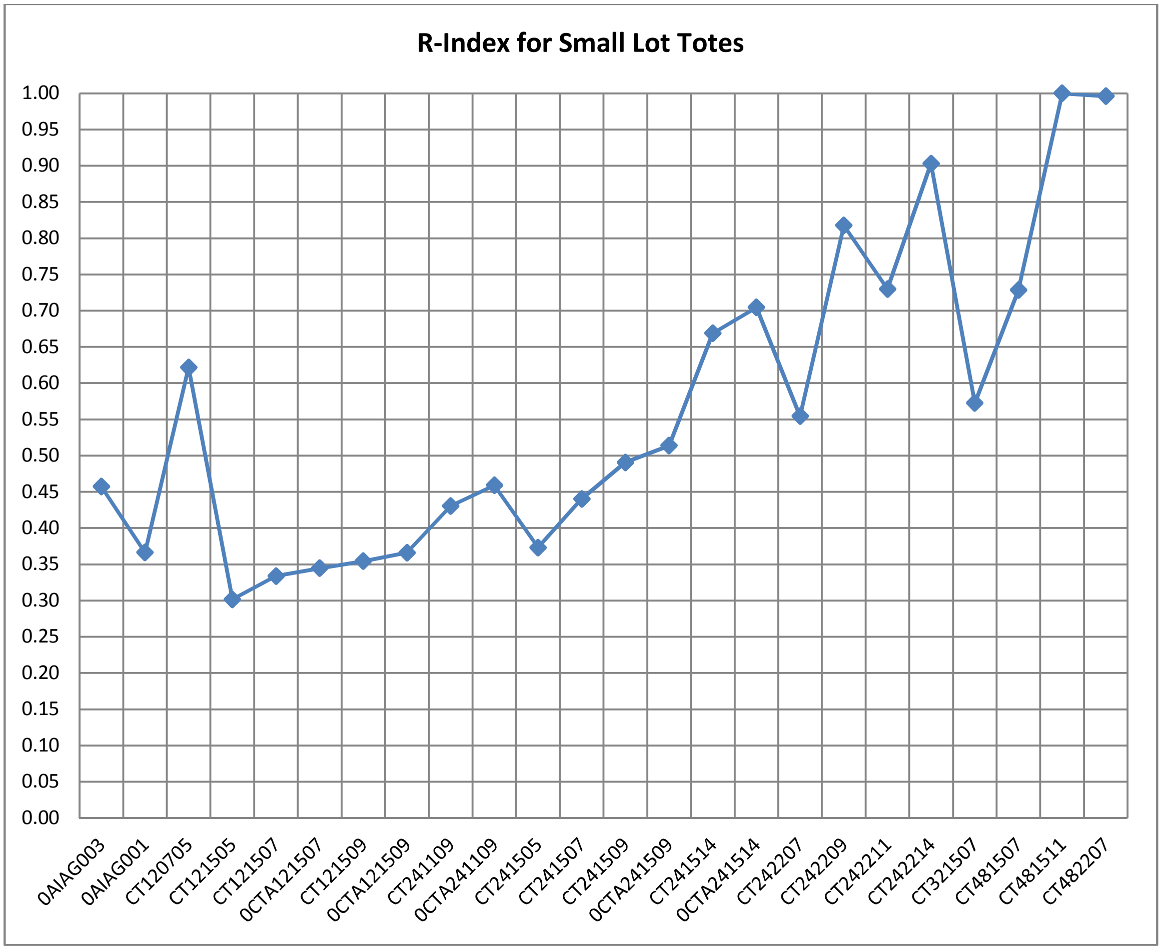


Figure 6.31 – R-Index for small lot totes: total cost comparison index.

However, even if the overall internal and external dimensions are identical, these containers have different weights because the ones with the ID starting with "0CTA" have also a lid integrated in their structure (heavier). Furthermore, in Figure 6.32, totes with the same overall dimensions and only slight differences in weight are highlighted by the tool with different environmental impacts: the higher impact is characteristic of tote types that are heavier (totes with lid).

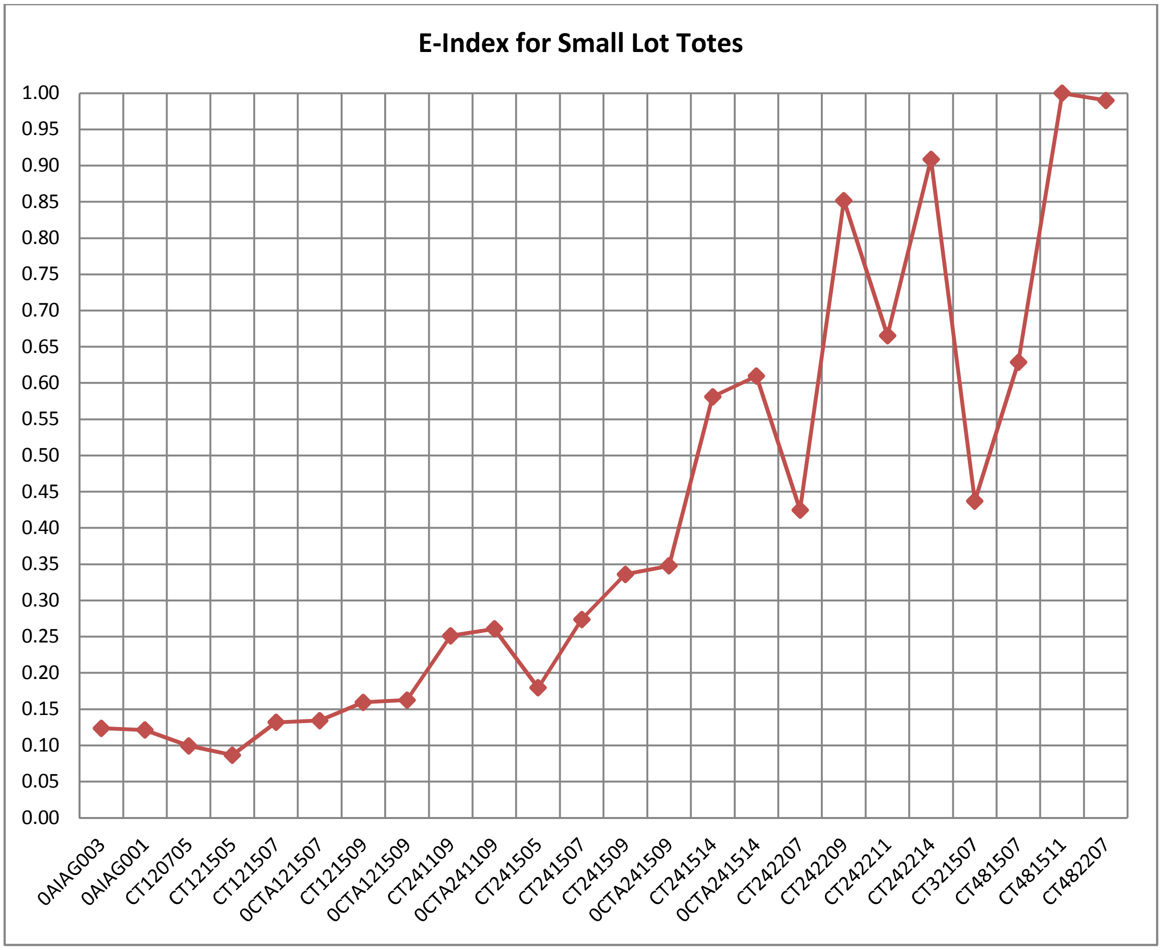


Figure 6.32 – E-Index for small lot totes: environmental impact comparison index.

Finally, Figure 6.33 shows the values of the total cost comparison index and environmental comparison index plotted on the same graph.

Unlike the previous air filter unit, there are greater discrepancies: i.e. for CT120705 the estimated environmental burden associated is low while the total cost impact is quite high. Furthermore, considering how those indices have been created and that R-Index assumes values between 0.30 and 1 while E-Index between 0.09 and 1, generally, the differences in environmental performance are even greater than total cost performance selecting one solution rather than another.

Assigning the rain clip sensor to standard tote CT121505 rather than CT481511, a reduction of the total cost equal to 70 % and reduction of the environmental impact equal to 91 % can be achieved.

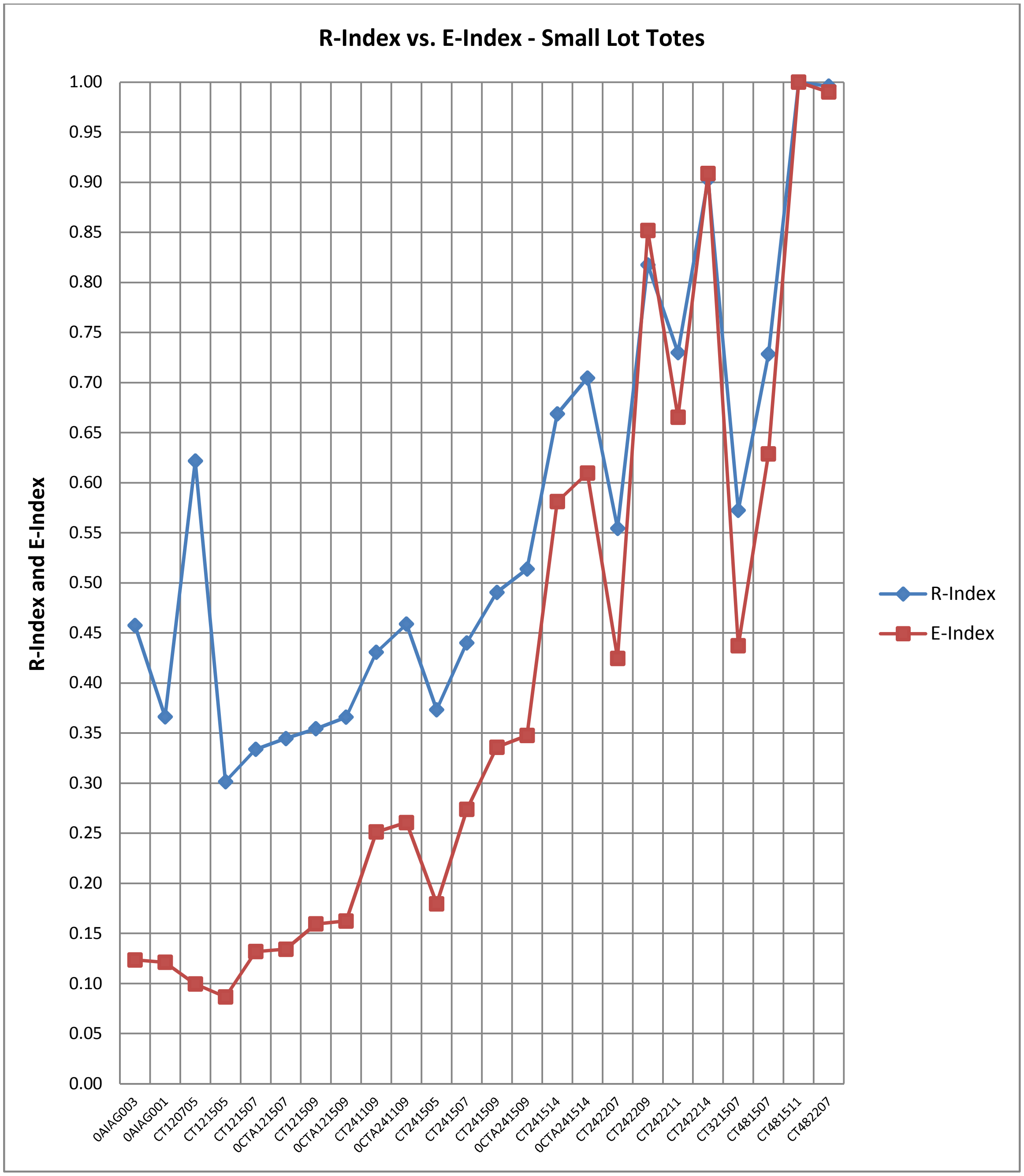


Figure 6.33 – Overall R-Index versus E-Index: final comparison for the selection of the optimal solution.

As a result, selecting the right container solution for each part number of the bill of material could bring significant cost savings and sustainability improvements to the logistics processes.

	Packaging ID. Number	*R-Index*	*E-Index*	*Total Cost Ranking*	*Environmental Ranking*
PLASTIC SMALL LOT TOTES	0AIAG003	**0.46**	**0.12**	**8**	**2**
	0AIAG001	**0.37**	**0.12**	**5**	**2**
	CT120705	**0.62**	**0.10**	**13**	**3**
	CT121505	**0.30**	**0.09**	**1**	**1**
	CT121507	**0.33**	**0.13**	**2**	**4**
	0CTA121507	**0.34**	**0.13**	**3**	**4**
	CT121509	**0.35**	**0.16**	**4**	**5**
	0CTA121509	**0.37**	**0.16**	**5**	**5**
	CT241109	**0.43**	**0.25**	**6**	**7**
	0CTA241109	**0.46**	**0.26**	**8**	**8**
	CT241505	**0.37**	**0.18**	**5**	**6**
	CT241507	**0.44**	**0.27**	**7**	**9**
	CT241509	**0.49**	**0.34**	**9**	**10**
	0CTA241509	**0.51**	**0.35**	**10**	**11**
	CT241514	**0.67**	**0.58**	**14**	**14**
	0CTA241514	**0.70**	**0.61**	**15**	**15**
	CT242207	**0.55**	**0.42**	**11**	**12**
	CT242209	**0.82**	**0.85**	**17**	**18**
	CT242211	**0.73**	**0.67**	**16**	**17**
	CT242214	**0.90**	**0.91**	**18**	**19**
	CT321507	**0.57**	**0.44**	**12**	**13**
	CT481507	**0.73**	**0.63**	**16**	**16**
	CT481511	**1.00**	**1.00**	**19**	**21**
	CT482207	**1.00**	**0.99**	**19**	**20**

Table 6.12 – R-Index and E-Index values, small lot totes ranking.

Figure 6.33 and Table 6.12 show that, as far as the rain clip sensor for 2014 KL Production Program is concerned, using small lot totes CT121505 is the optimal solution among the available ones both from an economic and total cost perspective. As with the previous model testing with the complete air filter and Fiat data, the model outputs lead to the same solution that was in fact actually selected by the Company after a long-lasting decision making process. The official Company Unit Load Data sheet is shown in Figure 6.34.

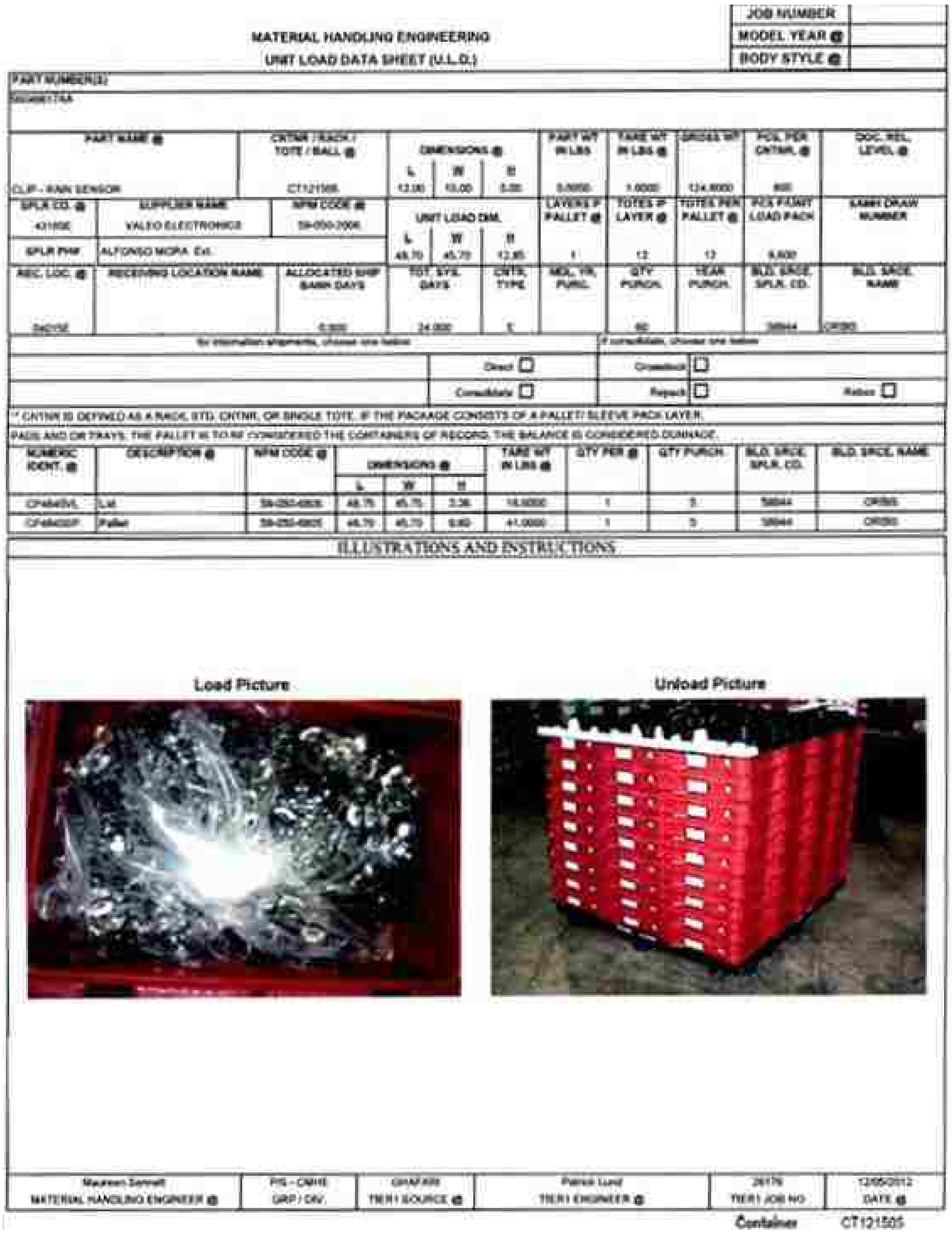


Figure 6.34 – Official Unit Load Data Sheet, rain clip sensor.

The overall result from this analysis is that the credibility and consistency of the model has been verified in two different operational environments and with two completely different components.

6.3.3 Accuracy of the Model

The packaging selection model is characterized by two different accuracy levels: 1) for the values of total cost components and CO_2 emission; and 2) for the total cost and environmental performance comparison.

The accuracy of the values of investment for new containers, manpower cost for handling, shipping cost and kilograms of carbon dioxide emitted in the atmosphere, provided as output of the model, is not strictly related to the model itself but to the accuracy of the data given as input. The higher the accuracy of the input data, the more accurte the output values will be.

When considering the two case studies from Fiat and Chrysler presented in the previous sections, the accuracy level can be considered very high for all the cost evaluations and quite high for all the environmental evaluations. In fact, cost computations performed by the tool have used real and accurate data provided directly by the Companies. The only uncertainty is due to the fact that the production volumes for a new model to be launched are forecasted for each year of the production program (i.e., forecasts made by Marketing and Commercial Departments). In developing the model, because its core objective is to provide a *first indication* about the best packaging solution for each part of the bill of material of a new production program, and the availability of the data in the early stages is not always assured, the inputs have been carefully checked with many experts from various company departments.

A reasonable level of accuracy in selecting the optimal packaging solution through comparing different solutions can be expected so long as peculiar characteristics of each container are available and consistent data are provided as input to the model.

Because the analysis focuses on relative differences between packaging solutions, even if very accurate operative input data are not available and the exact value of costs and carbon dioxide emissions cannot be computed, the uncertainties of the shared input parameters should equally affect each investigated solution. Thus, even though the output is not absolutely accurate, the tool should still be usable as a method to determine which packaging solution is preferred relative to others.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

Logistics is the integrated management of all activities required to move materials, components and products along the supply chain, from suppliers to manufacturing sites and out to the sales network. The main objective is to coordinate all these activities in a way that meets corporate and customer requirements, striving to maximize efficiency and reduce the impact of transport on the environment. Climate change is one of the major global challenges facing the world today. The automotive industry is being called upon to help stabilize the level of greenhouse gases in the atmosphere and to take an active role in the research and development of more sustainable solution able to reduce CO_2 emissions.

Costs and environmental burdens are associated to each step of the logistics process and the overall sustainability depends on the packaging solutions adopted. The first part of thesis investigated in detail the various packaging solutions as well as the material flow types available in the automotive industry. Moreover, life cycle costing and aspects of environmental assessment have been addressed to highlight the main cost components and environmental impacts affected by packaging.

