Design and Evaluation of

Sustainable Packaging in Supply Chain

Thesis submitted in accordance with the requirements of the University of Liverpool

For the degree of Doctor in Philosophy by

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September 2018

Acknowledgment

At the time I complete this thesis on 'Design and Evaluation of Sustainable Packaging in Supply Chain', I felt I owe so much to the people who have helped and supported me all though these years. I would like to send them with my sincere thanks.

First and foremost, I would like to express my gratitude to my supervisor Dr. Dong Li, for his continuous support, guidance and advice, as well as his patience, encouragement, and immense knowledge. Without his guidance and support, I can hardly imagine how I can complete this study.

My thanks extend to my second supervisor Dr. Paul Drake, as well as my advisor Prof. Lyons, and Prof. Song, for their valuable advice.

I would also like to send my gratitude to CGE, Weir & Carmichael and ENRICH project for sponsoring the research, otherwise the research would not have been completed.

I would also extend my special thanks to Yang from BJTU for helping with the java coding in the simulation tool; Julia, Martin, and Dean from Weir & Carmichael, Kevin from B&Q, Shuo from COSCO Logistics, Wei from Evergreen Shipping, for their precious support in data acquisition for this research.

Last but not least, my acknowledgment goes to my close friends in Liverpool and my parents in China, for their invaluable help and emotional support whenever I am in desperation. They directly and indirectly assisted me to complete this research and thesis.

Abstract

Sustainability is a multi-objective goal to achieve environmentally sound, socially just and economically viable. But existing packaging design research and practice usually does not cover all these aspects of sustainability.

As the increasing demand of packaging is leading to more packaging induced problems, packaging-related impact on sustainability is gaining increasing concern and recognitions from consumers, organisations, and governments.

Unlike conventional products, packaging's impact on sustainability does not reflect solely on itself at the product level; instead, comes from the logistics operations it involved, and from its interactions with packed goods and logistics operations at different phases of the supply chain. By exploring packaging and logistics interactions, this research proposed a framework for sustainable packaging system assessment, which integrates the packed goods, packaging and logistics into packaging logistics concept from holistic view. Then, a generic evaluation method was developed based on FMEA and QFD, to quantify the consideration of interactions between packaging, goods and logistic operations. It adds risk consideration into packaging's impact on sustainability. The proposed tool was then integrated into a simulation model for sustainable container supply chain evaluation, considering the container's similarity to packaging.

Different case studies were conducted to validate and triangulate the proposed evaluation tools, illustrating how the proposed method help with decision-making support for sustainable packaging and container supply chain design. By help identifying sustainable packaging solution, and balancing cost/benefit for different supply chain parties, utilisation of sustainable packaging is also promoted by this study.

Key words: sustainable evaluation; packaging logistics; packaging design; risk assessment; container supply chain

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Abbreviations and Definitions of Typical Terms

Typical abbreviations and terms frequently used in this research defined as follows:

CLSC	Closed-loop Supply Chain
CR	Customer Requirement
CSC	Container Supply Chain
DR	Design Requirement
FMEA	Failure Mode Effect Analysis
ETA	Event Tree Analysis
FTA	Fault Tree Analysis
LA	Logistic Activity
LCA	Life Cycle Assessment
MSW	Municipal Solid Waste
QFD	Quality Function Deployment
RF	Risk Factor
RPN	Risk Priority Number
PRN	Packaging Recovery Notes

Consequence: the outcome and impact of an accident or failure, which may include different aspects, e.g., human injuries, environmental pollution, property loss or damage, etc.

Container Supply Chain: all processes of cargo shipment in the format of container shipping from place of departure to the final destination, with integration of planning, coordination, implementation, control, and related data transfer (Rodrigue et al., 2013).

De-vanning: the removal process whereby a container is unsealed, and all cartons contained in the container are taken out (usually by or with the presence of the customer). Also called stripping or unstuffing of container.

Failure: any changes in the shape, size, or material properties of a structure, machine, or component that leads to its becoming unfit for its specified function. (Dhillon, 1988)

Packaging: the materials used to 'wrap' or contain the goods; also includes the technology and practice of enclosing products from manufacturing, distribution, storage, sale and use (Soraka, 2002). For differentiation, in the research, the product that is packed inside the packaging or container is called 'product' or 'cargo' or 'goods', and the product with packaging transforms to a 'package'.

Packaging logistics: synergies achieved by the integration of packaging design with logistic management with the potential for supply chain efficiency and effectiveness increase by improving packaging and packaging related logistical activities. (Saghir, 2004; Hellstrom & Saghir, 2006; García-Arca et al., 2014).

Chapter 1: Introduction

1.1 Research Background

1.1.1 Sustainability and Sustainable Packaging

Nowadays, ‘sustainability’ has become one of the most popular terms bandied about not only in science and politics, but even in research on packaging and the packaging industry. There are different definitions of sustainability. A widely cited one is that from the Brundtland Report (published in 1987 by the U.N.’s World Commission on Environment and Development): ’Meeting the needs of the present without compromising the ability of future generations to meet their own needs’. As illustrated in Figure 1.1, sustainability is the overlap of economic, environmental and social concerns, or, in other words, the joint consideration of ‘profit’, ‘planet’, and ‘people’. A sustainable system should cover these different dimensions to aim at an environmentally sound, socially just and economically viable world.

Figure 1.1 Concept of Sustainability (derived from Adams,2006; O'Neill, 2007)

Packaging is not limited to only the materials used to ‘wrap’ or contain manufactured (or processed or harvest) goods, but also refers to a coordinated system that covers ‘the process employed to contain, protect and transport an article or goods’, including the technology and practice of enclosing products. It covers the phases from manufacturing, distribution, storage, and sale to use, which integrates the roles of containing, protecting, preserveing, transporting, informing and selling (Soraka, 2002).

When talking about the sustainability of packaging, the afore mentioned three aspects of sustainability (economic, environmental and social) and their interdependencies also need to be addressed in any decision-making or design process. Although the concepts, principles and criteria of sustainability have been accepted and adopted in the packaging industry for quite some time, yet, according to Nordin and Selke (2010), in mush packaging-related research and empirical business practice in the packaging industry, the discussions are usually about achieving goals for only one or two aspects or criteria out of the three, typically focusing on either economic or environmental aspects of packaging sustainability. In the packaging industry, the packaging organisations also have their 'definitions' for 'sustainable packaging' in efforts to articulate a common understanding in the industry. Sustainable Packaging Alliance (SPA), in Australia, defined sustainable packaging on the basis of such principles as 'effective, efficient, cyclic and safe' (Sustainable Packaging Alliance, 2005). The Sustainable Packaging Coalition (SPC), in the USA, took a more synergistic view than the SPA, but also more specific and focused (particularly, on renewable energy and materials); their definition for 'sustainable packaging' includes the following criteria:

- Is beneficial, safe, and healthy for individuals and communities throughout its life cycle;
- Meets market criteria for both performance and cost;
- Is sourced, manufactured, transported, and recycled using renewable energy;
- Optimizes the use of renewable or recycled source materials;
- Is manufactured using clean production technologies and best practices;
- Is made from materials healthy throughout the life cycle;
- Is physically designed to optimize materials and energy;
- Is effectively recovered and utilized in biological and/or industrial closed loop cycles. (Sustainable Packaging Coalition, 2011)

Although defined according to different principles, criteria, and practice guidance, the core concept of sustainable packaging is still to consider the packaging system's social, economic, and environmental impacts throughout its life cycle. Therefore, to identify truly sustainable packaging (or packaging systems) in the packaging industry, an overall evaluation needs to be made to integrate different aspects of sustainability in this field.

1.1.2 The Packaging Induced Sustainability Issues in Supply Chain

1.1.2.1 Rapidly Growing Impact on Sustainability

As society develops, packaging demand and packaging material usage is rapidly increasing. At the same time, severe packaging-induced problems emerge, including packaging-related resource usage, energy consumption, pollution, and solid waste generation. In 2014, within EU alone, the annual packaging waste material increased to 82.32 million tons from the 76.59 million tons it had been in 2009 (Source: Eurostat, 2016). The growing impact of packaging is raising increasing concerns and recognitions from consumers, organisations (e.g., the World Packaging Organisation, and the European Organization for Packaging and the Environment), and governments (Gerard Prendergast, 1996). Stricter environmental requirements and regulations with regard to packaging have been developed and implemented in response to the perceived threat and increasing pressure brought by the packaging industry (Clara and Gian Paolo, 2012), for example, the EU's council directive on increasing recycling packaging material and reducing packaging waste level, and the UK's Producer Responsibility Obligations Regulation for Packaging Waste.

Apart from the environmental impact of solid waste and energy consumption due to the packaging, it also has economic and social impacts on the industry affecting different parties in the supply chain. Packaging is traditionally regarded as the 'interface' between the packed products and their end user or consumer (Saghir, 2002; Nordin, 2010). But there is also a significant interface between packaging and different logistics operations along the supply chain, as there is usually no direct interaction between the packed products and the various logistics processes. The packaging or a higher level packaging that contains a group of packed products directly engages in the logistic operations along the supply chain. These interfaces and interactions contribute to different impacts on different sustainability aspects in the supply chain operations (e.g., waste material due to over-packing; operation failure; energy and cost increase due to extra operation requirement; health and safety issues for operators and end users due to inappropriate packaging etc.); but, historically, these interactions and their impacts on sustainability are usually overlooked by researchers and practitioners in the packaging industry (Saghir, 2004).

1.1.2.2 Reusable Packaging

According to the UK Environment Agency (2015), although the recovery rate for UK packaging waste has increased from only 27% in 1998 to 67% in 2011, there are still 3.6 million tonnes of packaging material (out of a total of 10.93 million tonnes) that are unrecovered each year in the UK and typically constitute municipal solid waste that goes to landfills (UK Environment Agency, 2015). In order to increase the recycling rate of packaging waste, as well as to balance between profit and environment to make the packaging more sustainable, the recovery and utilization of reusable packaging has become one of the most popular subject of discussion and research in the area of sustainable packaging (Twede & Clarke, 2004).

But, once processes for collection, sorting, reprocessing, and reallocation of packaging were put in place, the reusable packaging (or packaging parts) could be re-introduced to the market after use, similar to a remanufacturing operation, which is regarded as a popular trend of manufacturing system in the 21st century (Coates, 2000).

Yet, from the supply chain perspective, the impact of the reuse of packaging (and the business management of this) is still being explored in research and practice. According to Vadde et al., (2007), typical issues of reusable packaging in supply chains include the pricing of reusable items (to balance cost and benefit allocation among different supply chain parties); the impact on sustainability brought about by reverse-channel and value-recovery operations; and analysis and estimation methods for reusable designs (compared to traditional one-off items, considering the life span and the way it is reused).

All in all, with a finite amount of non-renewable resources, the rapidly increasing waste material involving huge effort and cost, and growing awareness among consumers of ‘green’ issues (Mininni, 2007), research on sustainability in the packaging industry and sustainable packaging practices has increased.

1.1.3 Packaging Related Issue in Container Shipping Industry

1.1.3.1 Shipping Container and Packaging

A container can be regarded as a ‘permanent reusable article of transportation equipment’ and a ‘highly standardised packaging’ for transportation (Armstrong, 1981). According to heretical packaging layer concept, the ‘container’ in container shipping can be regarded as an outer packaging layer that contains numbers of group packaging with products packed inside. Just as in the packaging industry, the container supply chain in the shipping industry is also facing sustainability challenges, from waste material generation to cargo value loss due to inappropriate packaging. With many similarities between shipping container and reusable packaging (e.g., functions and role, hierarchical layered structure, closed-loop operation, interaction with value-adding service), many of the research models and theories can be applied to both the reusable packaging and the maritime container industries to address the sustainable issue, such as reverse logistics management theory (Rogers et al., 2012; Lambert et al., 2011; El Korchi & Millet, 2011; Kroon & Vrijens, 1995), optimal pricing decision of reusable items (Yan & Sun, 2012; Gu et al., 2008; Büşra et al., 2001), interaction of packaging with logistic operation issues (Verghese & Lewis, 2007; Hellstrom & Saghir, 2007; Lockamy, 1995), and so on.

1.1.3.2 Sustainable Issues in Container Shipping

Among all conventional modes of transportation, sea transport has the lowest greenhouse gas emissions (per tonne cargo per km journey), yet according to the International Maritime Organization (2014), the total emissions from the world's merchant fleet have reached an average of around 1000 million tonnes annually between 2007 and 2012, which accounts for 3.1% of all global CO_2 emissions. And within the shipping industry, container supply chain plays an important role, especially for cargo with high-value or high-quality requirement, as it accounts for more than 60% of global seaborne trading, a 9-trillion USD per annum market in value (Statista, 2010 & Clarksons, 2015). Containerisation has been rapidly expanding for decades, owing to its increasing cost saving and efficiency due to standardisation and compatibility across different transport modes between different industry players. World container port traffic has rapidly increased from 225 million TEU in 2000 to 679 million TEU in 2014 (The World Bank, 2014), which also resulted in significant greenhouse gas emission increases. The significant container-shipping-induced increase in CO_2 emissions is partly due to empty container movements, which is also regarded as an important operational factor in estimating CO_2 emissions in the container shipping industry (Yun, Lee & Choi, 2011).

As seaborne container shipping is playing a more and more important role in world trading, it is essential to ensure the safety of cargo and operation, for the sustainability of the business. According to the UK Protection and Indemnity Insurance Club (UK-P&I-Club), one of the oldest insurers of third party liabilities for ocean-going merchant ships, and the Through Transport Club (TTClub), a global insurer that serves the international transport and logistics community, cargo loss and damage are involved in 65% of shipping incidents, within which physical damage is the main type of failure (UK-P&I-Club, 2000; TTClub, 2010). And according to the Cargo Information Notification System, about 35% of incidents are found to be caused by poorly or incorrectly packed containers. But currently, logistics specialists and packaging designers are working independently, focussing only on either logistic operation planning or packaging design, respectively. The container is still usually being treated as 'black box' in container shipping planning and management research for sustainability, without the integrated consideration of such factors as container, packaging, cargo, and operations.

Being aware of the similarities between packaging and containers, and their sustainability issues, this research will regard 'container' as reusable packaging that has interactions with its inner ('lower') layer packaging and logistic operations for consideration of the container supply chain's sustainability. In consideration of the container's significant impact on sustainability during usage (repositioning when it is processed by different logistic operations), the 'container supply chain' researched in this study refers to the supply chain that utilises a container shipping format—how the supply chain performs according to sustainability measures when the containers are packed and utilised differently, rather than the supply chain of the container's production and life cycle as a general product.

1.2 This Study

The purpose of this study is to improve design and evaluation for packaging sustainability in the supply chain, in an effort to deal with the addressed sustainability issues brought by the packaging system to the supply chain. As the impacts on sustainability form packaging is found largely from the packaging related logistic operations (Saghir, 2004), to reduce the packaging-related risks and waste during operations in the supply chain can be an effective way to improve the packaging sustainability.

This research combines both theoretical research and the empirical practice of packaging in supply chain. Empirical practice and packaging product information are mainly provided by research partner in the research - a UK local packaging manufacturer in packaging industry.

1.2.1 Significance of the Research

Taking the background situation formerly introduced into consideration, this study researches the key elements of sustainable packaging design and evaluation. Literature of different research fields was reviewed, including sustainable design, packaging sustainability, and integration of packaging logistics sustainability. The following issues were culled from literature review and empirical practice:

1. Sustainability has environment, economic and social aspects. There are number of popular tools, road maps and techniques (Conrad & Jessica, 2005; Byggeth & Hochschorner, 2006; Waage, 2007; Svanes et al., 2010) that cover or partly cover the sustainability considerations for design and development. But most research and practices adopted by the industry on sustainable packaging has been focused on models covering individual aspect of the sustainability, while the other aspect(s) are ignored (Nordin & Selke, 2010). There is a need for developing approaches to evaluate and support the sustainable packaging design in packaging supply chain and industry to consider different aspects of packaging sustainability.

2. Most existing design and evaluation tools for general product and packaging product focus only on the product itself, designing the packaging at product level. But the packaging and logistics relations should not be ignored in the design and evaluation, packaging logistics should be considered as a whole system in design to achieve holistic optimum (Twede & Parsons, 1997; Saghir, 2002). Packaging is different from general products; the impact of the packaging usually is not that of a product, but rather, is largely a reflection of the operation process that it is involved in (Lockamy, 1995; Saghir, 2004). Therefore, research on the integration of packaging logistics sustainability with appropriate evaluation viewing perspective is needed.

3. The packaging logistics interactions researched in the existing literatures are mostly focused on packaging and logistics operations, without consideration of the packed goods as a core element or factor (Saghir & Jönson, 2001; Hellstrom & Saghir, 2007; García-Arca et al., 2014;). But in fact, goods/cargo is actually the core aim and objective for both packaging and logistics. For this reason, a sustainability evaluation should take into consideration the packed cargo/products when assessing the impact of interactions between packaging and logistics system.

4. Although many similarities between reusable packaging and container were addressed and many of the research models and theories can be applied to both reusable packaging and maritime containers- such as reverse logistics

management theory (Kroon & Vrijens, 1995; Lambert et al., 2011; El korchi & Millet, 2011, Rogers et al., 2012), optimal pricing decision of reusable items (Büşra et al., 2001; Gu et al., 2008; Yan & Sun, 2012), and the industrial packaging interaction with logistic operation issue (Lockamy, 1995; Verghese & Lewis, 2007; Hellstrom & Saghir, 2007) - yet the links between them are not researched in details anywhere in the literature. Missing such links, the container was treated as 'black box' in traditional research that ignoring its relations to the logistics operations and the packed goods inside. To investigate the container as a layer of packaging, the integrated evaluation for sustainable packaging can be able to apply in container shipping scenario. As a result, the container can be no longer treated as traditional 'black box' without consideration of what goods are inside the container and how the goods are packed. It can be helpful for sustainable container shipping decision making to identify better sustainable container shipping solutions considering more factors that relate to packaging and logistic operations.

5. Finally, risk can be linked to the performance of a process or business (Hoffmann et al., 2013; Arugaslan & Samant, 2014). And one of packaging's main roles and functions is the risk reduction for packaging-related operations. But the design and improvement of packaging logistics barely evaluated from the perspective of potential risk in the existing research. There would be contribution to apply the risk management method in the field of packaging logistics, using risk priority to present the performance of packaging in a positive way for design improvement, to indicate how suitable the packaging is for the logistics operations and packed cargo, considering the impact of their interactions on sustainability in the supply chain.

By exploring the packaging system's role and structure, and undertaking critical analysis of various sustainable design approaches currently used for packaging and product, this research tends to develop an integrated approach to sustainable packaging design and evaluation considering packaging's role and characteristics in the supply chain, as well as to evaluate container supply chain sustainability regarding the container as a layer of packaging. For the purpose of the study, three case studies in industry will be conducted to validate and triangulate the proposed approach, as well as to illustrate the application in different scenarios.

1.2.2 Research Goals

According to the situation of packaging's impact, the sustainability issue in packaging supply chain, as well as empirical practice in the packaging industry, the main research aim of this study is developed as follows:

Aim:

By undertaking a critical examination of sustainable design and evaluation techniques for packaging, this study aims to develop a design and evaluation method for a sustainable packaging system and the container supply chain in order to provide decision-making support for sustainable packaging and the container shipping business.

Objectives:

This study seeks to achieve this aim by breaking it down into the following three sub-objectives:

(1) Explore packaging and packaging-related impact on sustainability along its life cycle, considering the packaging-related risks and improvement for packaging logistics system in the supply chain; examine different design and evaluation practice for sustainability of packaging and general products.

(2) Identify relationships between packaging and containers in container supply chains for integrated assessment and design/planning, considering container as a coordinated packaging system instead of a 'black-box'.

(3) Establish an integrated evaluation framework to assess the sustainability of the coordinated packaging logistics system from a holistic view, considering the impact from the packaging-related risks along supply chain phases, and conduct case studies to support the proposed approach.

In addressing the issues raised in the stated objectives, a number of research questions were established, as shown in Table 1.1.

Table 1.1 Research Questions

Q1	How is the impact of packaging on sustainability different from that of general product along life cycle, and from what perspective should the sustainability of packaging be evaluated?
Q2	What are the similarities and differences between packaging and container in terms of their role in risk minimisation, characteristics, impact on sustainable performance in supply chain and decision factors for their sustainability evaluation?
Q3	How is the integrated sustainable evaluation to be applied in both packaging and shipping container scenarios- how does it help reducing packaging-related risks and waste, and support sustainability decision making?

1.2.3 Structure of Thesis

The thesis comprises seven chapters. The titles of all the chapters are summarised in Table 1.2. Chapter 1 introduces the general background and provide an overview of this study; Chapter 2 presents the review of the literature according to the goals set by this research; Chapter 3 describes the 'road map' of how this research was designed and implemented; Chapter 4 introduces the evaluation framework and approach that is proposed for sustainable packaging evaluation; Chapter 5 describes three case studies of packaging and container shipping using the proposed evaluation to support the sustainability improvement and triangulate the proposed approach in sustainability evaluation; Chapter 6 presents a discussions of the findings of this research; and Chapter 7 states the conclusions and limitations of this research.

Table 1.2 Thesis Structure

Chapter No.	**Title**
Chapter 1	Introduction
Chapter 2	Literature Review
Chapter 3	Research Design and Methodology
Chapter 4	Development of Sustainable Packaging Evaluation Approach
Chapter 5	Applications and Case Studies
Chapter 6	Findings and Discussions
Chapter 7	Conclusions and Recommendations

Chapter 2: Literature Review

2.1 Overview of Literature Review

In order to research sustainable packaging and provide design and evaluation solution, different topics at different levels were reviewed, the logic and arrangement of this review are summarised and illustrated in Figure 2.1. The review of literature began with a query on sustainability and sustainable design, looking at conventional criteria and design approaches for sustainability in existing research. Then, sustainability in packaging was reviewed to identify the packaging's different and unique characteristics compared to conventional product in sustainable design and impact on sustainability, as well as how existing research and practice deal with sustainable packaging evaluation. After that, the packaging and logistics operation relationship was reviewed to discover how their interaction impact on sustainability. Then to a higher level, from a supply chain perspective, the impact of packaging and packaging-related activities impact was reviewed. Then, the review would the existing research on integration (or partial integration) of these different topics related to packaging, logistics and sustainability; And finally, the review gaps and results were summarised.

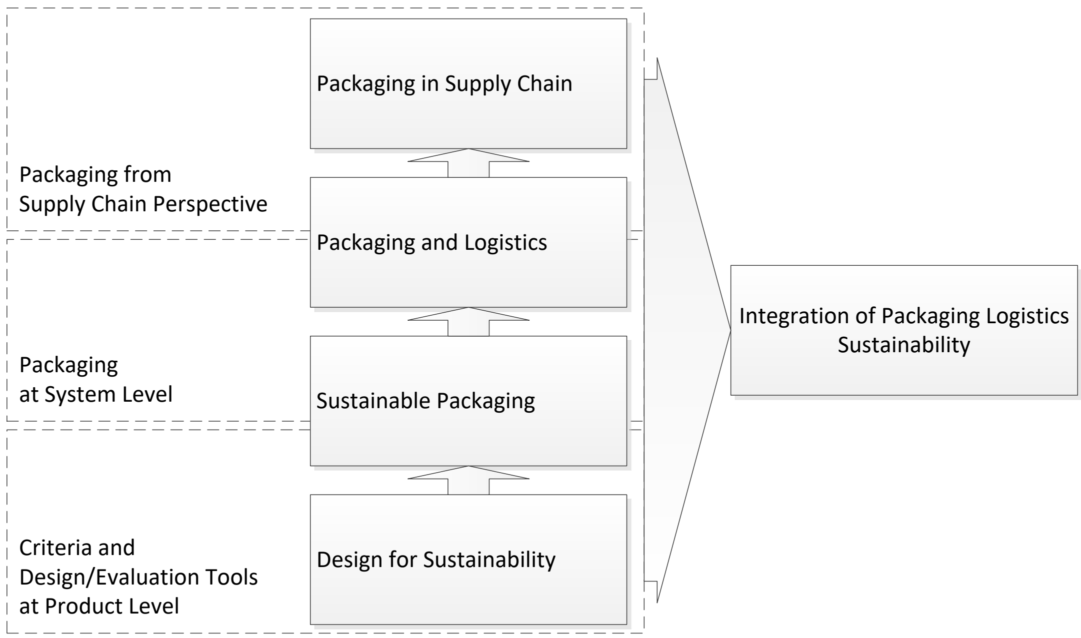


Figure 2.1 Structure of Literature Review

2.2 Sustainability and Product Design

2.2.1 Conventional Sustainable Product Design

Sustainable design and design for sustainability are popular topics in product design and development. According to Ullman (1997), although early design stages account for only 5% to 7% of the entire product cost, the decision made in the design stage would lock 70% to 80% of total product cost. This also applies to the impact of environmental and social aspects on sustainability. Since the product design stage largely determines how sustainable the product will be, a number of popular design tools, road maps, and techniques were developed and became essential for designers in ascertaining the sustainable level of the products and services (Byggeth & Hochschorner, 2006; Waage, 2007; Svanes et al., 2010; Ramani et al., 2010).

Life Cycle Assessment based tools

Life cycle assessment (LCA), a 'classical' analysis tool focusing on the whole life cycle of a product, was first introduced in the early 1960s for dealing with the problem of building energy consumption (Lindfors, 1995). LCA focuses on understanding and evaluating the environmental profile of a product or process, to assess the product's interactions with the environment by investigating the energy and material flows at every stage during the product's life cycle (Li et al, 2010). Figure 2.2 illustrates general steps in applying LCA to determine the environmental impact of a product or service (Lindfors, 1995). It covers different stages in the product supply chain, from raw material acquisition, manufacturing, transportation, distribution, use and maintenance, reuse and recycle, to disposal and waste management, but considering only the environmental impact based on the inventory flow analysis, apart from other aspects of sustainable criteria. There are also other disadvantages of tools based on LCA:

Firstly, intensive information input is required in order to conduct LCA, making it unsuitable for the early design stage (Choi & Ramani, 2009), when detailed specifications or operational settings are still in development; and this uncertainty becomes a major obstacle to LCA in the design stage (Yu & Kimura, 2001).

Secondly, LCA is costly and time-consuming, making it unsuitable for small or medium companies, which limits the application of these types of tools. And after the time-consuming analysis of traditional LCA, no recommendations or actions for improvement can be provided from the result.

Additionally, LCA results can vary widely according to the scope or boundary of the evaluation. A typical LCA focuses on one product in isolation, but the packaging's impact on sustainability is usually not limited to its own interaction with the environment, but rather is largely dependent on the operation in which it is involved.