Afterwards, the benefits from decreasing the number of standard container types used within the company supply chain and the resulting reduction of the container management complexity were presented and discussed. Analyses of Chrysler assembly plants were undertaken, and strategies and methodologies followed for reducing the standard container list introduced.

The main topic of this thesis involved creating a decision making model for selecting the optimal packaging solution both from total cost and environmental perspectives. In this regard, the various requirements from different company departments as well as tier-1s, suppliers and plants were gathered and taken into account in creating the model to ensure its consistency with real industrial circumstances. Novel economic and environmental approaches were used in the model, and Multi Criteria Decision Making theories were considered to incorporate and analyze the many input parameters.

In creating the model, three subsequent approaches were adopted. First, a macro-model was developed to highlight the key points and general procedure to be followed in selecting a packaging solution for each part number of the bill of material. Key factors were presented for assessing environmental performance assessment to select between expendable and returnable systems as well as for the choice of packaging material. Then, a very detailed procedure was developed to specifically select standard packaging. Finally, a tool was created to implement and automate this computational and evaluative process.

To test the model robustness, tests were performed using two completely different cases and components from Fiat and Chrysler to assess the consistency of the results provided as output by the tool, and its flexibility to different investigated situations. The obtained outcomes were compared with the actual solutions adopted by the companies. In both cases, the optimal solution suggested by the model is congruent with the solution actually adopted by the Company.

7.2 Original Contribution and Strengths of the Packaging Selection Model

The original contributions of the author of this research are:

- An extensive data gathering effort was undertaken to acquire information related to the various packaging solutions and material flow types available in the automotive industry. This topic has been underexplored and the information is not immediately apparent, nor is it widely known. Moreover, life cycle costing and environmental considerations were addressed to highlight the main cost components and environmental impacts arising from packaging. A benchmarking study of automobile OEM companies was also performed to highlight the main differences in logistic and container management.
- All the Chrysler plants were analyzed for standard container complexity reduction (reduction of the number of standard containers types used in the Company's supply chain) and the outcomes were processed and interpreted to give company relevant

directions about the executive actions to be implemented starting from new production programs. The research solutions are currently being implemented into company practices.

- The information, data and parameters gathered from the literature and company practices were utilized along with new, never-before-considered factors to develop the general framework of the packaging selection model, and then later to design the detailed procedure for selecting the optimal packaging solution and, finally, to create the overall decision making tool.
- The technical evaluation approach, formulas, and comparison indices presented in the model procedure and implemented into the tool were developed by the author based on the information and parameters gathered from the literature and the companies.
- Finally, the model was also tested by the author using data from Fiat and Chrysler and the results analyzed and validated. It was found that the predicted solutions closely match the actual, industrial solutions used by Chrysler Material Logistics Management and Fiat Logistic Engineering managers.

Based on the model, it was possible to determine that so long as a packaging solution fulfills all the imposed requirements, there are generally no dominating factors or factors overwhelming the other alternatives in the final selection. In terms of cost, its components generally have different weightings over the total value and this is true even within the same packaging macro-family. This consideration, along with the fact that a significant number of parameters are taken into account and that there are many interactions, underscores the difficulty in predicting effects. This situation emphasizes the value of this research for evaluating of the optimal packaging solution to be adopted in each specific case.

The most important strengths of the model and related tool are listed in the following:

- It takes into account all the various requirements actually considered by the companies for their operations.
- It considers economic and environmental aspects since the early stages of the decision making process, and estimates the total costs and carbon dioxide emissions for the

entire duration of the production program (with the accuracy dependent on the accuracy of the available input data): this could be helpful also in developing company business cases.

- It has been designed to be used in the very early stages of the decision making process of a new program, and so requires information available during the first steps of the new program launch, when some production and logistics processes have still yet to be completely engineered. At this stage, estimated data can be used to develop a preliminary assessment about the best solution within a set of possible alternatives.
- Input data can be simply inserted in an input sheet and all computations and evaluations are automatically performed.
- It provides the user with output measures, indices and graphs immediately, ready for interpretation and rapid comparison between different solutions.
- Flexibility is a core feature of this decision making model: it is possible to fill in the input sheet with part and containers characteristics, operational, logistics, material flow, quality, production, environmental input data and requirements even from completely different industrial applications.
- It can also be used to compare the actual state-of-the-art of the company with the state-of-the-art of competitors using as input parameters data characterizing competitors operations.
- It can help assess if new packaging solutions available in the market or used by competitors can outperform the ones currently used and if so, what actions should be undertaken.

7.3 Further Recommendations

The model considers several key parameters to assess comprehensively the optimal packaging solution from both an economic and environmental perspective. However, the comprehensiveness of the model/tool might be further improved by implementing the following addition research studies.

7.3.1 Further Studies on Error Estimation

As already explained in Chapter 6, the packaging selection model is characterized by two different accuracy levels: one for the value of total cost components and CO_2 emission, and one for the total cost and environmental performance comparison. The former is affected by the accuracy of the data given as inputs, while the latter is actually not affected by this limitation so long as peculiar characteristics of each container are available and consistent data are provided as input to the model (that is, any results would remain relative to each another).

Although challenging because of the tremendous amount of data required, future studies could assess the "bandwidth of error/accuracy" required for each input variable. This would reveal how sensitive each packaging solution is to changes in the input parameters. Because packaging solutions literally have some variable space, any one packaging solution may be sufficiently robust to tolerate some degree of error in input parameters; for example, a packaging solution may be able to realistically accommodate a few extra parts. Conversely, a packaging solution may be sized so precisely that there can be no variation in part dimension.

7.3.2 Recommended Use of the Model

The packaging selection model and decision making tool have been designed to be used by a company during the first steps of a new model production program launch. However, accurate data might not be available and assumptions will likely have to be made. Furthermore, some parameters (i.e., shipping cost, manpower cost, etc.) can change over time. Therefore, it is strongly recommended to re-run the model during the production phase when more precise or updated information are available, in order to assess the congruency of forecasted values of cost components and environmental impacts with their actual values.

Moreover, in some cases, selecting the container solution can be completed before the selection of the related material handling equipment because the equipment scenarios are only generally known. In this case, the model can be used in two, alternative ways: 1) select a container solution based on economic and environmental factors without specifically considering equipment parameters; or 2) re-assess the best packaging solution after specific equipment have been selected because of economic or operational advantages. Of course, the model can also be used iteratively between (1) and (2) above. This is actually another example of how the model can be used to obtain a preliminary solution and then later to assess the consistency of the previous outcomes should operational variables or constraints change.

7.3.3 Further Trade-Off between R-Index and E-Index

In designing the model, the R-Index and the E-Index have been developed separately in order to enable the user to assess the total cost and environmental impacts independently. Of course, in selecting the packaging solution, priorities can be assigned to the economic and/or environmental perspectives, or a trade-off can be made between the two depending on company's priorities. Currently, the tool provides as output both a visual comparison between the two overall indices (R and E), and a table with the indices values listed as well as the economic and environmental ranking of the investigated solutions. The user can then make tradeoffs by visually inspecting and comparing the outcomes.

However, it is possible that there are some circumstances in which it may be difficult to distinguish between several solutions on a visual basis if the outputs are "close". A further study could develop a new compound index that further integrates the two independent comparison indices, and then provides the user with a unique final comprehensive measure that already evaluates any tradeoffs in a rational and likely computational method.

7.3.4 Higher Level of Analyses – DfE Implications

The packaging selection model has been created to evaluate and choose the best possible solution for each single investigated part number and operational environment within a single assembly plant and associated supply chain. These outcomes can be used as input for further analyses at higher level (such as Design for Environment, or "DfE") which can suggest to packaging suppliers new packaging solutions that can optimize a wide range of industrial applications. Interesting, this approach can be applied at a company-wide level. For example, the model might arrive at one solution for one facility, and at a different solution for another facility. However, if both facilities are within the same company, it might be more efficient overall to select a packaging solution that while suboptimal for any one individual facility, may be the most eco-efficient for the company overall. This would help further improve the overall standardization level of packaging and equipment in the supply chain and achieve the significant economic and environmental benefits described in the body of this thesis work.

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APPENDICES

Appendix A: Packaging Selection Model Spreadsheets and Instructions

This Appendix presents the spreadsheets by which the packaging selection tool is composed as well as the instructions to be followed by the user.

Macro-Model Flow Chart

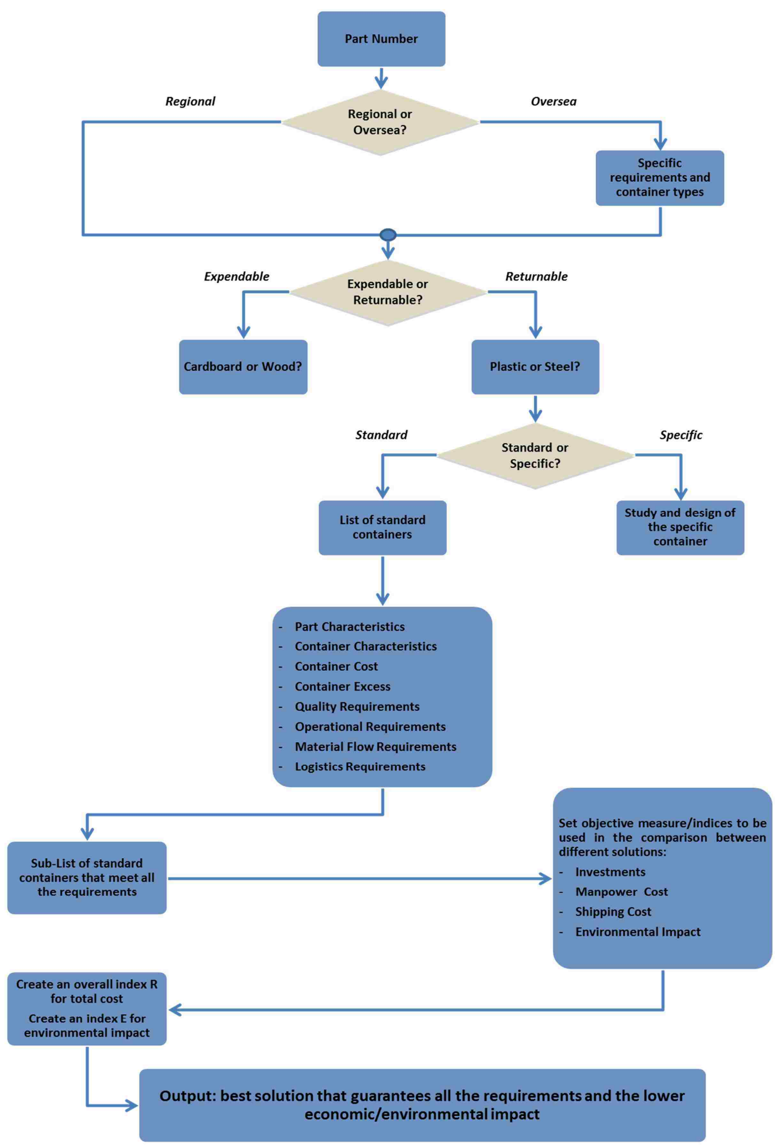


Figure A. 1 – Macro Model Flow Chart spreadsheet, screenshot..

Macro-Model Flow Chart spreadsheet provides the user with a first indication about how the packaging selection macro model works.

Input Sheet

Input Sheet spreadsheet has to be filled in by the user of the packaging selection tool with the majority of parameters and requirements elaborated by the model in its computations and evaluations. In the

Figure A. 2 – Input Sheet, screenshot 1.

Fill in Program Characteristics block with:

- program name
- program duration (number of years)

Fill in Part Characteristics block with:

- part number
- part description
- supplier name
- part dimensions (insert part dimensions from the greater to the smaller)
- part volume (automatically computed)
- part weight
- material classification (take this value from Matrix Class-Inventory Level spreadsheet)

Fill in Preliminary Info block with:

- shipping type (regional or oversea)
- packaging system to be used (expendable or returnable)
- packaging material (if material requirement existing)
- standard or specific container to be used
- bulk or tote requirements (if existing)

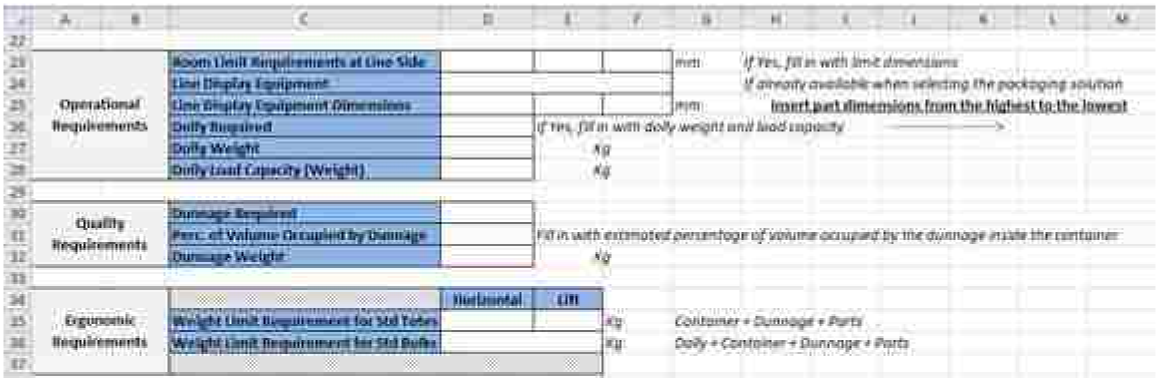


Figure A. 3 – Input Sheet, screenshot 2.

Fill in Operational Requirements block with:

- room limit requirements at line side (if existing)
- line display equipment (if established before the selection of the packaging solution to be adopted)
- line display equipment dimensions (insert part dimensions from the highest to the lowest)
- dolly required (yes/no)
- dolly weight
- dolly load capacity

Fill in Quality Requirements block with:

- dunnage required (yes/no)
- percentage of volume occupied by dunnage
- dunnage weight

Fill in Ergonomic Requirements block with:

- horizontal motion total weight limit for standard totes (container + dunnage + parts)
- lift motion total weight limit for standard totes (container + dunnage + parts)
- total weight limit for bulk containers (dolly + container + dunnage + parts)

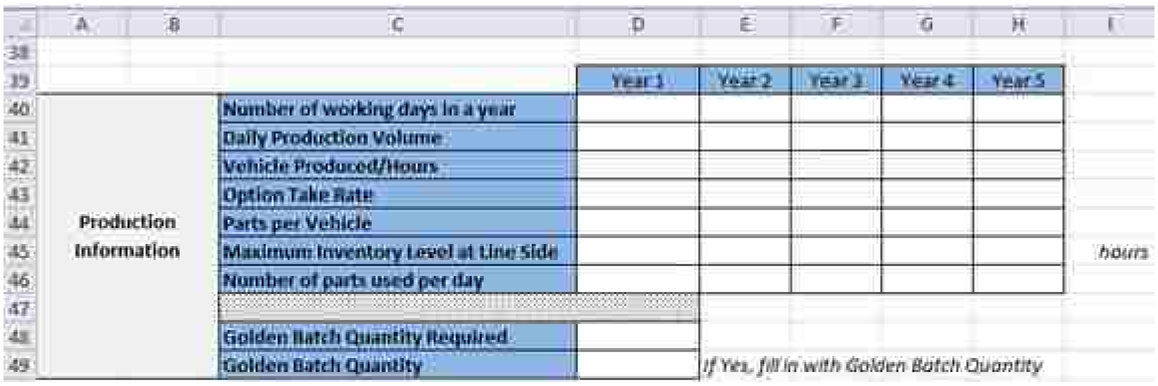


Figure A. 4 – Input Sheet, screenshot 3.

Fill in Production Information block with:

- number of working days per year
- daily production volume
- vehicle produced/hours
- option take rate
- parts per vehicle
- maximum inventory level at line side (take this value from Matrix Class-Inventory Level spreadsheet)
- number of parts used per day (automatically computed by the tool)

All these parameters have to be given as input for each year of the production program.

Moreover, fill in with:

- golden batch quantity required (yes/no)
- golden batch quantity

	A	B	C	D	E
50					
51			Manpower Cost Rate		
52			Estimated Time for Container Unloading from Truck and Delivering to the Storage Area		hours
53			Number of Containers Handled Simultaneously		
54			Estimated Time for Unit Load Unloading from Truck and Delinvering to the Storage Area		hours
55			Number of Unit Loads Handled Simultaneously		
56			Estimated Time for Picking Up the Std. Tote and Placing It on the Rack in the Storage Area		hours
57			Estimated Time for Picking Up the Std. Tote from the Rack in the Storage Area and Placing It on the Dolly for Line Delivery		hours
58			Estimated Time for Delivering the Container from Storage Area to the Line or Kitting/Re-Packing Area		hours
59			Number of Containers Delivered Simultaneously		
60	Material Flow Information		Estimated Time for Delivering the Std. Tote from Storage Area to the Line or Kitting/Re-Packing Area		hours
61			Number of Totes Delivered Simultaneously		
62			Estimated Time for Picking Up the Std. Tote and Line Feeding		hours

Figure A. 5 – Input Sheet, screenshot 4.

Fill in Material Flow Information block with:

- manpower cost rate
- estimated time for container unloading from transport vessel and delivery to the storage area
- number of containers handled simultaneously during unloading operations and delivery to the storage area
- estimated time for unit load unloading from the transport vessel and delivery to the storage area

- number of unit loads handled simultaneously during unloading operations and delivery to the storage area
- estimated time for picking up the standard tote and placing it on the rack in the storage area
- estimated time for picking up the standard tote from the rack in the storage area and placing it on the dolly for line delivery
- estimated time for delivering the container from the storage area to the line or kitting/re-packing area
- number of containers delivered simultaneously to the line or kitting/re-packing area
- estimated time for delivering the standard tote from the storage area to the line or kitting/re-packing area
- number of standard totes delivered simultaneously to the line or kitting/re-packing area
- estimated time for picking up the standard tote from the dolly and line feeding

	A	B	C	D	E
63			Estimated Time for Picking Up the Std. Tote from the Line and Placing It on the Dolly		hours
64			Estimated Time for Delivering the Empty Container to the Storage Area		hours
65			Number of Containers Delivered Simultaneously		
66			Estimated Time for Delivering the Empty Std. Tote to the Storage Area		hours
67			Number of Totes Delivered Simultaneously		
68			Estimated Time for Empty Container Picking Up from the Storage Area and Truck Loading		hours
69			Number of Containers Handled Simultaneously		
70			Estimated Time for Empty Unit Load Picking Up from the Storage Area and Truck Loading		hours
71			Number of Unit Loads Handled Simultaneously		

Figure A. 6 – Input Sheet, screenshot 5.

- estimated time for picking up the empty standard tote from the line and placing it on the dolly
- estimated time for delivering the empty container to the storage area
- number of empty containers handled simultaneously
- estimated time for delivering the empty standard tote to the storage area
- number of empty standard totes handled simultaneously
- estimated time for empty container picking up from storage area and transport vessel loading
- number of empty containers handled simultaneously during loading operations
- estimated time for empty unit load picking up from the storage area and transport vessel loading
- number of empty unit loads handled simultaneously during loading operations

Times have to be all expressed in hours.

Fill in Logistics Information block with:

- logistics system days for standard totes
- plant system days for standard totes
- total system days for totes (automatically computed by the tool)
- logistics system days for standard bulk containers
- plant system days for standard bulk containers
- total system days for standard bulk containers
- repair factor for plastic containers
- repair factor for steel containers
- service factor
- daily ship volume

Figure A. 7 – Input Sheet, screenshot 6.

Depending on the value of the daily ship volume, the tool automatically suggests a mode ship among RILC (Regional Integrated Logistics Center)/less than truck load, geographic/low frequency direct ship.

- distance from supplier to plant
- distance traveled by truck
- distance traveled by train (or other mode of transport for intermodal shipment)
- number of train cars

Depending on the distance between supplier and plant, the tool suggests the use of truck or train/intermodal: IF(D84>60, 3, IF(D84<20, 1, 2)).

Moreover the following measures can be automatically computed by the model (on the basis of average values) or inserted manually (if available) for a higher accuracy:

- shipping cost for truck
- shipping cost for train (or other mode of transport for intermodal shipment):
- shipping cost for train car

Mean of transport types used by the company and their dimensions can be inserted in the table within the Logistics Information Block. These data are then used by the model to compute the number of full and empty containers per selected mode of transport and cube saturation.