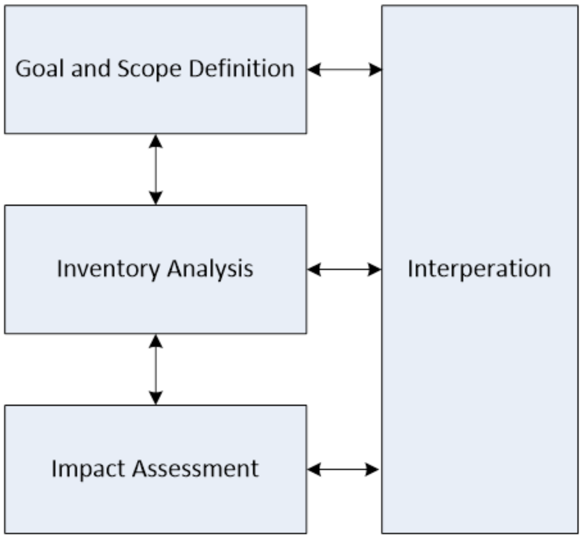


Figure 2.2 Main Phases of LCA Process (source: Lindfors, 1995)

Despite decades of research into environmental LCA, there is still much to be done (myEcoCost, 2012), as there are different kinds of impact in different industries, and the scope of impact varies across different scenarios. Accordingly, for the optimal use of LCA for evaluating sustainable packaging, the proper scope needs to be identified in each case, and the LCA needs to be simplified and streamlined (Koffler et al., 2008) to address the major impacts commensurate with the characteristics of the packaging system.

Eco-Design tools

Different variations of eco-design tools have been proposed and developed. MET (material, energy, and toxicity) Matrix and the 'Ten Golden Rules of Eco-Design' are popular eco-design tools, as an LCA can provide no recommendations as to what and how to improve after analysis (Conrad & Jessica, 2005). These are usually simple qualitative tools that summarise and provide a set of design principles and rules for the life cycle of a product, from an environmental perspective. The considerations are given in subject-qualitative terms and commonly in checklist style, e.g., 'Were any toxic materials used in the product?' or 'Compared to existing product, was less energy consumed in the use phase?' (Conrad & Jessica, 2005). These tools are easiest to use and most prevalent in industry for the design practitioner, but the subjective process requires extensive knowledge for proper application (Luttropp & Lagerstedt, 2006). At the same time, the trade-off between different impacts at different stages is still a problem. Therefore, these tools provide more detailed recommendations for sustainable design, but barely concrete sustainable design solutions that can be developed via these tools considering wider impact of the product on sustainability at different supply chain stages.

Design for X

Design for X (DfX) is another common tool in product design, whereby a wide range of specific design guidelines are variables labelled X, where X could have different value and possible disciplines, e.g., design for cost (DfC), design for manufacture (DfM), design for logistics (DfL), design for environment (DfE), design for recycling (DfR), etc. Just as with the checklist-style eco-design tools, this set of design tools provides useful practical guidelines for specific areas of improvement for redesign and rethinking during product design and development (Sherwin & Bhamra, 1999). Within the wide range of label X, DfE emphasises consideration of such environmental issues as business opportunities in new products, new processes, or new technologies (Ramani, 2010), and therefore became one of the popular sustainable design tools for product designers.

Elements within this design tool set (e.g., DfE, DfL, etc.) were tightly related to packaging and could be used for sustainable packaging design and evaluation, but the challenges remained that for each of these X elements, the set of guidelines were different but may interfere or overlap with each other; the tool is suitable for consideration of only one aspect at a time, without solving the trade-off in possible conflict analysis resulting under different variables. Although it provided different ways for designers to take environmental considerations in product design, yet it is simply a list of guidelines to be considered. In order to accurately reflect on reality, detailed analysis using other tools are still required and thus heavily increase the complexity of the task. Using this tool appropriately essentially becomes a cross-functional activity that required involvement of different people from different department or even different supply chain parties, and new interfaces are required to be developed to accomplish this task (Johansson, 2002).

Quality Function Deployment based tools

Another type of common design tools for eco or sustainable design is based on quality function deployment (QFD). QFD is a traditional method for converting the voice of the customer (VOC), or customer needs, into production requirements, known as the voice of the engineer (VOE) for product and service design. It utilises a 'house of quality' series (shown in Figure 2.3) that measures the relationships between various factors. QFD is good for decoupling a complex multi-criteria decision-making process into simpler steps in each matrix, providing potential benefit for the design and development process by 'getting people thinking in the right directions and thinking together' (Hauser & Clausing, 1988). Therefore, it provides better interface for cross-functional design activity compared to formally introduced DfX based tools.

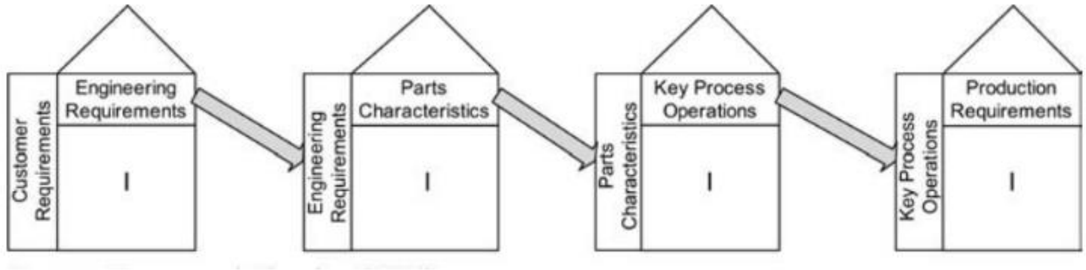


Figure 2.3 Schematic Diagram of QFD Approach (source: Hauser and Clausing, 1988)

When the QFD method is extended to apply to sustainable design and development, environmental impacts of the products are put into the matrix as new customer requirements, to generate the 'green quality function deployment' or 'house of ecology' (Masui et al., 2003).

The disadvantage of existing QFD-based tools is that, if the correlations in the matrix are all based on a designer's view of the requirement of knowledge of the environment, quality, and engineering, the result would very likely lack any consideration of the whole life cycle (Bouchereau & Rowlands, 2000). To mitigate this, matrix criteria should be designed to involve different experts' views at different stages of the life cycle or supply chain.

The common design methods introduced above all have advantages and drawbacks. What is needed in practice is to integrate different design tools for sustainable product design and evaluation, so as to provide a more holistic approach to bridging the limitations of different design tools (Ramani et al., 2010). And given the complexity of products and supply chains nowadays, a collaborative design and evaluation tool across different organisations to cover different disciplinary boundaries is sorely needed.

2.2.2 Sustainable Design Dimensions

Sustainability is a broad concept for considering the bottom line of planet, people, and profit. When deigning for sustainability, detail dimensions and measuring criteria for sustainability need to be carefully considered, and a proper perspective for sustainability needs to be chosen.

Gnoni et al (2011) proposed sustainable design tools to support decision makers on supply-chain sustainability for both strategic (e.g., selection of a distribution or packaging strategy) and operative decisions (e.g., monitoring of supplier performances). This research used the following criteria as 'sustainable targets' for an integrated sustainable supply-chain design approach:

- Optimize use of resources;
- Optimize release of emission;
- Optimize use of raw materials;
- Reduce waste;
- Reduce packaging; and
- Reduce use of auxiliary materials.

These criteria, used in this research, covered the different phases and environmental elements of supply chain from supplier to production to customer, but it mainly covered only the environmental aspects of sustainability, leaving the other aspects and the trade-off between these aspects of sustainability out of consideration.

Similarly, in the construction industry, research has been done to explore sustainable design (Bergman, 2012), which summarised the eco design criteria for that industry, including water efficiency, energy efficiency (passive and active), environmental quality (indoor toxicity, thermal comfort, biophilia, and air filtration), and materials. Unlike Gnoni et al. (2011), not limiting the evaluation to environmental considerations, Bergman (2012) also explored the relationships between eco (environmentally)-friendly considerations and other aspects of the 'triple bottom line' (people, planet, and profit) in the sustainability context (O'Neill, 2007). Bergman (2012) believed that quantifying ecology and equity is still a very 'complicated' and 'controversial' process, but the concept that good business and good products 'embrace these aspects of sustainability' is not, and it can be operated in different ways. To achieve the goal of sustainability, a 'balancing act' should be considered. Bergman (2012) also argued that there is no consensus as to whether 'sustainability is truly an ultimate and adequate goal', or, if not, whether what we currently do for sustainability design and development should be described as attempts to go beyond 'being less bad' and beyond 'mere' sustainability. The aim is not just minimising negative effects, but also encouraging positive impacts. Bergman (2012) therefore chose the way of 'positive design' to describe design sustainability, defined as 'creation of system that contributes to fulfilment of human needs while preserving or complementing the nature world'. This view of sustainability differentiates 'real human needs' from 'wants', and also speaks of complementing the natural world rather than simply 'maintaining' it (as previous views minimising negative impacts only stated that the health of the planet should not be compromised, but say nothing about repairing existing damage). From the point of view of 'positive design', Bergman (2012) used return-on-investment calculations for eco-friendly building design solutions to analyse the benefit to sustainability and the trade-off between environmentally friendly and economically profitable actions through the added extra cost and operations savings comparison of the eco-design solutions.

Eco-indicator 99 (Netherlands Ministry of Housing, 2000) is still one of the most widely used impact assessment methods based on Life Cycle Assessment (myEcoCost, 2012), which allows the expression of environmental impact in one single score (a dimensionless figure, Eco-indicator point). Different from Bergman's (2012) view of 'positive design', it is a 'damage-oriented' method to consider the impacts on sustainability; the 'environment' is defined in Eco-indicator 99 by three types of damage: Human Health; Ecosystem Quality; and Resources. It considers environmental impact of material extractions, production processes, transport processes, energy generation processes, and disposal scenarios. The advantage is that different environmental impacts can be aggregated into a single score by a designative weighting procedure to give more meaningful weighting factors and results (Netherlands Ministry of Housing, 2000) than traditional LCA. But unfortunately, when using this eco-indicator value to compare two materials with completely different processes and resources, a very large margin of error should be allowed for significantly large uncertainties (Netherlands Ministry of Housing, 2000). Also, this indicator focuses on the extraction, transformation, transportation, and disposal of the material itself; any impact from the product during usage is not considered.

Lacasa et al. (2016) provided a good example for considering different dimensions in sustainability design in the research. The indicators used for consideration of sustainability in this research include: Global Warming Potential (total emissions of greenhouse gases, calculating the radiative force over a period of 100 years) and Eco-indicator 99 (weighs different impact categories into a single score) for the environmental aspect; Value Added and Eco-efficiency for the economic dimension; Working Hours and Hourly Wage as social dimension indicators. This research addressed the three dimensions of sustainability in the analysis, but considered only the manufacturing of the product, absent the impact of the product during usage after shipped to customers and consumers.

The design for sustainability in general product in different industries has been well developed to cover different dimensions of sustainability, but in packaging research field and industry, the situation is different. Although the concepts, principles, and criteria of sustainability have been accepted and adopted in the packaging industry for some time, yet, most often, in the empirical business practice in packaging industry, and in packaging-related research, the discussion are usually towards achieving goals for only one or two aspects out of the three, typically in the economic or environmental aspects of packaging sustainability (Nordin and Selke, 2010). Detailed criteria used for sustainable packaging in the packaging industry in particular will be discussed later, in section 2.3.2. This provides an opportunity to research on packaging sustainability to consider and integrate different dimensions of sustainability together for an overall assessment and design.

Summary

To summarise this part of the review: in sustainability design research, whether from the perspective of 'positive design' or 'damage oriented' evaluation, the balancing of environmental, social, and economic needs should remain the essence of the sustainability agenda for sustainable design and evaluation, so as to cover the different dimensions of sustainability. But in the packaging industry and research field, currently, it is still a challenge. Research is still in need in the packaging industry to consider multi aspects of sustainability for sustainable packaging.

2.3 Sustainable Packaging

2.3.1 Packaging and the Packaging System

Traditionally and narrowly, packaging is the 'container' for a product in a narrow sense at product level, as defined by Kotler and Keller (2006) that the packaging is 'all the activities of designing and producing the container for a product'. This narrow definition could be further developed to extend to the function of packaging as defined by Mishra and Jain (2012) that the packaging is the 'wrapping material 'around a consumer item that helps to 'contain, identify, describe, protect, display, promote' or 'make the product marketable and keep it clean'. The above narrow definition usually comes from the marketing or design perspective of the packaging, seeing the packaging as one single product and focussing on the packaging's 'interface' (marketing functions) between suppliers and end users.

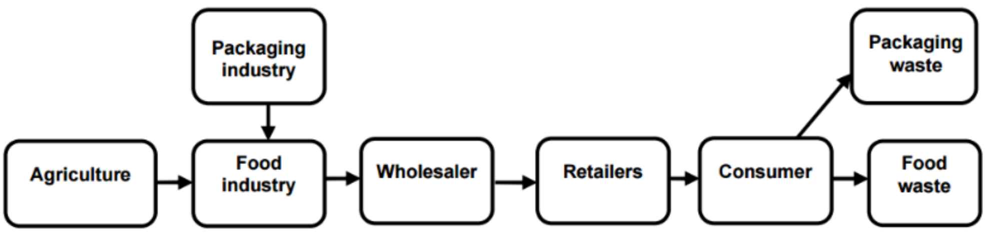


Figure 2.4 Life Cycle Analysis of Packaging in Food Supply Chain (Williams, 2011)

The isolated 'product level' perspective of packaging is illustrated in Figure 2.4 (Williams, 2011), typically research on the LCA of packaging uses a simplified scenario that assumes the packaging as only one item that goes in and out of the system only once, ignoring the different layers of consumer packaging and industrial packaging that occur d in the middle of supply chain.

However, as suggested in different ways by most research on ‘packaging system’ and ‘packaging logistics’, instead of one single layer (product), the packaging’s scope should be extended, as the packaging product usually does not stand alone when it is being utilised, transported, and consumed. Therefore, packaging is regarded as a combination of more than one single product—in other words, a system (Saghir, 2002).

To describe different types/layers of packaging, there are different ways of classification, from different perspectives (illustrated in Figure 2.5 and Figure 2.6), such as according to the packaging material (e.g., paper, cardboard, plastic, burlap, glass, foam), the packaging life time or life span (e.g., one-trip packaging and multiple-trip or reusable packaging), the position or layer level on which the packaging interacts with packed products (e.g., primary packaging, group packaging, logistical packaging), as well as the phase being used in the supply chain (logistic or transport packaging, retail packaging, consumer packaging).

A useful classification that aptly describes the relations between packaging layers is illustrated in Figure 2.5. According to this classification, packaging can be classified into three hierarchical types, reflecting their respective levels (layers):

> ***Primary packaging*** – also known as consumer packaging; packaging that comes into direct contact with (or directly ‘wraps’) the cargo product, requiring direct interaction with the end-user or consumer;
>
> ***Secondary packaging*** – packaging that is designed to accommodate several primary packed packages, usually handled at the wholesaler or retailer level in the supply chain;
>
> ***Tertiary packaging*** – an assembly of a number of primary or secondary packages, (e.g., a pallet, a transport unit, a roll container) (Hellstrom & Saghir, 2007); also known as ‘group packaging’, which is designed to facilitate protection, display, handling, and/or transport of a number of primary packages (Jönson, 2000; Saghir, 2004).

This classification provides insight and structure when considering the iterations between different factors within the packaging system, since different packaging layers interact with an operation in different supply chain phases and the interaction (or compatibility) between different layers also contributes to different performance in terms of sustainability.

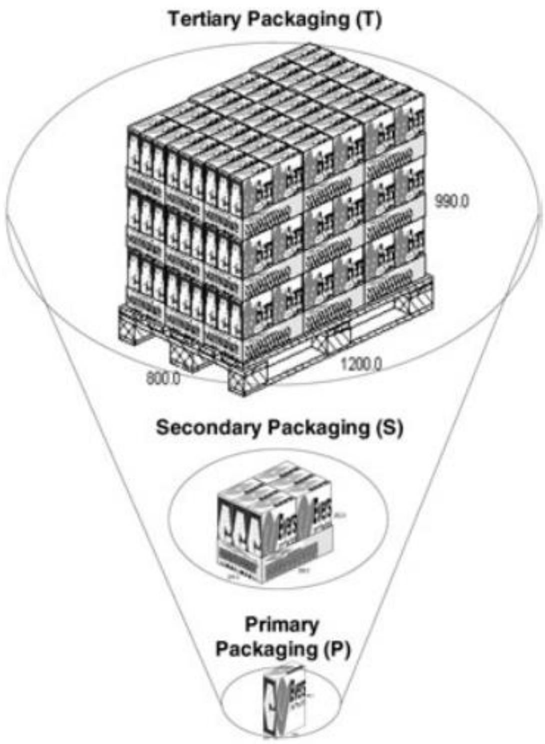


Figure 2.5 Different Packaging Layer (Hellstrom and Saghir, 2007)

Figure 2.6 by O'Neill (2007), shows another type of classification to describe packaging, based on business flow, wherein the packaging is handled and the package goes through various phases of meeting retail or end-user requirements, with different suitability for different phases of the supply chain:

Industrial Packaging – packaging used only within the supply chain, internally to business-to-business flow, with its value and effect mainly reflective of improving logistic efficiency and safety; but usually does not meet the final packaging requirement from end-users or retailing use, with less compromise in supply chain operation suitability for marketing requirement than retail-ready packaging.

Retail Ready Packaging – shelf-ready packaging or consumer packaging; refers to the kind of packaging format that is suitable for both shelf replenishment and supply chain requirements, as well as for interaction with retail store shoppers or end-users; goes to end-consumer as the interface of the product package to the end-user, usually facilitating features that are easily identified, opened, merchandised, shopped, and disposed of; marketing and information communication are a more important function of this kind of packaging than of industrial packaging.

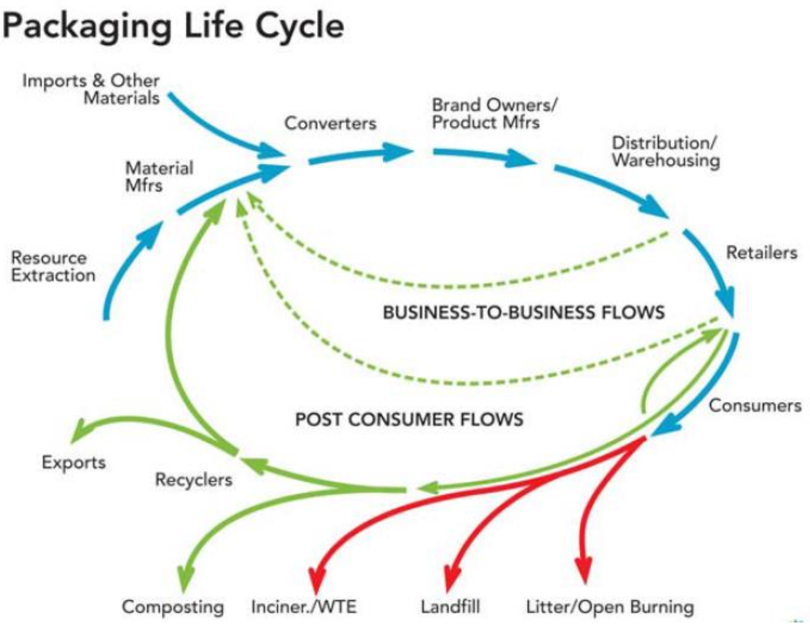


Figure 2.6 Different Material Flows where the Packaging is Used (O'Neill, 2007)

This classification relates the packaging types to supply-chain settings and phases, but limits packaging to a single, common, stand-alone 'product' for evaluation, absent any consideration of the system with its different layers and with impact between those layers. It is very common that during the distribution of the product along the supply chain, the product is not packed with only one layer of packaging, but instead by a system comprising different layers of packaging with impact and interaction between those layers. Packaging system should therefore be degraded as a combination of different packaging layers that interact with each other (Hellstrom & Saghir, 2007; Roese & Nilsson, 2009).

Therefore, the perspective of sustainable packaging should also encompass the sustainability of the packaging system. Bergman (2012) suggested that 'eco-optimism' mainly includes 2 categories: **tweaks** – incremental steps, which are just the 'nuts and bolts' of sustainable design, necessary but not fulfilling; and **rethinking -** which usually involves taking a step back (which is not the same as going backwards). To improve the packaging sustainability at the product level of the packaging itself is the small incremental step, while taking into account the whole packaging system, all along the supply chain, represents the 'rethinking' approach from a holistic view (to optimise the trade-off between packaging and supply chain performance and between different sustainability criteria throughout different supply-chain phases).

Traditionally, the analysis of packaging and performance of life-cycle assessment on packaging has mostly focused on packaging itself as a traditional product, excluding the packed product within (Williams & Wikström, 2010). There have been discussions regarding the correct scope for packaging LCAs; a growing number of researchers believe that environmental assessment of packaging 'should not be performed in isolation from the product it contains', which neglects the packaging's significant impact on the environment during the life cycle of both the packaging and the packed product (Grönman et al., 2013; Molina-Besch, 2016).

2.3.2 Sustainable Packaging Criteria

The criteria for general sustainable design has been previously reviewed and discussed, but when it comes to the research field and the packaging industry, the criteria commonly used are sometimes different.

Packaging Evaluation Criteria in Industry

As previous packaging management approaches focused too much on short-term financial performance, and not enough on the need for a holistic approach to packaging (Olsmats & Dominic, 2003). The packaging scorecard was developed by Kaplan & Norton (1996) and utilised for research on sustainable packaging. Table 2.1 (derived from Olsmats & Dominic, 2003; Palsson & Hellstrom, 2016) illustrated the theoretical framework of the packaging scorecard. It contained a set of packaging criteria geared to sustainable packaging (although not covering all different dimensions of sustainability as formerly discussed), covering different phases in the lifecycle and interactions with different supply chain parties (relative functional criteria and supply chain parties indicated by an 'X' in Table 2.1).

Existing research utilised the packaging scorecard as measuring criteria for packaging and a sustainable packaging system. Olsmats & Dominic (2003) conducted research that used linguistic scoring on the packaging scorecard criteria to evaluate the packaging's overall performance, identifying a packaging system's strength or weakness in a systematic way and providing a better overview and understanding of packaging performance along the supply chain. But the weakness is that it is useful only as a mapping tool, without detailed suggestions on solutions for improvement.

Table 2.1 Packaging Scorecard Criteria for Different Supply Chain Phases (derived from: Olsmats & Dominic 2003; Palsson & Hellstrom, 2016)

Criteria	**Description**	**Supplier**	**Transport/Distribution and Wholesale**	**Retail**	**Consumer**
Machinability	Ability of packaging to be processed effectively in the production line	X			
Product protection	Ability to protect the product	X	X	X	X
Flow information	Capability to provide information in the supply chain	X	X	X	
Volume and weight efficiency	Ability to make use of all the available volume and load capacity	X	X	X	
Right amount and size	Adapt to right quantity and turnover		X	X	X

Handleability	Ability to facilitate handling		X	X	X
Other value-adding properties	Other functions than the basic requirements	X			X
Product information	Ability to display product information				X
Selling capability	Ability to sell and advertise the product			X	X
Safety	Ability to protect the product from shoplifters			X	
Reduced use of resources	Reduced environmental load	X			X
Minimal amount of waste	Amount of waste from the packaging			X	X
Minimal use of hazardous substances	Amount of hazardous substances in the packaging	X			X

Packaging cost	The cost of the packaging	X			
Stackability	Ability to stack as many shipment units as possible in warehouse and during shipping	X	X	X	
Unwrapping	Easy to remove unnecessary packaging material			X	X
Traceability	Capability to trace packaging/products in the supply chain	X	X	X	
Recyclability	Amount of packaging that can be recycled	X	X		X
Reverse handling	Ability to facilitate reverse handling	X	X		X
Packaging design	Attractiveness of the packaging design				X

Based on the packaging scorecard, Palsson and Hellstrom (2016) conducted different case studies for different layers of packaging in different supply chains, using a satisfaction score for packaging scorecard criteria to identify areas of improvement for different packaging.

Since the packaging scorecard was originally developed to expand previous financial-perspective-only packaging management in order to include business process and customer perspective (Olsmats & Dominic, 2003), this evaluation tool was not specifically developed from the perspective of sustainability. And it is a set of packaging-related consideration guidelines for better packaging design, without detailed quantified measures or priority weightings for different criteria. To utilise the packaging scorecard for sustainable packaging evaluation, the criteria need to be altered to fit the concept of sustainability from a holistic point of view.

Different from the packaging scorecard, research based on LCA with different measuring criteria was also adopted by research for sustainable packaging to provide quantified evaluation results. Verghese and Lewis (2007) and Robertson et al. (2014) researched the packaging from a life cycle perspective along the supply chain, covering stages of packaging, repacking, transport, distribution, and disposal. Additionally, they added the consideration of packed goods quality into the evaluation when assessing the packaging system, which reflected on the important impact owing to the interactions between packaging and packed goods. But the only measuring criteria for sustainability used were emissions.

To include more dimensions of sustainability, Dobon et al. (2011) conducted case studies for sustainable packaging in food supply chain based on LCA of packaging. The criteria include environmental, cost, and social terms, summarised as follow:

> ***Environment Measure:*** Life Cycle Assessment, converting emission, road congestions, road casualties, and noises into cost;
>
> ***Economy Measure:*** Life Cycle Costing, covering cost of packaging life cycle, food losses, production losses, transports, internal costs, etc.;

Society Measure: Willingness to Pay, calculating the difference between customer's willingness to pay for the packaging alternative (retail price on top of benchmark base model) and the internal cost of the packaging alternative.

Using these criteria, the environmental, economic, and social impacts were all converted into cost for comparison. This is good to cover different aspects for the triple bottom-line of sustainability, but the cases were limited to different packaging in the same logistics and supply chain setting, nor did they reflect the packaging and logistics interactions mentioned in packaging logistics theory, nor was the impact from packaging on packed product and service quality considered in this research.

Consumer Perceptions of Sustainable Packaging

Consumer input is an important consideration in improving packaging design and packaging system deployment (Jedlička, 2015). Despite increasing awareness of environmental concerns and willingness of pro-environmental activity by consumers in many countries (shown as the several kinds of reported green behaviour in Figure 2.7), most of the consumers were not clear about the concept of sustainability; this significant terminology gap was addressed between consumers and industry (Nordin & Selke, 2010).

Unlike industry, which understands sustainable packaging mostly as financially and environmentally cost-effective throughout its supply chain, it was found that, in the eyes of most consumers, sustainable packaging is regarded at the product level: focusing only on the final consumer packaging of the product and typically perceived sustainable packaging as recyclable consumer packaging (Young, 2010), and emphasising the material of packaging products without consideration of the packaging's impact before the goods were put on the shelf. Thus, consumers' willingness to engage in sustainable behaviour could be misled by 'greenwashed' packaging product or by 'greener' consumer packaging that actually has a severe impact on sustainability along the supply chain.

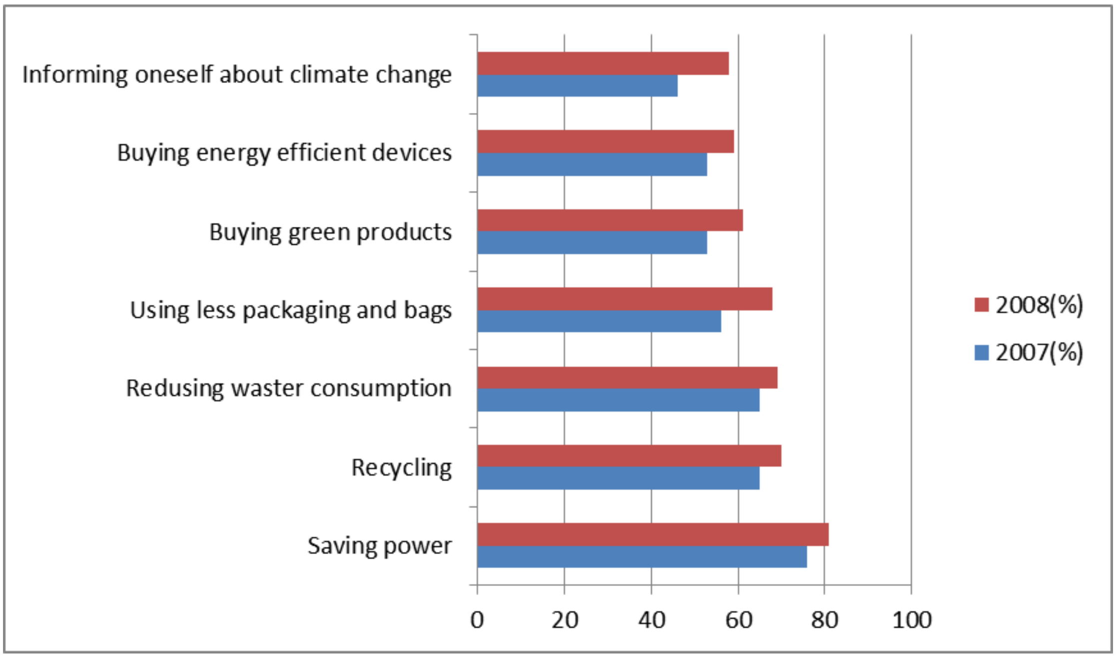


Figure 2.7 Awareness and Willingness to Environmental Acts by Consumers in Most Countries (Source: World Business Council for Sustainable Development, 2010)

According to a survey by the World Business Council for Sustainability (2008), more than half of consumers (53%) were concerned about sustainability but not willing to act, and the two main reasons for this were 'Don't want to compromise quality' and 'Lack of knowledge' (World Business Council for Sustainability, 2008). It has been determined that, apart from lack of knowledge, another perception bias that significantly influenced consumer behaviour towards sustainability is the common misunderstanding by many consumers that 'sustainable packaging compromises product service quality'. But, in fact, sustainability should be an optimal result that has already taken different factors into account, not just a 'greener' product with lower performance, as misunderstood by these consumers.

Therefore, providing an overall evaluation for sustainable packaging with clear criteria—e.g., criteria that ease complexity for decision-making consumers in differentiating 'greenwashed' packaging products from a real sustainable packaging system, thereby increasing consumer knowledge and conversion from sustainable willingness to behaviour—would likely have positive social impact (Nordin & Selke, 2010).

Summary

To summarise this part of the review: unlike conventional products, packaging's impact does not reflect solely on itself at the product level; rather, it is a system with different layers that interact with each other as well as having an impact on the packed goods themselves at different phases of the supply chain. Additionally, appropriate measuring criteria are yet to be identified in order to cover different aspects of sustainability for packaging.

2.4 Packaging and Logistics

Packaging was found to have a great impact on the main strategies for reducing the environmental impact of logistics by early research (Livingstone & Sparks, 1994). And in today's global supply-chain environment, packaging is regarded as one of the most important areas in which to achieve smooth logistics operations (Lancioni & Chandran, 1990).

2.4.1 Packaging Related Logistic Processes

Although every supply chain structure varies and the logistic activities related to packaging are different from each other, they can consist of combinations of basic logistic activities. Hellstrom and Saghir (2007) validated this opinion by conducting different supply chain case studies for different goods with different scenarios, and derived the general 'basic elements' of packaging-related supply-chain activities, as in Table 2.2.

Table 2.2 General Logistic Activities (derived from Hellstrom & Saghir (2007))

Logistic Activities	**Description**
Control and Verification	a process wherein the operator inspects or verifies the condition of the packaging, or the cargo;

Labelling	an operation wherein the operator applies label or mark or places identification onto the packaging or packed product;
Filling (Auto and Manual)	a packing process wherein the equipment (auto) or Operator (manual) fills the packaging with product and packs or seals the package;
Handling (Auto and Manual)	a process wherein the equipment (auto) or operator (manual) lifts and places the package for a short distance;
Storage	a process wherein the package is sorted in a warehouse;
Waiting	a short process wherein the package is settled in a place after the previous process and awaits the next logistic operation;
Transport	a process wherein the package carried by vehicle travels from one place to another.

As summarised by Hellstrom and Saghir (2007), different logistics settings are broken down into these 'basic elements' of logistic activities, of which different sequences and combinations can be used as elements to represent or construct a complex supply chain for general usage.

2.4.2 Packaging Logistics Concept

Considering the close relationship and interaction between packaging and logistics, the definition of a packaging system was further developed and widened in scope, and the concept of 'packaging logistics' was proposed by both industry and the scientific community. Thus Saghir (2002) defined packaging as a 'coordinated system' for product safety, security, efficiency, and effective operation, including handling, transport, distribution, storage, retailing, consumption and reuse, recovery, and disposal to maximise consumer value, sales, and profit (also known as 'packaging logistics'), which regards the packaging as a system and considers the interactions between packaging, marketing, and logistics, covering most of the functions of packaging in a logistic system. This understanding aptly addresses the issue that packaging and logistics were traditionally designed and developed separately by packaging designers and logistics specialists, respectively ignoring benefit and cost, due to the interactions within the packaging logistics system. Though much research on this concept has yielded sound analysis of the trade-off and considerations when developing the whole system in a holistic way (Hellstrom & Saghir, 2007; Saghir, 2004; Saghir, 2002), yet most of the analysis and evaluation are qualitative, providing qualitative output for packaging system design and evaluation, with no clear quantitative measurement and output for precisely decision-making support when developing the system.

Figure 2.8 Packaging Logistics as the Overlap of Three Factors (Saghir, 2004)

The concept of 'packaging logistics' was further developed by García-Arca et al. (2014) from the perspective of sustainability, and was widely expanded into 'sustainable packaging logistics', defined as: 'the process of designing, implementing, and controlling the integrated packaging, product and supply chain systems in order to prepare goods for safe, secure, efficient and effective handling, transport, distribution, storage, retailing, consumption, recovery, reuse or disposal, and related information, with a view to maximizing social and consumer value, sales, and profit from a sustainable perspective, and on a continuous adaptation basis' (García-Arca et al., 2014). This provides a good perspective and conceptual basis for a holistic view of a packaging logistics system from a sustainability point of view. However, there was merely detailed quantitative analysis or evaluation tool following this concept to further explore the sustainability of packaging logistics system.

2.4.3 Identifying Packaging-Logistics Interactions

Employing the concept of packaging logistics, the interactions between packaging and logistics can be analysed. The important way the packaging system influences the sustainability of the logistic operations is the potential process failure, operation difficulties, waste material generation, as well as health and safety risks due to unsuitable packaging, cargo, and logistic processes. To address this type of potential failure, risk management tools could be referred to.

Failure Mode and Effects Analysis

First introduced by NASA in the 1960s, Failure Mode and Effects Analysis (FMEA) is a widely applied engineering technique and hazard-identification method aimed at defining, identifying, and better understanding particular potential failures, problems, errors, and their causes, as well as their corresponding effects or influences on the system or on consumers in terms of a particular known product or process (Pillay & Wang, 2003). Likewise, Omdahl (1988) suggests that FMEA be regarded as a useful method for identifying the potential risks associated with possible failures and seeking corrective actions to reduce, even eliminate, the potential failures, problems, or errors derived from the process, design, or service ahead of reaching the end users, with flexibility to be applied in terms of a qualitative analysis or a semi-quantitative analysis (Pillay & Wang, 2003; Rausand & Hoyland, 2004).

The core principle of FMEA is using failure Occurrence Probability (P), Severity (S), and Detection Difficulty (D) to compute the Risk Priority Number (RPN) that prioritises different potential failures. This is able to offer quick and useful feedback to the process and in turn make it possible for the company to correct existing potential quality issues (Stamatis, 2003). In certain circumstances, DD is not considered to take priority over factors P and S (Fu et al., 2014).

All in all, FMEA is a systematic tool for identifying potential component failures, analysing potential corresponding effects on the system, and providing corrective advice in terms of preventing possible failure modes.

Event Tree Analysis

Event tree analysis (ETA) is an inductive approach widely used to explore possible consequences of failures, and the relationship between main and sub-failure events, step by step (Huang et al., 2000), a technique that is suitable for both qualitatively and quantitatively analysis.

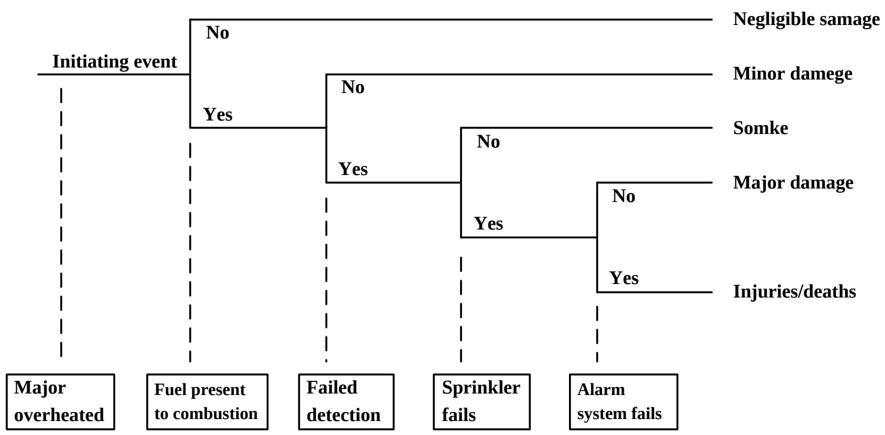


Figure 2.9 Example of Event Tree Analysis Model for Failure Event (source: Fu at al., 2014)

An example of conducting ETA is illustrated in Figure 2.9, where the event's effect on sub-event and sub-subs as a casual chain are identified by carrying out either quantitative or qualitative analysis, and the probability of occurrence for each possible final consequence are presented in the tree shape diagram. The event tree is diagrammatically constructed based on inductive bottom-up logic, the probability of each sub-event in each node being accumulated to estimate the final probability of each end event. When conducting an ETA, the occurrence probabilities for each possible consequence (end event) are calculated by multiplying conditional probabilities at each node from initiating event to the end events along their respective routes (Fu et al., 2014). ETA has power to reveal the mechanism behind each failure consequence, but the structure of the event tree requires a large amount of resources in terms of investigation time and full system information.

Summary

To summarise this part of the review: packaging links the logistic activities from operation level to sustainable performance level, the packaging systems' impact is therefore also reflected in the logistics operations. It would be necessary to develop an evaluation or measurement approach to facilitate the choice among different packaging alternatives to increase sustainability for a packaging system design from a global perspective (Palsson & Hellstrom, 2016), considering the packaging logistics interactions' impact on different dimensions of sustainability at different stages with different supply chain parties. And to consider the interactions, risk management tools can be useful and practical.

2.5 Packaging in Supply Chains

Packaging would have different impact on different supply chain partners at different stage, however in current practice, the collaboration between supply chain actors regarding packaging development is often limited (Palsson & Hellstrom, 2016), resulting in inefficient packaging solutions from a supply chain point of view (Molina-Besch & Palsson 2014).

2.5.1 Impact of Packaging on Supply Chain Operations

As formerly discussed, according to Grönman et al., (2013) and Molina-Besch (2016), packaging as a system has significant influence on sustainability during the packaging and packed product's life cycle. Although packaging does not influence the supply chain structure directly, yet the logistical operations are influenced by the packaging system in terms of sustainability, and the combination of these general logistical processes forms the supply chain phases and further comprises the supply chain structure. Summarised in Table 2.3, and according to Molina-Besch (2016), Grönman et al. (2013), Verghese et al. (2012), Wever (2011), Garnett (2007), and Williams et al. (2012), the packaging links to different environmental impacts along the packed products' entire life cycle in different phases (in the given example of packaging impact in food supply chain). To investigate the packaging's impact on packed goods (e.g., food), Molina-Besch (2016) proposed 'prioritization guidelines for green food packaging development', and, based on frequency, qualitatively discussed the potential for improvement in sustainable packaging for a food supply chain. It provided a good insight on the significant impact of packaging on sustainability along packed goods' life cycle in different phases, but the criteria it used didn't include all different aspects of sustainability; also, this research is specific to packaging in a food supply chain.

Table 2.3 Packaging's Environmental Impact on Packed Product's Different Life Cycle Phases (summarised from Molina-Besch 2016; Grönman et al., 2013; Verghese et al., 2012; Wever, 2011; Garnett, 2007; and Williams et al., 2012)

Packed product life cycle phase	**Influence of packaging on the environmental impact in the supply chain of packed product**
Primary production and processing phase	Packaging influences the amount of product loss along the supply chain - indirectly influences the amount of raw materials and energy consumed in this primary production and processing phase.

Packaging phase	The packaging choice influences the type and the amount of resources and energy for the packaging materials and product packaging operation.
Transportation and retailing phase	Packaging adds weight and volume to products but also helps better maintain the condition of packed goods (e.g. extend the shelf life of food). Therefore, it influences the overall energy consumption of transportation, handling and storage.
Use phase	Packaging heavily impacts the interaction between users and products, and in this way influences the amount of packed product loss (e.g., food waste in households).
End-of-life phase	The packaging decision influences the amount of packaging waste that ends up as landfill, and also influences the waste management of packaging and product end-of-life processes.

2.5.2 Reusable Packaging and Reverse Logistics

In different literature, the term ‘reusable packaging’ is used interchangeably with the term ‘returnable packaging’. By ISO (2005), reusable packaging is one of the returnable transport items (RTI), or returnable items, which refers to all assembling products in transport, stock, handling, or product protection within the supply chain system that can be returned for future use, e.g., containers, pallets, plastic boxes, roll cages, racks, trays, crates, and lids (Karkkainen et al., 2004; Young et al., 2002; Crainic et al., 1993).

When packaging needs to be returned and reused, the requirements of the supply chain correspondingly change. For reusing the packaging, a closed-loop supply chain is needed. Guide et al. (2009) defined a closed-loop supply chain as a system to design, control, and operate activities to gain value from the entire life cycle of products, through five main phases: (i) remanufacturing as a technical problem; (ii) valuing the reverse logistics process; (iii) coordinating the reverse supply chain; (iv) closing the loop; and (v) prices and markets. Jayaraman et al. (1999) suggested that a closed-loop supply chain contains forward and reverse logistics. Forward logistics provides solutions about products or services moving from supplier to customer; vice-versa for reverse logistics.

Just as in a forward supply chain, reusable packaging plays a crucial role in the safe and efficient delivery of goods within a closed-loop supply chain (Paine, 1981; Bovea et al., 2006). As defined by, Gustafsson et al. (2008), returnable packaging is 'a type of transport packaging that can be returned for reuse'. Fleischmann (2001) declared that the returnable packaging comprises both primary and secondary packaging, and Breen (2006) claimed that most reusable transportation packaging is used within B2B flows.

Reusable packaging is gaining increasing popularity for the potential extra benefit and cost reduction it entails, as observed by Twede (2004): ***in cost aspect***—liability risk reduction, regaining of material value, and reduction in new production operation; ***in terms of marketing and service***—improvement in customer satisfaction, increase in availability of spare parts, green image building for companies, and potential time saving; and ***for environmental considerations***—it reduces the material-waste-induced environmental impact. Moreover, with stricter government environmental regulations and policies, it is required in order for companies to reduce waste (Kroon, 1995). According to Johansson and Helstron (2007), although an RTI fleet and closed-loop supply chain in a company needs an initial investment, it could relatively reduce operating costs in subsequent years.

In this scenario, the company only buys new materials, components, or parts when customer demand exceeds the supply of re-used products in the closed-loop supply chain system. As the result, the returning used products can reduce the use of resources and extend the product life cycle. However, the green packaging helps the customer achieve better environmental performance, but the packaging supplier's development and manufacturing cost increases and profit margin shrinks, as mentioned both in the literature (Gu et al., 2008) and during interviews with practitioners in the packaging industry, using reusable packaging systems to replace one-trip packaging would bring different cost and benefit to different parties in the supply chain.

There are different structures of reverse logistics systems for reusable items, summarised by Karkkainen et al. (2004), as shown in Table 2.4. And given the benefits of using reusable packaging in various different scenarios (Thierry et al., 1995; Fidler, 2000; Stock et al., 1992; Gustafsson et al., 2008; and Rogers & Tibben-Lembke, 1998) for the sustainability evaluation of packaging systems, identification and consideration of different end-of-use scenarios need to be covered to clearly analyse the trade-off between efforts of processing the end-of-life product for reuse and the benefit gained by this activity in terms of sustainability.

Existing research (Guo & Ma, 2013; Yan & Sun, 2012; Gu et al., 2008; Vadde et al., 2007; Büşra et al., 2001) also reveals that under different scenarios of reusable packaging (or reverse logistics settings for reusable components), the cost and benefit for different supply chain parties varied and thus needs to be clearly identified and balanced.

Table 2.4 Different Types of Return Logistics System (source: Karkkainen, 2004)

System	Essence	Ownership	Return	Storage	Maintenance	Control	Deposit	Monitoring
Switch Pool Systems	Sender & Recipient Allotment	Each participant	-	Each participant	Each participant	Each participant	-	Account
	Everyone (including carrier) has allotment	Each participant (includes carrier)	-	Each participant	Each participant	Each participant	-	Account
Systems with Return Logistics	Transfer System	Central agency	Central agency	Sender	Sender	Sender	-	Sender
	Depot System with Bookkeeping	Central agency	Central agency	Central agency	Central agency	Central agency	-	Account
	Depot System with Deposit	Central agency	Central agency	Central agency	Central agency	Central agency	Deposit	Not necessary
System without Return Logistics	Rental System	Central agency	Sender	Sender	Sender	Sender	Rent	Unavailable

2.5.3 Cost Structure of Reusable Packaging Operation

The use of returnable items like packaging would bring extra expenditures in development and operation. This cost was usually allocated unevenly to different supply chain parties or passed along to the end consumer. Therefore, the cost of packaging and any increase in packaging expenditures for return and reuse need to be considered when identifying a cost-effective sustainable packaging system. As summarised in Table 2.5 (Mishra & Jain, 2012), the packaging-related cost can generally be broken down into these items. This reveals the extra expenditure and efforts for reusable packaging utilisation, which is helpful when evaluating the life cycle cost and impact for sustainable packaging solutions.

Table 2.5 Packaging Related Cost (derived from Mishra & Jain, 2012)

Packaging material cost	the cost of the packaging and quality control cost
Storage and handling cost of empty packages	includes the handling cost of bulky packages, heavy materials of construction, drums, etc.
Packaging operation cost	includes the cost involved in operations, e.g., package cleaning, product filling, labelling, etc.
Storage of filled packages	includes the cost incurred to shift the goods from one form of packaging to another
Transportation cost of filled packages	involves transportation cost by sea, air, etc.
Loss and damage cost	relates to loss and damage during operation, transportation delivery, etc.
Insurance cost	varies, depending on the vulnerability of the package
Effect of packages on sales	the influence of the package on sales

Obsolescence cost	Occurs- when changes in packaging materials, packages, and labels take place
Package developmental cost	include the evaluation cost, pilot test cost, field testing cost, consumer research cost, feedback cost, final trial cost, etc.

2.5.4 Container Shipping as Packaging Supply Chain

Container Shipping Supply Chain

Similar to the packaging's role in the supply chain, a container is used as a standardised outer 'packaging layer' for cargo during the transportation (Armstrong, 1981). Just as with the packaging logistics concept, the container supply chain is not the supply chain of the container itself (in terms of how the container is made as a product from raw material, sent to user, used, and disposed of at the end of its life cycle); rather, it is defined as all processes of shipping metal boxes (with cargo) from place of departure to final destination with integration of planning, coordination, implementation, control, and related data transfer (Rodrigue et al., 2013), which refers to cargo shipment in the format of container shipping from a supply chain perspective.

The focus of the concept shifts from an asset-driven to a supply-chain driven perspective (Fransoo & Lee, 2013). But it is not only the simple process of carrying items overseas by container; it also includes hinterland transport and operations, such as stripping, stuffing, storing, and handling containers (Kemme, 2012), as shown in Figure 2.10. It extends the traditional 'quay-to-quay' overseas shipping service to better support the 'door-to-door' service by integrating the sea and land transportation, which promotes the merchandise transport revolution (Bernhofen et al., 2013).

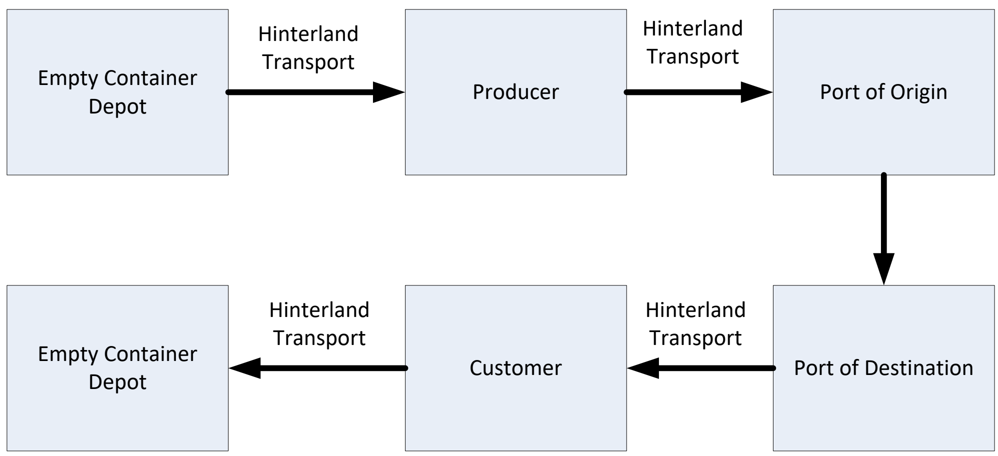


Figure 2.10 Physical Flow in Container Supply Chain (source: Hecht & Pawlik, 2007)

Compared to traditional transportation modes, container shipping has advantages in cost reduction, hazards reduction, and efficiency improvement, as suggested by Hecht and Pawlik (2007), specifically:

1) Container shipping is a cost effective means of transport, by simplifying packaging and reducing packaging investment (Hecht & Pawlik, 2007). The hard surface of a container better protects the cargo than most common packaging and can be handled in different weather.

2) Transporting goods in container reduces frequency of handling operations and intensive labour requirements, and improves the operational efficiency and turnover time with use of large scale equipment.

3) It also provides high efficiency of cargo handing by minimizing the transhipment operations and enables huge volumes of goods to be transported by different modes. In a typical scenario, the port turnaround time could be reduced from 3 weeks to about 1 day (Rodrigue et al., 2013).

Container shipping therefore becomes an efficient means of transport that seamlessly links road transport and sea transport, and covers almost the entire overseas transport market (Kemme, 2012).

Risks in Container Shipping

While the container supply chain's contribution to world economic prosperity is recognised by different communities, some serious hazards to the goods can also be brought by this mode of transportation mode, as suggested by Yang et al., (2010), such as inappropriate physical operations and other increasing threats related to terrorist attacks and pirates. Attempts have been made by different researchers to identify the risks for cargo loss in container shipping from different perspectives:

1) Terrorist attacks and pirating; risks from attacks by illegal persons such as terrorists and pirates (Noda, 2004; Drewry, 2009; Fu et al., 2010; Yang et al., 2010)

2) Cargo stolen or tampered with during container transport, or other physical risks (Noda, 2004)

3) Weather-induced cargo loss (Notteboom, 2006)

4) Perishable and deteriorating cargo damage in refrigerated containers (Tseng et al., 2012)

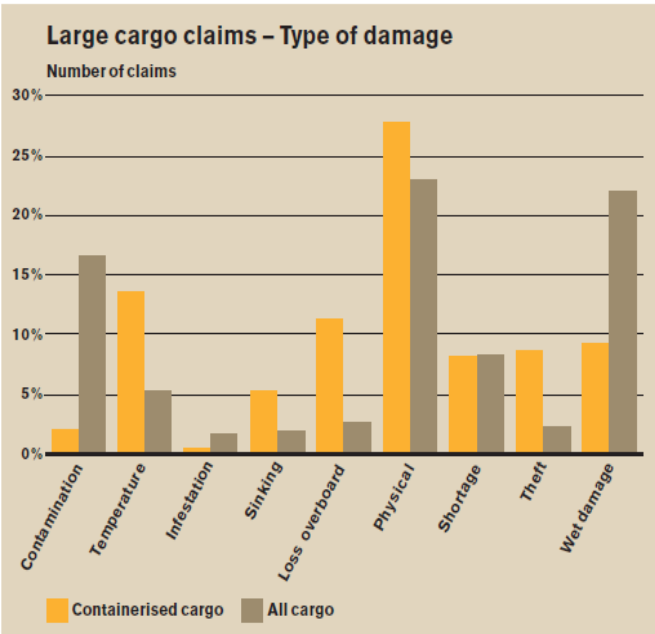


Figure 2.11 Different Type of Damage for Shipping Incident Claims (source: UK-P&I-Club, 2000)

Therefore, it is believed that the risks inherent in the container shipping industry have a variety of causes. Among shipping incidents in the container supply chain, 65% are related to cargo loss and damage, and physical damage is the dominant main type of failure (around 27%) for these incidents (UK-P&I-Club, 2000; TTClub, 2010), as shown as Figure 2.11.

Table 2.6 Main Causes of Damage and Loss in Container Shipping (source: UK-P&I-Club, 2000)

Packaging Related Incident Cause	**Non-Packaging Related Incident Cause**
• Increased use of weak retail packaging • Inadequate ventilation • Lack of expert packaging • Wrong choice of container • Poor condition of container • Lack of clear carriage instructions • Ineffective internal cleaning • Contaminated floors (taint) • Wrong temperature settings • Poor distribution of cargo weight • Wrong air flow settings • Stack weights exceeded • Damaged, worn, mixed securing equipment • Wrong use of temperature	• Lack of effective container interchange inspection • Ineffective sealing arrangements • Condensation • Overloading • Wrongly declared cargo • B/L temperature notations misleading/unachievable • Lack of refrigeration points • Organised crime • Heavy containers stowed on top of light ones • Fragile cargoes stowed in areas of high motion • Heat sensitive cargoes stowed on/adjacent to heated bunker tanks or in direct sunlight • Poor monitoring of temperatures

About 35% of incidents are found to be caused by poorly or incorrectly packed containers, according to the Cargo Information Notification System. Table 2.6 lists the main causes of container cargo damage and loss according to the UK-P&I-Club (2000), and the packaging-related causes (regarding what to use for accommodating the goods and how to place them in the container) are separately listed in the left column, showing the large packaging-related impact on the container supply chain in terms of cargo damage and value loss.

Summary

To summarise this part of the review: although every supply chain structure varies, they are all composed of general logistic processes that are influenced by the packaging system; on the other hand, different types of packaging also require different supply chain settings and management for proper operation. The packaging and supply-chain structure are found to be related to each other, in terms of having an impact on sustainability measures. Similar definitions and similar container-logistics-cargo interaction modes were reviewed and identified between container shipping and packaging logistics; the packaging evaluation tools could be expected to apply in a container context for sustainable container supply-chain evaluation. This provides a good chance to develop a generic assessment approach for general packaging and container supply chain, regardless of their different supply chain structures and settings. Yet, such generic evaluation for packaging and container supply chain is still in need to be researched and developed.