Finally, average costs per kilometer for truck, rail, ship and plane can be expressed making the distinction between direct shipment and shipment though consolidation center. In the case data available do not allow to make this distinction, fill in with the same available mean value both the cells.

Figure A. 8 – Input Sheet, screenshot 7.

Fill in Environmental Information block with:

- Kg of CO_2 per liter of fuel consumed by the truck
- Km traveled by the truck per liter of fuel consumed
- Kg of CO_2 per vehicle and per Km (automatically calculated by the tool)
- Kg of CO_2 per Km and per Ton for train or other mode of transport (intermodal shipment)

	A	B	C	D	E
122					
123	Environmental Information		Truck	kg CO2/Liter	
124				Km/Liter	
125				Kg CO2/Vehicle *Km	
126			Train (or Other Mode of Transport)	Kg CO2/Km*Ton	

Figure A. 9 – Input Sheet, screenshot 8.

Fill in Packaging Life Information block with:

- average life for a steel container
- average life for a plastic container

	A	B	C	D	E
128					
129	Packaging Life Information		Average Life for a Steel Container		years
130			Average Life for a Plastic Container		years

Figure A. 10 – Input Sheet, screenshot 9.

In the case very accurate data are not available, fill in with a meaningful estimation of the considered parameter. The accuracy of the forecasted value of investment, manpower cost for handling, shipping cost and carbon dioxide emissions will be directly related to the accuracy of the input parameters, while the comparison between the different solutions will maintain its consistency also using good estimations instead of very accurate values.

Matrix Class-Inventory Level

Starting from material classification of the investigated part, Matrix Class-Max Inventory Level spreadsheet provides the user with the maximum inventory level suggested by World Class Logistics principles. This value has to be filled in the Input Sheet and it is used by the tool to find out the container types of the standard list able to fulfilling this requirement.

The matrix does not provide unique values for the maximum inventory level but three possible alternative (choice 1, choice 2, choice 3) since the maximum inventory level is also dependent on the efficiency of logistics and production activities. Whenever possible the user has to select choice 1 to decrease the capital tied up in inventory, but in case of constraints given by efficiency and operations matters, a higher inventory level can be selected (choice 2 or choice 3).

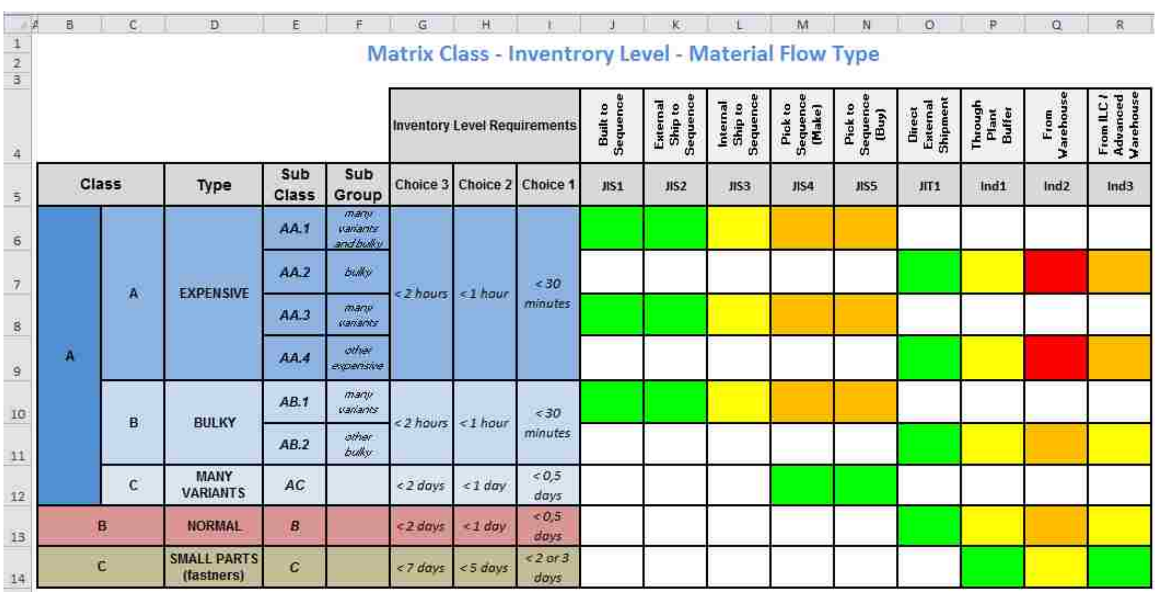


Figure A. 11 – Matrix Class-Inventory Level spreadsheet.

These are just suggested values, thus the maximum inventory level requirement of the Input Sheet can also be filled in with different values due to company needs.

Finally, an indication about the suggested material flow types to be adopted for each material class is provided (even if not directly used by the tool). Also in this case the tool gives to the user the possibility to select one of the different suggested material flow types depending on company operations needs and constraints. Whenever operationally-possible, material flow types have to be selected in this color-order of preference: green, yellow, orange, red. This way, higher benefits in terms of total cost reduction for logistic operations will be achieved.

Number of Containers per Transport Vessel Computation

The tool provides a "Number of Containers per Transport Vessel Computation" spreadsheet for each mode of transport used (more than one in the case of intermodal transportation). The user has to fill in with:

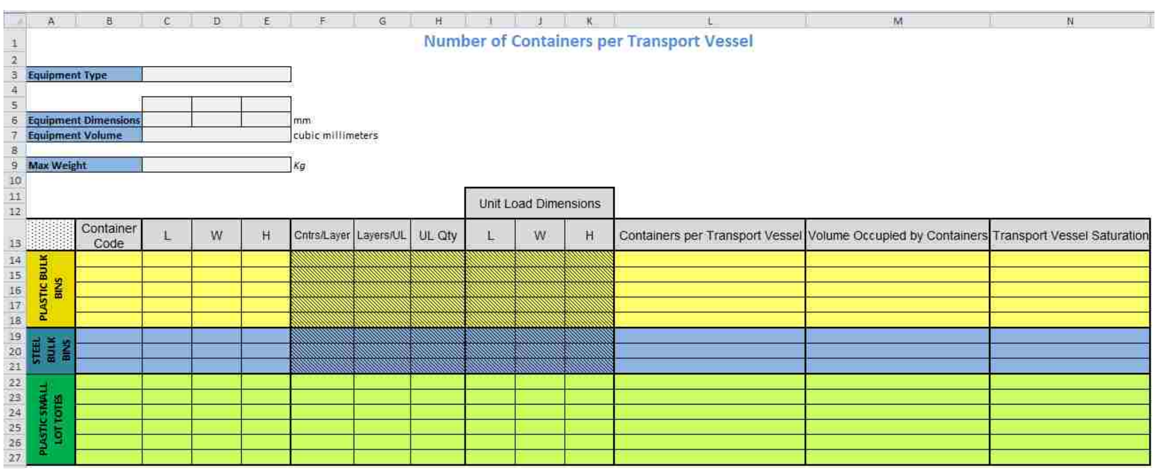


Figure A. 12 – Number of Containers per Transport Vessel Computation spreadsheet.

- equipment type used for transportation
- equipment dimensions
- equipment volume (automatically computed by the tool)

- maximum weight
- container codes
- container length
- container width
- container height
- number of totes per unit load layer
- number of layers per unit load
- number of totes per unit load
- unit load length
- unit load width
- unit load height (automatically computed by the tool)

The formula used implemented in the tool to calculate the value of the first raw of each column is reported in the following.

- number of containers per transport vessel (for plastic bulk and steel bulk containers): =MAX(INT(D$6/C14)*INT(C$6/D14)*INT(E$6/$E14),INT(C$6/C14)* INT(D$6/D14)* INT(E$6/$E14))
- number of containers per transport vessel (for plastic totes): =(MAX(INT(D$6/I22)*INT(C$6/J22)*INT(E$6/K22),INT(C$6/I22)*INT(D$6/J22)* INT(E$6/K22)))*H22
- volume occupied by containers: =L14*PRODUCT(C14:E14)
- transport vessel saturation: =M14/C$7

Requirements Check and Computations

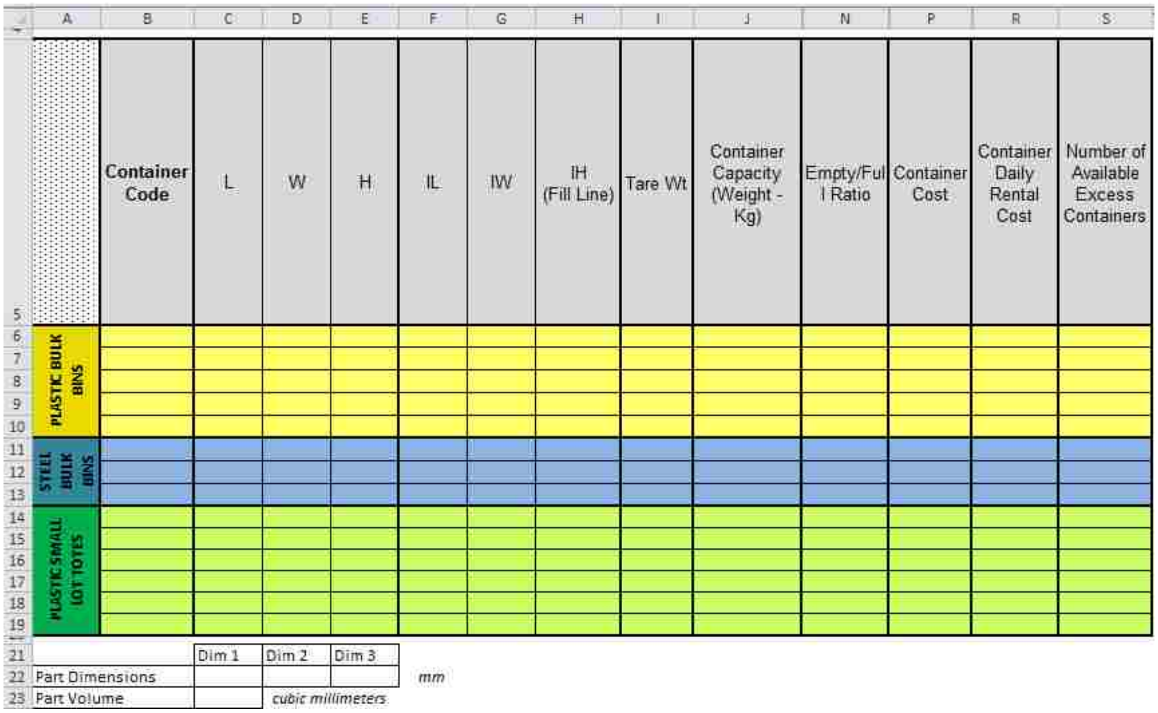


Figure A. 13 – Requirements Check and Computations spreadsheet, screenshot 1.

Requirements Check and Computations is the spreadsheet in which the most of automatic computations and assessments are performed by the tool.

The user has to fulfill the spreadsheet with:

- container codes
- container outer length
- container outer width
- container outer height
- container inner length
- container inner width
- container inner height (fill line)
- container weight
- container load capacity
- container empty/full ratio

- container cost (in case containers are purchased)
- container daily rental cost (in case containers are rented)
- number of available excess containers available in the supply chain

Part dimensions and part volume are automatically retrieved by the tool from Input Sheet.

U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF
									To be taken into account only if the line side equipment has already been estabilished		
Inner Volume	Inner Volume, with Dunnage Volume Correction	Dim 1	Dim 2	Dim 3	Dim 1 Container > Dim 1 Part	Dim 2 Container > Dim 2 Part	Dim 3 Container > Dim 3 Part	Room Limit > Max Container Dimension	Dim 1 Container < Dim 1 Line Side Equipment	Dim 2 Container < Dim 2 Line Side Equipment	Dim 3 Container < Dim 3 Line Side Equipment

Figure A. 14 – Requirements Check and Computations spreadsheet, screenshot 2.

After giving these parameters as input, the tool automatically performs several computations and assessments, using the formula (first row) presented in the following:

- inner volume:
  =F6*G6*H6
- inner volume with dunnage correction:
  =U6-('Input Sheet'!D$31*'Requirements Check-Computations'!U6)
- dim 1:
  =F6

- dim 2:

  =G6
- dim 3:

  =H6
- dim 1 container > dim 1 part:

  =W6>C22

  The tool provide the value “True” or “False”, if “False” the cell is automatically highlighted in red color.
- dim 2 container > dim 2 part:

  =X6>D22

  The tool provide the value “True” or “False”, if “False” the cell is automatically highlighted in red color.
- dim 3 container > dim 3 part:

  =Y6>E22

  The tool provide the value “True” or “False”, if “False” the cell is automatically highlighted in red color.

The following four points have to be considered only if the related requirements have been filled in the Input Sheet:

- room limit > max container dimension

  ='Input Sheet'!D$23>'Requirements Check-Computations'!C6

  The tool provide the value “True” or “False”, if “False” the cell is automatically highlighted in red color.
- dim 1 container < dim 1 line side equipment:

  =C6<='Input Sheet'!D$25
- dim 2 container < dim 2 line side equipment:

  =D6<='Input Sheet'!E$25
- dim 3 container < dim 3 line side equipment:

  =E6<='Input Sheet'!F$25

	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AS	AT	AU
4														
5	Estimated Density	Estimated Volume Occupied by the Parts	Estimated Parts' Weight	Estimated Total Weight	Est. Weight < Weight Limit	Density Correction	Corrected Total Weight	Estimated Volume Occupied by the Parts (With Weight Limit)	Volume Filling Percentage	Inventory Level at Line Side (Hours)	Inventory Level at Line Side < Max Inventory Level	Computation of Number of Container Needed	Number of Container Needed	Number of Container to Purchase
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														

Figure A. 15 – Requirements Check and Computations spreadsheet, screenshot 3.

- estimated density:

  =TRUNC(V6/C23)

- estimated volume occupied by the parts:

  =AG6*'Input Sheet'!D$13

- estimated parts' weight:

  =AG6*('Input Sheet'!D$14)

- estimated total weight:

  =AI6+I6+'Input Sheet'!D$32

- estimsted weight < weight limit, for bulk containers:

  =IF('InputSheet'!D$36="",AJ6<J6,MIN('InputSheet'!D$36,'RequirementsCheck-Computations'!J6))

  The tool provide the value “True” or “False”, if “False” the cell is automatically highlighted in red color.

- estimsted weight < weight limit, for totes:

  =AJ14<(MIN(J14,'Input Sheet'!D$35,'Input Sheet'!E$35))

  The tool provide the value “True” or “False”, if “False” the cell is automatically highlighted in red color.

- density correction:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF('Input Sheet'!D$48="No", (IF(AJ6>J6, (J6-I6-'Input Sheet'!D$32)/'Input Sheet'!D$14, 'Requirements Check-Computations'!AG6)), 'Input Sheet'!D$49), ""), ""), "")
- corrected total weight:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE,AL6*'Input Sheet'!D$14+I6+'Input Sheet'!D$32, ""), ""), "")
- estimated volume occupied by the parts (with weight limit):
  =IF(Z6=TRUE,IF(AA6=TRUE, IF(AB6=TRUE,AL6*'Input Sheet'!D$13, ""), ""), "")
- volume filling percentage:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE,AN6/U6, ""), ""), "")
- inventory level at line side (hours):
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE,AL6/('Input Sheet'!D$42*'Input Sheet'!D$44), ""), ""), "")
- inventory level at line side < max inventory level:
  =IF(Z6=TRUE,IF(AA6=TRUE, IF(AB6=TRUE,AP6<'Input Sheet'!D$45, ""), ""), "")
  The tool provide the value "True" or "False", if "False" the cell is automatically highlighted in red color.
- computation of number of container needed:
  =(IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,(IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, ((MAX(('Input Sheet'!D$41*'Input Sheet'!D$44*'Input Sheet'!D$43),('Input Sheet'!E$41*'Input Sheet'!E$44*'Input Sheet'!E$43),('Input Sheet'!F$41*'Input Sheet'!F$44*'Input Sheet'!F$43),('Input Sheet'!G$41*'Input Sheet'!G$44*'Input Sheet'!G$43),('Input Sheet'!H$41*'Input Sheet'!H$44*'Input Sheet'!H$43))/'Requirements Check-Computations'!AL6)*'Input Sheet'!D$78*'Input Sheet'!D$80*'Input Sheet'!D$82),""),""),""),"")),""),""),""),""))
- number of container needed:
  =(IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,IF((ROUNDUP (AS6,0)=1), ROUNDUP(AS6,0)+1, ROUNDUP(AS6,0)), ""), ""), ""), ""))

- number of container to purchase:
  =(IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,AT6-S6, ""), ""), ""), ""))

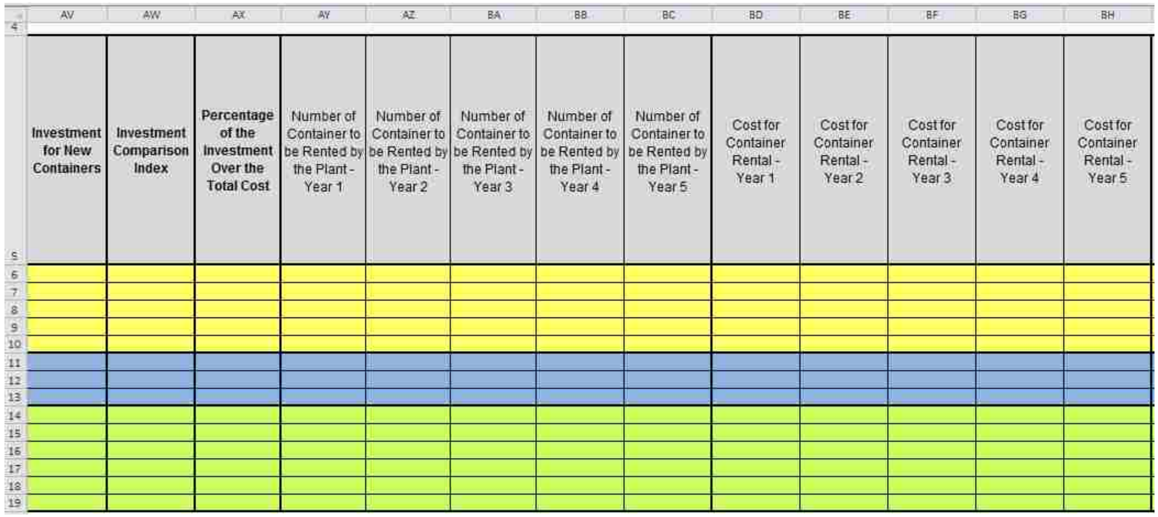


Figure A. 16 – Requirements Check and Computations spreadsheet, screenshot 4.

- investment for new containers:
  =(IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, AU6*P6*('Input Sheet'!D$6/'Input Sheet'!D$129), ""), ""), ""), ""))
- investment comparison index:
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,AV6/MAX(AV$6:AV$19), ""), ""), ""), "")
- percentage of the investment over the total cost:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,AV6/FX6, ""), ""), ""), "")

The following 13 points have to be considered only if the containers are rented by the company (instead of purchased):

- number of container to be rented by the plant - year 1:
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE, IF(AQ6=TRUE,ROUNDUP((('Input Sheet'!D$41*'InputSheet'!D$44*'InputSheet'!D$43)/'RequirementsCheckComputatins'!AL6)*'Input Sheet'!D$77*'Input Sheet'!D$80*'Input Sheet'!D$82,0), ""), ""), ""), "")

- number of container to be rented by the plant - year 2:
=(IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,ROUNDUP((('InputSheet'!E$41*'InputSheet'!E$44*'InputSheet'!E$43)/'RequirementsCheckComputations'!AL6)*'InputSheet'!D$77*'InputSheet'!D$80*'InputSheet'!D$82,0), ""), ""), ""), ""))
- number of container to be rented by the plant - year 3:
=(IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,ROUNDUP((('InputSheet'!F$41*'InputSheet'!F$44*'InputSheet'!F$43)/'RequirementsCheckComputations'!AL6)*'Input Sheet'!D$77*'Input Sheet'!D$80*'Input Sheet'!D$82,0),""),""),""),""))
- number of container to be rented by the plant - year 4:
=(IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,ROUNDUP((('InputSheet'!G$41*'InputSheet'!G$44*'InputSheet'!G$43)/'RequirementsCheckComputations'!AL6)*'InputSheet'!D$77*'Input Sheet'!D$80*'Input Sheet'!D$82,0),""),""),""),""))
- number of container to be rented by the plant - year 5:
=(IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE, ROUNDUP((('InputSheet'!H$41*'InputSheet'!H$44*'InputSheet'!H$43)/'RequirementsCheckComputations'!AL6)*'InputSheet'!D$77*'InputSheet'!D$80*'InputSheet'!D$82,0), ""), ""), ""), ""))
- cost for container rental - year 1:
=(IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, AY6*R6, ""), ""), ""), ""))
- cost for container rental - year 2:
=(IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, AZ6*R6, ""), ""), ""), ""))
- cost for container rental - year 3:
=(IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, BA6*R6, ""), ""), ""), ""))
- cost for container rental - year 4:
=(IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, BB6*R6, ""), ""), ""), ""))

- cost for container rental - year 5:

  =(IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, BC6*R6, ""), ""), ""), ""))

	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU
4													
5	Total Cost for Container Rental - Entire Program Duration	Container Rental Comparison Index	Percentage of the Container Rental Cost Over the Total Cost	Number of Turns per Day - Year 1	Number of Turns per Day - Year 2	Number of Turns per Day - Year 3	Number of Turns per Day - Year 4	Number of Turns per Day - Year 5	Estimated Time for Container Unloading and Storing - Hours per Year - Year 1	Estimated Time for Preparing the Dolly for Delivery - Hours per Year - Year 1	Estimated Time for Delivering the Container to the Line or Kitting/Re-Packing Area - Hours per Year - Year 1	Estimated Time for Empty Container Storing and Loading - Hours per Year - Year 1	Total Handling Manpower Time - Hours per Year - Year 1
6	€ 33.30	0.11	0.17%	4.4572917	4.4572917	4.4572917	4.4572917	4.4572917	110.1136465		158.6693316	268.78298	537.565956
7	€ 49.06	0.16	0.15%	9.725	9.725	9.725	9.725	9.725	240.247956		346.1876325	586.43559	1172.87118
8	€ 46.20	0.15	0.15%	6.1128571	6.1128571	6.1128571	6.1128571	6.1128571	151.0130009		217.6036547	368.61666	737.233311
9	€ 54.00	0.18	0.23%	4.9755814	4.9755814	4.9755814	4.9755814	4.9755814	122.9175589		177.1192538	300.03681	600.073625
10	€ 51.06	0.17	0.24%	4.195098	4.195098	4.195098	4.195098	4.195098	103.6363732		149.3358415	252.97221	505.944429
11	€ 303.75	1.00	0.25%	42.79	42.79	42.79	42.79	42.79	1057.091006		1523.225583	2580.3166	5160.63318
12	€ 101.25	0.33	0.30%	8.558	8.558	8.558	8.558	8.558	211.4182013		304.6451166	516.06332	1032.12664
13	€ 88.00	0.29	0.37%	4.0367925	4.0367925	4.0367925	4.0367925	4.0367925	99.72556664		143.7005267	243.42609	486.852187
14													
15													
16													
17													
18	€ 93.57	0.31	0.13%	106.975	106.975	106.975	106.975	106.975	243.4691094	67.287275	1019.303264	1195.4851	2525.54475
19													

Figure A. 17 – Requirements Check and Computations spreadsheet, screenshot 5.

- total cost for container rental - entire program duration:

  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(BD6:BH6), ""), ""), ""), "")

- container rental comparison index:

  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,BI6/MAX(BI$6:BI$19), ""), ""), ""), "")

- percentage of the container rental cost over the total cost:

  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,BI6/GA6, ""), ""), ""), "")

- number of turns per day - year 1:

  =(IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, (IF(Z6=TRUE, IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,('InputSheet'!D$41*'InputSheet'!D$43*'Input Sheet'!D$44)/AL6, ""), ""), ""), "")), ""), ""), ""), ""))

- number of turns per day - year 2:
  =(IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,('InputSheet'!E$41*'Input Sheet'!E$43*'Input Sheet'!E$44)/AL6, ""), ""), ""), ""))
- number of turns per day - year 3:
  =(IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,('InputSheet'!F$41*'Input Sheet'!F$43*'Input Sheet'!F$44)/AL6, ""), ""), ""), ""))
- number of turns per day - year 4:
  =(IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,('InputSheet'!G$41*'Input Sheet'!G$43*'Input Sheet'!G$44)/AL6, ""), ""), ""), ""))
- number of turns per day - year 5
  =(IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,('InputSheet'!H$41*'Input Sheet'!H$43*'Input Sheet'!H$44)/AL6, ""), ""), ""), ""))
- estimated time for container unloading and storing - hours per year - year 1 (bulk containers):
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,(IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,((('Input Sheet'!D$41*'Input Sheet'!D$40*'Input Sheet'!D$43*'Input Sheet'!D$44)/'Requirements Check-Computations'!AL6)*'Input Sheet'!D$52)/'Input Sheet'!D$53, ""), ""), ""), "")), ""), ""), ""), "")
- estimated time for container unloading and storing - hours per year - year 1 (totes):
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,((('Input Sheet'!D$41*'InputSheet'!D$40*'InputSheet'!D$43*'InputSheet'!D$44)/('RequirementsCheckComputations'!AL14*'N.ContainersperTr.Vessel1'!H22))*('InputSheet'!D$54))/'Input Sheet'!D$55+(BL14*'Input Sheet'!D$40*'Input Sheet'!D$56), ""), ""), ""), "")
- estimated time for preparing the dolly for delivery - hours per year - year 1:
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,BL14*'Input Sheet'!D$40*'Input Sheet'!D$57, ""), ""), ""), "")
- estimated time for delivering the container to the line or kitting/re-packing area - hours per year - year 1 (bulk containers):
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,(BL6*'Input Sheet'!D$40*'Input Sheet'!D$58)/'Input Sheet'!D$59, ""), ""), ""), "")

- estimated time for delivering the container to the line or kitting/re-packing area - hours per year - year 1 (totes):
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,(BL14*'Input Sheet'!D$40*'InputSheet'!D$60)/'InputSheet'!D$61+(BL14*'InputSheet'!D$40*'Input Sheet'!D$62), ""), ""), ""), "")
- estimated time for empty container storing and loading - hours per year - year 1 (bulk containers):
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,(BL6*'InputSheet'!D$40*('InputSheet'!D$64))/'InputSheet'!D$65+(BL6*'InputSheet'!D$40*('InputSheet'!D$68))/'Input Sheet'!D$69, ""), ""), ""), "")
- estimated time for empty container storing and loading - hours per year - year 1 (totes):
- =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,BL14*'Input Sheet'!D$40*'InputSheet'!D$63+(BL14*'InputSheet'!D$40*'InputSheet'!D$66)/'Input Sheet'!D$67+((('Input Sheet'!D$41*'Input Sheet'!D$40*'Input Sheet'!D$43*'Input Sheet'!D$44)/('Requirements Check-Computations'!AL14*'N. Containers per Tr. Vessel 1'!H22))*('Input Sheet'!D$70))/'Input Sheet'!D$71, ""), ""), ""), "")
- total handling manpower time - hours per year - year 1:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(BQ6:BT6), ""), ""), ""), "")

	BV	BW	BX	BY	BZ	CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ
4															
5	Estimated Time for Container Unloading and Storing - Hours per Year - Year 2	Estimated Time for Preparing the Dolly for Delivery - Hours per Year - Year 2	Estimated Time for Delivering the Container to the Line or Kitting/Re-Packing Area - Hours per Year - Year 2	Estimated Time for Empty Container Storing and Loading - Hours per Year - Year 2	Total Handling Manpower Time - Hours per Year - Year 2	Estimated Time for Container Unloading and Storing - Hours per Year - Year 3	Estimated Time for Preparing the Dolly for Delivery - Hours per Year - Year 3	Estimated Time for Delivering the Container to the Line or Kitting/Re-Packing Area - Hours per Year - Year 3	Estimated Time for Empty Container Storing and Loading - Hours per Year - Year 3	Total Handling Manpower Time - Hours per Year - Year 3	Estimated Time for Container Unloading and Storing - Hours per Year - Year 4	Estimated Time for Preparing the Dolly for Delivery - Hours per Year - Year 4	Estimated Time for Delivering the Container to the Line or Kitting/Re-Packing Area - Hours per Year - Year 4	Estimated Time for Empty Container Storing and Loading - Hours per Year - Year 4	Total Handling Manpower Time - Hours per Year - Year 4
6	110.1136465		158.669332	268.782978	537.565956	110.113647		158.669332	268.782978	537.565956	110.113647		158.669332	268.782978	537.565956
7	240.247956		346.187633	586.435589	1172.87118	240.247956		346.187633	586.435589	1172.87118	240.247956		346.187633	586.435589	1172.87118
8	151.0130009		217.603655	368.616656	737.233311	151.013001		217.603655	368.616656	737.233311	151.013001		217.603655	368.616656	737.233311
9	122.9175589		177.119254	300.036813	600.073625	122.917559		177.119254	300.036813	600.073625	122.917559		177.119254	300.036813	600.073625
10	103.6363732		149.335841	252.972215	505.944429	103.636373		149.335841	252.972215	505.944429	103.636373		149.335841	252.972215	505.944429
11	1057.091006		1523.22558	2580.31659	5160.63318	1057.09101		1523.22558	2580.31659	5160.63318	1057.09101		1523.22558	2580.31659	5160.63318
12	211.4182013		304.645117	516.063318	1032.12664	211.418201		304.645117	516.063318	1032.12664	211.418201		304.645117	516.063318	1032.12664
13	99.72556664		143.700527	243.426093	486.852187	99.7255666		143.700527	243.426093	486.852187	99.7255666		143.700527	243.426093	486.852187
14															
15															
16															
17															
18	243.4691094	67.287275	1019.30326	1195.4851	2525.54475	243.469109	67.287275	1019.30326	1195.4851	2525.54475	243.469109	67.287275	1019.30326	1195.4851	2525.54475
19															

Figure A. 18 – Requirements Check and Computations spreadsheet, screenshot 6.

- estimated time for container unloading and storing - hours per year - year 2 (bulk containers):
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,((('Input Sheet'!E$41*'InputSheet'!E$40*'InputSheet'!E$43*'Input Sheet'!E$44)/'Requirements Check-Computations'!AL6)*'Input Sheet'!D$52)/'Input Sheet'!D$53, ""), ""), ""), "")
- estimated time for container unloading and storing - hours per year - year 2 (totes):
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,((('Input Sheet'!E$41*'InputSheet'!E$40*'InputSheet'!E$43*'InputSheet'!E$44)/('Requirements Check-Computations'!AL14*'N. Containers per Tr. Vessel 1'!H22))*('Input Sheet'!D$54))/'Input Sheet'!D$55+(BM14*'Input Sheet'!E$40*'Input Sheet'!D$56), ""), ""), ""), "")
- estimated time for preparing the dolly for delivery - hours per year - year 2:
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,BM14*'Input Sheet'!E$40*'Input Sheet'!D$57, ""), ""), ""), "")
- estimated time for delivering the container to the line or kitting/re-packing area - hours per year - year 2 (bulk containers):
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,(BM6*'Input Sheet'!E$40*'Input Sheet'!D$58)/'Input Sheet'!D$59, ""), ""), ""), "")
- estimated time for delivering the container to the line or kitting/re-packing area - hours per year - year 2 (totes):
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,(BM14*'Input Sheet'!E$40*'InputSheet'!D$60)/'InputSheet'!D$61+(BM14*'InputSheet'!E$40*'Input Sheet'!D$62), ""), ""), ""), "")
- estimated time for empty container storing and loading - hours per year - year 2 (bulk containers):
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,(BM6*'Input Sheet'!E$40*('InputSheet'!D$64))/'InputSheet'!D$65+(BM6*'InputSheet'!E$40*('Inp ut Sheet'!D$68))/'Input Sheet'!D$69, ""), ""), ""), "")

- estimated time for empty container storing and loading - hours per year - year 2 (totes):
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,BM14*'Input Sheet'!E$40*'InputSheet'!D$63+(BM14*'InputSheet'!E$40*'InputSheet'!D$66)/'Input Sheet'!D$67+((('Input Sheet'!E$41*'Input Sheet'!E$40*'Input Sheet'!E$43*'Input Sheet'!E$44)/('Requirements Check-Computations'!AL14*'N. Containers per Tr. Vessel 1'!H22))*('Input Sheet'!D$70))/'Input Sheet'!D$71, ""), ""), ""), "")
- total handling manpower time - hours per year - year 2:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(BV6:BY6), ""), ""), ""), "")
- estimated time for container unloading and storing - hours per year - year 3 (bulk containers):
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,((('Input Sheet'!F$41*'InputSheet'!F$40*'Input Sheet'!F$43*'Input Sheet'!F$44)/'Requirements Check-Computations'!AL6)*'Input Sheet'!D$52)/'Input Sheet'!D$53, ""), ""), ""), "")
- estimated time for container unloading and storing - hours per year - year 3 (totes):
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,((('Input Sheet'!F$41*'InputSheet'!F$40*'InputSheet'!F$43*'Input Sheet'!F$44)/('Requirements Check-Computations'!AL14*'N. Containers per Tr. Vessel 1'!H22))*('Input Sheet'!D$54))/'Input Sheet'!D$55+(BN14*'Input Sheet'!F$40*'Input Sheet'!D$56), ""), ""), ""), "")
- estimated time for preparing the dolly for delivery - hours per year - year 3:
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,BN14*'Input Sheet'!F$40*'Input Sheet'!D$57, ""), ""), ""), "")
- estimated time for delivering the container to the line or kitting/re-packing area - hours per year - year 3 (bulk containers):
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,(BN6*'Input Sheet'!F$40*'Input Sheet'!D$58)/'Input Sheet'!D$59, ""), ""), ""), "")

- estimated time for delivering the container to the line or kitting/re-packing area - hours per year - year 3 (totes):
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,(BN14*'Input Sheet'!F$40*'InputSheet'!D$60)/'InputSheet'!D$61+(BN14*'Input Sheet'!F$40*'Input Sheet'!D$62), ""), ""), ""), "")
- estimated time for empty container storing and loading - hours per year - year 3 (bulk containers):
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,(BN6*'Input Sheet'!F$40*('InputSheet'!D$64))/'InputSheet'!D$65+(BN6*'InputSheet'!F$40*('Inpu t Sheet'!D$68))/'Input Sheet'!D$69, ""), ""), ""), "")
- estimated time for empty container storing and loading - hours per year - year 3 (totes):
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,BN14*'Input Sheet'!F$40*'InputSheet'!D$63+(BN14*'InputSheet'!F$40*'Input Sheet'!D$66)/'Input Sheet'!D$67+((('Input Sheet'!F$41*'Input Sheet'!F$40*'Input Sheet'!F$43*'Input Sheet'!F$44)/('Requirements Check-Computations'!AL14*'N. Containers per Tr. Vessel 1'!H22))*('Input Sheet'!D$70))/'Input Sheet'!D$71, ""), ""), ""), "")

- total handling manpower time - hours per year - year 3:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(CA6:CD6), ""), ""), ""), "")
- estimated time for container unloading and storing - hours per year - year 4 (bulk containers):
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,((('Input Sheet'!G$41*'InputSheet'!G$40*'InputSheet'!G$43*'Input Sheet'!G$44)/'Requirements Check-Computations'!AL6)*'Input Sheet'!D$52)/'Input Sheet'!D$53, ""), ""), ""), "")
- estimated time for container unloading and storing - hours per year - year 4 (totes):
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,((('Input Sheet'!G$41*'InputSheet'!G$40*'InputSheet'!G$43*'InputSheet'!G$44)/('Requirement s Check-Computations'!AL14*'N. Containers per Tr. Vessel 1'!H22))*('Input

Sheet'!D$54))/'Input Sheet'!D$55+(BO14*'Input Sheet'!G$40*'Input Sheet'!D$56), ""), ""), ""), "")

- estimated time for preparing the dolly for delivery - hours per year - year 4: =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,BO14*'Input Sheet'!G$40*'Input Sheet'!D$57, ""), ""), ""), "")
- estimated time for delivering the container to the line or kitting/re-packing area - hours per year - year 4 (bulk containers): =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,(BO6*'Input Sheet'!G$40*'Input Sheet'!D$58)/'Input Sheet'!D$59, ""), ""), ""), "")
- estimated time for delivering the container to the line or kitting/re-packing area - hours per year - year 4 (totes): =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,(BO14*'Input Sheet'!G$40*'InputSheet'!D$60)/'InputSheet'!D$61+(BO14*'InputSheet'!G$40*'Input Sheet'!D$62), ""), ""), ""), "")
- estimated time for empty container storing and loading - hours per year - year 4 (bulk containers): =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,(BO6*'Input Sheet'!G$40*('InputSheet'!D$64))/'InputSheet'!D$65+(BO6*'InputSheet'!G$40*('Input Sheet'!D$68))/'Input Sheet'!D$69, ""), ""), ""), "")
- estimated time for empty container storing and loading - hours per year - year 4 (totes): =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,BO14*'Input Sheet'!G$40*'InputSheet'!D$63+(BO14*'InputSheet'!G$40*'InputSheet'!D$66)/'Input Sheet'!D$67+((('Input Sheet'!G$41*'Input Sheet'!G$40*'Input Sheet'!G$43*'Input Sheet'!G$44)/('Requirements Check-Computations'!AL14*'N. Containers per Tr. Vessel 1'!H22))*('Input Sheet'!D$70))/'Input Sheet'!D$71, ""), ""), ""), "")
- total handling manpower time - hours per year - year 4: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(CF6:CI6), ""), ""), ""), "")

- estimated time for container unloading and storing - hours per year - year 5 (bulk containers):
=IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,((('InputSheet'!H$41*'InputSheet'!H$40*'InputSheet'!H$43*'InputSheet'!H$44)/'Requirements Check-Computations'!AL6)*'Input Sheet'!D$52)/'Input Sheet'!D$53, ""), ""), ""), "")

	CK	CL	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX	CY
4															
5	Estimated Time for Container Unloading and Storing - Hours per Year - Year 5	Estimated Time for Preparing the Dolly for Delivery - Hours per Year - Year 5	Estimated Time for Delivering the Container to the Line or Kitting/Re-Packing Area - Hours per Year - Year 5	Estimated Time for Empty Container Storing and Loading - Hours per Year - Year 5	Total Handling Manpower Time - Hours per Year - Year 5	Estimated Cost for Container Unloading and Storing - Year 1	Estimated Cost for Preparing the Dolly for Delivery - Year 1	Estimated Cost for Delivering the Container to the Line or Kitting/Re-Packing Area - Year 1	Estimated Cost for Empty Container Storing and Loading - Year 1	Total Handling Manpower Cost - Year 1	Estimated Cost for Container Unloading and Storing - Year 2	Estimated Cost for Preparing the Dolly for Delivery - Year 2	Estimated Cost for Delivering the Container to the Line or Kitting/Re-Packing Area - Year 2	Estimated Cost for Empty Container Storing and Loading - Year 2	Total Handling Manpower Cost - Year 2
6	110.113647		158.669332	268.782978	537.565956	€ 429.44		€ 618.81	€ 1,048.25	€ 2,096.51	€ 429.44		€ 618.81	€ 1,048.25	€ 2,096.51
7	240.247956		346.187633	586.435589	1172.87118	€ 936.97		€ 1,350.13	€ 2,287.10	€ 4,574.20	€ 936.97		€ 1,350.13	€ 2,287.10	€ 4,574.20
8	151.013001		217.603655	368.616656	737.233311	€ 588.95		€ 848.65	€ 1,437.60	€ 2,875.21	€ 588.95		€ 848.65	€ 1,437.60	€ 2,875.21
9	122.917559		177.119254	300.036813	600.073625	€ 479.38		€ 690.77	€ 1,170.14	€ 2,340.29	€ 479.38		€ 690.77	€ 1,170.14	€ 2,340.29
10	103.636373		149.335841	252.972215	505.944429	€ 404.18		€ 582.41	€ 986.59	€ 1,973.18	€ 404.18		€ 582.41	€ 986.59	€ 1,973.18
11	1057.09101		1523.22558	2580.31659	5160.63318	€ 4,122.65		€ 5,940.58	€ 10,063.23	€ 20,126.47	€ 4,122.65		€ 5,940.58	€ 10,063.23	€ 20,126.47
12	211.418201		304.645117	516.063318	1032.12664	€ 824.53		€ 1,188.12	€ 2,012.65	€ 4,025.29	€ 824.53		€ 1,188.12	€ 2,012.65	€ 4,025.29
13	99.7255666		143.700527	243.426093	486.852187	€ 388.93		€ 560.43	€ 949.36	€ 1,898.72	€ 388.93		€ 560.43	€ 949.36	€ 1,898.72
14															
15															
16															
17															
18	243.469109	67.287275	1019.30326	1195.4851	2525.54475	€ 949.53	€ 262.42	€ 3,975.28	€ 4,662.39	€ 9,849.62	€ 949.53	€ 262.42	€ 3,975.28	€ 4,662.39	€ 9,849.62
19															

Figure A. 19 – Requirements Check and Computations spreadsheet, screenshot 7.