2.6 Integration of Design for Packaging Logistics and Sustainability

As previously discussed, the impact of packaging logistics on sustainability involves multiple factors and criteria. These factors derive primarily from the packaging product level (different cargo characteristics should be compatible with different packaging); then, too, the packaging does not stand alone, it comes as part of a system with multiple layers, and interactions between those layers. The next factor is the logistic process, as its interaction with the packaging system and cargo package contributes to its significant impact on sustainability. Then, in addition to these factors, supply-chain settings or structure is another layer of factors to be considered, as it is composed of different combinations of logistic processes, which influence and are influenced by the packaging system in terms of sustainability. Current research in packaging hardly integrates all these factors into one general design and evaluation approach (Chonhenchob et al., 2008; Robertson et al., 2014; Prendergast & Pitt; 1996, Dobon et al., 2011).

Not only are the factors multiple, the ultimate objective of the sustainable packaging logistics is also a multiple-criteria decision that involves considerations of environment, economy, and society. Multiple-criteria decision-making techniques can be useful in this regard.

Analytic Hierarchy Process

Analytic hierarchy process (AHP) was developed by Saaty (1980) and designed to solve complex multi-criteria decision problems. It organises the basic rationality by breaking down a problem into its smaller constituent parts and then calling for simple pairwise comparison judgements to develop priorities in hierarchy. AHP requires the decision makers to deliver judgments on the relative importance of each criterion and then specify a preference for each decision alternative, considering all criteria. AHP is especially appropriate for complex decisions which involve the comparison of decision criteria that are difficult to quantify (Pillay & Wang, 2003). It is based on the assumption that, when facing a complex decision, the natural human reaction is to cluster the decision criteria according to their common characteristics. As sustainability is a multi-objective measure to be assessed, AHP is a suitable technique to achieve this goal.

Since AHP was introduced three decades ago, it has found many useful applications. These include maritime application (Ugboma et al., 2006), transportation system study (Shang et al., 2004), risk and safety assessment (Sii & Wang, 2003), financial and business application (Ayag, 2005), industrial engineering application (Yang et al., 2003), and many more. This is because AHP has several useful characteristics (Anderson et al., 2015), such as being able to handle situations in which the unique subjective judgements of the individual decision maker constitute an important part of the decision-making process, it being relatively easy to handle multiple criteria, and being able to effectively handle both qualitative and quantitative data. The AHP method usually includes following steps (Chang et al., 2012):

1) Establish a hierarchy model in terms of the problem to be solved.

2) Construct the comparison matrix according to a series of judgments.

3) Calculate the weighting vectors of comparison matrixes.

4) Check the consistency of pairwise comparisons.

Make a final decision based on the results of this process.

Integrated Tools for Sustainable Design

As discussed in a previous section, the design and evaluation tools for sustainability have limitations and drawbacks for certain occasions. Therefore, efforts have been made by researchers to provide a more holistic approach to the design process by integrating different design tools and assessment techniques (Ramani et al., 2010), e.g., life-cycle costing with LCA ; multicriteria decision making with LCA (Khan, 2004), to bridge limitations of different tools towards sustainable evaluation; integrating QFD and AHP for maritime supply chain design (Lam, 2014); combining QFD and FMEA for order-processing design, adding the design-failure risks consideration into QFD for process design (Tanik, 2010).

Summary

To summarise this part of the review: the integration of sustainable packaging logistics involves multiple input factors to consider, as well as multi-criteria objectives to achieve. The various factors and interactions between packaging and logistics need to be considered while the impact on different aspects of sustainability need to be taken into account. Particularly, to consider the unique characteristics of packaging that its impact on sustainability largely reflects as the interactions (operation risks) with given logistic processes. No existing approach is perfectly suitable for this situation; it is therefore suggested to develop an approach that integrates different evaluation tools and techniques for this design and evaluation task.

2.7 Summary of Literature Review

As addressed in the literature review, the following concludes the key gaps and challenges in this research field and potential contribution by solving these issues.

Firstly, most existing design and evaluation tools for product life cycle focus only on the product itself, but packaging logistic evaluation should be considered as a whole system in a design to achieve a holistic optimum. The packaging interactions described in the research on packaging logistics only consider the interactions between packaging layers and between packaging and logistic process. But the packed goods or cargo are not considered, even though they have interactions with the packaging logistics system.

Secondly, research has been rare on packaging (especially reusable packaging) evaluation that not only evaluates the environmental impact but also considers the impact on an economics perspective (effectiveness and efficiency) quantitatively at the same time along the packaging's life cycle for different supply chain parties. If this were fully considered in evaluation, the tool would be more effective and practical for profit/cost incentive practitioners, as it could identify the 'greenest' option without compromising the economic performance or a most 'sustainable' option after considering the trade-off between economic and environmental aspects of sustainability.

Therefore, a new integrated approach needs to be developed to include the scope of packaging-related operation interaction and consider the cargo characteristics in order to correctly assess and present the impact for better packaging system design from a holistic point of view.

Additionally, the link between reusable packaging and containers has yet to be discovered and understood. Although many similarities (e.g., functions and roles, hierarchical layered structure, closed-loop operation, interaction with value-adding service) between these two are addressed and many of the research models and theories can be applied to both reusable packaging and maritime containers—e.g., reverse logistics management theory (Rogers et al., 2012; Lambert et al., 2011; El

Korchi & Millet, 2011; Kroon & Vrijens, 1995); optimal pricing decision of reusable items (Yan & Sun, 2012; Gu et al., 2008; Büşra et al., 2001); the industrial-packaging-interacts-with-logistical-operations issue (Verghese & Lewis, 2007; Hellstrom & Saghir, 2007; Lockamy, 1995)—yet the full and detailed comparison between them is not researched in any of the literature. If this comparison is completed and a link between them is forged, the theories from these two fields can easily be modified to be applied to and benefit each other (e.g., to adopt the packaging logistic outcome to facilitate integration design and planning for container supply chain as the container's interaction with inner layer sub-packaging and interaction with logistic operation could also influence the supply chain performance; or to apply sophisticated container-routing planning theory to help with the reverse logistics for emerging reusable packaging).

Furthermore, it is the lack of an integrated approach for logistical operations, planning, and container-packaging system selection, aiming at 'sustainability' (as, traditionally, the container is usually treated as a 'black box' in analysis without consideration of what goods are inside and how the goods are packed). All of this provides opportunities to apply risk-assessment principles to the evaluation of the interactions between these factors.

Chapter 3: Research Design and Methodology

3.1 Research Paradigm

A researcher's paradigm or world view shows his perspective on the world, providing a foundation for the research. It is important to know the paradigm guiding the research, even for articles that do not explicitly state it. Every author has a world view (Hall, 2012).

Different world views have different stances on common elements of ontology (view of nature of reality), epistemology (how we gain knowledge of what we know), axiology (the role of value in research), methodology (the process of research), and rhetoric (the language of research) (Creswell & Plano, 2007). As stated by Hall (2012), paradigm issues should be a major concern in all mixed-methods research. And among the elements of an author's paradigm, the assumptions about reality (ontology) and about how knowledge is obtained (epistemology) are crucial, as they provide the legitimacy for the mixed-methods inquiry. Although different literature suggests different classification/categorisation of paradigms, there are at least two basic types of paradigms that are widely held: Positivism (typically inherent in quantitative research) and Constructivism (often underlying qualitative research) (Glogowska, 2011). And these two seemingly incompatible world views posed a major challenge for this researcher, who has attempted to bring the two methods together in a valid way. Three approaches to paradigm choice have been identified in past research: the a-paradigmatic approach (methodology independent of epistemology, and thus dominant over it); the multiple-paradigm approach (drawing on more than one paradigm, regardless of their contradictory ontological and epistemological assumptions); and the single-paradigm approach. The third of these paradigms is widely held, while the first two have proved problematic (Hall, 2012).

The world view of the current research stands on the third paradigm, repudiating positivism and constructivism. Instead of adopting either (or both) both positivism and/or constructivism, respectively, for the quantitative and/or the qualitative processing of the data, this research follows a realist/post-positivist paradigm, with a (realist) ontology that sees reality as imperfectly 'real' and probabilistically apprehensible, and a (post-positivist) modified objectivist epistemology that sees our findings as probably true (Healy & Perry, 2000). Instead of theorising a perfect or ultimatly 'real' reality, eliminating all bias, a realist paradigm accepts both biased and unbiased perspectives, as long as the bias is known, understood, and explained. With appreciation of the known unknown and its limitations, the quantitative result does not stand for the ultimatly 'real' or perfectly true. The research will utilise elements of different type (e.g., literature and linguistic input, case study, numerical analysis, etc.), piece by piece, as 'evidence' to triangulate and support the research findings and outcome as 'imperfect true' with explanation of assumptions, known biases, and limitations under a realist paradigm. Many parts of this multidisciplinary research are, after all, exploratory, seeking and providing new perspectives to gain more understanding of packaging's essential role and packaging-related sustainable situations in the supply chain.

3.2 Methodology and Research Design

After research gaps identified from the literature review, in alignment with the chosen paradigm, in order to achieve the research aims and answer the research questions, this research was designed according to the research design roadmap diagram outlined in Figure 3.1.

Research is always influenced by its design, for better or for worse (Creswell, 2003). Therefore, choosing a suitable research method is crucial to solving the challenges being researched. There are two main types of research method, namely the inductive and the deductive approach, the former being 'bottom up' (moving from observation towards theory-building), while the latter is 'top down' (testing a theory against data) (Marcoulides, 1998). This research has taken an inductive approach, building up an evaluation method and theory from different sources of input.

In terms of data types and analysis, this research is designed to utilise and process a mixture of both qualitative and quantitative input, including research literature, interviews of practitioners on site visits, business reports from packaging suppliers and users, and expert judgment-scoring surveys. All these data are used for the same aim of the design and evaluation method development, for sustainable packaging and sustainable container supply chain decision making support.

According to the research design, as illustrated in Figure 3.1, this research is composed of the following three parts:

The first part of our research design is the literature review and empirical input, to identify the challenges of current sustainable packaging design and evaluation tools, and to provide basic elements for building up a sustainable packaging evaluation framework and method. The literature review covers topics related to sustainable packaging design and evaluation, from conventional sustainable design tools for general products to sustainable packaging product design development, and from packaging at the single product level to the packaging system level, packaging logistics level, and integrated packaging supply-chain level.

After challenges identified from the literature review and empirical practice for sustainable packaging design and evaluation, the second part of this research is the development of a design and evaluation tool. To fill the lack of a sustainable packaging evaluation tool, follow the idea of LCA, an evaluation framework is proposed from a holistic viewpoint to cover different criteria on sustainability related to packaging and packaging system. The proposed evaluation framework utilised the outcomes from literature review, integrated different viewing points of both packaging designer and logistic specialist using interviews to include their practical experiences in order to avoid sub-optimum or 'green-wash' packaging products. According to LCA, different scope would lead to significantly different analysis results. Therefore, the proposed framework is a good foundation, providing a proper viewpoint and appropriate evaluation boundary according to the characteristics of packaging products, showing what to measure and how far to consider for sustainable packaging evaluation.

But how to quantified the consideration of impact from packaging logistics interactions on operation and sustainability is not provided by existing literature.

Therefore, for this urgent need of packaging logistic impact considerations, an evaluation matrix series is developed to solve this issue. As the task of this is to estimate the impact of given packaging and logistics settings, risk management tool FMEA is referred to. Also, it is a multi-factor and multi-disciplinary problem that requires expertise from different people at different position of the supply chain, design tool QFD is combined, which is good to evaluate interactions between multi-factors and enable different people's involvement for different step (matrix). In development of the matrix, both research literature and packaging experts' opinions from practitioner interviews were referred to when identifying generic factors for packaging, cargo and logistics activities.

Once container supply chain's similarities to packaging are compared from literature, based on the proposed framework and evaluation matrix for sustainable packaging, the proposed evaluation method is then further integrated into a simulation model for a more complex context (sustainable container supply chain) to provide decision support for sustainable container supply chain. Compared to packaging logistics scenario, this simulation adds considerations of more container-shipping-related factors identified from literature and shipping industry personnel, and shipping specialists, regarding the container as an outer layer of packaging instead of a 'black-box' in a container-shipping context. Simulation is good to solve problems with complex factors and variables like the container context, thus is chosen for this part of task. At the same time, multi-criteria decision making technique is also combined into this simulation to integrate the performance of different aspects of sustainability into single index for the ease of decision-making support. Fuzzy membership mechanism is also embedded in the simulation to minimise the potential human judgment bias from expert scoring.

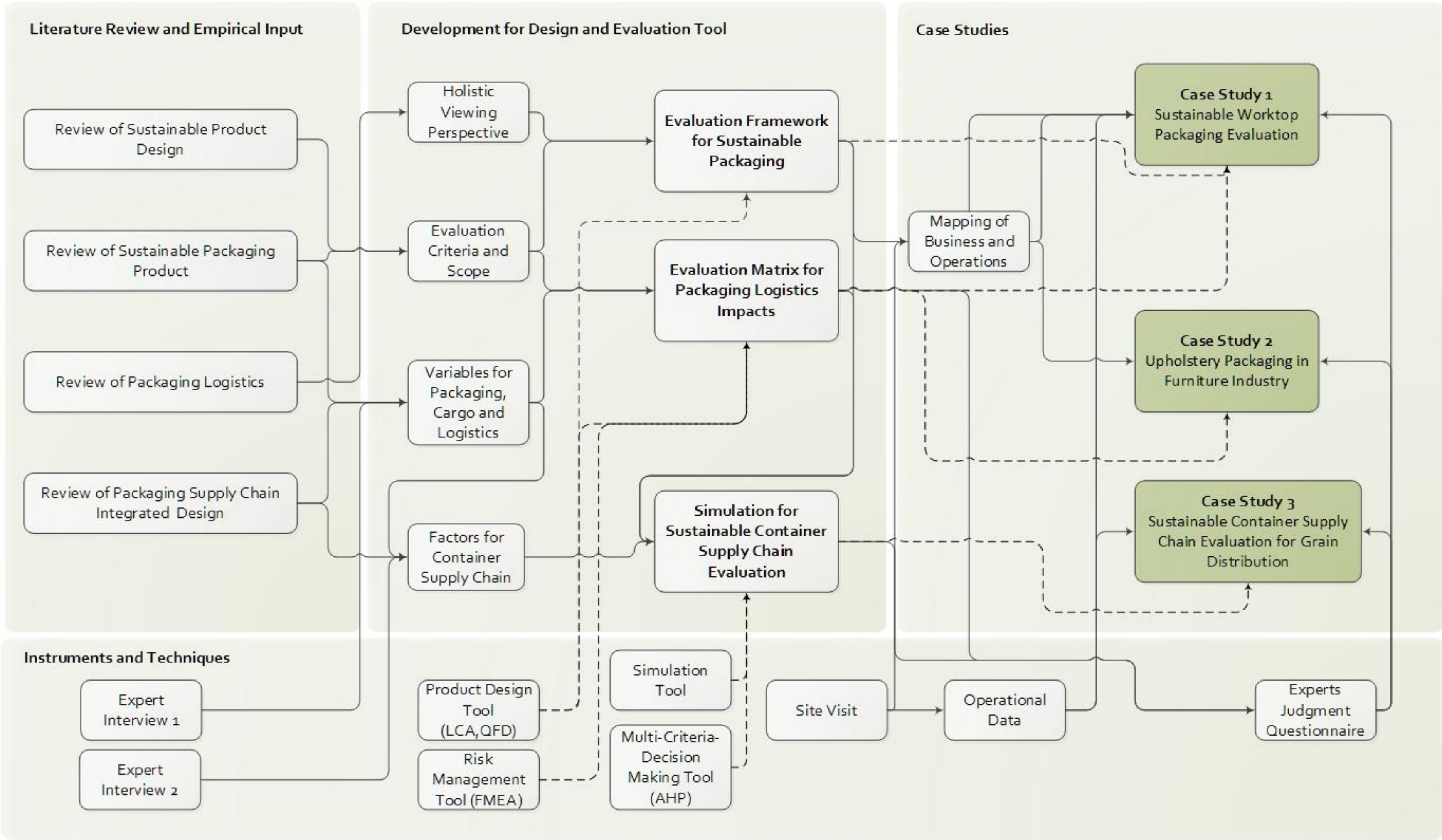


Figure 3.1 Research Road Map

The third part of the current research is a series of case studies. Case studies are good for gaining a deep understanding of a phenomenon (or set of phenomena) by providing a rich, more holistic description of it; they are also good for answering 'how' questions (Hellstroem & Saghir,2007). The case studies used here are conducted as triangulation support, to illustrate and validate the proposed evaluation and design method.

Utilising both sustainable evaluation framework and packaging impact analysis proposed in last part, case study 1 (on worktop packaging) illustrates a sustainable packaging framework in combination with a packaging logistics impact system. Both quantitative and qualitative inputs are used from site visit (flow mapping), operation data, and expert judgements (questionnaire), in order to provide a sustainable evaluation result and design improvement recommendations for different packaging alternatives.

Case study 2 is a series case study on different furniture packaging, to illustrate the application of a proposed evaluation matrix alone in a situation of limited availability of information and operation data. Also, by comparing different packaging's impacts on different types of furniture products in different supply chain phases, the matrix provides packaging selection decision making strategy support for this industry. Data for this case study come from site visit (for process and flow mapping), and expert judgements questionnaire, without numerical operational data.

Case study 3 introduces different inter-continental distribution scenarios in the container shipping supply chain for a grain product, using the proposed integrated simulation approach. This illustrates the application of a proposed packaging design and evaluation method in a container shipping context, and provides triangulation and validation support for the proposed methods. While, at the same time, providing suggestions on supply chain structure and container packaging solutions for sustainable container shipping scenarios.

3.3 Data Sources and Data Collection

The data used in this research is of different types. The following introduces the data resources and collection plan, based on the elements shown in Figure 3.1.

In developing the evaluation framework, evaluation matrix, and simulation tools, the data used are mostly secondary data from the literature. Besides literatures, short interviews of logistics personnel and container shipping personnel are also conducted, given the consideration that the framework is designed to include both literature and professional practice in the field. Short semi-structure interviews are employed to explore and gain practice knowledge on their daily operations when determining the factors and criteria for the proposed evaluation. The semi-structured interviews to logistics (interview 1 in Figure 3.1) and container shipping personnel (interview 2 in Figure 3.1) each lasted about an hour. During the interviews, pre-structure questions were asked, including lists of factors that the author has already identified from the literature were shown to the interviewees, asking for their coherence or different comments according to their experience from practice based on the interviewees, additional questions were added to invite them provide extra related factors and examples according to their daily operations practice, to acquire further clarification and in-depth knowledge. In this way, the development process of the evaluation tool considers both input from the literature and experience from empirical practice. In order to get valid input from appropriate experts, professionals that are familiar with the researched topic, specialised in operations and engaged in researched packaging product were selected for the interviews. The interviewees of this part are operations manager of a UK retailing group, and the project manager of a Chinese shipping line, respectively, for the packaging evaluation and container supply chain evaluation (detailed information about the interviewees are introduced in each case study section respectively). The interview questions can mainly be divided into three sequential parts for discussion and investigation (interview template shown in Appenix III):

(1) The interviewees' experience in the field; General operations related to researched topic in the interviewees' organisation;

(2) Factors of packed product that influence or influenced by the packaging logistics, and examples of the impacts;

(3) Possible operation failure impacts and influences related to packaging logistics.

The short interviews were conducted together with research business partner (packaging provider), transcribed and summarised into report, interpretations from the researcher and the research business partner were compared and refined in order to faithfully represent the interview data, leading to the impact factors that used in the proposed framework and evaluation tool.

In the case studies, different types of data are collected and utilised.

For all three case studies, the operational data are secondary data, derived from trial reports from logistic providers, business reports from packaging suppliers, quotations from the shipping company, and emission factors from government reports.

The operations and material mapping data used in the case studies are derived from site visits to packaging suppliers and logistic providers, operation mappings were confirmed by the packaging and logistics providers for the case studies.

The experts' judgment (score) for the case studies are collected by anonymous questionnaire via email and post. In order to get trustworthy experts' scoring input, experts in the supply chains that are using and familiar with the researched packaging products were selected from the business partner's contact database. For case studies 1 and 2, the management and operations staff of packaging providers, logistics providers, and end users are invited to provide their judgement score as part of the packaging evaluation input. The experts taking part in the scoring process for case study 1 and 2 are described in detail in Table 5.3 and Table 5.8. There are 6 and 14 pairs (each pair containing the evaluation for both one-off and reusable packaging for the same product) of evaluation scoring answers by 6 and 7 experts, respectively. Similar to Saghir and Jönson (2010) that used several typical cases to represent the industry, the sample used in this study is not large, but the result is reasonable and trustworthy, as the participants are all experts involved in packaging or logistics-related design and operations. Also, considering that most of the reusable packaging products are still new to market, with not many users currently, the selected sample number is sufficient to identify and describe the phenomenon in depth for the case studies and answer the research questions.

For case study 3, the expert judgment scores are collected via email and paper-based questionnaire from 6 experts in an anonymous format. The participants each work in a different phase of the supply chain, and detailed descriptions of the participants are listed in Table 5.16. The sampling covers different levels of personnel and different container-shipping-related organisations, effectively providing a holistic view of the supply chain being researched. But the sample size is relatively small, due to difficulties in personnel contact and communication. Thus, to mitigate the potential negative impact from the small sample and human judgement, fuzzy membership and AHP approaches were designed and used in the proposed simulation model for sustainable container supply chain evaluation in case study 3.

Chapter 4: Design and Development of Sustainable Packaging Evaluation Approach

This chapter introduces the design and development of the evaluation approach for sustainable packaging and container supply chain, taking different sustainability aspects into account. A quantified method is designed and proposed to consider the impacts from the interactions between packaging and logistics, which is essential for packaging's impact on sustainability but is not yet available in the existing research in the literature.

4.1 Development of Sustainable Packaging Evaluation Framework

4.1.1 Viewing Perspective and Evaluation Scope for Sustainable Packaging

The LCA- based tool is one of the most popular assessment tools for sustainability, as it helps with understanding a product's interaction with the environment at different stage of the product's life cycle (Li et al., 2010). This concept is useful and suitable for the sustainable packaging evaluation in this research, as the packaging's impact on sustainability is not restricted to the stage when the packaging product is manufactured; rather, the impact on sustainability at different stages needs to be investigated and considered.

As emphasised by LCA research: with different evaluation scope, the result usually varies significantly, depending on the degree to which the impact is measured and subject to how far the indirect impact is considered. Thus, in one common LCA method, the first critical phase of the impact evaluation is to clearly define the 'Goal and Scope' (Vieira et al., 2016).

In order to evaluate what phenomena are to be designed to assess, it is crucial to carefully choose a proper viewpoint from which to define the scope and degree to be measured for a good alignment of what is intended to be evaluated and what is actually evaluated in the process. Traditionally, there are two different viewpoints adopted by different researchers and personnel:

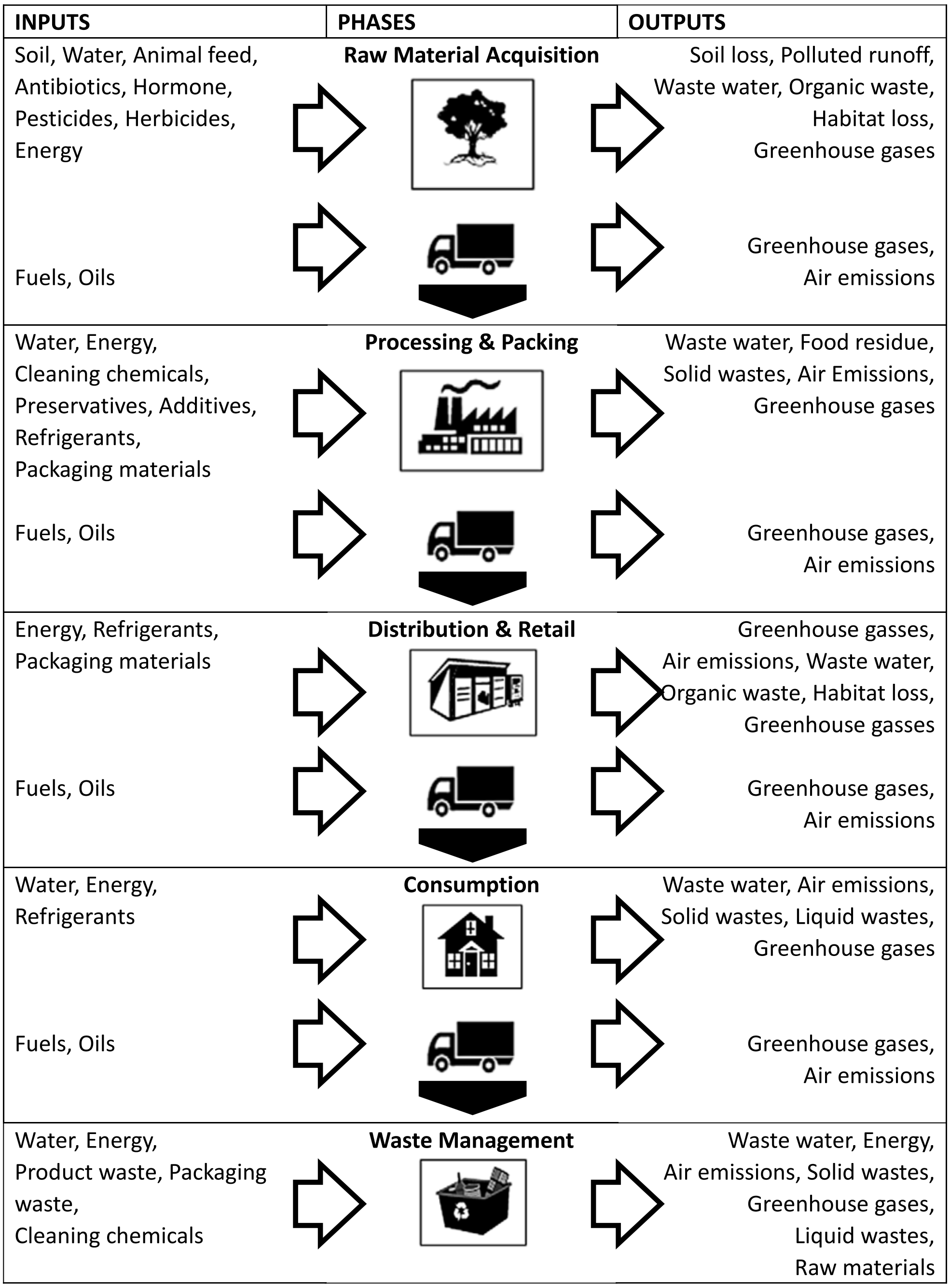


Figure 4.1 Impacts on Sustainability across Supply Chain derived from Nordin and Selke (2010)

One perspective is the logistic specialist's viewing perspective, which focuses only on the logistics process itself. It heavily emphases the logistics process performance, but usually ignores the impact of preparation and end-of-life treatment of the packaging material, which easily results in over-packing and contributes to negative impact on sustainability. For example, as summarised by Nordin and Selke (2010) in Figure 4.1, the impact on sustainability across the supply chain are considered to cover different forms at different stage along the supply chain for different supply chain partners;

packaging is also involved at most stages, as that contributes to the impact. But the packaging's impact after end-of-use (e.g. different scenarios when it is reused, recovered or recycled) and different layers of packaging is not considered from this perspective.

In contrast, the packaging designer's point of view usually regards the packaging as a normal product, where the life cycle of a packaging product is emphasised at the product level, while the interactions between different packaging layers, packaging systems, and logistics processes are ignored. An example of life-cycle impact of packaging from a product viewpoint is shown in session 2.3.1, Figure 2.4 (Williams, 2011).

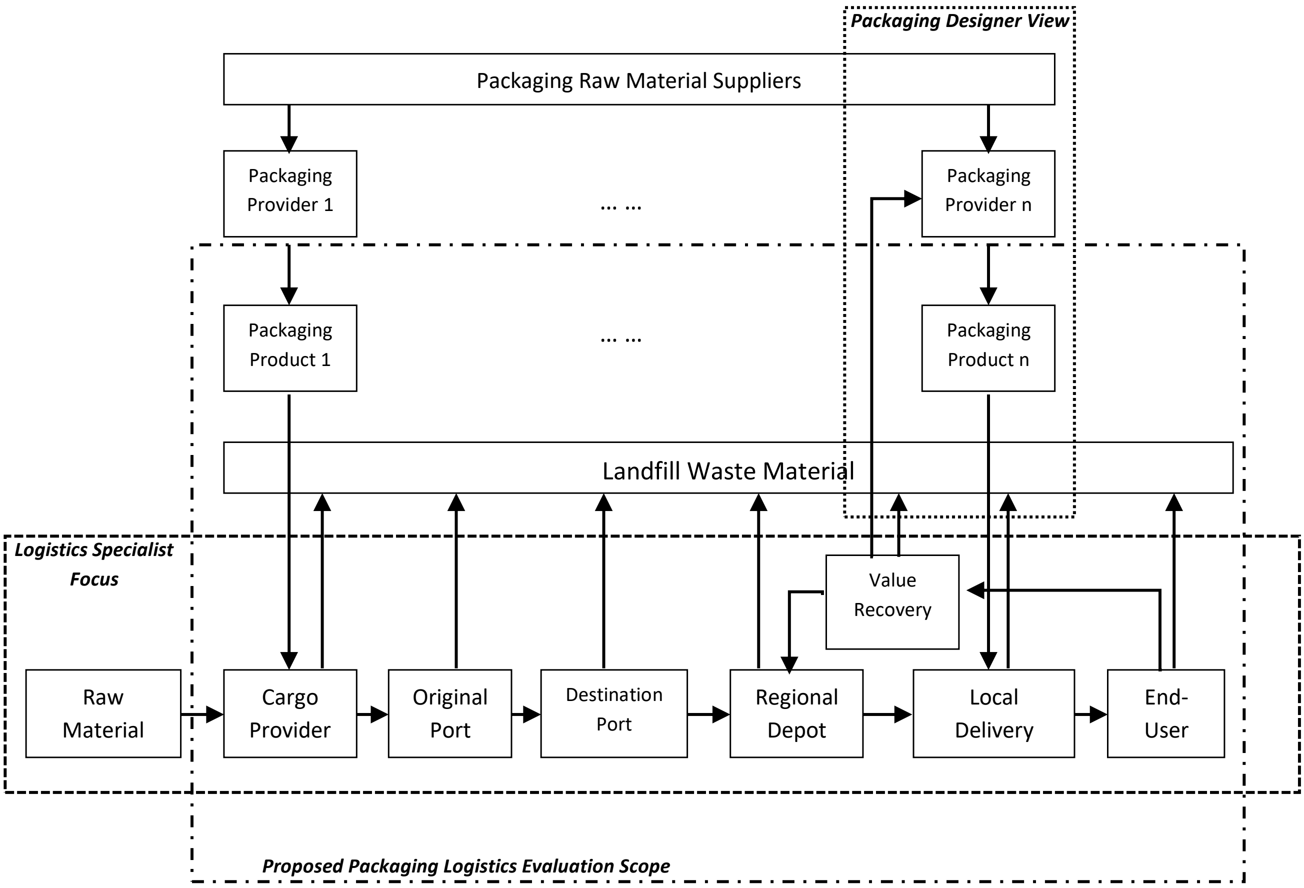


Figure 4.2 Evaluation Scope and Viewing Angle

Thus, to carefully identify and select packaging-related process and impact is important for evaluation effectiveness. Unlike traditional viewing angles of logistic specialists and packaging designers, to avoid a sub-optimal result and to consider the impact on sustainability by the packaging through the supply chain, a proper evaluation scope and reasonable system boundary need to be carefully defined for the evaluation.

Figure 4.2 illustrates the different viewing perspectives of different personnel within the material flow of cargo products and packaging products. A proper perspective from which to consider packaging's interactions and impact should be different from either of the traditional views previously mentioned. The dash-dot line area in Figure 4.2 shows the designed scope of the proposed evaluation. The proposed viewing angle covers packaging-related logistics activities, including the impact on sustainability from the embodied packaging impact (the accumulated packaging material impact on sustainability before it comes into the evaluation system) when they are manufactured, and after the point when the packaging products enter the logistics system with packed cargo along different logistic processes and phases, tracing down to the end-of-use and end-of-life treatment of packaging products (e.g., reuse, recovery, and landfill processes). This viewing angle and scope are able to provide a profile of sustainability for the packaging along its life cycle. The proposed perspective and boundary is designed to measure how sustainable the packaging solution decision would be, with consideration of the packaging material itself and the influence on sustainability it brings into the logistics operations at different stages of the supply chain.

4.1.2 Proposed Evaluation Framework and Criteria

After a proper evaluation scope is proposed for sustainable packaging evaluation, showing how far to measure the impact on sustainability along the packaging's life cycle, a framework is needed to cover the indicators that reflect on the packaging related impact on sustainability.

Based on the sustainability concept, the evaluation should cover different dimensions of sustainability to avoid sub-optimal results, including economic, environmental and social aspects of packaging (Nordin & Selke,2010; Dobon et al., 2011). Therefore, the framework is designed in Table 4.1 assesses the sustainability from these three main aspects.

Table 4.1 Evaluation Framework for Sustainability Packaging

Economic	Efficiency	Cost of Packaging Material
		Cost of Logistics
		Operation /Labour Cost
	Effectiveness	Product Value Reduction
		Service Lead-Time
Environmental		Packaging Material Emissions
		Transport Emissions
		Waste Material Generation
Social		Toxicity Pollution
		Operation Health and Safety

Each of the three main dimensions of sustainability can be broken down into several measurable criteria for quantitative measurement and considerations of the packaging and packaging-induced operation’s impact on sustainability along the packaging life cycle. Details of the measuring criteria are listed in Table 4.1 and introduced as follows:

For the economic dimension, the packaging's impact on sustainability should be efficient and effective (Sustainable Packaging Alliance, 2010; Ma & Moultrie, 2017). The main measures in this dimension include impacts on cost and service performance of utilising selected packaging in the system along the packaging's life cycle.

First of the packaging costs in efficiency cluster is the material cost of packaging itself. The cost of packaging material represents the 'embodied manufacturing cost', holding cost and design expenditures, etc., of the packaging (Mishra & Jain, 2012). As reusable packaging can be used more than once, this cost of material is averaged to cost per trip for every time used, absorbed by the designed/predicted or tested life-span of the packaging material (Chonhenchob et al., 2008). Other costs in efficiency mainly include the cost of logistic operations and labour, which covers costs of different packaging-related operation processes along the life cycle of packaging, e.g., filling, labelling, transport of filled packages, etc., which have been summarised by Dobon et al. (2011) and Mishra and Jain (2012). Unlike traditional one-off packaging, the reusable packaging needs additional reverse logistic operations. Therefore, the cost not only covers the normal forward supply for cargo delivery from manufacturer downstream towards end-user, but also need to include the extra cost and effort of reprocessing all the end-of-use reusable packaging material in the reverse channel back to the depot from the customer after delivery, such as cost of reverse transport, sorting, inspections, cleaning and re-deployment (Mishra & Jain, 2012).

In the effectiveness cluster measures, packaging-related economic impacts on service to customer are considered. Product quality (value reduction) and lead-time are the main concerns when considering the packaging's impact on product from this perspective, and used as criteria by Chonhenchob et al. (2008) and Dobon et al. (2011). Product value reduction includes various possible situations that influence the cargo value during the delivery of the packed cargo from manufacturer to end-user, due to inappropriate packaging or logistics operations, such as cargo damage, loss, or contamination. The service lead-time measures the conformance of delivery lead-time to the promised delivery time, which indicates the effectiveness of the packaging used for this cargo under this supply chain setting in terms of service performance of time.

The environmental impact is mainly assessed from the carbon emissions and waste material generated by the system along the life cycle of the packaging, as adopted in existing research on sustainable design and packaging evaluation (Olsmats & Dominic, 2003; Dobon et al., 2011; Robertson et al., 2014; Palsson & Hellstrom, 2016).

The key emissions are the packaging material emissions and transport emissions. Packaging material emissions reflects the process of raw material acquisition and manufacturing of the packaging material, which is embodied in different packaging product/material into the evaluation system when the packaging material is ready to use. Packaging material emissions are estimated by packaging material weight and corresponding material manufacturing emission factor according to WRAP (2008) and US EPA guidelines. Transport emissions are the most significant among the different phases after the packaging comes into the supply chain system, including both journeys of carrying packages with cargo as well as empty reusable packaging material transport. Transport emissions can be calculated using transport mode factor with load weight and travel distance according to the IPCC (2007) and DEFRA (2012) guidelines.

Waste material related to packaging includes the end-of-life packaging and the packaging induced damage cargo that can no longer be reuse. All these impacts will be calculated as absorbed (averaged) by each trip according to the life-span of reusable packaging material.

For social aspect impact on sustainability, very little of the literature on packaging cover this dimension, since the social impact is usually not easy to quantify. Many variables are difficult to quantitatively measure and integrate with other criteria, e.g., customer's willingness to purchase green products and people's awareness of green business (Nordin & Selke, 2010). Thus, the social aspects to consider in this study mainly derived from traditional design tools for eco design (Conrad & Jessica, 2005) and interviews with reusable packaging retailing company personnel. They include toxicity and health safety, the possible toxicity pollution of the packaging material or packaging-failure-induced toxicity material, and potential health and safety issues during operation that is harmful to people.

From the proposed scope and holistic viewing perspective, as these criteria in different dimensions of sustainability are considered, the evaluation can avoid sub-optimal results and provide useful understanding to identify sustainable packaging and help with sustainable packaging decision making.

4.2 Design and Development of Packaging Logistics Interaction Impact Evaluation Tool

4.2.1 Integration Concept of Packaging Logistics and Packed Goods

As discussed in the literature review, the packaging's impact on sustainability is not isolated, not limited to the product level; rather, its interaction with logistics operations has been Bywell documented in the packaging logistics research (Saghir, 2002; Saghir, 2004; Hellstrom & Saghir, 2007; García-Arca et al., 2014). For the tight relationship between packaging and logistics, the concept of 'Product-Service-System' (PSS) has also been around for many years, in which different aspects (technological, social, environmental, goods-and-services) are viewed together from a systematic perspective (Mont & Tukker, 2006), regarding 'value in use' for both goods and services (Baines et al., 2007). And as mentioned in the literature, the interaction between packaging logistics and packed goods can also have an essential impact on sustainability, but the current packaging logistics concept has not taken the packed cargo into consideration. Therefore, within the proposed evaluation scope and measuring criteria, a concept that adds packed cargo characteristics to packaging logistics to consider their interaction's impact on sustainability is designed and proposed, as in Figure 4.3. Combining the original concept of packaging logistics and product-service-system, the proposed concept considers the sustainability of a system that includes cargo, packaging, and logistics. Under this concept, packaging and logistics processes interact with each other, forming the 'service' for the packed product; meanwhile, the packed product is interacting with the packaging logistics service to work together for the impact on sustainability.

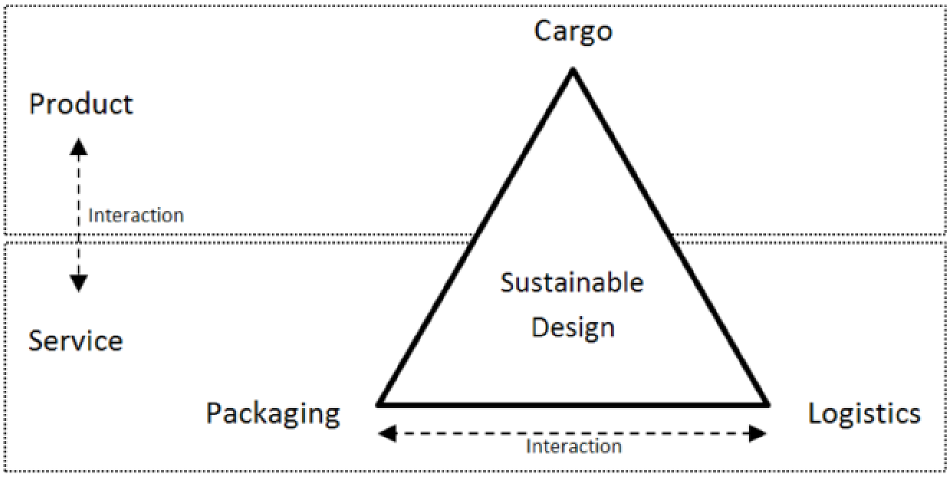


Figure 4.3 Proposed Concept of Sustainable Packaging Logistics System Design and Evaluation

4.2.2 Impact Assessment Model Development for Packaging Logistics Interaction

Following the concept of interactions between packaging, logistics, and packed cargo (Figure 4.3), an evaluation model is designed in this research to help analyse and understand the impact of the interactions between these elements and provide results of a quantified analysis for use in decision making on choosing suitable packaging alternatives in sustainable packaging design and development.

The impact from packaging–logistics interactions has been qualitatively researched and mapped out in the literature to highlight the form of impact for different stages and provide design guidelines (Saghir, 2002; Saghir, 2004; Hellstrom & Saghir, 2007;), but they are neither quantified nor systematic. Some research has quantitatively it measured for certain processes (Saghir & Jönson, 2001), but is limited to a specific process in a specific phase.

To holistically consider the interactions between the aforementioned elements, a traditional design tool (QFD) is chosen to tackle the problem of multi-interactive factors in design consideration. QFD was chosen as it can provide correlations between different interacting factors and it has been used in both sustainable supply chain design and green product design (Masui et al., 2003; Khan, 2004; Suziyanti et al., 2012; Lam, 2014). Also, QFD can decouple a complex multi-criteria decision-making process into simpler ones in a different matrix, and therefore is suitable for the complex inter-disciplinary decision in packaging logistics impact on sustainability at different stages of the supply chain by allowing different personnel in different fields working together for the evaluation (Hauser & Clausing, 1988).

To quantify the impact of packaging logistics and cargo interactions, firstly, the way these interactions impact sustainability needs to be understood. According to the interviews with the packaging designers and the lone retailing supply chain operations manager about packaging's and logistics' role and impact on sustainability, the interactions between packaging logistics and packed goods mainly reflected on the risk of packed cargo during all logistical processes along the supply chain, including possible process failures, potential operations difficulties, and product value decrease due to inappropriate packaging, incompatible logistics packaging process, or unsuitable packaging logistics for packed goods etc. And these potential failures further impact sustainable measures of cost, time, and waste generation as well as health and safety threats, etc. As revealed by UK-P&I-Club (2000), packaging-related issues predominantly contribute to shipping incidents, and the impact on sustainability (in terms of cost, emissions, and operator risk) is usually much higher than the packaging material itself. Therefore, to evaluate the impact of these interactions, FMEA can be considered, as it is a systematic inductive reasoning approach to identify potential failure (impact) at an early stage, as long as there is some known information (Stamatis, 2003), which is extremely helpful when new solutions are designed or proposed, as not all information along the life cycle is available to use.

Different from a traditional FMEA application area and format, the proposed method utilises a risk analysis concept in QFD format to present the packaging impact on sustainability performance. By combining QFD and FMEA, Tanik (2010) has conducted order processing design, adding in the design failure risks consideration. Unlike packaging design and evaluation in this study, the elements of FMEA (Probability and Severity) are used as context and factored into the QFD to present the impact result of interactions between factors of packaging, packed goods, and logistical activities from a holistic viewpoint in order to calculate the risk of packed cargo being processed in a given packaging logistic setting.

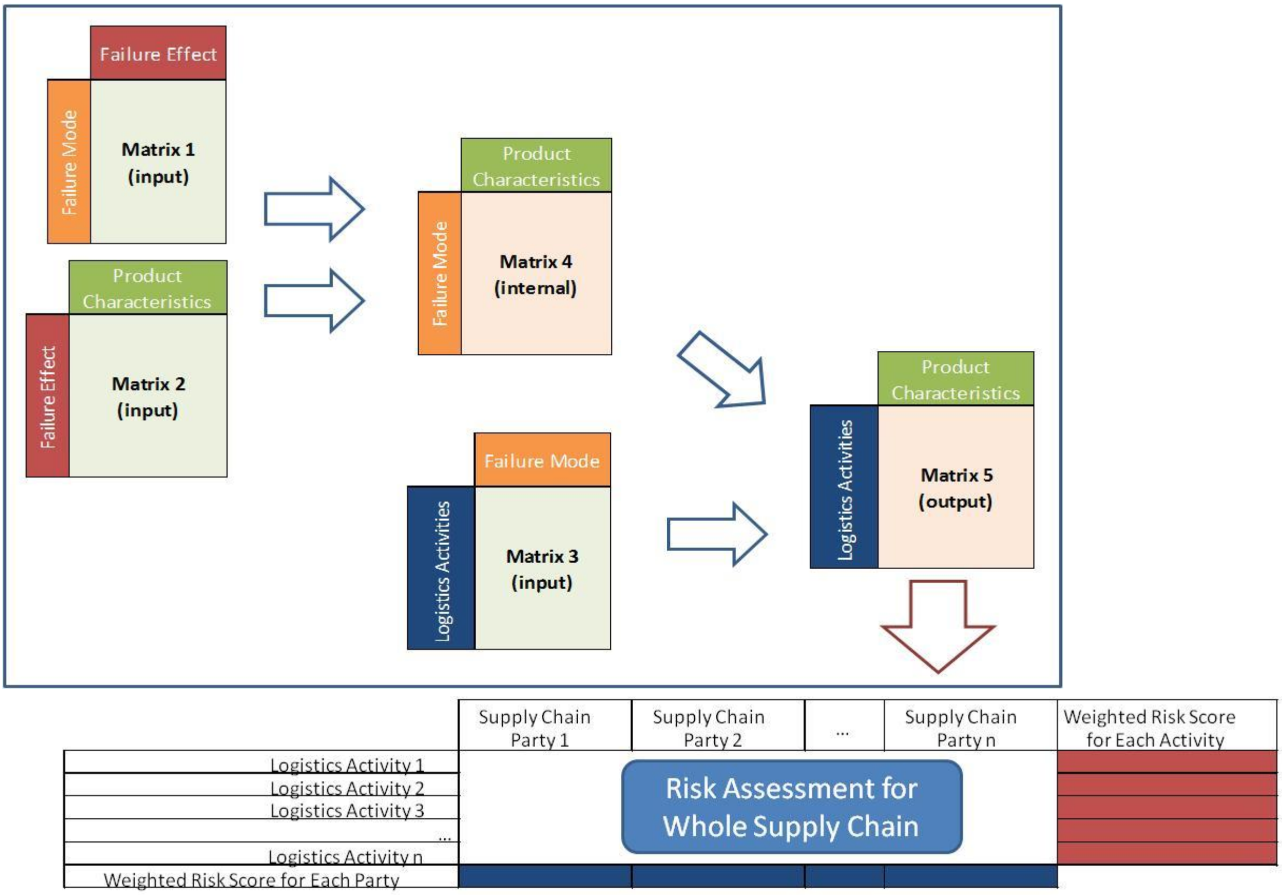


Figure 4.4 Schematic Diagram of Proposed Evaluation for Packaging Logistics Interaction

As a result of the above considerations, to integrate QFD and FMEA together, an approach composed of a set of matrices is developed to identify and quantify the potential risk impact brought by packaging and packaging-related logistics process for distribution of packed product, as illustrated in Figure 4.4.

Following the idea of FMEA, the format of QFD and the proposed interaction concept illustrated in Figure 4.3, the impact evaluation approach is designed as in Figure 4.4. The process is constituted by a set of QFD-style matrices, transforming one by one in a cascading sytle. The key interacted elements of packaging, packed goods and logistics processes, are used as factors in these cascading QFD matrices to transfer into a final result. Firstly, three input matrices need to be scored by the respondent:

> ***Failure Mode vs Failure Effect (Matrix 1*)** - showing the possibility of different consequences induced by the different failure event (what may happen to the package when different type of failure event occur?);
>
> ***Failure Effect vs Product Characteristics (Matrix 2)*** - representing the severity of each consequence according to the requirement of the product characteristics (How badly would each type of operation failure event impact on the packed product according to the product's unique characteristics?); and
>
> ***Logistics Activities vs Failure Mode (Matrix 3)*** - representing the probability of occurrence of failure event during each type of logistics process in the organisation (How likely is each type of failure event to occur during each type of logistical operation?).

These input matrices cover the important elements of traditional FMEA, namely ***Probability (P)*** and ***Severity (S)***. In this study, the ***Detective Difficulty (D)*** is not considered to take priority over the ***P*** and ***S*** factors (Fu et al., 2014), and, currently, there is no active mitigation approach to largely change the ***D*** measure in the researched packaging range.

By multiplying Matrix 1 and Matrix 2, Matrix 4 is generated, which represents the ***Risk Priority Number (RPN)*** of each failure mode for the packed product. This matrix is then further multiplied by input Matrix 3, taking account of different failure events' occurrence probability in each logistic process, transferred into the final matrix, ***Matrix 5 – Logistics Process vs Product Characteristics***, which can be summed up as: activities to reveal the risk priority level of the packaging system in delivering this certain cargo in the given logistics settings. In this way, all factors of packaging, logistics and packed goods are integrated and considered within the evaluation to assess the impact of interactions between them.

In terms of scoring the input matrix, similar to traditional FMEA and RCA (root cause analysis), a 7-point Likert-scale measure is designed to be used for the importance and interventions measurement (Pham, et al., 2010). Compared to a 5-scale measurement, it provides higher levels of differentiation, and compared to a 10-scale measurement, it is easier for the respondent to answer, simplifying the scoring process. Compared to directly using precise numerical historical data (e.g., for occurrence probability or frequency, or actual recorded value loss for operations failure each time), the utilisation of a Likert-scale measurement in the proposed evaluation approach has following advantages:

> Firstly, it avoids asking for sensitive information about the enterprise (which is usually a crucial concern for the respondent being interviewed or being asked to fill in the scoring questionnaire), but still effectively collects the information needed for the analysis.
>
> Secondly, the recorded operation failure usually only covers those failures that actually happened, ignoring near-miss situations and difficult operations being carried out, while the Likert scale is able to collect respondents' personal views and perspectives, that already integrate any non-recorded near-miss situation or potential difficulty or danger to the operation's fulfilment, according to his experience and view. In this way, the 'social' aspect in the sustainability concept that concerns the operation's health and safety issue is better embedded in the evaluation by this design.
>
> Thirdly, the designed tool utilises judgement and prospect in a different, simple matrix, simplifying the scoring task for each step, but it is able to consider complex relations between factors when the different matrices work together. Also, it is good for predicting results based on current information instead of waiting to know all the facts and information (Stamatis, 2003), which

is particularly useful at the design or trial stage, when not all facts and statistics are available.

In order to make the evaluation a general one that suits different scenarios, the factors in the matrices are chosen to be general ones. The following description takes a closer look at the proposed packaging logistics interaction matrix and explains the factors designed into the matrix.

In the input matrix, the following dimensions are designed to be used as input factors: Logistics Activities (LA), Failure Mode (FM), Failure Effect (FE), and Product Characteristics (PC), as conceptualised in Figure 4.3.

For logistics activities (LA), triangulated by empirical practice of the logistics depot and packaging logistics literature, Hellstroem and Saghir (2007) conducted mappings of different packaging-related activities in different supply chains, and suggested that although the logistics processes varied among different supply chains, they can be summarised into several general types, as discussed in the literature review. These are adopted in this evaluation to use as general activities:

LA1 Control and Verification – a process whereby the operator inspects or verifies the condition of the packaging, or the cargo;

LA2 Labelling – an operation whereby the operator applies a label or mark or places identification onto the packaging or packed product;

LA3/4 Filling (Auto and Manual) – a packing process whereby the equipment (auto) or operator (manual) fills the packaging with product and packs or seals the package;

LA 5/6 Handling (Auto and Manual) – a process whereby the equipment (auto) or operator (manual) lifts and reposition the package ata short distance;

LA 7 Storage – a process whereby the package is stored in a warehouse;

LA 8 Waiting – a short process whereby the package is settled in a place after a previous process and awaits the next logistical operation;

LA 9 Transport – a process whereby the package, carried by vehicle, travels from one place to another.

Factors of Failure Modes and Effects in the proposed approach are collected from interviewing logistics personnel for their daily operations practice and summarised from known general types of operation failure result. Failure Modes represent the cause of a failure event, showing what happens to the package during the operation, generally including:

Item Unidentified – package cannot be verified or identified in order to be processed in the next operation;

Item Tampered – package being tampered with, so the packed product no longer meets the description in terms of quantity or type;

Item Dropped – package drops down during operation;

Item Bended – package being bended or folded during operation;

Bump – package encounters unexpected bumping or vibration during operation process;

Contaminate – package is exposed in unexpected environment with contamination during operation.

Failure Effects are the consequence of the failure modes, indicating what will be the failure-event-of-package-processing-operation's impact on the packed product. In the proposed matrix, the following general failure effects are adopted from interviews with logistics personnel according to their daily operations and history failure record:

Wrong Item – the packed product is not the expected item that is needed;

Item Lose – one or more packed products are missing or cannot be correctly located;

Breakage – a packed product has major physical damage or scrape;

Scratch – a packed product has a minor physical defect that does not influence the main function;

Dirty/Dusty – a packed product contains unexpected dirt or dust that influences the product to some degree.

Product Characteristics used in the proposed approach are summarised from the literature (Lockamy, 1995; Saghir & Jonson, 2001; Verghese & Lewis, 2007) and confirmed by interviews with logistics personnel. Commonly, the packaging-logistics-related characteristics of product delivered in the package can be generally described in the following dimensions: Value, Size, Shape, Weight, Hardness, Pliability, Appearance, Fragility, Likeness to Shift, Sensitivity to Temperature, and Quantity in Each Package.

In this way, the factors used in the impact evaluation matrix are all general variables, and therefore the proposed evaluation approach becomes a general tool that can be used for different packaging, product, and supply chain scenarios.