- estimated time for container unloading and storing - hours per year - year 5 (totes):
=IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,((('Input Sheet'!H$41*'InputSheet'!H$40*'InputSheet'!H$43*'InputSheet'!H$44)/('Requirements Check-Computations'!AL14*'N. Containers per Tr. Vessel 1'!H22))*('Input Sheet'!D$54))/'Input Sheet'!D$55+(BP14*'Input Sheet'!H$40*'Input Sheet'!D$56), ""), ""), ""), "")
- estimated time for preparing the dolly for delivery - hours per year - year 5:
=IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,BP14*'Input Sheet'!H$40*'Input Sheet'!D$57, ""), ""), ""), "")
- estimated time for delivering the container to the line or kitting/re-packing area - hours per year - year 5 (bulk containers):
=IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,(BP6*'Input Sheet'!H$40*'Input Sheet'!D$58)/'Input Sheet'!D$59, ""), ""), ""), "")
- estimated time for delivering the container to the line or kitting/re-packing area - hours per year - year 5 (totes):

=IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,(BP14*'Input Sheet'!H$40*'InputSheet'!D$60)/'InputSheet'!D$61+(BP14*'Input Sheet'!H$40*'Input Sheet'!D$62), ""), ""), ""), "")

- estimated time for empty container storing and loading - hours per year - year 5 (bulk containers):

  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,(BP6*'Input Sheet'!H$40*('InputSheet'!D$64))/'InputSheet'!D$65+(BP6*'InputSheet'!H$40*('Inpu t Sheet'!D$68))/'Input Sheet'!D$69, ""), ""), ""), "")

- estimated time for empty container storing and loading - hours per year - year 5 (totes):

  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE,BP14*'Input Sheet'!H$40*'InputSheet'!D$63+(BP14*'InputSheet'!H$40*'Input Sheet'!D$66)/'Input Sheet'!D$67+((('Input Sheet'!H$41*'Input Sheet'!H$40*'Input Sheet'!H$43*'Input Sheet'!H$44)/('Requirements Check-Computations'!AL14*'N. Containers per Tr. Vessel 1'!H22))*('Input Sheet'!D$70))/'Input Sheet'!D$71, ""), ""), ""), "")

- total handling manpower time - hours per year - year 5:

  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(CK6:CN6), ""), ""), ""), "")

- estimated cost for container unloading and storing - year 1:

  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,BQ6*'Input Sheet'!D$51, ""), ""), ""), "")

- estimated cost for preparing the dolly for delivery - year 1:

  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!BR14, ""), ""), ""), "")

- estimated cost for delivering the container to the line or kitting/re-packing area - year 1:

  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!BS6, ""), ""), ""), "")

- estimated cost for empty container storing and loading - year 1:

  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!BT6, ""), ""), ""), "")

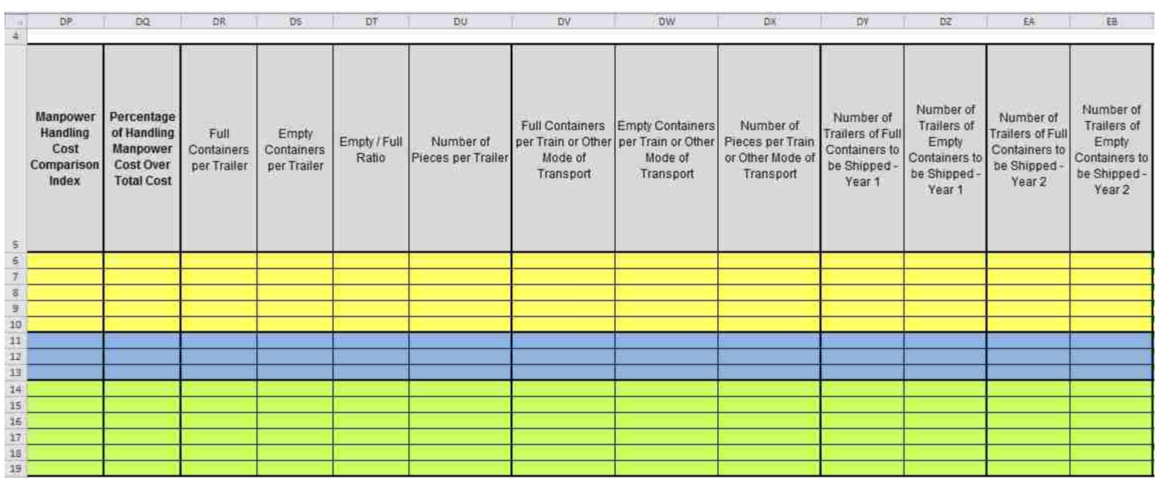
- total handling manpower cost - year 1:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(CP6:CS6), ""), ""), ""), "")
- estimated cost for container unloading and storing - year 2:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,BV6*'Input Sheet'!D$51, ""), ""), ""), "")
- estimated cost for preparing the dolly for delivery - year 2:
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!BW14, ""), ""), ""), "")
- estimated cost for delivering the container to the line or kitting/re-packing area - year 2:
- =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!BX6, ""), ""), ""), "")
- estimated cost for empty container storing and loading - year 2:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!BY6, ""), ""), ""), "")
- total handling manpower cost - year 2:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(CU6:CX6), ""), ""), ""), "")

	CZ	DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK	DL	DM	DN	DO
4																
5	Estimated Cost for Container Unloading and Storing - Year 3	Estimated Cost for Preparing the Dolly for Delivery - Year 3	Estimated Cost for Delivering the Container to the Line or Kitting/Re-Packing Area - Year 3	Estimated Cost for Empty Container Storing and Loading - Year 3	Total Handling Manpower Cost - Year 3	Estimated Cost for Container Unloading and Storing - Year 4	Estimated Cost for Preparing the Dolly for Delivery - Year 4	Estimated Cost for Delivering the Container to the Line or Kitting/Re-Packing Area - Year 4	Estimated Cost for Empty Container Storing and Loading - Year 4	Total Handling Manpower Cost - Year 4	Estimated Cost for Container Unloading and Storing - Year 5	Estimated Cost for Preparing the Dolly for Delivery - Year 5	Estimated Cost for Delivering the Container to the Line or Kitting/Re-Packing Area - Year 5	Estimated Cost for Empty Container Storing and Loading - Year 5	Total Handling Manpower Cost - Year 5	**Total Handling Manpower Cost - Entire Duration of the Program**
6	€ 429.44		€ 618.81	€ 1,048.25	€ 2,096.51	€ 429.44		€ 618.81	€ 1,048.25	€ 2,096.51	€ 429.44		€ 618.81	€ 1,048.25	€ 2,096.51	€ 10,482.54
7	€ 936.97		€ 1,350.13	€ 2,287.10	€ 4,574.20	€ 936.97		€ 1,350.13	€ 2,287.10	€ 4,574.20	€ 936.97		€ 1,350.13	€ 2,287.10	€ 4,574.20	€ 22,870.99
8	€ 588.95		€ 848.65	€ 1,437.60	€ 2,875.21	€ 588.95		€ 848.65	€ 1,437.60	€ 2,875.21	€ 588.95		€ 848.65	€ 1,437.60	€ 2,875.21	€ 14,376.05
9	€ 479.38		€ 690.77	€ 1,170.14	€ 2,340.29	€ 479.38		€ 690.77	€ 1,170.14	€ 2,340.29	€ 479.38		€ 690.77	€ 1,170.14	€ 2,340.29	€ 11,701.44
10	€ 404.18		€ 582.41	€ 986.59	€ 1,973.18	€ 404.18		€ 582.41	€ 986.59	€ 1,973.18	€ 404.18		€ 582.41	€ 986.59	€ 1,973.18	€ 9,865.92
11	€ 4,122.65		€ 5,940.58	€ 10,063.23	€ 20,126.47	€ 4,122.65		€ 5,940.58	€ 10,063.23	€ 20,126.47	€ 4,122.65		€ 5,940.58	€ 10,063.23	€ 20,126.47	€ 100,632.35
12	€ 824.53		€ 1,188.12	€ 2,012.65	€ 4,025.29	€ 824.53		€ 1,188.12	€ 2,012.65	€ 4,025.29	€ 824.53		€ 1,188.12	€ 2,012.65	€ 4,025.29	€ 20,126.47
13	€ 388.93		€ 560.43	€ 949.36	€ 1,898.72	€ 388.93		€ 560.43	€ 949.36	€ 1,898.72	€ 388.93		€ 560.43	€ 949.36	€ 1,898.72	€ 9,493.62
14																
15																
16																
17																
18	€ 949.53	€ 262.42	€ 3,975.28	€ 4,662.39	€ 9,849.62	€ 949.53	€ 262.42	€ 3,975.28	€ 4,662.39	€ 9,849.62	€ 949.53	€ 262.42	€ 3,975.28	€ 4,662.39	€ 9,849.62	€ 49,248.12
19																

Figure A. 20 – Requirements Check and Computations spreadsheet, screenshot 8.

- estimated cost for container unloading and storing - year 3:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,CA6*'Input Sheet'!D$51, ""), ""), ""), "")
- estimated cost for preparing the dolly for delivery - year 3:
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!CB14, ""), ""), ""), "")
- estimated cost for delivering the container to the line or kitting/re-packing area - year 3:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!CC6, ""), ""), ""), "")
- estimated cost for empty container storing and loading - year 3:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!CD6, ""), ""), ""), "")
- total handling manpower cost - year 3:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(CZ6:DC6), ""), ""), ""), "")
- estimated cost for container unloading and storing - year 4:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,CF6*'Input Sheet'!D$51, ""), ""), ""), "")
- estimated cost for preparing the dolly for delivery - year 4:
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!CG14, ""), ""), ""), "")
- estimated cost for delivering the container to the line or kitting/re-packing area - year 4:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!CH6, ""), ""), ""), "")
- estimated cost for empty container storing and loading - year 4:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!CI6, ""), ""), ""), "")

- total handling manpower cost - year 4:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(DE6:DH6), ""), ""), ""), "")
- estimated cost for container unloading and storing - year 5:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,CK6*'Input Sheet'!D$51, ""), ""), ""), "")
- estimated cost for preparing the dolly for delivery - year 5:
  =IF(Z14=TRUE, IF(AA14=TRUE, IF(AB14=TRUE, IF(AQ14=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!CL14, ""), ""), ""), "")
- estimated cost for delivering the container to the line or kitting/re-packing area - year 5:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!CM6, ""), ""), ""), "")
- estimated cost for empty container storing and loading - year 5:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!D$51*'Requirements Check-Computations'!CN6, ""), ""), ""), "")
- total handling manpower cost - year 5:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(DJ6:DM6), ""), ""), ""), "")



DP	DQ	DR	DS	DT	DU	DV	DW	DX	DY	DZ	EA	EB
Manpower Handling Cost Comparison Index	Percentage of Handling Manpower Cost Over Total Cost	Full Containers per Trailer	Empty Containers per Trailer	Empty / Full Ratio	Number of Pieces per Trailer	Full Containers per Train or Other Mode of Transport	Empty Containers per Train or Other Mode of Transport	Number of Pieces per Train or Other Mode of Transport	Number of Trailers of Full Containers to be Shipped - Year 1	Number of Trailers of Empty Containers to be Shipped - Year 1	Number of Trailers of Full Containers to be Shipped - Year 2	Number of Trailers of Empty Containers to be Shipped - Year 2

Figure A. 21 – Requirements Check and Computations spreadsheet, screenshot 9.

- total handling manpower cost - entire duration of the program:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, CT6+CY6+DD6+DI6+DN6, ""), ""), ""), "")
- manpower handling cost comparison index:
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,DO6/MAX(DO$6:DO$19), ""), ""), ""), "")
- percentage of handling manpower cost over total cost:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,DO6/FX6, ""), ""), ""), "")
- full containers per trailer:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,'N. Containers per Tr. Vessel 1'!L14, ""), ""), ""), "")
- empty containers per trailer:
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE, IF(AQ6=TRUE,TRUNC(DR6*DT6, 0), ""), ""), ""), "")
- empty / full ratio:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,N6,""),""),""),"")
- number of pieces per trailer:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,DR6*AL6, ""), ""), ""), "")
- full containers per train or other mode of transport:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('N. Containers per Tr. Vessel 2'!L14)*'Input Sheet'!D$99, ""), ""), ""), "")
- empty containers per train or other mode of transport:
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,TRUNC(DV6*DT6, 0), ""), ""), ""), "")
- number of pieces per train or other mode of transport:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,DV6*AL6, ""), ""), ""), "")

- number of trailers of full containers to be shipped - year 1:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('Input Sheet'!D$41*'Input Sheet'!D$40*'Input Sheet'!D$43*'Input Sheet'!D$44)/DU6, ""), ""), ""), "")
- number of trailers of empty containers to be shipped - year 1:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,DY6/DT6, ""), ""), ""), "")
- number of trailers of full containers to be shipped - year 2:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('Input Sheet'!E$41*'Input Sheet'!E$40*'Input Sheet'!E$43*'Input Sheet'!E$44)/DU6, ""), ""), ""), "")
- number of trailers of empty containers to be shipped - year 2:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,EA6/DT6, ""), ""), ""), "")
- number of trailers of full containers to be shipped - year 3:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('Input Sheet'!F$41*'Input Sheet'!F$40*'Input Sheet'!F$43*'Input Sheet'!F$44)/DU6, ""), ""), ""), "")

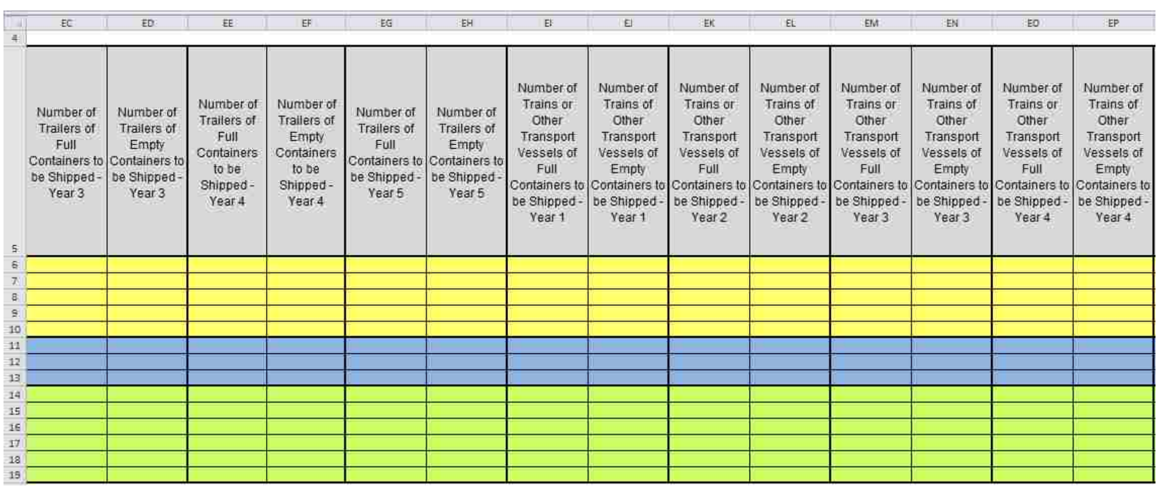


Figure A. 22 – Requirements Check and Computations spreadsheet, screenshot 10.

- number of trailers of empty containers to be shipped - year 3: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,EC6/DT6, ""), ""), ""), "")
- number of trailers of full containers to be shipped - year 4: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('Input Sheet'!G$41*'Input Sheet'!G$40*'Input Sheet'!G$43*'Input Sheet'!G$44)/DU6, ""), ""), ""), "")
- number of trailers of empty containers to be shipped - year 4: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,EE6/DT6, ""), ""), ""), "")
- number of trailers of full containers to be shipped - year 5: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('Input Sheet'!H$41*'Input Sheet'!H$40*'Input Sheet'!H$43*'Input Sheet'!H$44)/DU6, ""), ""), ""), "")
- number of trailers of empty containers to be shipped - year 5: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('Input Sheet'!H$41*'Input Sheet'!H$40*'Input Sheet'!H$43*'Input Sheet'!H$44)/DU6, ""), ""), ""), "")
- number of trains or other transport vessels of full containers to be shipped - year 1: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('Input Sheet'!D$41*'Input Sheet'!D$40*'Input Sheet'!D$43*'Input Sheet'!D$44)/DX6, ""), ""), ""), "")
- number of trains of other transport vessels of empty containers to be shipped - year 1: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,EI6/DT6, ""), ""), ""), "")
- number of trains or other transport vessels of full containers to be shipped - year 2: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('Input Sheet'!E$41*'Input Sheet'!E$40*'Input Sheet'!E$43*'Input Sheet'!E$44)/DX6, ""), ""), ""), "")

- number of trains of other transport vessels of empty containers to be shipped - year 2: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,EK6/DT6, ""), ""), ""), "")
- number of trains or other transport vessels of full containers to be shipped - year 3: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('Input Sheet'!F$41*'Input Sheet'!F$40*'Input Sheet'!F$43*'Input Sheet'!F$44)/DX6, ""), ""), ""), "")
- number of trains of other transport vessels of empty containers to be shipped - year 3: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,EM6/DT6, ""), ""), ""), "")
- number of trains or other transport vessels of full containers to be shipped - year 4: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('Input Sheet'!G$41*'Input Sheet'!G$40*'Input Sheet'!G$43*'Input Sheet'!G$44)/DX6, ""), ""), ""), "")
- number of trains of other transport vessels of empty containers to be shipped - year 4: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,EO6/DT6, ""), ""), ""), "")
- number of trains or other transport vessels of full containers to be shipped - year 5: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,('Input Sheet'!H$41*'Input Sheet'!H$40*'Input Sheet'!H$43*'Input Sheet'!H$44)/DX6, ""), ""), ""), "")
- number of trains of other transport vessels of empty containers to be shipped - year 5: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,EQ6/DT6, ""), ""), ""), "")
- number of trailers of full containers to be shipped during the entire duration of the program: =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,SUM(DY6,EA6,EC6,EE6,EG6), ""), ""), ""), "")

	EQ	ER	ES	ET	EU	EV	EW	EX	EY	EZ	FA	FB	FC
4													
5	Number of Trains or Other Transport Vessels of Full Containers to be Shipped - Year 5	Number of Trains of Other Transport Vessels of Empty Containers to be Shipped - Year 5	Number of Trailers of Full Containers to be Shipped During the Entire Duration of the Program	Number of Trailers of Empty Containers to be Shipped During the Entire Duration of the Program	Number of Trailers of Full and Empty Containers to be Shipped During the Entire Duration of the Program	Number of Trains or Other Transport Vessels of Full Containers to be Shipped During the Entire Duration of the Program	Number of Trains or Other Transport Vessels of Empty Containers to be Shipped During the Entire Duration of the Program	Number of Trains or Other Transport Vessels of Full and Empty Containers to be Shipped During the Entire Duration of the Program	**Total Shipping Cost - Entire Duration of the Program - Truck**	**Total Shipping Cost - Entire Duration of the Program - Train or Other Mode of Transport**	**Total Shipping Cost - Entire Duration of the Program**	**Shipping Cost Comparison Index**	**Percentage of the Shipping Cost Over the Total Cost**
6	0.59466271	0.132147269	95.1460337	35.9440572	131.090091	2.97331355	0.66073634	3.6340499	€ 7,663.53	€ 1,970.34	€ 9,633.86	0.42	33.05%
7	0.576642628	0.169148504	92.2628205	40.1035726	132.366393	2.88321314	0.84574252	3.72895566	€ 7,738.14	€ 2,021.79	€ 9,759.93	0.43	21.35%
8	0.963816964	0.260491071	154.210714	64.185	218.395714	4.81908482	1.30245536	6.12154018	€ 12,767.41	€ 3,319.02	€ 16,086.44	0.70	35.44%
9	0.663809537	0.287650799	106.209526	58.0612075	164.270733	3.31904769	1.438254	4.75730168	€ 9,603.27	€ 2,579.35	€ 12,182.62	0.53	30.01%
10	0.606322763	0.252479017	97.0116422	51.7196427	148.731285	3.03161382	1.26239509	4.2940089	€ 8,694.83	€ 2,328.16	€ 11,022.99	0.48	27.75%
11	0.873104779	0.873104779	139.696765	139.696765	279.393529	4.3655239	4.3655239	8.73104779	€ 16,333.35	€ 4,733.86	€ 21,067.21	0.92	12.66%
12	0.582069853	0.582069853	93.1311765	93.1311765	186.262353	2.91034926	2.91034926	5.82069853	€ 10,888.90	€ 3,155.91	€ 14,044.81	0.61	26.99%
13	0.583442659	0.583442659	93.3508255	93.3508255	186.701651	2.9172133	2.9172133	5.83442659	€ 10,914.58	€ 3,163.35	€ 14,077.93	0.61	39.98%
14													
15													
16													
17													
18	0.951460337	0.951460337	152.233654	152.233654	304.467308	4.75730168	4.75730168	9.51460337	€ 17,799.16	€ 5,158.70	€ 22,957.86	1.00	25.68%
19													

Figure A. 23 – Requirements Check and Computations spreadsheet, screenshot 11.