After the scores transfer into Matrix 5, another challenge is how to integrate the RPN score for each activity, since in this matrix every logistics activity correlates with different product characteristics. A simple average or sum is not good, as some activities relate to more characteristics than others. Using top-3 or top-5 relevance would be better than an average or sum, but this may lose some interaction-and-impact correlations in the final RPN. Therefore, a weighted sum is applied to integrate the sub-RPN by the end of Matrix 5 (***Logistics Processes vs Product Characteristics***); instead of being treated equally for each product characteristic, they are weighted with different priorities. The weighting is designed to represent the importance of the product characteristics. The following chart (Figure 4.5) shows how the weighting is designed to be calculated:

	PC_1	PC_j	PC_n	
LA_1				
LA_i		S_{ij}		$W.RPN_i$
LA_m				
	W_1	W_j	W_n	

Figure 4.5 Illustration of Weighted RPN in Matrix 5

As illustrated in Figure 4.5, the weighting for each element S_{ij} is subject to the priority of its corresponding Product Characteristic (PC_j). since the PC_j carried from previous matrix transfer already contains the consideration-of-failure mode and effect on product characteristics, therefore, the sum of the S_{ij} column represents the priority of PC_j, and thus the priority weighting W_j for the PC_j column should be set accordingly, as shown in the equation below (1), which compares the related priority or importance of PC_j within all PCs, since a larger sum for PC_j means larger importance of this product characteristic in design and evaluation.

$$W_j = \frac{\sum_{i=1}^{m} S_{ij}}{\sum_{j=1}^{n} \sum_{i=1}^{m} S_{ij}} \qquad (1)$$

Then the weighted RPN for each logistics activities is calculated using the weighting W_j, which comes to:

$$W.RPN_i = \sum_{j=1}^{n} S_{ij} W_j \qquad (2)$$

The output risk priority in package delivery (under the evaluated setting of packaging and logistics) indicates the impact of this combination in this phase of supply chain (or to this supply chain partner), together with operation process mapping and analysis; this can be used to represent the impact or suitability of the packaging, packed goods and the chosen operation solution combination. It also differentiates the different impacts of this packaging combination on different supply chain partners at different phases. The RPN can provide useful packaging decision support:

For the same product, during different phases (supply chain parties) it could have a different result, revealing the cost and benefit allocation for different supply chain partners. It can be used for better balancing of cost and benefit brought by the packaging for supply chain partners to overcome the imbalance barrier that obstruct the adoption of a sustainable packaging system.

For the same packaging logistics combination, the RPN varies among different logistic operations, indicating the potential improvement and what are the critical logistic processes in a given scenario.

For different products, their characteristics can be extracted as the input of the tool, and the output can tell whether the packaging and logistic processes are suitable for them to share according to the output (risk priority value) of the tool.

When conducting the evaluation tool, in order to get the input for the evaluation matrices, a questionnaire is designed and delivered to experts, operators, and packaging users at different stages of the supply chain, for their judgement and opinion as input of the matrix. The questionnaire is attached as Appendix.

4.2.3 Comparison with Traditional Risk Assessment Tools

In order to validate the meaning and calculation result of the proposed matrix transfer method, the numerical process is illustrated and compared with a traditional risk-assessment tool. This would numerically validate the calculation of the proposed evaluation method and provide a basis of comparison for effectiveness, ease of use, and suitability for general usage between proposed tool and traditional tool.

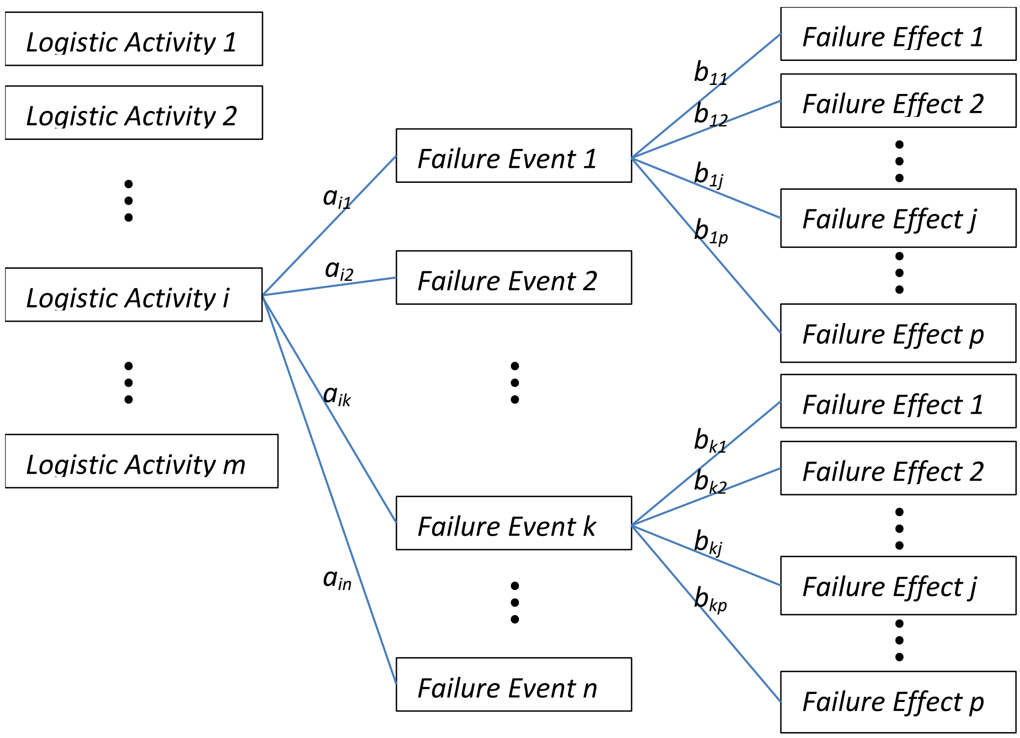


Figure 4.6 Illustration of Expanded Event Tree and Fault Tree

Take the probability matrix of ***'Logistic Activity vs Failure Event'*** as an example: Figure 4.6 illustrates how a typical traditional risk assessment approach evaluates the impact of each failure mode and effect, as in the Event Tree Analysis (ETA) and Fault Tree Analysis (FTA) risk assessment methods. With the assumption that each failure event can result in a listed failure effect individually (with different probabilities), as shown in Figure 4.6, when estimating the failure occurrence probabilities based on ETA and FTA calculation:

For each *activity i*, the occurrence probabilities of *Failure Event 1* to *Failure Event n* are given as a_{i1} to a_{im} , respectively. Each *Failure Event k* (k = 1, 2, …, n) can induce different *Failure Effect j* (*1* to *p*) with probability of b_{k1} to b_{kp} , individually.

The *Failure Effect 1* to *p* is a list that summarises all possible failure consequences that ever (or potentially) occurs in the system.

For example, b_{12} shows the probability of *Failure Effect 2* within the occurrence of *Failure Event 1*, which can be represented as:

$$b_{12} = P(Failure\ Effect\ 2 \mid Failure\ Cause\ 1) \qquad (3)$$

Combining with the consideration of the event occurrence probability of *failure Event 1* in *Logistic Activity i* is a_{i1}, the probability of a *Failure Event 1* - induced *Failure Effect 2* during *Logistic Activity i* can be calculated as:

$$P(Failure\ Cause\ 1 \mid Logistic\ Activity\ i)P(Failure\ Effect\ 2 \mid Failure\ Cause\ 1) = a_{i1}\, b_{12} \tag{4}$$

Therefore, the probability of certain *Failure Event k* induced *Failure Effect j* can be represented as:

$$P(Failure\ Cause\ k \mid Logistic\ Activity\ i)P(Failure\ Effect\ j \mid Failure\ Cause\ k) = a_{ik}\, b_{kj} \tag{5}$$

Once summarising all conditional probability for each *Failure Effect j* induced by all different failure events during *Logistic Activity i*, total Probability of *Failure Effect j* during *Logistic Activity i* is represented as:

$$\sum_{k=1}^{n} P(Failure\ Cause\ k \mid Logistic\ Activity\ i)P(Failure\ Effect\ j \mid Failure\ Cause\ k) = \sum_{k=1}^{n} a_{ik} b_{kj} \tag{6}$$

This expression can be compared to the Matrix Multiplication proposed in the evaluation method, which can be explained by the calculation shown below.

The Matrix A (size m*n) is the probability of failure event occurrence: *Logistic Activities* vs *Failure Event* (causes to effects), which can be presented as:

$$\begin{bmatrix} a_{11} & \cdots & a_{1k} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{i1} & \cdots & a_{ik} & \cdots & a_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mk} & \cdots & a_{mn} \end{bmatrix} \tag{7}$$

Similarly, Matrix B (size n*p, shown below) represents the probability of failure effect induced by each failure event: *Failure Events* vs *Failure Effects*.

$$\begin{bmatrix} b_{11} & \cdots & b_{1j} & \cdots & b_{1p} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ b_{k1} & \cdots & b_{kj} & \cdots & b_{kp} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ a_{n1} & \cdots & b_{nj} & \cdots & b_{np} \end{bmatrix} \quad (8)$$

Therefore, in the new Matrix C (size m*p, *Logistic Activities* vs *Failure Effects*) formed by multiplication of A and B, each element C_{ij} can be calculated by the matrix multiplication rule, which equals:

$$a_{i1}b_{1j} + a_{i2}b_{2j} + \cdots a_{ik}b_{kj} \cdots + a_{in}b_{nj} = \sum_{k=1}^{n} a_{ik}b_{kj} \quad (9)$$

The expression of matrix calculation result in Equation 9 conforms to the result from the FTA calculation result in Equation 6. Validated by traditional risk assessment methods FTA and ETA, the proposed matrix transfer result (*Logistic Activities* vs *Failure Effects*) can correctly present the occurrence probability of each possible failure effect (consequence) during each logistics activity. Similar numerical validation applies to other matrices in the proposed method.

Since in the traditional ETA model, every event node can only contain two branches, for a size of (for example) 6 (causes) by 9 (end consequences), the event tree needs to go through 96 (6 × 16) different branches, while the proposed matrix needs a scoring value of 54, which reduces the workload (consideration) and time consumption for the evaluation. The more interdependent the failure event and consequences, the easier and faster the proposed method would be in favour.

Both approaches can be used to explore the mechanism of failure event and provide priority for improvement, but the proposed method can be easily used for different types of products, packaging and logistics, or supply chain structure, as the factors designed in the matrix summarise general variables for packaging logistics interactions. The traditional Failure Tree or Fault Tree Analysis, however, needs the failure tree to be built from scratch for every different case, which requires experts with wide knowledge and deep understanding of the scenarios.

Importantly, the proposed model enables co-operations in design and evaluation to facilitate practical work by assessment teams, by decoupling assessment into different matrices. Different experts can focus on their own domains independently and work together collaboratively to integrate the assessment process. On the contract, traditional FTA and ETA could not decouple the task to different experts for different parts of the evaluation.

4.3 Integrated Approach for Sustainable Container Supply Chain Evaluation

4.3.1 Container Supply Chain and Packaging Logistics

Just as the concept of packaging logistics, the container supply chain does not refer (nor is it limited) to the supply chain of the container itself, i.e., how the container is made as a product from raw material, how it is delivered to its users to be used, and how it is reprocessed or disposed of at its end-of-life. Instead, according to Fransoo and Lee (2013), 'container supply chain' refers to a container shipment or cargo shipment in the form of container shipping from a supply chain perspective, which shifts the focus from an asset-driven to a supply-chain-driven perspective.

There is scant research in the literature on provision of a detailed comparison between reusable packaging and maritime containers; likewise, between packaging logistics and container shipping. But, for the known similarity in the definition, their roles within the supply chain, and the characteristics of the two (packaging and container), it can be useful to compare and identify the similarity and difference between them, so that the theory and research can be altered and applied to each other across these two research fields. After reviewing and comparing the literature, some of the key similarities and differences between packaging and container are listed in Table 4.2 (summarised from the literature on recovery value in the closed-loop supply chain, and from the literature on delivery performance and risk measurement, e.g., Gu et al., 2008; Lambert et al., 2011; Rogers et al., 2012; Yan & Sun, 2012;). This would contribute to building a connection between packaging and container, to be a consideration reference when adopting theories between the one and the other.

Table 4.2 Comparision between Reusable Packaging and Container

	Difference		Similarity
	Reusable Packaging	**Container**	
Design and Product Feature	Less standardised; More customised features for different cargo and operations; Less common to share between different goods; Flexible to be used for end-customer;	More standardised; Less customisation features; Often shared between different cargo and goods; Mostly used for between-business flow;	Can be reuse to bear multiple trips after end-of use;
Logistics Operation	Logistics operation for packaging and goods: packaging, verifying, handling, transporting, storage, etc.;	Common container operation: loading, unloading, handling, storage, etc. and their constituted value-adding service like consolidation, deconsolidation, cross-docking and so on;	The condition of the packaging/container needs to be monitored for reuse and extra operations (e.g., checking, sorting, cleaning) needed for reuse;
Failure Mode and Consequence	Failure modes focus more on physical aspect; Environmental impact of failure mainly reflects on waste material of per unit package damage;	The failure consequence of delay, inappropriate, can be significant to customer satisfaction, cargo value loss, operation, and operator satisfaction; usually with higher cost and environmental impact for failure as the unit cargo is larger;	The failure in operating the packaging or container can lead to cargo or packaged goods' negative consequence that impact on sustainability of the business;

Cost Structure	Value recovery relatively low for end-of-use; Usually not able to accommodate large amount of goods, therefore, operation cost per unit cargo is relatively high;	Large end-of-use value to be recovered; Compared to high volume and value of contained cargo, the operation cost per unit cargo is relatively low;	Both with decision on return or reverse logistics for end-of-use items;
Empty Flow	Insignificant environmental impact for empty return when the end-of-use items are returned in the same journey of delivery and large return demand can be consolidated to one trip.	Significant sustainability impact for empty return or redirect flow as every return item require its own return flow.	Reuse-inducing empty travel for both contributes to environmental and economic impact.

This comparison is also used in this study as a reference when developing an integrated design, planning, and evaluation tool for a sustainable container supply chain that integrates the container, the sub-packaging inside the container, and container-related operation process into one single integrated assessment. The theory origins from packaging logistics in packaging industry, can thus be applied in container supply chain context to help sustainable container supply chain decision making and process improvement.

4.3.2 Sustainability Evaluation Framework for Container Supply Chain

After similarity and difference between packaging and container supply chains, based on the same concept of packaging logistics impact evaluation, the proposed evaluation for packaging can be altered for a container shipping context.

Similar to packaging logistics evaluation, in order to evaluate the sustainability of the container supply chain, a proper framework is needed to describe what should be measured and how far it should be considered in the container shipping supply chain. Table 4.3 summarises a container supply chain operation and service-sustainable key performance indicators (KPIs) (Gunasekaran et al., 2004; Song, 2010; Lai, 2012), where 'efficiency' indicates how the resources are utilised, and 'effectiveness' measures how well the goals of the operation are accomplished.

Table 4.3 Sustainable KPIs for Container Operation and Services (source: Gunasekaran et al., 2004; Song, 2010; Lai, 2012)

Container Operations' Value	**Measurement Criteria**	**Key Performance Indicators**
Efficiency	Business cost	Total logistics management costs Return processing cost
	Environment cost	Energy costs Carbon emissions
Effectiveness	Lead-time	Inventory days of supply Response time
	Service quality	Delivery/Handling performance Oder fulfilment

With reference to this container operation value and the concept of sustainability, the main criteria to be measured are cost, environmental impact, and service quality, simplified in this study as cost, carbon emissions, and service lead-time. Under this framework, the business costs, environmental impact, service lead-time, and service quality are the key factors to be measured for the analysis of container supply chain solution design. The detailed composition of these key sustainable performance indicators to be measured in the framework is introduced as follow:

- **Service Lead-Time (LT)**

  Lead-time is an important parameter in the supply chain that directly relates to the effectiveness measure, like customer satisfaction and service quality. It significantly influences the operations cost and affects the utilisation of equipment and facilities in the supply chain. In this research, the lead-time covers the whole door-to-door journey of the cargo, from when the cargo is sent out from the original depot/factory until the empty container is back at the container yard under the shipping line's (or container owner's) control, shown as the closed-loop material flow in Figure 4.7.

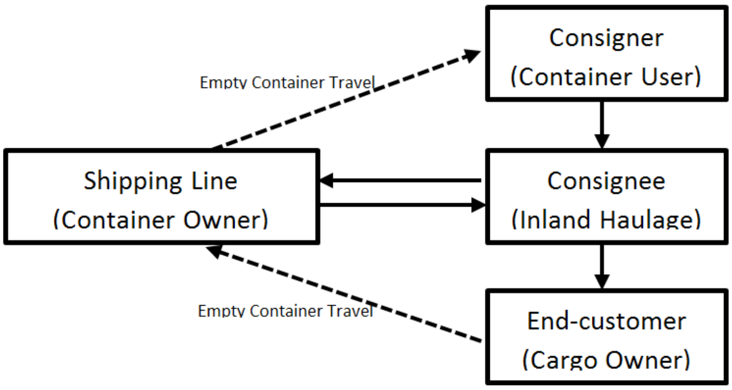


Figure 4.7 Closed-Loop Flow for Container in Supply Chain

- **Cost (C)**

As shown in Figure 4.8, the total cost considered in this research is composed of Sea Freight Cost (C_s), Loading and Discharging Cost (C_d), Fixed Documentation Cost (C_f), Inland Haulage Cost (C_h), Container Internal Packaging Cost (C_p), Container Leasing Cost (C_l), and potential Environmental or Emissions Cost (C_e). To estimate these costs, the following rates are considered: Freight Rate (£/TEU), Discharging Rate (£/TEU), Inland Haulage Rate (£/TEU), Carbon Trading Price (£/TEU), Container Leasing Price (£/day·TEU), and Return Container Re-allocation Fee (£/TEU). The total cost is the sum of all possible costs mentioned above that occurs during the cargo shipping along the container supply chain to the end-customer. And then, for easier comparison between different scenarios, the cost is calculated as a per-unit cargo cost for the logistic solution from an end-customer-oriented perspective.

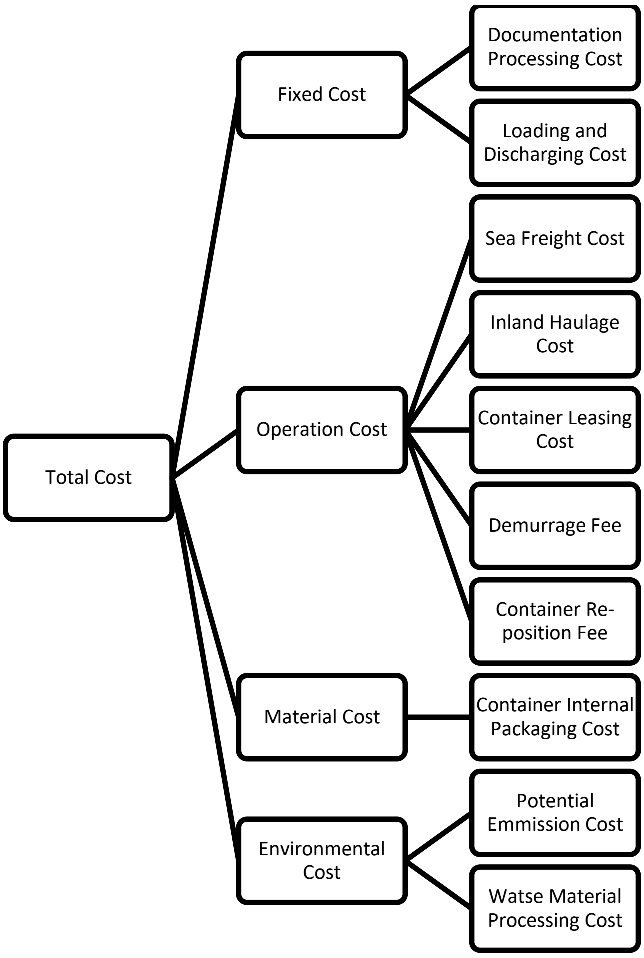


Figure 4.8 Breakdown of Cost Structure for Container Shipping

- **Carbon Emission (E)**

This part mainly includes the emissions of the packaging material manufacturing, disposal or processing of waste material and the transport emissions, which utilises the factors of Consignment Weight (tonne), Distance of Each Transport Mode (km) and Emission Factors of Each Mode (kgCO2 / kgCargo.km) according to IPCC (2007), which can be expressed as:

$$E = E_t + E_m = \sum_{i=1}^{n} W_i \cdot D_i \cdot EF_i + E_m \quad (10)$$

Where E_t and E_m represent transport emission and material processing emissions respectively; W_i, D_i, and EF_i, refer to consignment weight, transport distance and unit emission factor for the transport mode.

4.3.3 Evaluation Scope and Boundary for Container Supply Chain

As discussed previously, the scope and boundary of the evaluation are crucial to the validity of assessment (to assess what is supposed to be evaluated). Fransoo and Lee (2013) have illustrated the contractual and operational relationship between supply chain partners in the container supply chain (shown in Figure 4.9), which reveals the actual 'container supply chain' from a supply-chain perspective instead of 'the supply chain of container' as a 'product'.

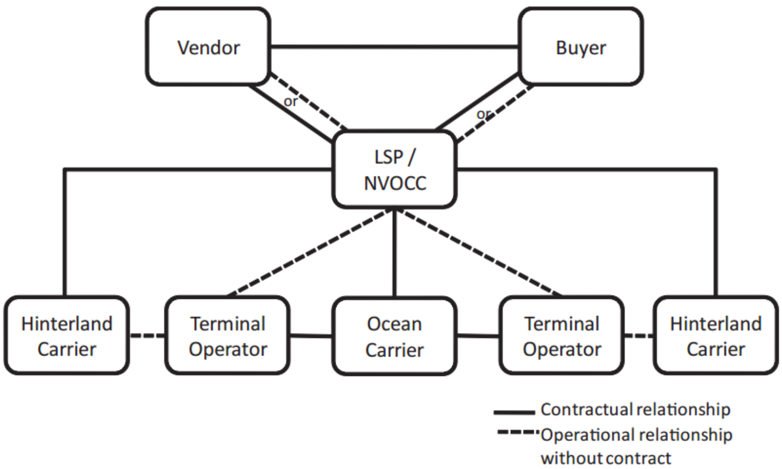


Figure 4.9 Relationship between Parties in Container Supply Chain (source: Fransoo & Lee, 2013)

Traditionally, much research focused on the 'port-to-port' or 'quay-to-quay' analysis, which focuses only on the sea transport mode. But the fact is that although sea transport distance and time are much larger than for other modes within the supply chain during inter-continental trading, yet inland haulage has a more significant impact on cost and emissions, which largely determines the sustainability performance of the solution. Also, as stated by Fransoo and Lee (2013), the container supply chain focus is shifting from an asset-driven basis (concerned more with a single process or facility) to a supply-chain-driven basis (more concerned with end-customer-oriented service).

Therefore, to avoid a sub-optimal solution evaluation, and to evaluate the scenario from the customer's or service user's perspective (as the customer or cargo owner on the top of the contractual relationship in the container supply chain is much more concerned about the cargo's arrival at the end-customer's premises than about the cargo's arrival at any particular destination port or interchange depot), the proposed evaluation is based on a 'door-to-door' scenario rather than a traditional 'quay-to-quay' analysis, covering the phase from when the consolidated cargo is received by the shipping line in the yard to the point when the cargo is received by the end-customer and the empty container is back under the control of the shipping line, as illustrated in Figure 4.10.

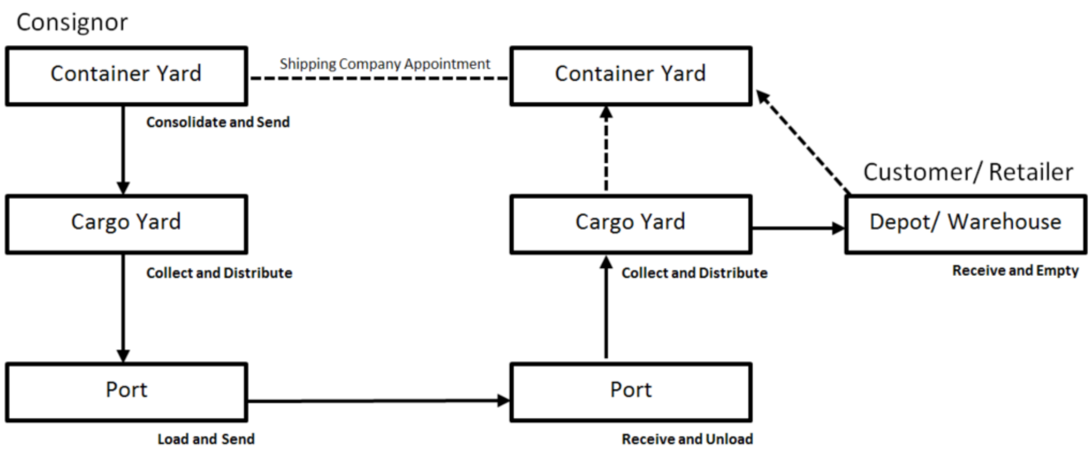


Figure 4.10 Proposed Door-to-Door Evaluation Scope

4.3.4 Operation Risk Consideration for Container Supply Chain

Similar to the packaging logistics scenario, the previously introduced calculation for sustainable KPIs under the framework of a sustainable container supply chain is an ideal situation, one without the consideration of potential operational risks and failures. To integrate the consideration of the impact from potential operational failures and risks, the impact evaluation of packaging logistics is altered and applied to a container shipping context. As for the complexity of composition and factors in a container supply chain, different factors like operational sites and routes need to be considered for their impact on sustainability KPIs.

- **Operation Risk Evaluation Matrix for Container Supply Chain**

According to container shipping supply chain's operation performance goal and general cargo characteristic classification information, the risk and impact matrix in packaging logistics evaluation is modified for a container-shipping-specific context as in Figure 4.11,

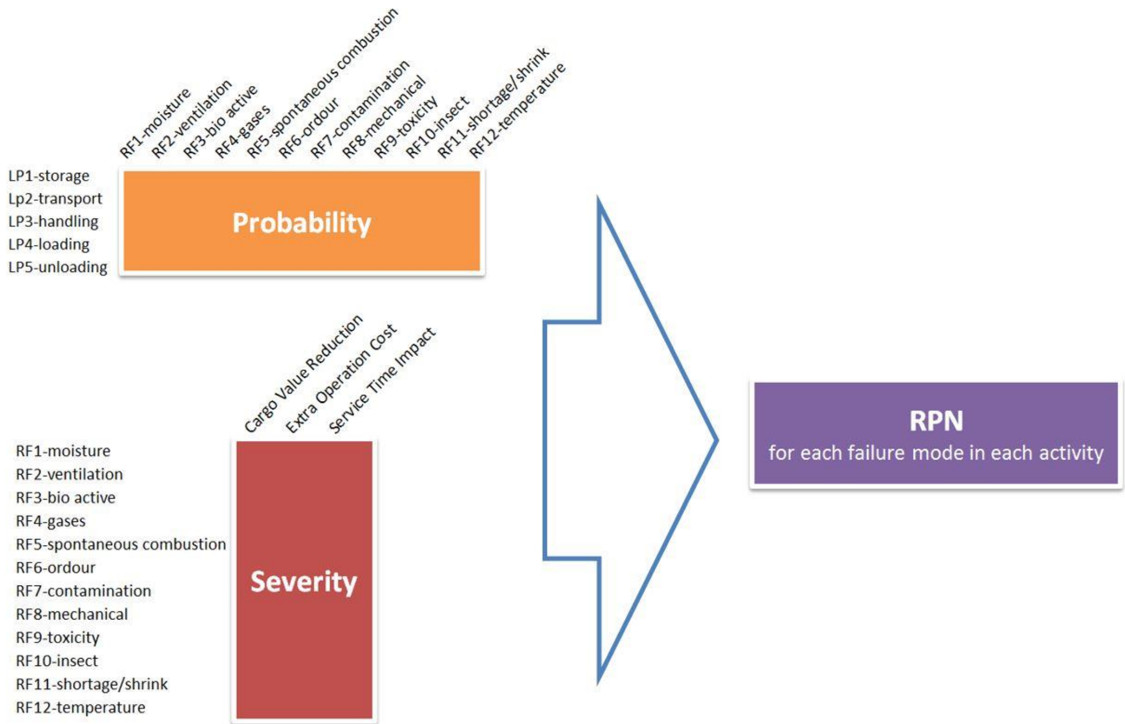


Figure 4.11 Evaluation for Packaging and Logistics Activities Interaction in Container Context

The risk factors in each transport node are considered as the interaction between package and logistics activities by a proposed set of matrices referring to FMEA (Failure Mode Effect Analysis), which is shown in Figure 4.11. The probability matrix reveals the occurrence probability of each risk factor during each logistics process according to the given logistics setting, and the severity indicates the consequence for the cargo according to the cargo characteristics. These can be used in the simulation model as input (to be introduced later in this section) or to perform a RPN for each logistics activity as decision support.

- **Factors Identification for Container Supply Chain Evaluation Model**

Although as shown in Table 4.2 that the container supply chain has more variety of value-adding service (like consolidation, cross-docking, deconsolidation, and so on), yet they can all be decomposed to common or general logistics activities and operations in terms of physical movement, including storage, transport, handling, loading, and unloading. Therefore, these general logistics processes are selected to be used as the 'Logistics Process' factors in the container supply chain evaluation.

As analysed in the review of the literature, the container is more than a coloured box, and should not be simply regarded as a 'black' box in the analysis. There are many different types of potential failure threatening the cargo inside the container during a shipping operation, such as: mechanical stress during transportation of different types; packaging or the manner of packaging does not fit the purpose; the cargo is not properly packed against the expected conditions of the specific expected means of transportation; defeats in container selections and inspections; if the container has a defect of sealing, odour, or any operative function, certain cargo inside the container could face value loss in certain environments; load plan (how the goods and cargo are packed inside the container); load securing (how the container is secured in the vehicle or equipment); operation facility (what equipment and assets are used for the operation); climate status; humidity; and so on. All in all, there are many risk factors that impact container shipping operations and could spell failure; they include how the cargo is packed inside the container, how the container is processed (facility, equipment, and operational environment), what types of transportation modes are chosen, and what type of cargo is carried. These considerations, however, provide the solution alternatives and diversities when the solutions are analysed and compared.

There are different types of risks related to the cargo, but they can be summarised into mainly 12 types of risk factors covering different categories of cargo with different characteristics, according to the German Insurance Association GDV (2002). These general potential risk factors are used in the input matrix for the evaluation. The risk factors related to cargo characteristics including following:

RF1-Moisture and Humidity: the relative humidity or water content of cargo and its surroundings, and water absorption capacity (maximum equilibrium moisture content) of packed cargo; this refers not only to the situation that the cargo absorbs moisture from an excessively humid environment, but also includes situations where a hygroscopic cargo's water is being released into its surroundings, to reach the point of moisture equilibrium in the container.

RF2-Ventilation: the requirement of ventilation provision for the cargo, such as the need of air exchange, or circulation to ensure fresh air or air flow, supplied in a timely manner to the cargo in the container; also, this sometimes refers to the prohibition of ventilation for certain type of goods in some instances.

RF3-Bio active: this represents biotic activity of cargo during shipping, as the cargo constantly interacts with the operation's environment, passively or actively. This risk factor can be classified into five different categories, according to GDV (2002)

BA 0: no biotic activity. The cargo remains in passive behaviour during the transportation and is non-living.

BA 1: 1st-order biotic activity. This refers to living organisms with intrinsic metabolism (mainly anabolic metabolism), such as livestock and poultry.

BA 2: 2nd-order biotic activity. This includes living organisms in which respiration processes predominate, such as fruits, grains, vegetables, etc.

BA 3: 3rd-order biotic activity. This refers to goods without respiration processes, but with biochemical, microbial processes; usually this type of goods is not hermetically sealed (for instance, fish, meat, dried fruit, processed grain, etc.).

BA 4: 4th-order biotic activity. Goods processed and fully sealed, with no biochemical or microbial processes taking place in the cargo during the transportation. Such goods (e.g., preserved foods, beverages, etc.) are fully isolated from the environment.

RF4-Gases: Changes in cargo's sensitivity to different gaseous content, such as reaching upper limit of admissible CO_2 or high oxygen content-induced oxidation, or conversion of ethylene to ethylene-sensitive goods.

RF5-Self-heating and Spontaneous combustion: Hazard that is due to self-heating, induced by cargo's attributes of fibre or oil content, and external environment like temperature, humidity, oxygen, and so on.

RF6-Odour: Odour risk factor includes active and passive types. Active odour risk represents the release of odour by the cargo, while passive odour risk comes from the cargo's sensitivity to foreign odours. This can provide recommendation for a mixed goods situation to avoid mixing of certain cargoes with each other.

RF7-Contamination: Contamination risk factor also includes two situations, namely active and passive behaviour, depending on the cargo causing the contamination or the cargo is sensitive to contamination by other products.

RF8-Mechanical: This risk comes from sensitivity of the cargo to mechanical operation and inappropriate processes, such as pressure, abrasion, nobbing, etc.

RF9-Toxicity/Hazards to Health: This refers to hazards to health and safety, usually due to excess concentration or lack of certain gas composition in the environment, such as elevated carbon dioxide level, oxygen shortages, and toxic substances present in the cargo.

RF10-Insect infestation/Diseases: Cargo susceptible to molds, bacteria, and microorganisms; also includes situations in which cargo gets infested by insects, small animals, or other living organisms.

RF11-Shortage/shrink: This refers to a reduction in cargo's weight caused by water vaporisation, as well as loss of volume owing to breakage or theft, etc.

RF12-Temperature: Cargo has requirement on temperatures during different phases or for different operations, such as: in transit, loading, and storage. Excessively high or low temperatures during logistical operation and temperature variations are associated with risk. And for come cargo, the condensation formation will also be influenced by temperature variation in containers or in holders.

Once the risk factors have been classified, the variety of cargo can also be categorised. For the common cargo being transported, according to GDV (2002), they can be divided into different categories and sub-categories, as shown in Table 4.4, including main categories of food, light industry products and heavy industry products, with the category code to be used in Table 4.5.

Table 4.4 Category of Common Cargo

Main Industry Code	**Category Code**	**Sub-category Code**
A - Food	A1 - Cereals	
	A2 - Food Industry Residues	
	A3 - Fats and Oils of Animal and Vegetable Origin	
	A4 - Oil Bearing Seeds	
	A5 - Spices	
	A6 - Foods of Vegetable Origin	A6a - Fresh Fruit and Vegetables

		A6b - Dried Fruit and Vegetables
		A6c - Nuts
	A7 - Foods of Animal Origin	A7a - Meat
		A7b - Fish
		A7c - Diary Products
	A8 - Raw Materials of Semi-luxury Item	A8a - Soluble Beverage Material
		A8b - Beverage
		A8c - Sugar
B - Light Industry Products	B1 - Semi-finished Lumber Products	
	B2 - Rubber	
	B3 - Textile Products	
	B4 - Vegetable-derived Fibres, Textile Materials	
	B5 - Animal-derived Fibres Materials	
C - Heavy Industry Products	C1 - Lumber Products	
	C2 - Machinery	
	C3 - Metal and Steel Products	
	C4 - Minerals	
	C5 - Motor Vehicles	

Clarifying the category of cargo (coded from A1 to C5) and types of risk factors (coded as RF1 to RF12), Table 4.5 is generated for help with decision-making support, in which the correlation between risk factors and cargo cluster is established. This is used as reference for later scoring considerations. The correlations are presented in linguistic terms to describe the relationship (Wang et al. 2008).

'H' - High - represents a tight relationship between the risk factor and the type of cargo, indicating this type of cargo has characteristics that are easily affected by the risk factor;

'M' – Medium - shows some relationship between the cargo and the risk, indicating moderate influence of the risk factor on this type of cargo;

'L' – Low - means that there is hardly any correlation; the risk factor can barely affect this type of cargo.

Table 4.5 Relationship between Different Types of Cargo and Risk Factors in Container Supply Chain

	RF1	RF2	RF3	RF4	RF5	RF6	RF7	RF8	RF9	RF10	RF11	RF12
A1	H	H	M	M	M	H	H	M	H	H	M	H
A2	H	H	M	M	H	H	H	L	H	H	M	H
A3	H	H	M	M	M	H	H	M	H	L	M	H
A4	H	H	M	M	M	H	H	H	H	M	M	H
A5	H	H	M	L	M	H	H	H	H	H	M	H
A6a	H	H	M	H	L	H	H	H	M	H	M	H
A6b	H	H	M	L	M	H	H	H	M	H	M	H
A6c	H	H	M	M	H	H	H	H	M	H	H	H
A7a	H	M	M	M	L	H	H	H	M	H	H	H
A7b	H	M	M	L	L	H	H	M	H	H	M	H
A7c	H	H	M	M	L	H	H	H	M	M	M	H

A8a	H	H	M	M	L	H	H	M	M	M	M	H
A8b	H	M	L	M	L	M	L	H	L	M	M	H
A8c	H	H	M	L	L	H	H	H	L	M	L	H
B1	H	M	L	L	H	M	M	M	L	L	L	L
B2	H	M	M	M	H	M	H	M	L	M	M	H
B3	H	M	L	L	H	H	H	H	L	M	H	M
B4	H	H	M	M	H	M	H	H	M	H	M	H
B5	H	H	M	M	H	H	H	H	M	M	M	H
C1	H	H	M	L	H	H	H	H	L	H	M	M
C2	H	M	L	M	L	L	M	H	L	M	M	M
C3	H	M	L	H	L	L	H	H	L	L	M	L
C4	H	M	L	M	L	H	H	H	L	L	M	M
C5	M	M	L	H	L	M	H	H	L	M	M	L

By cross-referencing risk factor and cargo information, experts are invited to give a score (1 to 10) to each block of the input matrix for risk evaluation in Figure 4.11. The first matrix is logistic activities versus package (packed cargo) risk factors, which represents the probability of different failure type/mode occurrence during different logistics processes, considering the properties of the package. The second matrix is the severity impact for the packed cargo when a certain type of failure occurs.

As detailed above, in the designed evaluation matrix, the logistics activities are designed to include general logistics operations of storage, transport, handling, loading, and unloading, which covers generic logistic activities common to different supply chain structures; the risk factors are also generic, covering most characteristics of different types of generic cargo and different general types of failures in logistic processes, including issues or sensitivities in moisture, ventilation, bio-active, gases, spontaneous combustion, odour, contamination, mechanical, toxicity, insect, shortage/shrinkage, and temperature.

Thus, the proposed evaluation matrix is also a universal tool suitable for different transport modes and different cargo in different scenarios. These matrices can be used to produce a RPN (Risk Priority Number) to assign a risk level of processing the cargo in a given packaging during certain logistics processes in each transportation node within the given supply chain structure. In line with the numerical analysis of sustainable performance measures, the RPN is helpful for identifying the potential operation improvement and for decision making on choosing proper packaging and suitable routes for container supply chain.

4.3.5 Integrate Operation Risk into Consideration for Sustainable Container Supply Chain Evaluation

Establishment of an evaluation framework, numerical model and identification of the risk evaluation factors provide a solid base for the integrated evaluation of sustainable container supply chain. For the complexity of factors and various impacts of operational risks on different sustainability KPIs, a simulation model is proposed to integrate the operation risk consideration into the sustainability evaluation model. The simulation can better integrate the influences of different variables to reveal the complex impact of multi-factors on different dimensions of sustainability measurements (Van der Vorst et al. 2005; Vorst, 2009). To this need and consideration, an agent-based simulation model is developed.

- **Integrated Simulation Model Overview**

It is an agent-based simulation model, which treated each cargo, transportation node (both distribution centres and ports) as an intelligent agent (details refer to Table 4.6) to simulate the whole process of the container supply chain. As intelligent agent unit, each time of simulation, the cargo agent is able to store the cargo, container packaging and route information, also to record the cost, time and emission along the supply chain when it is being processed in each operation. And the transportation nodes are also agent units, can be configured to process different packed cargo according to preassigned operation procedures, and react differently for different container-packaging –cargo combinations.

As shown in the schematic diagram in Figure 4.12, the simulation model is divided into an information layer (upper) and a physical layer (lower). The information layer represents the control of flow of information input and decision output, which stores the settings, data, and measurement information of the simulation, including the simulation conditions (e.g., the accumulated failure type/rate, weighting/preference for different sustainability indicators); performance on sustainability are measured, recorded, and processed from the physical layer, to provide a comparable result of different possible solutions (combination of container packaging and logistic planning) for decision-making support result on container supply chain sustainability.

Table 4.6 Agents in the Proposed Simulation Model

Agent	**Representation**
Cargo	Specific goods with specific characteristics relating to the container packaging and operations environment.
Vessel	Climate-controlled vessel with specific energy consumption and emission factors for ocean transport.
HGV	Road vehicle with specific energy consumption and emission factors for hinterland transport.
Depot	Either a production factory that generates cargo according to demand control, or a distribution centre that receives, stores, and processes the cargo following its embedded workflow.
Port	Sea port that receives or sends vessel loaded with cargo, and conducts container related operation according to its given process flow.

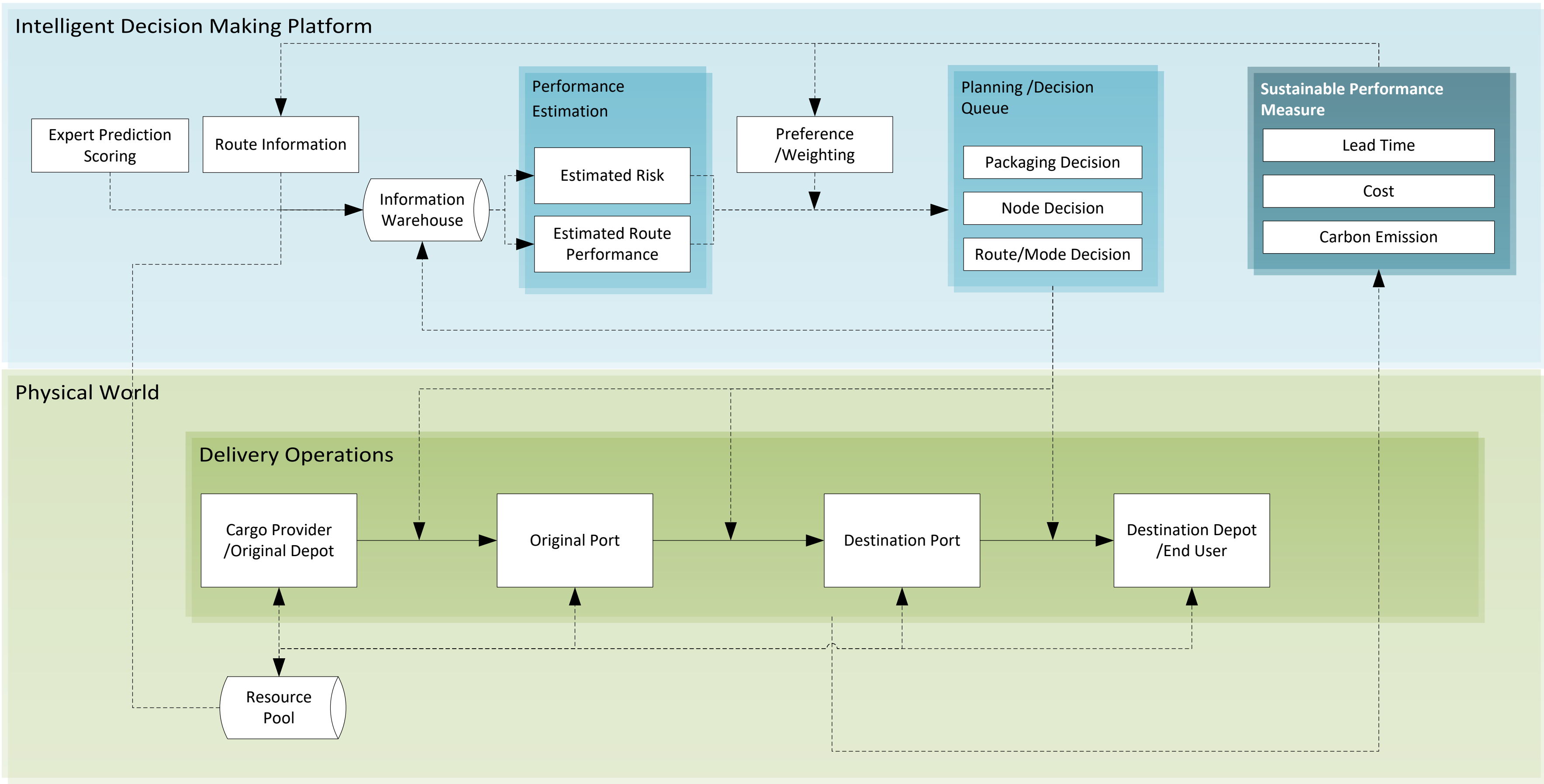


Figure 4.12 Schematic Diagram of the Proposed Simulation Model

In the physical simulation layer, each transport node is designed as an intelligent agent that embeds different combinations of logistics operations (as logistic activities in probability matrix) for incoming and outgoing cargo according to actual process flow that is coded for the transportation node. This layer is the simulation of physical flow of the supply chain. The transportation nodes deal with the packed cargo whenever the cargo travels through the node following its route plan.

Example of operation flow chart for one transportation node is shown as the software screenshot in Figure 4.13, where each of the events for the agent is linked to cargo processing logistics operation in the physical world. Each agent-handling activity in the transport node's operations chart represents an actual container cargo logistics operation (e.g., the 'source' represents the cargo generation process pulled by demand; the 'resourceAttach' module links to the goods consolidated into the container packaging 'resource' becoming a container cargo; 'loading' is the process whereby the container cargo is handled to be loaded onto a vehicle or vessel, etc.).The physical layer simulation output will be stored by the information layer for decision-making support provision.

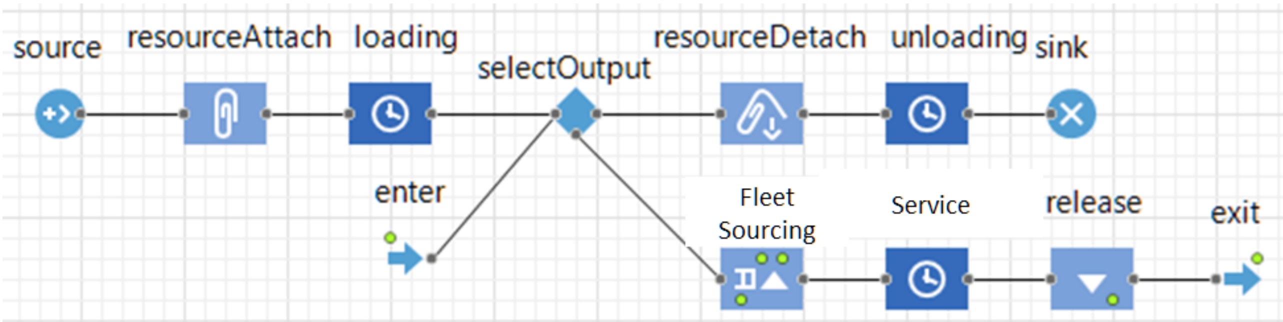


Figure 4.13 Example of Discrete Event Based Physical Process Flow within Typical Transport Node

- **Failure Risk Event Simulation**

As previously stated, the cargo agent records the packaging information in it and when it is processed by each logistic operation, the embedded failure event will be simulated by the simulation model to determine how long will it take for each activity and whether any type of failure occurs during this process. The failure events are designed as discrete events in the simulation model, according to the probability that it generates based on the probability score.

The probability is not evenly nor uniformly distributed for the scale score; instead, it follows a trapezoidal distribution, unevenly referring to fuzzy membership function (Reznik et. al., 1998; Abdelgawad & Fayek, 2012). Traditionally, the fuzzy membership function is used to describe the degrees of belief or confidence level of linguistic variables for subjective judgement on discrete events (Yang et al., 2005).

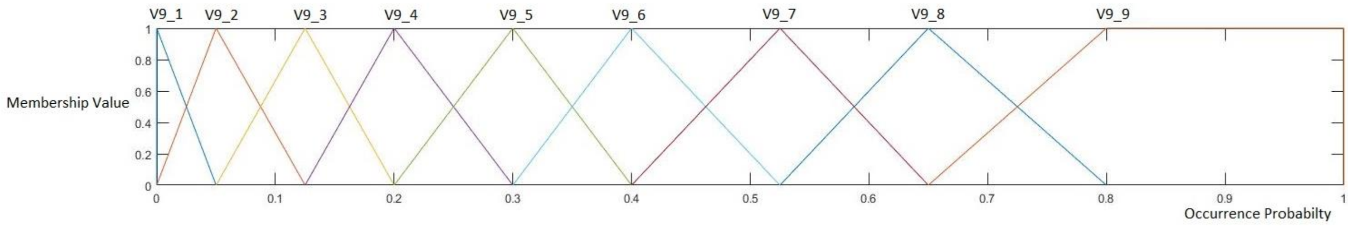


Figure 4.14 Fuzzy Membership of Failure Event Occurrence Distribution

Differently from the simulation, the membership function is to be used to generate pseudo-random confirmations of the distribution pattern described as fuzzy membership function, to work out whether any failure event occurs for each logistics activity according to the characteristics of container packaging and the transport node the cargo is traveling through, as shown in Figure 4.14. The details for the event occurrence probability distribution can be seen in Table 4.7.

If any failure occurs (calculated by the physical simulation layer according to the event distribution in each logistic activity, which varies for different packaging solutions and different transport nodes), the impact will be accumulated and recorded by the cargo agent. The impact also varies depending on the consequence severity, adding different delay (few hours in the simulation) or/and extra cost (extra work and value reduction) as the impact of failure event to the solution being simulated. With this help of simulation, the risk of carrying the cargo in a given packaging following a given route in the supply chain is transferred to sustainable performance KPIs for decision-making support.

Table 4.7 Probability Ranges for Different Probability Levels (refers to Reznik et. al.,1998)

Variables	**Verbal Expression**	**Distribution Shape**
V9_1	Very Low: not consider, we believe not, unlikely	(0, 0, 0.05)
V9_2	Very Low to Low: probably not, very slight probability	(0, 0.05, 0.125))
V9_3	Low: some probability	(0.05, 0.125, 0.2)
V9_4	Low to Medium: less than even chance, fair possible	(0.125, 0.2, 0.3)
V9_5	Medium: probable, even chance, about even chance	(0.2, 0.3, 0.4)
V9_6	Medium to High: we believe, better than even chance	(0.3, 0.4, 0.525)
V9_7	High: very probable	(0.4, 0.525, 0.65)
V9_8	High to Very High: we are convinced	(0.525, 0.65, 0.8)
V9_9	Very High: Certain, virtually certain	(0.65, 0.8, 1)

The result of physical layer simulation will reveal the sustainable performance (Cost, Time, and Emissions) each time the cargo flow through the whole supply chain route, performances are accumulated and recorded by each cargo agent and summarised. Also, in the information layer, estimated probability of overall failure for different solution and estimated sustainable performance will be updated when the cargo completes its whole journey. Then the sustainable performance in different aspects can be integrated in the information layer of the simulation mode using the AHP-processed pair-wise comparison weighting to generate final sustainable index for decision making support.

- **Weightings for Different Sustainable KPIs**

Once the simulation physical layer outputs the performance results of cost, time, and emissions, the information layer need to consider the different importance of these performance factors and integrate them into a sustainability index for decision-making support. In order to integrate the sustainable KPIs in different aspects, an AHP pair-wise comparison process is used for the sustainability performance result of the simulation model. The comparison input comes from experts' views (will be described in data collection section) and research literature (Saaty, 1990; Harilaos & Christos, 2010; Song, 2011; Sarfaraz & Jurgita, 2012). The process can be described in the following steps:

Step One: Construct Comparison Matrix for Pair-wise Comparison

The criteria for consideration include sustainable KPIs of

C1 - Lead-Time

C2 – Cost

C3 - Carbon Emissions

Therefore, the matrix can be established as

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \tag{11}$$

The expert opinion input will be the 1-to-9 score for each a_{ij}, where a_{ij} represents the relative importance of criteria C_i to criteria C_j , within which 1 represents 'equal importance', 3 represents 'moderate importance', 5 is 'essential importance', 7 represents 'very vital importance', and 9 represents 'extreme vital importance'.

Step Two: Calculate the Weighting Vector for Matrix A

Normalise the matrix A by column:

$$\overline{a_{ij}} = a_{ij} \ / \ \sum_{i=1}^{3} a_{ij} \tag{12}$$

Summarise each row from the normalised matrix:

$$\overline{W_i} = \sum_{j=1}^{3} \overline{a_{ij}} \tag{13}$$

Normalise the W_i from last step to generate the normalised Eigen vector:

$$W_i = \overline{W_i} \ / \ \sum_{i=1}^{3} \overline{W_i} \tag{14}$$

The weighting vector W=(W_1, W_2, W_3) represents the calculated weighting for criteria 1 to 3, respectively.

Step Three: Consistency Check for Pair-wise Comparison

Since the AHP pair-wise comparison contains two directions of comparison between every two criteria, it is important to ensure the comparison is rational and logically consistent during the whole process by subjective judgement. As explained by Saaty and Vargas (1991), this can be checked by Consistency Index (CI) of the matrix. The CI can be calculated as:

$$\lambda_{max} = \sum_{i=1}^{n} \frac{[AW]_i}{nW_i} \tag{15}$$

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{16}$$

Where *n* represents the number of criteria in the vector (*n*=3 in this proposed matrix). Then the Consistency Index (CI) and Random Consistency Index (RI, shown in Table 4.8, in this case when *n*=3, RI=0.58) are compared to generate a Consistency Ratio (CR) as:

$$CR = \frac{CI}{RI} \tag{17}$$

Table 4.8 RI Value for Consistency Check (Saaty and Vargas,1991)

n	3	4	5	6	7	8	9	10	11
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

When the value of Consistency Ratio (CR) is smaller than or equal to 10%, the inconsistency is acceptable (Saaty & Vargas, 1991) with no need to revise subjective judgment. Otherwise, judgements need to be revised to form a new comparison matrix until the result meets CR<10%.

Using the weighting generated by the AHP pair-wise comparison process for integrating the normalised sustainable KPIs, a final sustainability index can be generated for the solution being evaluated. This final output of the simulation represents the overall sustainability performance after consideration of different aspects of sustainability and their different level of importance, as well as taking the impact of potential failure into account during the operations along the supply chain.