- number of trailers of empty containers to be shipped during the entire duration of the program:
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,SUM(DZ6,EB6,ED, EF6,EH6), ""), ""), ""), "")
- number of trailers of full and empty containers to be shipped during the entire duration of the program:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(ES6:ET6), ""), ""), ""), "")
- number of trains or other transport vessels of full containers to be shipped during the entire duration of the program:
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,SUM(EI6,EK6,EM, EO6,EQ6), ""), ""), ""), "")
- number of trains or other transport vessels of empty containers to be shipped during the entire duration of the program:
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,SUM(EJ6,EL6,EN6, EP6,ER6), ""), ""), ""), "")

- number of trains or other transport vessels of full and empty containers to be shipped during the entire duration of the program:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(EV6:EW6), ""), ""), ""), "")
- total shipping cost - entire duration of the program – truck:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, EU6*'Input Sheet'!D$96, ""), ""), ""), "")
- total shipping cost - entire duration of the program - train or other mode of transport:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, EX6*'Input Sheet'!D$100, ""), ""), ""), "")
- total shipping cost - entire duration of the program:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(EY6:EZ6), ""), ""), ""), "")
- shipping cost comparison index:
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,FA6/MAX(FA$6:FA$19), ""), ""), ""), "")
- percentage of the shipping cost over the total cost:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,FA6/FX6, ""), ""), ""), "")

	FE	FF	FG	FH	FI	FJ	FK	FL	FM	FN	FO	FP	FQ
4													
5	Total Weight to be Shipped (Ton) - Year 1	Total Weight to be Shipped (Ton) - Year 2	Total Weight to be Shipped (Ton) - Year 3	Total Weight to be Shipped (Ton) - Year 4	Total Weight to be Shipped (Ton) - Year 5	Total Kg of CO_2 Emission - Truck - Year 1	Total Kg of CO_2 Emission - Truck - Year 2	Total Kg of CO_2 Emission - Truck - Year 3	Total Kg of CO_2 Emission - Truck - Year 4	Total Kg of CO_2 Emission - Truck - Year 5	**Total Kg of CO_2 Emission - Truck - Entire Duration of the Program**	Total Kg of CO_2 Emission - Train or Other Mode of Transport - Year 1	Total Kg of CO_2 Emission - Train or Other Mode of Transport - Year 2
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
19													

Figure A. 24 – Requirements Check and Computations spreadsheet, screenshot 11.

- total weight to be shipped (ton) - year 1:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,((AM6*(('Input Sheet'!D$41*'InputSheet'!D$40*'InputSheet'!D$44*'InputSheet'!D$43)/'Requirement sCheck-Computations'!AL6))/1000)+((('Input Sheet'!D$41*'Input Sheet'!D$40*'Input Sheet'!D$44*'InputSheet'!D$43)/'RequirementsCheck-Computations'!AL6)*I6)/1000, ""), ""), ""), "")
- total weight to be shipped (ton) - year 2:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,((AM6*(('Input Sheet'!E$41*'InputSheet'!E$40*'InputSheet'!E$44*'Input Sheet'!E$43)/'Requirements Check-Computations'!AL6))/1000)+((('Input Sheet'!E$41*'Input Sheet'!E$40*'Input Sheet'!E$44*'InputSheet'!E$43)/'Requirements Check-Computations'!AL6)*I6)/1000, ""), ""), ""), "")
- total weight to be shipped (ton) - year 3:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,((AM6*(('Input Sheet'!F$41*'InputSheet'!F$40*'Input Sheet'!F$44*'Input Sheet'!F$43)/'Requirements Check-Computations'!AL6))/1000)+((('Input Sheet'!F$41*'Input Sheet'!F$40*'Input Sheet'!F$44*'InputSheet'!F$43)/'Requirements Check-Computations'!AL6)*I6)/1000, ""), ""), ""), "")
- total weight to be shipped (ton) - year 4:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,((AM6*(('Input Sheet'!G$41*'InputSheet'!G$40*'InputSheet'!G$44*'InputSheet'!G$43)/'Requirement sCheckComputations'!AL6))/1000)+((('InputSheet'!G$41*'InputSheet'!G$40*'InputS heet'!G$44*'Input Sheet'!G$43)/'Requirements Check-Computations'!AL6)*I6)/1000, ""), ""), ""), "")
- total weight to be shipped (ton) - year 5:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,((AM6*(('Input Sheet'!H$41*'InputSheet'!H$40*'InputSheet'!H$44*'InputSheet'!H$43)/'Requirement sCheck-Computations'!AL6))/1000)+((('InputSheet'!H$41*'InputSheet'!H$40*'Input Sheet'!H$44*'InputSheet'!H$43)/'RequirementsCheck-Computations'!AL6)*I6)/1000, ""), ""), ""), "")

- total kg of CO_2 emission - truck - year 1:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!E$125*'Input Sheet'!D$91*'Requirements Check-Computations'!EU6, ""), ""), ""), "")
- total kg of CO_2 emission - truck - year 2:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!E$125*'Input Sheet'!D$91*'Requirements Check-Computations'!EU6, ""), ""), ""), "")
- total kg of CO_2 emission - truck - year 3:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!E$125*'Input Sheet'!D$91*'Requirements Check-Computations'!EU6, ""), ""), ""), "")
- total kg of CO_2 emission - truck - year 4:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!E$125*'Input Sheet'!D$91*'Requirements Check-Computations'!EU6, ""), ""), ""), "")
- total kg of CO_2 emission - truck - year 5:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, 'Input Sheet'!E$125*'Input Sheet'!D$91*'Requirements Check-Computations'!EU6, ""), ""), ""), "")
- total kg of CO_2 emission - truck - entire duration of the program:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(FK6:FN6), ""), ""), ""), "")
- total kg CO_2 emission - train or other mode of transport - year 1:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,FE6*'Input Sheet'!E$126*'Input Sheet'!D$92, ""), ""), ""), "")
- total kg of CO_2 emission - train or other mode of transport - year 2:
  =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,FF6*'Input Sheet'!E$126*'Input Sheet'!D$92, ""), ""), ""), "")

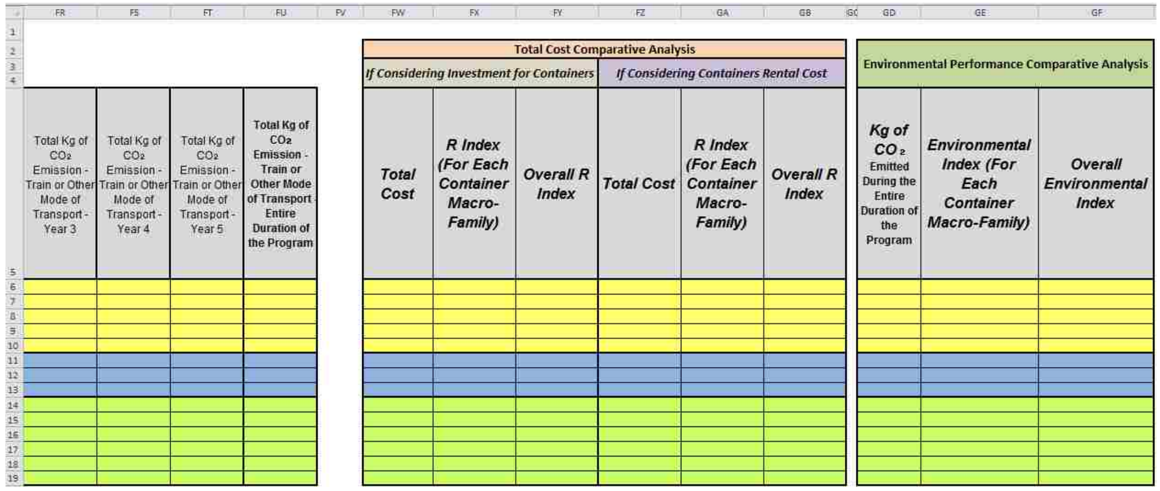


Figure A. 25 – Requirements Check and Computations spreadsheet, screenshot 12.

- total kg of CO_2 emission - train or other mode of transport - year 3: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,FG6*'Input Sheet'!E$126*'Input Sheet'!D$92, ""), ""), ""), "")
- total kg of CO_2 emission - train or other mode of transport - year 4: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,FH6*'Input Sheet'!E$126*'Input Sheet'!D$92, ""), ""), ""), "")
- total kg of CO_2 emission - train or other mode of transport - year 5: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,FI6*'Input Sheet'!E$126*'Input Sheet'!D$92, ""), ""), ""), "")
- total kg of co2 emission - train or other mode of transport - entire duration of the program: =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE,SUM(FP6:FT6), ""), ""), ""), "")

Finally, the tool provides a total cost comparative analysis both for the case in which containers have to be purchased (investment) and rented (rental cost), as well as an environmental comparative analysis:

- total cost (if considering investment for containers): =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, AV6+DO6+FA6, ""), ""), ""), "")

- R Index (for plastic bulk containers, if considering investment for containers): =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,FW6/MAX(FW$6:FW$10),""),""),""),"")
- R Index (for steel bulk containers, if considering investment for containers): =IF(Z11=TRUE,IF(AA11=TRUE,IF(AB11=TRUE,IF(AQ11=TRUE,FW11/MAX(FW$11:FW$13),""),""),""),"")
- R Index (for totes, if considering investment for containers): =IF(Z14=TRUE,IF(AA14=TRUE,IF(AB14=TRUE,IF(AQ14=TRUE,FW14/MAX(FW$14:FW$19),""),""),""),"")
- overall R Index (if considering investment for containers): =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,FW6/MAX(FW$6:FW$19),""),""),""),"")
- total cost (if considering container rental cost): =IF(Z6=TRUE, IF(AA6=TRUE, IF(AB6=TRUE, IF(AQ6=TRUE, BI6+DO6+FA6, ""), ""), ""), "")
- R Index (for plastic bulk containers, if considering container rental cost): =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,FZ6/MAX(FZ$6:FZ$10),""),""),""),"")
- R Index (for steel bulk containers, if considering container rental cost): =IF(Z11=TRUE,IF(AA11=TRUE,IF(AB11=TRUE,IF(AQ11=TRUE,FZ11/MAX(FZ$11:FZ$13),""),""),""),"")

  R Index (for totes, if considering container rental cost): =IF(Z14=TRUE,IF(AA14=TRUE,IF(AB14=TRUE,IF(AQ14=TRUE,FZ14/MAX(FZ$14:FZ$19),""),""),""),"")
- overall R Index (if considering container rental cost): =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,FZ6/MAX(FZ$6:FZ$19),""),""),""),"")
- kg of co2 emitted during the entire duration of the program: =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,SUM(FO6,FU6),""),""),""),"")

- environmental index (for plastic bulk containers):
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,GD6/MAX(GD$6:GD$10),""),""),""),"")
- environmental index (for steel bulk containers):
  =IF(Z11=TRUE,IF(AA11=TRUE,IF(AB11=TRUE,IF(AQ11=TRUE,GD11/MAX(GD$11:GD$13),""),""),""),"")
- environmental index (for totes):
  =IF(Z14=TRUE,IF(AA14=TRUE,IF(AB14=TRUE,IF(AQ14=TRUE,GD14/MAX(GD$14:GD$19),""),""),""),"")
- overall environmental index
  =IF(Z6=TRUE,IF(AA6=TRUE,IF(AB6=TRUE,IF(AQ6=TRUE,GD6/MAX(GD$6:GD$19),""),""),""),"")

Graphs

In Graphs spreadsheet the user can obtain comparative information within each container macro-family. Comparative graphs provided as output in this spreadsheet are:

- filling percentage for plastic bulk containers
- filling percentage for steel bulk containers
- filling percentage for plastic small lot totes

Figure A. 26 – Graphs spreadsheet, screenshot 1 (example).

Figure A. 27 – Graphs spreadsheet, screenshot 2 (example).

To be considered by the user in the case containers are purchased by the company:

- investment for plastic bulk containers
- investment for steel bulk containers
- investment for plastic small lot totes

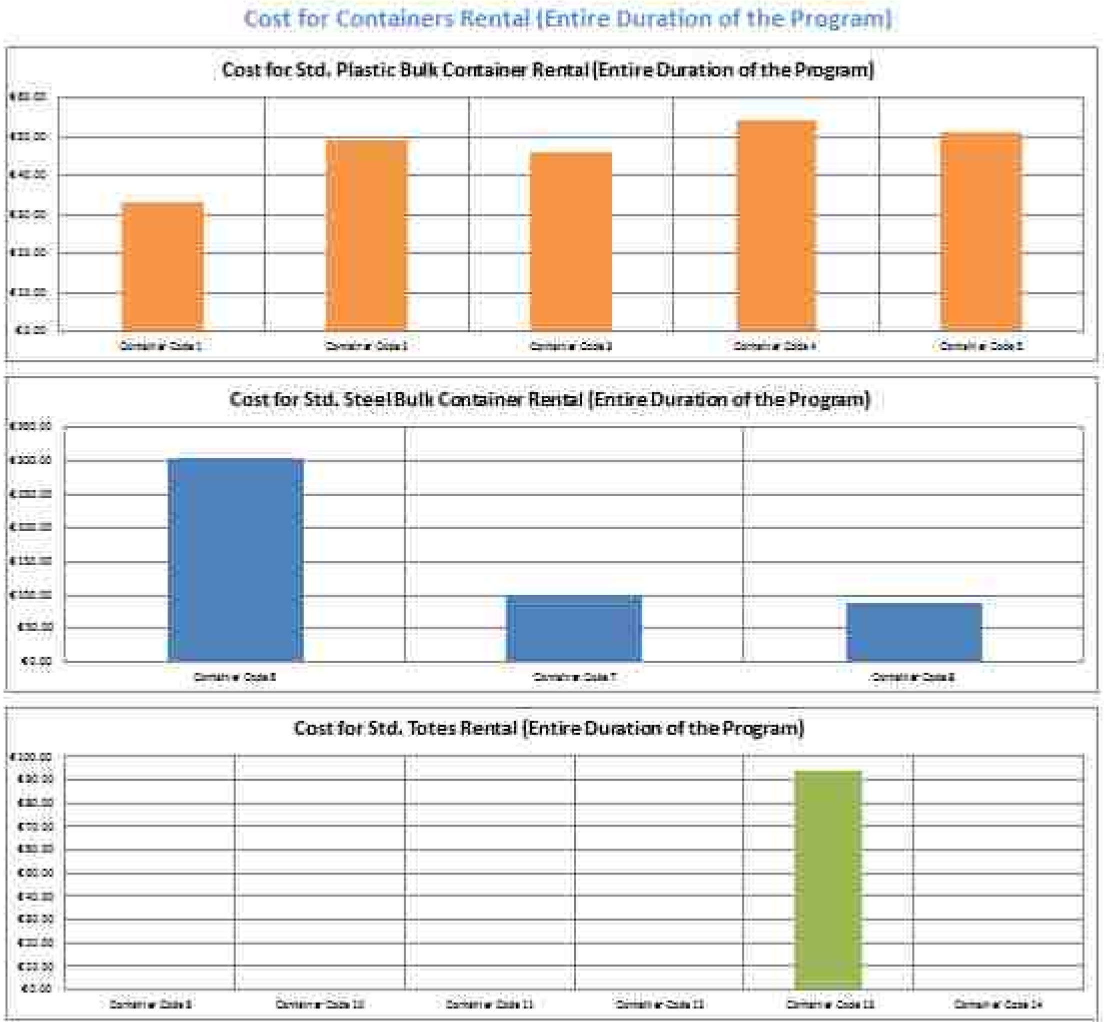


Figure A. 28 – Graphs spreadsheet, screenshot 3 (example).

To be considered by the user in the case containers are rented by the company:

- rental cost for plastic bulk containers (entire duration of the program)
- rental cost for steel bulk containers (entire duration of the program)
- rental cost for plastic small lot totes (entire duration of the program)

Figure A. 29 – Graphs spreadsheet, screenshot 4 (example).

Moreover, in Graphs spreadsheet the user can assess:

- manpower cost for plastic bulk containers handling (entire duration of the program)
- manpower cost for steel bulk containers handling (entire duration of the program)
- manpower cost for plastic small lot totes handling (entire duration of the program)

Figure A. 30 – Graphs spreadsheet, screenshot 5 (example).

- shipping cost for plastic bulk containers (entire duration of the program)
- shipping cost for steel bulk containers (entire duration of the program)
- shipping cost for plastic small lot totes (entire duration of the program)

Overall Graphs

Overall Graphs spreadsheet allows the user to obtain comparative information at overall level, without grouping containers into macro-families. This outcome of the tool is very useful when pre-requisites about the container macro-family to be selected are not established. Comparative graphs provided as output in this spreadsheet are:

- filling percentage
- container density (number of parts contained)

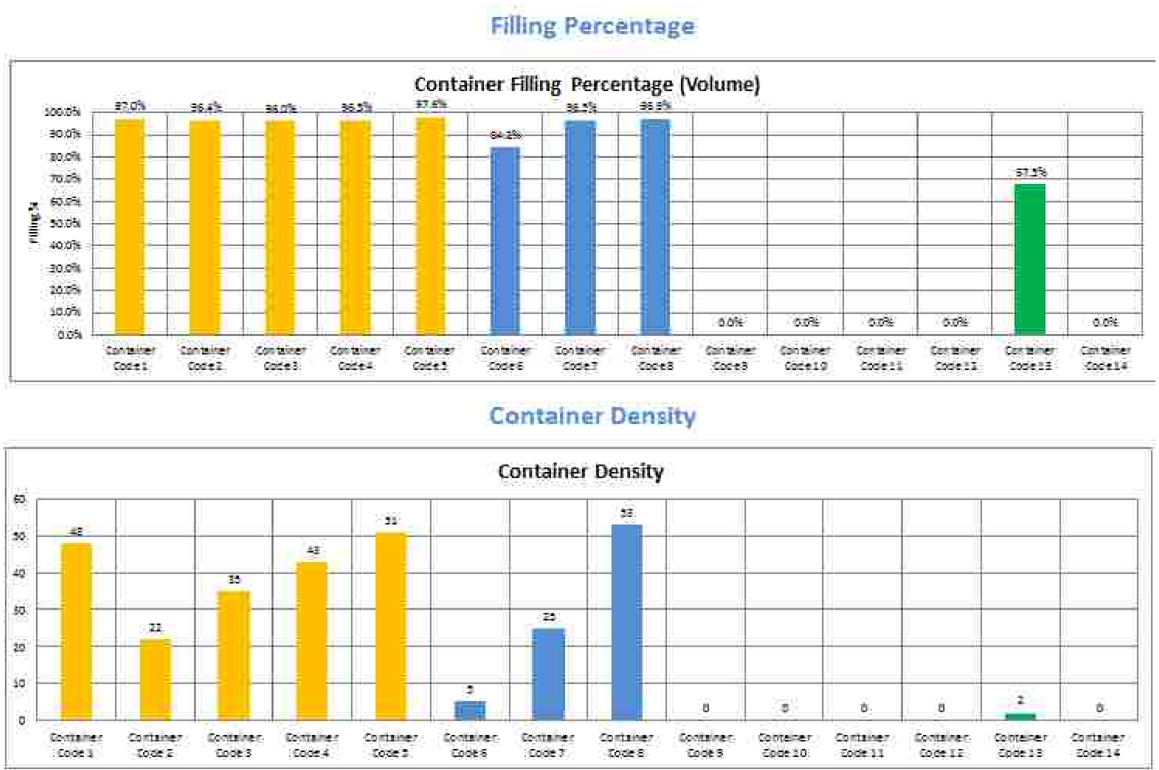


Figure A. 31 – Overall Graphs spreadsheet, screenshot 1 (example).

- investment for new containers (to be considered by the user if containers are purchased)
- rental cost for containers, entire duration of the program (to be considered by the user if containers are rented)

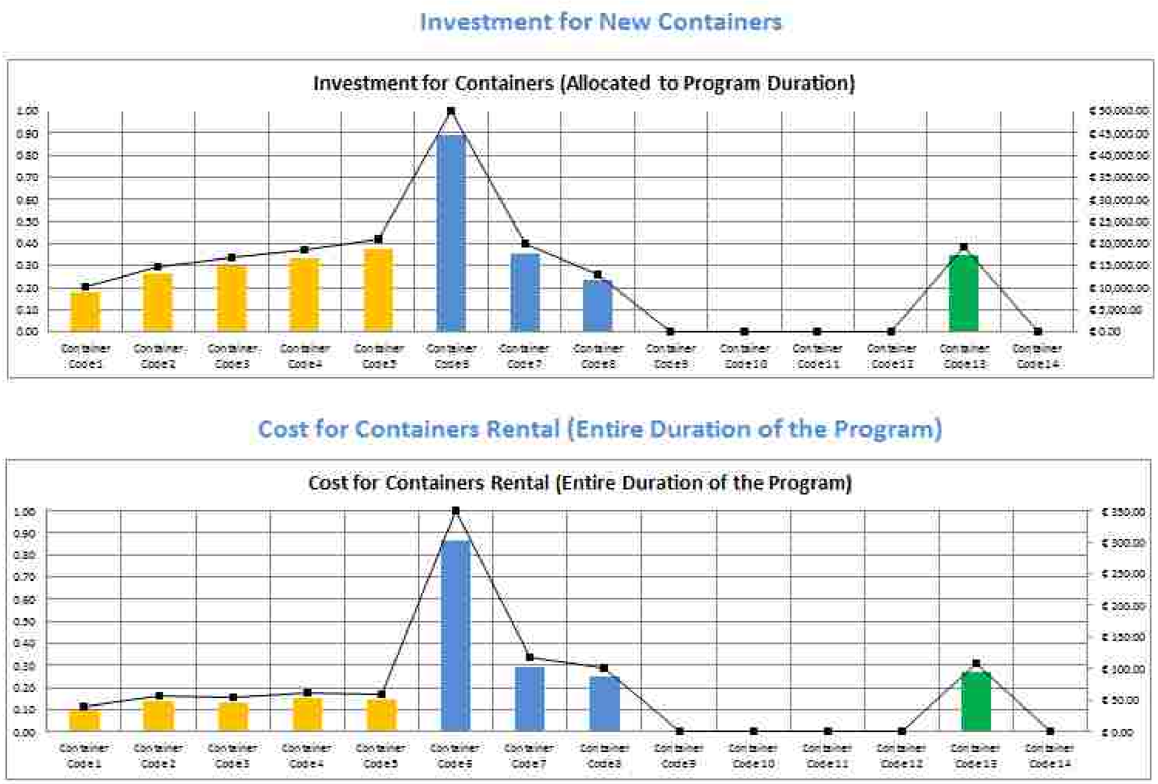


Figure A. 32 – Overall Graphs spreadsheet, screenshot 2 (example).

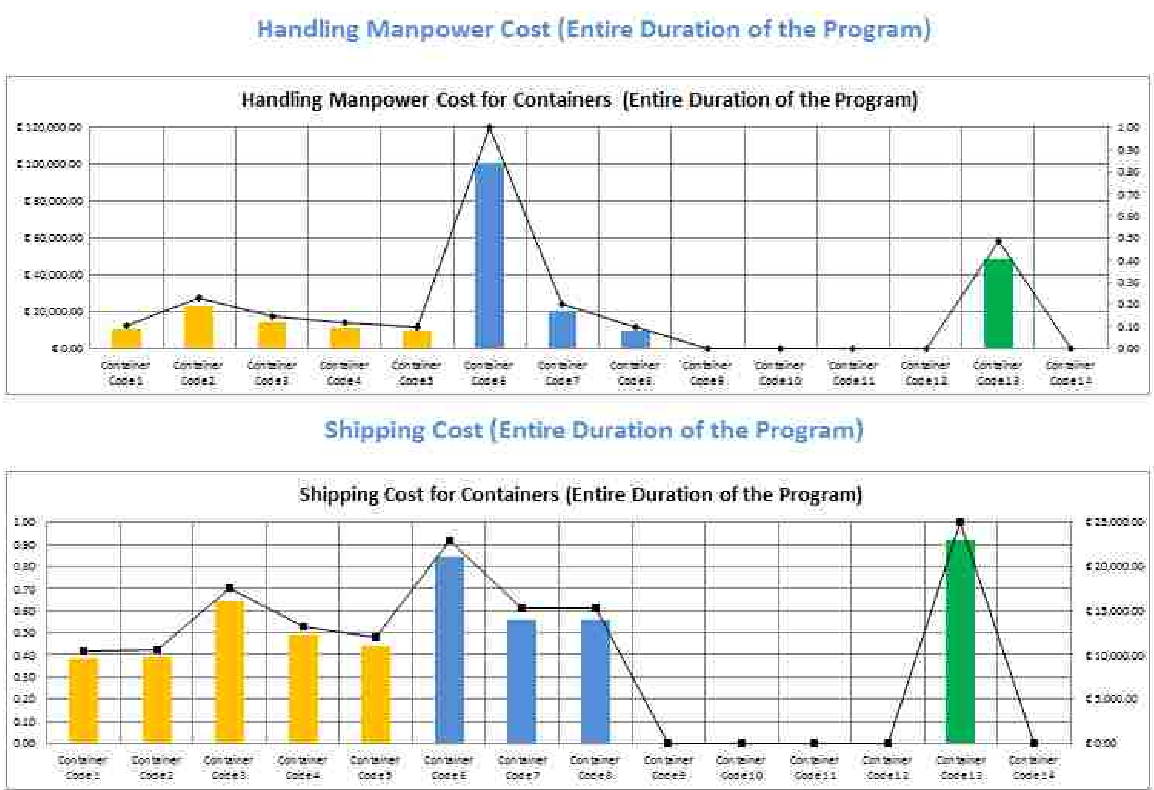


Figure A. 33 – Overall Graphs spreadsheet, screenshot 3 (example).

Kg of CO_2 Emitted (Entire Duration of the Program)

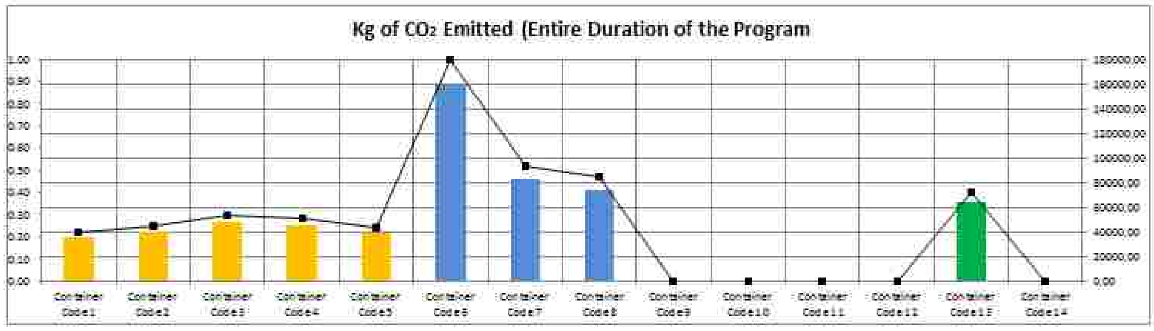


Figure A. 34 – Overall Graphs spreadsheet, screenshot 4.

- manpower cost for container for container handling (entire duration of the program)
- shipping cost for containers (entire duration of the program)
- kilograms of carbon dioxide emitted (entire duration of the program)

The user can obtain both an estimation (whose accuracy is dependent on the data given as input) of the values of the measures computed by the tool (bar graphs) and a direct comparison index (black line with markers, assuming values between 0 and 1). The comparison index maintains its consistency even in the case estimated data are given as input to the tool.

A zero value of the index indicates a solution which is not applicable while. Values closest to zero (but different to zero) highlight better solutions to reduce costs (cost graphs) and environmental impact (environmental performance graph).

Total Cost Evaluations

Total Cost Evaluations spreadsheet provides the user with a comparative analysis of the total cost performance of each container solution on container macro-family basis.

Values of the R-Index equal to zero highlight solutions which have not passed all the requirements check performed by the tool. Values closer to zero (and different from zero) indicate solutions able to optimize total cost performances.

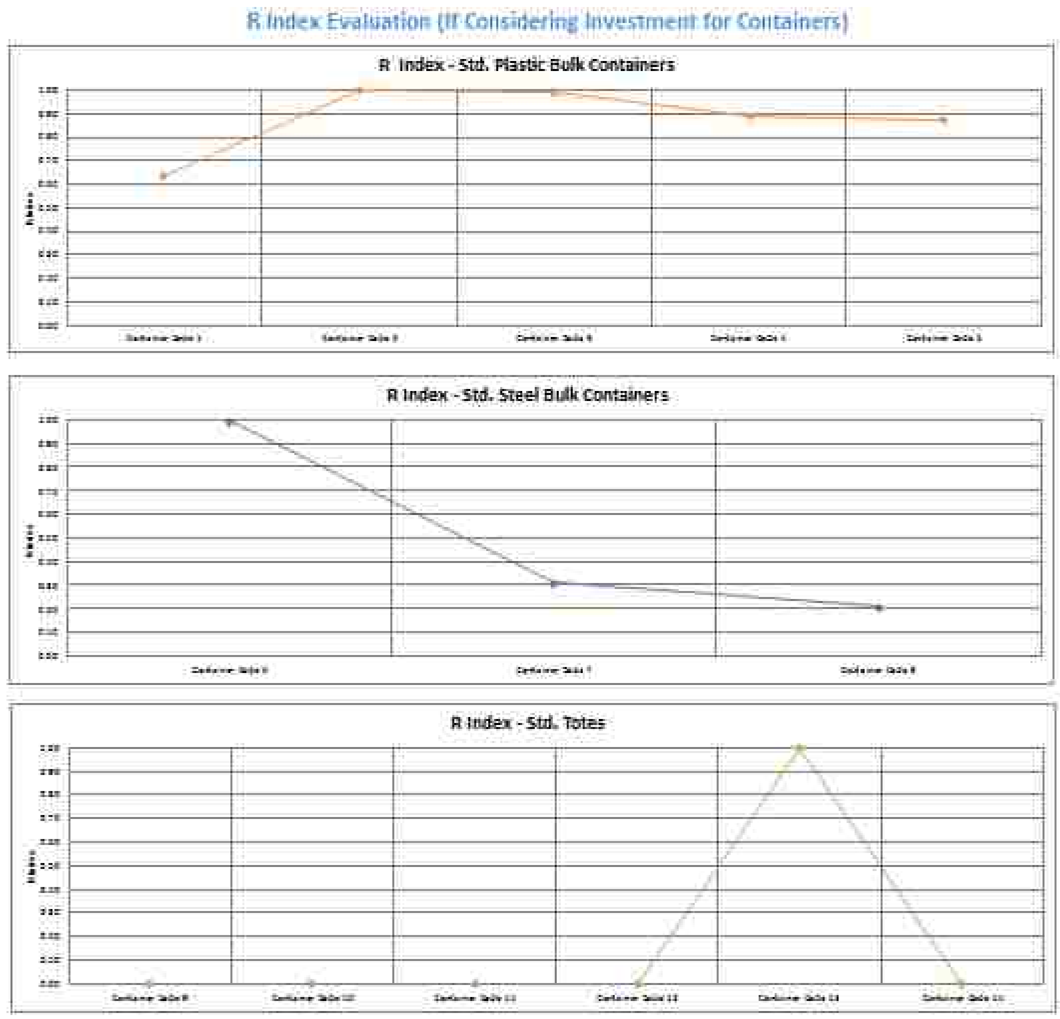


Figure A. 35 – Total Cost Evaluations spreadsheet, screenshot 1 (example).

The tool computes the R-Index and shows the output graphs both considering the investment for new containers and the rental cost for containers.

The user has to take into account the graphs presenting the right company situation.

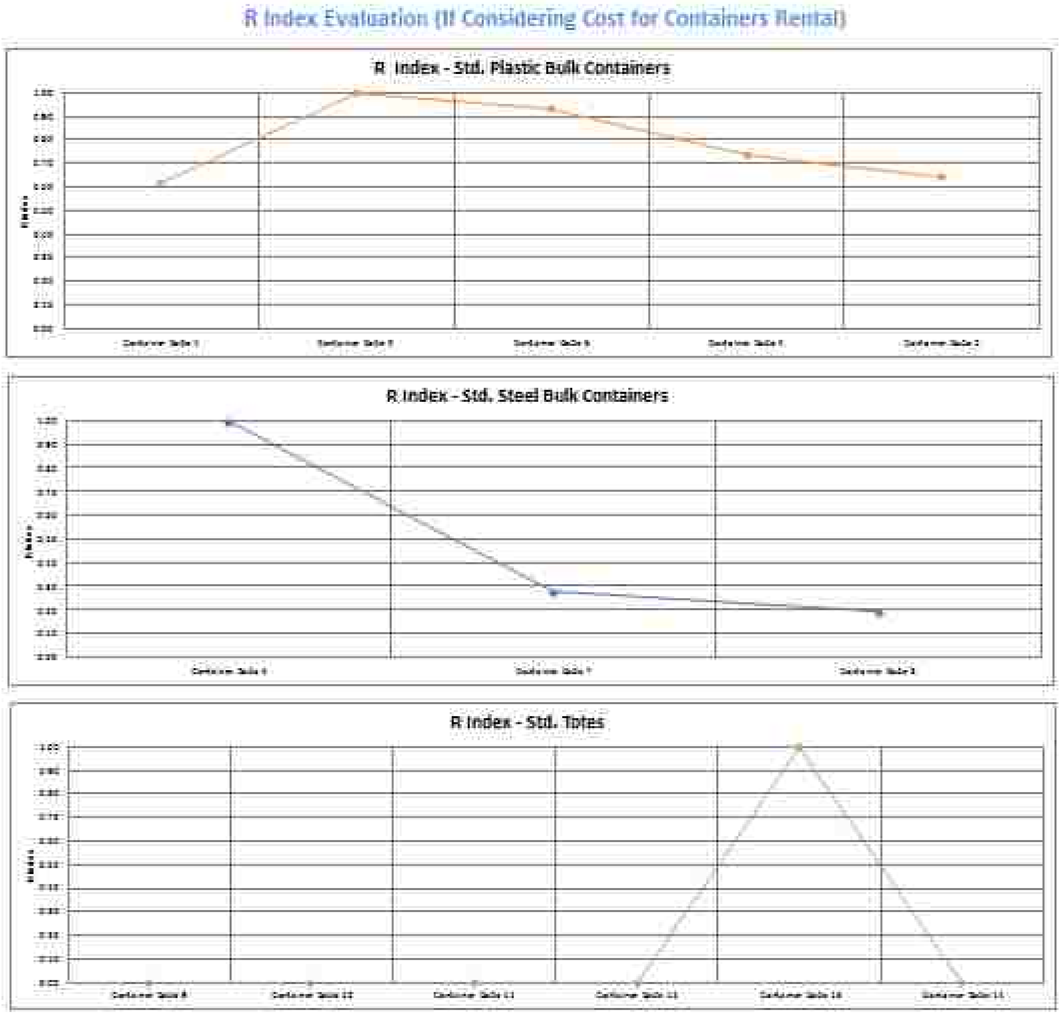


Figure A. 36 – Total Cost Evaluations spreadsheet, screenshot 2 (example).

Environmental Evaluations

Environmental Evaluations spreadsheet provide the user with a comparison made at macro-family basis of the kg of carbon dioxide emitted for shipments during the entire duration of the production program.

E-Index is used to compare different container solutions within the macro-family. The index assumes values from 0 to 1. Values equal to zero indicates not-applicable solutions, while values closest to zero point out solutions preferable from an environmental perspective (lower carbon dioxide emissions).

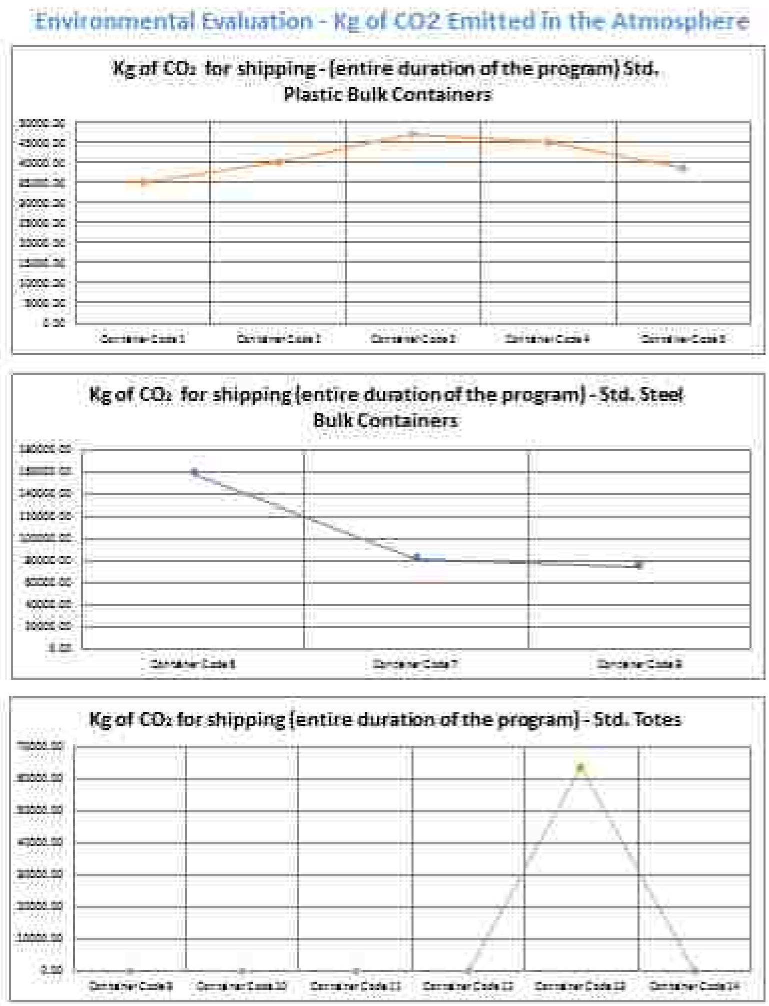


Figure A. 37 – Environmental Evaluations spreadsheet (example).

R-Index vs. E-Index

R-Index vs. E-Index spreadsheet provides on the same graphs values of the total cost index and environmental index. This way, the user of the tool can assess cost and environmental performances of each container (at macro-family basis) at the same time.

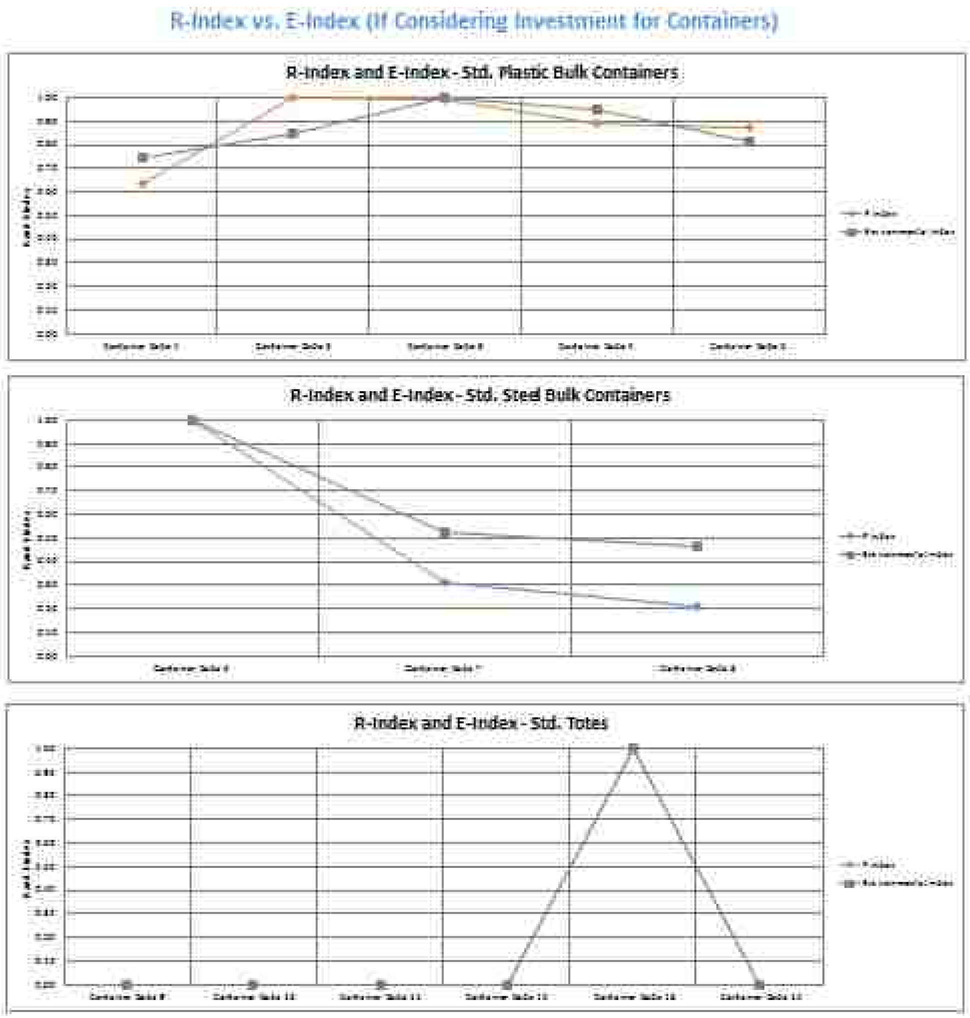


Figure A. 38 – R-Index vs. E-Index spreadsheet, screenshot 1 (example).

The tool provides this output both for the case in which containers are purchased and rented. The user has to take into account the appropriate graphs.

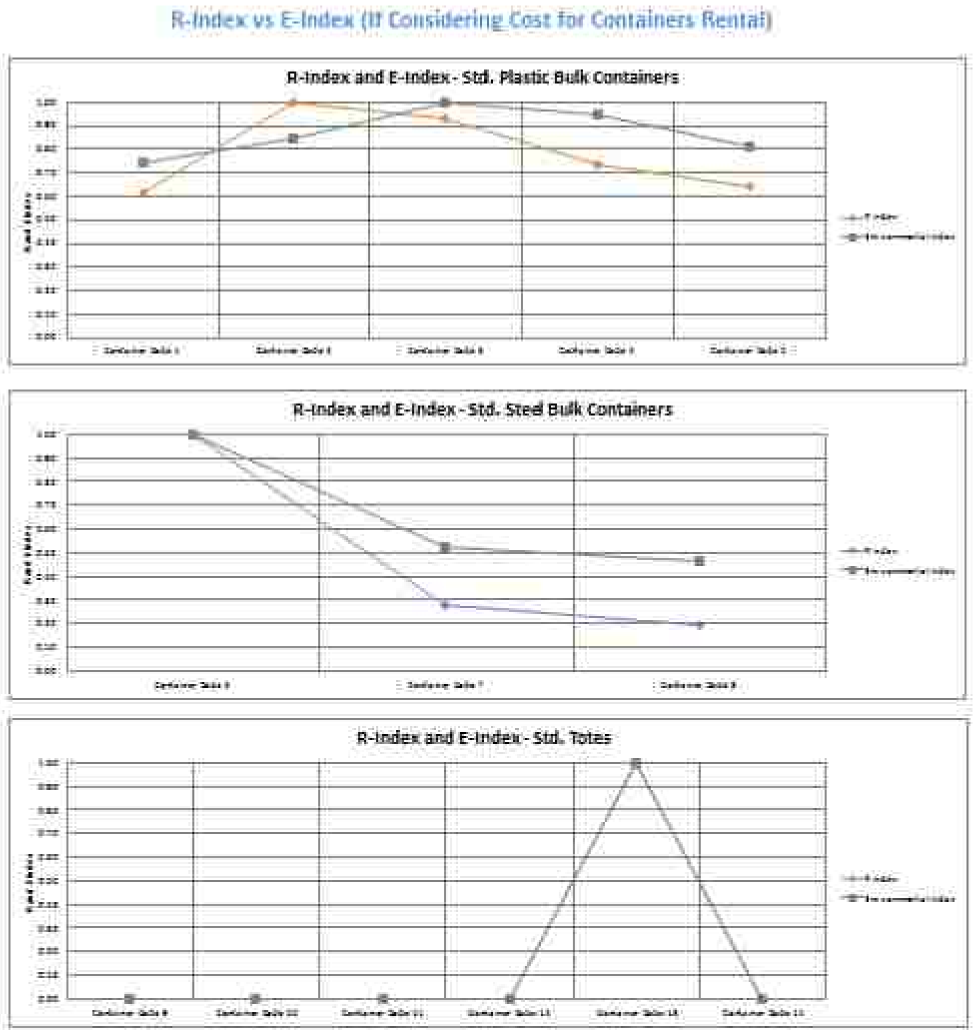
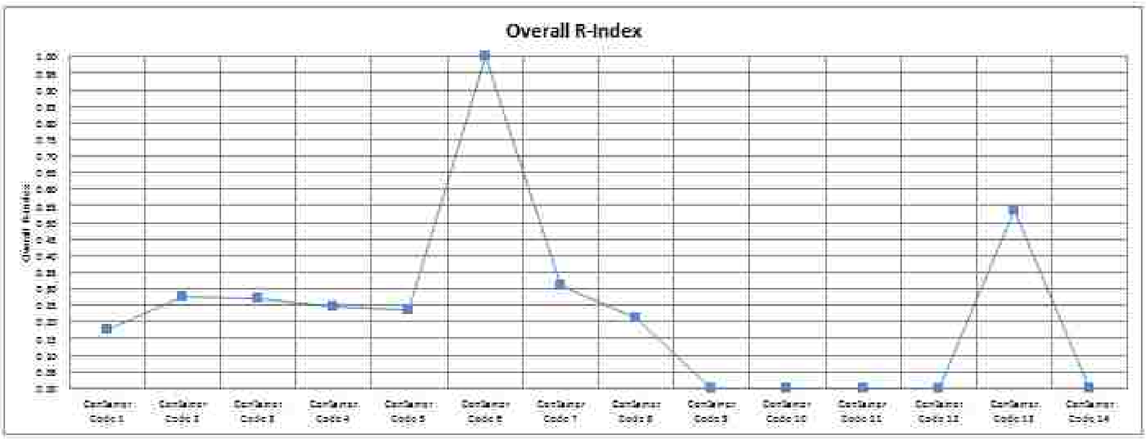


Figure A. 39 – R-Index vs. E-Index spreadsheet, screenshot 2 (example).

Overall R-Index

Overall R-Index spreadsheet allows the user to obtain an immediate total cost comparison of all the standard container solutions of the company.

Overall R-Index (If Considering Investment for Containers)



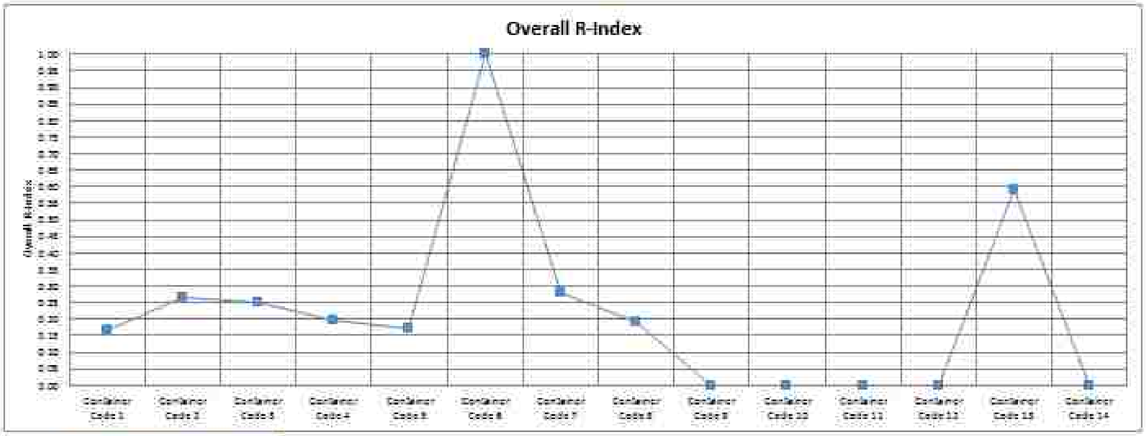
	Container Code	*Overall R Index*
PLASTIC BULK BINS	Container Code 1	0.18
	Container Code 2	0.27
	Container Code 3	0.27
	Container Code 4	0.24
	Container Code 5	0.24
STEEL BULK BINS	Container Code 6	1.00
	Container Code 7	0.31
	Container Code 8	0.21
PLASTIC SMALL LOT TOTES	Container Code 9	
	Container Code 10	
	Container Code 11	
	Container Code 12	
	Container Code 13	0.54
	Container Code 14	

Figure A. 40 – Overall R-Index spreadsheet, screenshot 1 (example).

Values of the overall R-Index equal to zero indicate solutions which cannot fulfill all the imposed requirements. Values closest to zero denote better solutions from a total cost perspective.

Also in this case the tool provides two different outputs, one considering the investment for new containers and one considering rental cost). The user has to consider one of the two graphs depending on the investigated situation (standard containers purchasing or containers rental).

Overall R-Index (If Considering Cost for Containers Rental)



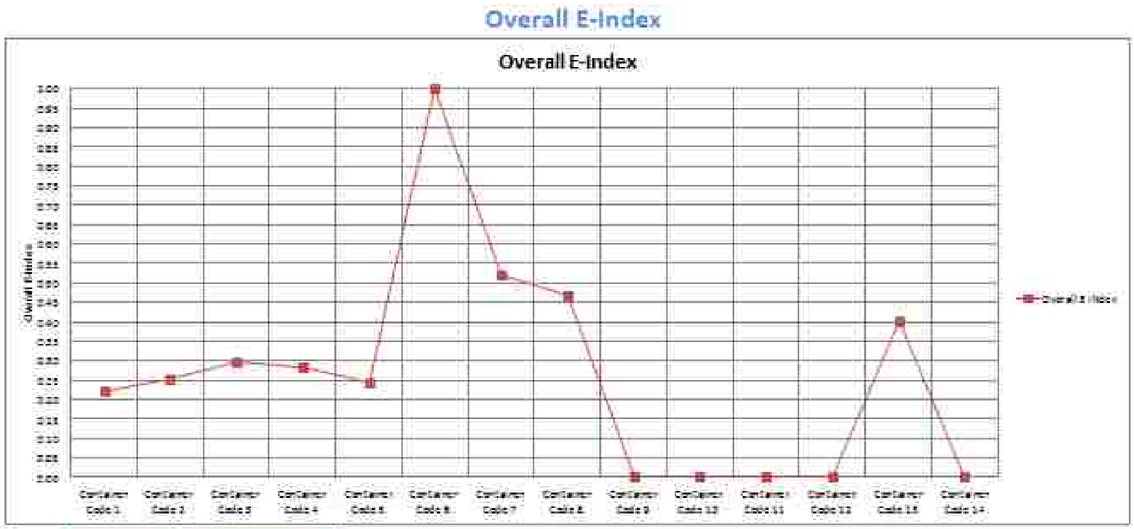
	Container Code	Overall R Index
PLASTIC BULK BINS	Container Code 1	0.17
	Container Code 2	0.27
	Container Code 3	0.25
	Container Code 4	0.20
	Container Code 5	0.17
STEEL BULK	Container Code 6	1.00
	Container Code 7	0.28
	Container Code 8	0.19
PLASTIC SMALL LGT TOTES	Container Code 9	
	Container Code 10	
	Container Code 11	
	Container Code 12	
	Container Code 13	0.59
	Container Code 14	

Figure A. 41 – Overall R-Index spreadsheet, screenshot 2 (example).

Overall E-Index

Overall E-Index spreadsheet allows the user to obtain an immediate environmental performance comparison of all the standard container solutions of the company.

Values of the overall E-Index equal to zero indicate solutions which are not applicable since they not meet all the imposed requirements. Values closest to zero denote better solutions able to reduce as much as possible the emission of CO_2 in the atmosphere.

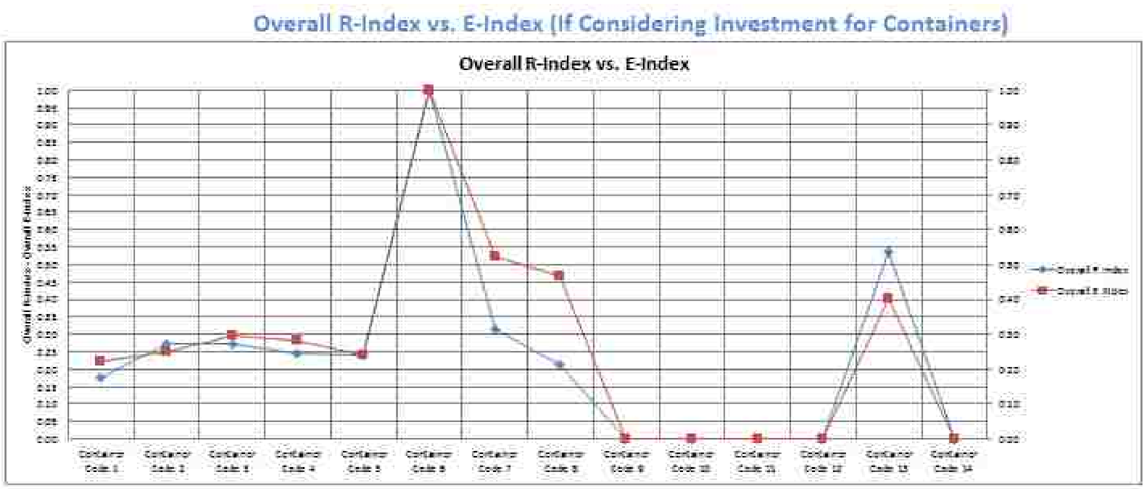


	Container Code	Overall Environmental Index
PLASTIC BULK BINS	Container Code 1	0.22
	Container Code 2	0.25
	Container Code 3	0.30
	Container Code 4	0.28
	Container Code 5	0.24
STEEL BULK	Container Code 6	1.00
	Container Code 7	0.52
	Container Code 8	0.47
PLASTIC SMALL LOT TOTES	Container Code 9	
	Container Code 10	
	Container Code 11	
	Container Code 12	
	Container Code 13	0.40
	Container Code 14	

Figure A. 42 – Overall E-Index spreadsheet (example).

Overall R-Index vs. Overall E-Index

Overall R-Index vs. Overall E-Index spreadsheet provides on the same graphs values of the total cost index and environmental index. This way, the user of the tool can assess cost and environmental performances of each container at the same time. Containers are compared without considering their macro-family, thus an overall comparison of all the possible solutions of the company is performed. Values of the indices equal to zero point out solutions which have not passed all the requirements check carried out by the tool in the Requirements Check and Computations spreadsheet. Solutions with Overall R-Index and Overall E-Index closest to zero (and different from zero) are preferable, since they are able to guarantee the lowest total cost and environmental impact between the different investigated container solutions.



	Container Code	Overall R Index	Overall Environmental Index
PLASTIC BULK BINS	Container Code 1	0.18	0.22
	Container Code 2	0.27	0.25
	Container Code 3	0.27	0.30
	Container Code 4	0.24	0.28
	Container Code 5	0.24	0.24
STEEL BULK	Container Code 6	1.00	1.00
	Container Code 7	0.31	0.52
	Container Code 8	0.21	0.47
PLASTIC SMALL LOT TOTES	Container Code 9		
	Container Code 10		
	Container Code 11		
	Container Code 12		
	Container Code 13	0.54	0.40
	Container Code 14		

Figure A. 43 – Overall R-Index vs. Overall E-Index spreadsheet, screenshot 1 (example).

The tool gives as output two different graphs, one relates to the case in which containers are bought by the company while the other considers the container rental cost.

	Container Code	Overall R Index	Overall Environmental Index
PLASTIC BULK BINS	Container Code 1	0.17	0.22
	Container Code 2	0.27	0.25
	Container Code 3	0.25	0.30
	Container Code 4	0.20	0.28
	Container Code 5	0.17	0.24
STEEL BULK	Container Code 6	1.00	1.00
	Container Code 7	0.28	0.52
	Container Code 8	0.19	0.47
PLASTIC SMALL LOT TOTES	Container Code 9		
	Container Code 10		
	Container Code 11		
	Container Code 12		
	Container Code 13	0.59	0.40
	Container Code 14		

Figure A. 44 – Overall R-Index vs. Overall E-Index spreadsheet, screenshot 2 (example).

If the company purchases standard containers, the user has to take into account the first graph. On the contrary, if the company rents standard containers, the user has to consider the second graph.

Overall R-Index vs. Overall E-Index spreadsheet is able to provide the user with a rapid overall indication of the best container solution to be selected. This is a powerful outcome of the tool: all the computations and requirements checks performed in the previous spreadsheets finally converge here.

Total Cost Components Sensitivity Analysis

Cost Sensitivity Analysis spreadsheet provides the user with an analysis of the weights that each cost component has over the total cost, for each standard container solution. Thanks to this analysis, the user can know if all the costs are almost equally influential for the economic performance of the container solution or if it is possible to focus just on some of them able to incorporate the most of the cost impact.

There are two different outputs: one for the case in which containers are purchased and one for the case in which containers are rented.

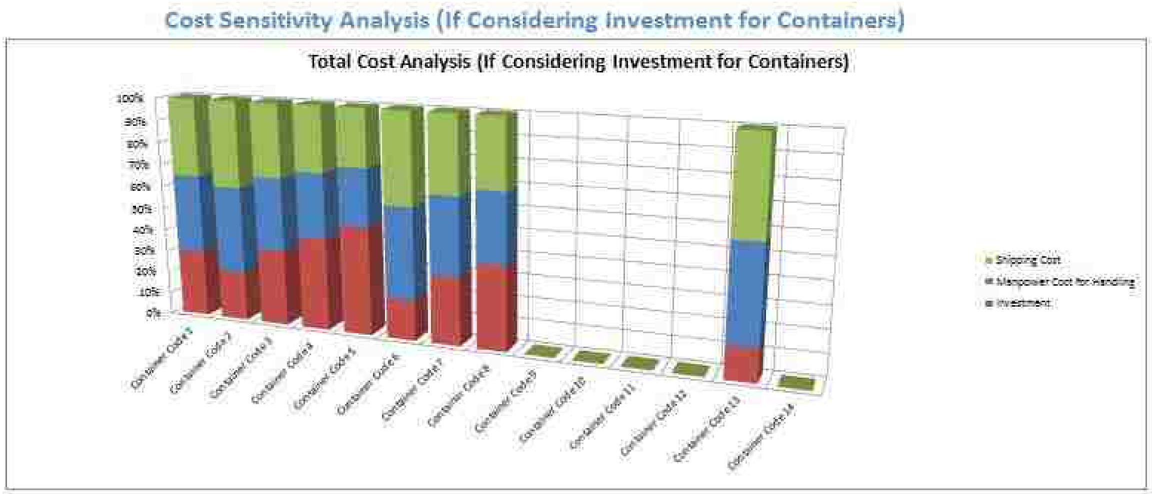


Figure A. 45 – Cost Sensitivity Analysis spreadsheet, screenshot 1 (example).

Figure A. 46 – Cost Sensitivity Analysis spreadsheet, screenshot 2 (example).

VITA AUCTORIS

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