Chapter 5: Applications and Case Studies

Case studies in the packaging and container shipping industry are introduced and conducted in this chapter. Case studies are good for gaining and enhancing a deeper understanding of phenomena by providing a rich description from a holistic viewpoint (Hellstroem & Saghir,2007). These case studies are used to illustrate the general application of the proposed evaluation and design tool, while providing triangulation to support and validate the proposed evaluation method. They not only describe how to conduct the proposed evaluation to identify preferable solutions, but also provide in-depth understanding of how packaging logistics impacts sustainability and how to improve the design as support for packaging decision-making.

Case study 1 is an evaluation of worktop packaging alternatives. Applying the proposed evaluation framework for sustainable packaging helps with sustainable packaging solution selection and design. Also, it compares the different sustainability results with and without consideration of operational risk impacts, using both numerical analysis and evaluation matrix for assessing the risk impact.

Case study 2 is an evaluation of different furniture packaging, applying the proposed risk impact evaluation. It illustrates the application of the proposed evaluation matrix alone in the face of limited availability of information and operational data. By comparing different packaging solutions and different types of furniture products, it not only further triangulates and supports the validation of the proposed evaluation matrix, but also provides useful packaging-selection support for packaging decisions in this industry.

Case study 3 is an evaluation of sustainable container shipping solutions in the container supply chain using the proposed integrated simulation approach. It not only helps identify a better alternative in terms of sustainability, but also provides container shipping decision support for different scenarios. And just as in the other two case studies, through demonstrating the application of the proposed method in a real case, it is used for support and triangulation of the proposed method.

5.1 Case Study 1 - Sustainable Worktop Packaging Evaluation

To showcase the application of the evaluation tool designed in this research and to triangulate the universality of the proposed evaluation as a general tool for sustainable packaging, case studies of different packaging solutions under different scenarios were conducted. In this case study, different packaging and logistics solutions for the shipping of (wooden or marble) worktops are examined. Figure 5.1 shows the process of conducting this case study: following the proposed framework, the packaging alternatives are identified, with physical and material flow mapped out. Then, according to the framework, numerical analysis is conducted to evaluate the sustainability of the selected packaging solution, and the results with and without consideration of operational risk are compared. At the same time, the proposed evaluation matrix for risk impact estimation is conducted, with sensitivity analysis, and compared with the numerical analysis result.

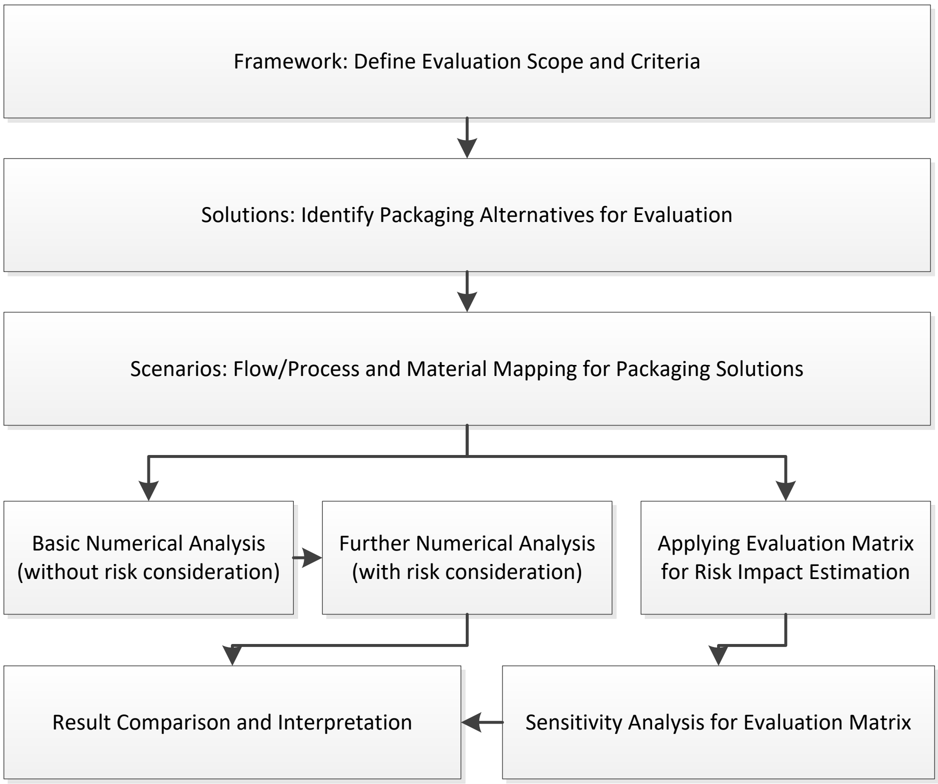


Figure 5.1 Process of Conducting Case Study 1

5.1.1 Different Packaging Solution and Delivery Scenario

In this case study, the 'worktop cover' is used as one of the evaluated packaging components. The 'worktop cover' is a newly developed form of reusable packaging, designed to replace the traditional packaging combination of one-off cardboard packaging during stowage, handling, and delivery of the worktops. It is starting to be put into use by a big 'do-it-yourself' (DIY) retailing group in the UK. In the case study, a comparative evaluation is made, to compare the new packaging solution with the old one, to identify sustainable packaging solutions and further provide critical improvement area as suggestions.

The two different sets of packaging solution being evaluated and compared are shown with details in Figure 5.2 and Figure 5.3, with packaging combination details in Table 5.1. The packaging solutions are both for the retailing group's longest, heaviest and commonest types of wooden worktop, sized at 2m, 3m or 3.6m long by 60cm wide.

Figure 5.2 Solution One: Single-trip Cardboard Box Packaging Solution

Figure 5.3 Solution Two: the 'Worktop Cover' Reusable Packaging Solution

The worktop is manufactured in mainland Europe. For both solutions, the worktops will be stacked in racks, with interval sheets in-between, and loaded into containers being shipped to the UK. There is hardly any difference between the two solutions before the worktop arrives in-country. On arrival in the UK, the container is de-vanned and the packaging is used in the retailing group's 'Home Delivery Network' (the flow is illustrated in Figure 5.4) from their central depot: from the main depot to the retailing store or end-user via its 12 delivery hubs (out-bases) around the UK with its own fleet. The reusable packaging needs to be returned to the central depot after delivery of the product, and be inspected, cleaned, and readied for next usage, whereas the single-trip packaging would typically remain in the end-user's possession after delivery.

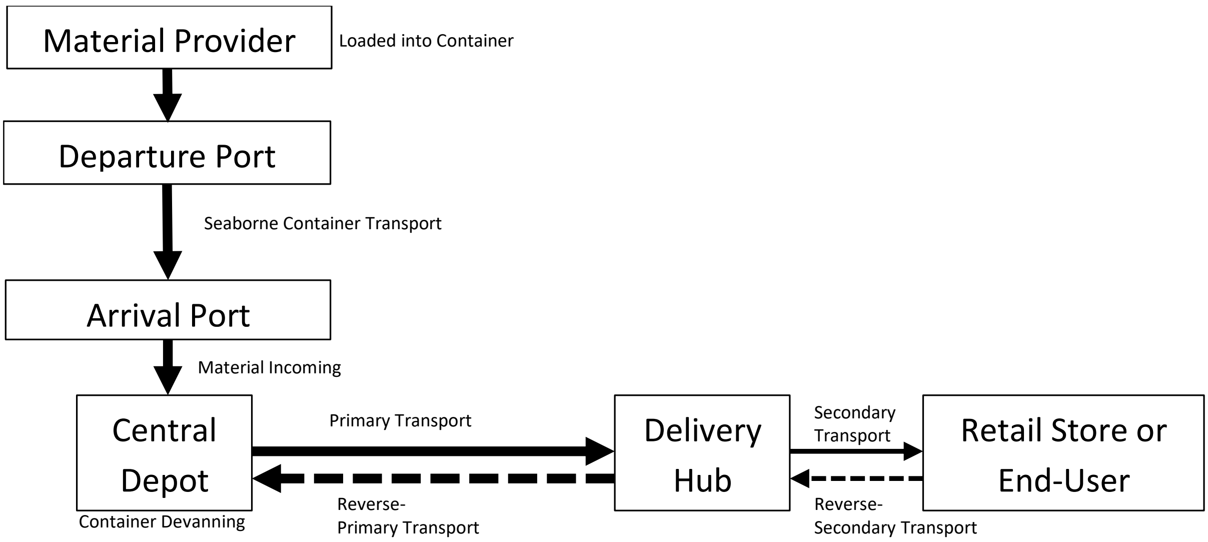


Figure 5.4 General Route of Worktop Material Flow

The major difference occurs after the worktops are packed and delivered from the retailing group's central depot, so the evaluation assumes that the different packaging solutions make no difference in terms of packaging performance and logistics planning during the shipping, before the point where the worktop products arrive and are de-vanned from the container at the retailing group's main depot (Central Fulfilment Centre) in central UK (Branston). The process mapping of the packaging logistics system provides the details of the packaging combination and the logistics process during the delivery, as shown in Table 5.1 and Table 5.2 respectively. These are used as the basic setting of the packaging logistics system being evaluated, and the analysis is based on these given settings.

Table 5.1 Packaging Materials for the Two Solutions during Different Phase

<table>
<tr><th colspan="2"></th><th>Material Incoming</th><th>Primary Transport</th><th>Secondary Transport</th><th>Reverse-Secondary</th><th>Reverse-Primary</th></tr>
<tr><td rowspan="2">One-off Cardboard Box Solution</td><td>Packaging Material in Use</td><td>PE Film*
Pallet
Packaging Strap</td><td>PE Film
Cardboard Box
Tape
Barcode Sticker
Pallet</td><td>PE Film
Cardboard Box
Tape
Barcode Sticker</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Packaging Waste Generated</td><td colspan="5">Cardboard Box, PE Film, Tape and Barcode sticker in End-User premises (every trip)</td></tr>
<tr><td rowspan="2">Reusable Cover Solution</td><td>Packaging Material in Use</td><td>PE Film
Pallet
Packaging Strap</td><td>PE Film
Reusable Cover
Barcode Sticker
Pallet</td><td>PE Film
Reusable Cover
Barcode Sticker</td><td>Reusable Cover
Barcode Sticker</td><td>Reusable Cover
Barcode Sticker</td></tr>
<tr><td>Packaging Waste Generated</td><td colspan="5">Reusable Cover and Barcode Sticker in Central Depot (end of life-span only)
PE Film in End-User premises (every trip)</td></tr>
</table>

*PE = polyethylene.

Table 5.2 Logistic Activities in Different Places for the Two Different Forms of Packaging

	Central Depot	**Delivery Hub**	**End-User**
One-off Cardboard Box Solution	Scan/Verification Equipment Handling Storage Scan/ Verification Manual Filling Labelling Manual Handling Equipment Handling Waiting Transport	Scan/ Verification Equipment Handling Waiting Transport	Scan/ Verification Manual Handling
Reusable Cover Solution	Scan/ Verification Equipment Handling Storage Scan/ Verification Manual Filling Labelling Manual Handling Equipment Handling Waiting Transport Scan/ Verification (for return) Waiting (for reuse)	Scan/ Verification Equipment Handling Waiting Transport Manual Handling (for return)	Scan/ Verification Manual Handling

As shown in Table 5.1 and Table 5.2, for both cardboard and reusable cover solutions, the worktops come to the central depot wrapped with thin polyethylene (PE) wrapping film and strapped onto the pallet; after scanning/verification and equipment handling, they will be in the storage process, waiting to be picked up in the warehouse. When the pick-up order is activated, the scan/verification process is undergone again and then the worktop is manually packed into secondary packaging (filling process). For the cardboard solution, it is packed into a folded cardboard box and sealed with tape, a barcode sticker is applied (labelling process), it is carried for stacking on a pallet (manual handling), and moved by forklift to dispatching area waiting for dispatch (equipment handling). For the reusable cover solution, the difference is that the worktop in this phase will be packed into reusable packaging with imbedded Correx sheet (400 GSM Corrugated Polypropylene Sheet) and self-sealing Velcro closure instead of a cardboard box with sealing tape. Following the primary transport from the central depot to an out-base (delivery hub) in such packaging, the package is then scanned again and reloaded by forklift into a smaller home-delivery vehicle and waiting to be transported to the end-user. After the secondary transport from out-base to end-user, the worktop package undergoes one more scan process, to ensure that the right product is delivered, and is then manually handled to end-user's assigned place at end-user's premises. After this, cardboard box packaging is left in the end-user's possession and (presumably) disposed of, while the reusable packaging will be returned via the reverse route back to the central depot, inspected and cleaned, and await the next trip.

5.1.2 Data Collection

The data used in this case study comes from the commercial report, new packaging trial report, interviews, and questionnaires. People engaged in this expert scoring system include managing and operations staff in the retailing group, including operators in the depot and logistics managers; packaging designers, assembly operators, warehouse operators at the packaging provider; and other end-user of the worktop. The sampling covers different phases and different levels of people engaged in the supply chain who related in some way to the packaging system being evaluated. This is enough for a triangulation case study for tool development, as similar research literature has suggested (Hellstrom & Saghir, 2007; Van der Vorst et al., 2009). Table 5.3 shows details on personnel in the field where the input information resources come from.

Table 5.3 Personnel Involved in Information Input for Packaging Data

Position	**Nature of Business/Organisation**	**Experience in the Field**
Production Manager	Packaging Provider - Supplier	High
Product Design and Development Director	Packaging Provider - Supplier	High
Production Operator	Packaging Provider - Supplier	Medium
Warehouse Operator	Packaging Provider - Supplier	Medium
Operation Manager	DIY Retailing - Depot	High
Operator	DIY Retailing - Depot	Medium

5.1.3 Assumptions

The proposed evaluation for sustainable packaging logistics system is based on following assumptions:

1) The operational cost is based on the commercial report and interview with packaging supplier and logistics provider in the case study.

2) The reusable packaging life span is based on the average times of packaging supplier test and customer trial.

3) The phase of transportation before the cargo arrives at the depot is the same for both solutions; hence it is not taken into consideration in this case study scenario.

4) The logistics service and reverse logistics service are assumed to be fulfilled by the same supply chain partner.

5) Since the packed cargo is the same for both solutions, in the evaluation the measurement for criteria is converted to per cargo item equivalent.

6) The scenario is simplified in the research to assume the cargo is already packed into the container at the original depot by the cargo owner or consigner and ready to be transported to the port for maritime shipping.
7) With the assumption that there is no stock-out situation for the cargo and the packaging, the resources are all available on request.
8) The route length is assumed to be the half of the average coverage distance of all depot to represent a typical delivery scenario.
9) The emission reporting is based on 'direct GHG emissions' (see Guidelines to Defra / DECC's GHG Conversion Factors), which refers to those emissions emitted at the point of use of a fuel/energy carrier, but does not include the indirect emissions prior to the use of a fuel/energy carrier (e.g., the impact of transforming a primary energy source into an energy carrier when the energy is produced instead of consumed).
10) The environmental impact of transport-induced carbon emissions is not folded into the 'cost', as there is no direct carbon charge for the transportation company; instead, they are already reflected in the fuel price.

5.1.4 Analysis and Results

Once the process mapping is completed, to identify the process and gather information needed for the evaluation, we evaluate the sustainability of the packaging logistics system, starting according to the framework previously introduced in the traditional way, and looking at the cost and carbon emissions of the packaging material and transportation.

The cost of packaging material and transportation is shown in Table 5.4. According to the retailing group's report, the cost of transporting the cardboard-packaged product to the retail store or end-user (including the single-trip cardboard packaging material) is around £3 per item per trip; the transport cost for the reusable packaging is around £2 per item per trip (including return journey and quality monitoring); and the reusable packaging material itself costs £25 each. Therefore, the cost per trip for cardboard box solution is £3 a trip, while the cost per trip for reusable cover solution can be calculated as £5.75 or £4.5 (on the basis of 7-trip and 10-trip life-spans, respectively). The life-span is designed to be over 10 trips, and the trial report shows that this reusable packaging life-span varies between 3 and 14 in the trial operation, an average of 7 trips, but it was suggested by the retailing group's logistics manager that the life-span can be much longer (an average of at least 10 trips is achievable) when the operators are familiar with the packaging (after systematically training for using the reusable items). The results show that: the initial cost and extra operational cost (e.g., monitoring, cleaning) is much higher for the reusable packaging solution in this case; but, as the number of reuse trips increases, the absorption cost for each trip can be lower, but is still higher than the single-trip packaging solution. However, this direct cost has not taken any damaged cargo into account, which will be considered in the interaction between packaging and logistics.

Table 5.4 Cost of Packaging and Processing for the Two Solutions

<table>
<tr><th></th><th>Cardboard Box Solution</th><th>Reusable Cover Solution</th></tr>
<tr><td>Cost of Packaging Material</td><td rowspan="2">£3</td><td>£25</td></tr>
<tr><td>Cost of Transport per Trip</td><td rowspan="2">£2</td></tr>
<tr><td>Reuse Processing Extra Cost per Trip</td><td>£0</td></tr>
<tr><td>Overall Cost Per Trip</td><td>£3</td><td>£5.57 (7 trips life-span)
£4.5 (10 trips life-span)</td></tr>
</table>

When considering effectiveness, namely, quality and lead-time, the promised lead-time by the retailing group is delivery within 5 weeks (including international shipment from the manufacturer in the Europe), while the actual UK delivery time from depot to end-user is usually between one and two days within the UK (and the retailing group has stock for common worktops stored at its central depot). As the planning of logistics is similar, and the promised lead-time is with sufficient time margin, therefore the lead-time is not impacted directly by the packaging difference. It is only impacted when the packed worktop is damaged or of less-than-acceptable quality (usually induced by packaging and packaging-related operations) and needs redelivery. According to the retailing group's report, delivery using the new, reusable-cover solution in place of the cardboard-box solution has reduced the damage rate from 6% down to 2% (which will be discussed later in the interaction between packaging and logistics).

The environmental impact is mainly evaluated from carbon emissions and waste material generation. The carbon emissions level is calculated from the production of the packaging material itself as well as the transportation for the cargo delivery (with no consideration of the manufacturing process for the packaged product, as no significant emissions process, such as heating or special treatment process, is needed in stitching/assembling the packaging product from the packaging material).

Table 5.5 shows the evaluation of the main packaging material's environmental impact. The emissions level is calculated using the weight of each material (kg) and the emissions factors of producing this material (kg CO_2 emissions per kg material). The results show that although the reusable packaging made of degradable polypropylene does not sound as 'green' as cardboard, yet it consumes less material (30% less in weight), and, as it can be reused many times, the initial carbon emissions of the material can be reduced for each trip (on the basis of a 10-trip life-span, the emission is 79% less than for the cardboard packaging, which is 1.54 kg CO_2 emissions lower than for the cardboard packaging solution for every item shipped out).

Table 5.5 Environmental Impact of Packaging Material for the Two Solutions

	Cardboard Box Solution		Reusable Cover Solution
Material	Cardboard	Tape	Polypropylene
Emission Factor ($kgCO_2e/kg$)	0.60	1.81	1.81
Weight (kg)	3.20	0.015	2.22
Packaging Material GHG Emission per item ($kgCO_2e$)	1.92	0.027	4.02
Packaging Material GHG Emission per trip ($kgCO_2e$)	1.947		0.574 (7 trips life-span) 0.402 (10 trips life-span)
Packaging Waste per Trip (kg)	3.20	0.015	0.317 (7 trips life-span) 0.222 (10 trips life-span)
Packaging Recovery Notes Price for Material (£/tonne)	1.25	17	17
Cost for Packer/Filler and Seller Obligation per Item Shipped (£)	0.00426		0.00539 (7 trips life-span) 0.00377 (10 trips life-span)

The packaging waste is calculated in the lower half of Table 5.5. The single-trip packaging will be left in the end-user's possession, becoming landfill waste if no additional recycling channel is used, which means at least more than 3.2 kg waste cardboard is generated by the cardboard-packaging solution for every worktop delivered to the end-user, while, based on a 10-trip life-span, the reusable packaging solution contributes only 0.222 kg waste material for every shipment, which is a 93% reduction in the quantity of packaging waste material generation. The waste material contributes to extra waste material cost (as the packer/filler and seller obligation); it is calculated using given PRNs Price (Packaging Recovery Notes Price or commercial viability for the cost of packaging recovery notes). Based on a 10-trip life-span for the reusable cover, the cost of waste material (packer/filler and seller obligation) for each trip is 11.3% lower than for the single-trip cardboard solution (based on 2013 prices).

Different packaging solutions can also have different transportation journeys. In this case, as a trade-off for less waste material, the reusable packaging needs an extra reverse journey back to the central depot. Table 5.6 shows the calculation of transport emissions of the application of the two packaging solutions, on the assumption that the one-trip packaging contributes to no transportation requirement and therefore no emissions for the potential empty truck return; the emissions are only calculated based on consignment weight. The freight weight is calculated by adding the weight of a wooden worktop (average 50 kg) and the weight of an individual cardboard box or reusable cover. The distance is calculated using the average distance from Branston to one of the 12 out-bases (primary transport phase, 305 km) plus the average coverage of each out-base (secondary transport phase, 61 km).

Table 5.6 Transport Emission of the Two Packaging Solutions

	Cardboard Box Solution	**Reusable Cover Solution**
Delivery Consignment Weight (kg)	53.20	52.22
Distance of Transport (km)	366	366
Reverse Transport Weight (kg)	N/A	2.22
Reverse Transport Distance(km)	N/A	366
Emission Factor (kgCo_2/tonne.km)	0.12168	0.12168
Transport Emissions (kgCO_2)	2.37	2.42

The different transport emissions performances induced by the utilisation of different packaging solutions are also calculated in Table 5.6. The calculation is based on IPCC's carbon emissions calculation:

$$C_t = \sum_{i=1}^{n} (W_i \times D_i \times EF_i) \qquad (18)$$

Where C_t is the carbon emissions of energies in transportation activity; W_i represents the consignment weight; D_i shows the distance of transportation phase i, and EF_i is the emission factor for phase i. The emission factor for the freight transport comes from Diesel HGV Road Freight Conversion Factors (source: 2012 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting).

Apart from the difference considered above, the cargo damage rate is also related to packaging, considering the interaction between packaging and logistics activities. So far, the evaluation is concentrating on the material and logistics respectively, not considering the packaging logistics interaction in performance. When considering the interaction, especially the damage induced by inappropriate packaging and logistics, some of the results could change. The key changes of performance and priority before and after considering this interaction are summarised and compared in Table 5.7 and explained as follows:

According to the group report, the damage rate has been reduced from 6% down to 2% using reusable packaging in place of cardboard box packaging. The price of the worktop varied from £50 to over £400 per piece, for an average of £100 per piece; this can significantly change the cost evaluation in Table 5.4. When the damage rate and cargo value are considered, the cost per trip for cardboard box solution increases from £3 up to £9 (6% damage of £100-value worktop), while the cost per trip for reusable packaging solution only increases from £4.5 up to £6.5, which changes the previous finding that the single-trip packaging solution is more cost-efficient than the reusable solution. Moreover, the indirect cost of redelivery to replace the damaged worktop also needs to be considered, which makes the reusable packaging's cost performance even better.

Table 5.7 Changes of Sustainability Results Before and After Consideration of Packaging-induced Risks and Damage

		without consideration of risks and damage	**with consideration of risks and damage**
Cost per trip	single-trip packaging	*£3	£9
	reusable packaging	£4.5	*£6.5 (become preferable)
Environmental cost for damage and waste material treatment per trip	single-trip packaging	£0.00426	£0.01026
	reusable packaging	*£0.00377	*£0.00577 (43.76% less than the alternative)
Transport emission per trip CO2	single-trip packaging	*2.37 kg CO_2	2.51 kg CO_2
	reusable packaging	2.42 kg CO_2	*2.46 kg CO_2 (become preferable)

*indicate the preferable packaging between the two in given consideration

Damaged goods also influence the environmental impact results, as the damaged wooden worktop is neither accepted/utilised by the end-user nor the retailing group and will become additional waste output of the system. As the PRNs price somehow indirectly reflect on the collection and reprocessing of the waste material, in this case, PRN price for wood (£2/tonne) is used to estimate the waste material cost. Considering the average weight of a worktop is 50 kg, the cost of waste material for the single-trip packaging solution increased from £0.00426 up to £0.01026 per accepted item delivered to the end-user, while the cost with reusable packaging solution (with its lower damage rate) only increased from £0.00377 up to £0.00577 for every successful delivery, based on a 10-trip life-span, which is 43.76% less than the single-trip packaging.

The transportation emissions will also change because of redelivery to replace damaged cargo. This means there will be an extra 6% versus 2% increase in transport emissions for single-trip versus reusable packaging solutions, respectively. The transportation emissions for the single-trip packaging solution will no longer be the better one, as the CO_2 emissions increases from 2.37 kg per trip up to 2.512 kg, while the transportation emissions for the reusable packaging solution only increases from 2.42 kg CO_2 per trip up to 2.46 kg CO_2 per trip.

Therefore, the evaluation result will change after considering the impact of packaging on logistics and packaging-logistics-related damage. But this impact, including damage rate, is not easy to predict before carrying out the new solution; also, the damage rate does not reflect the difficulties of carrying out the operation in the given packaging setting, nor reveal the minor defects that might influence the operation or end-user. This is the reason the QFD-FMEA matrix evaluation is proposed. The questionnaire for the matrix is delivered to operators in this case to get their feedback on the packaging logistics performance in delivering the worktop (reflected as potential failure consequence evaluation of the delivery), covering different types of failure during all their logistics operations and severity of consequences according to the cargo characteristics. The evaluation for reusable packaging is shown in Figure 5.5 as an example. The same questionnaire and analysis is used for the cardboard packaging solution. The comparison results of the two solutions is illustrated in Figure 5.6.

M1 — POSSIBILITY (mode-->effect)

Failure Mode (Cause)	Failure Effect (Result): wrong item	item lose	breakage /scrap	scratch/scrub	dirty/dusty
item unidentify	0.8	0.2	0	0	0
tampered	0.25	0.7	0	0	0.05
drop	0.01	0.01	0.12	0.66	0.2
bend	0	0	0.9	0.1	0
bump /vibrate	0	0	0.15	0.85	0
contaminate	0	0	0	0.05	0.95

M2 — Severity of effect impacted by product characteristics

Effect of the Failure	Product Characteristics: Value	Size	Shape	Weight	Hardness	Pliability	Appearance	Fragility of product	Product likely to settle of shift	Sensitive to temperature	How many units of each package
	120(mid)	)0*600*40	angle flat b	mid	low	low	loss finishi	low	mid	no	1
wrong item	7	0	0	0	0	0	0	0	0	0	0
item lose	7	0	0	0	0	0	0	0	0	0	0
breakage /scrap	5	0	3	4	3	5	0	0	0	0	0
scratch/scrub	3	0	0	0	3	2	1	1	2	0	0
dirty/dusty	1	3	0	0	0	0	8	0	0	0	0

M3 — PROBABILITY (activity-->mode)

Logistics Activities	Failure Mode(cause): item unidentify	tampered	drop	bend	bump /vibrate	contaminate
Control/Va	2	0	0	0	0	0
Lablling	1	0	0	0	0	0
Filling(Auto	0	0	0	0	0	0
Filling(Man	0	0	0	4	4	0
Handling(E	0	0	2	2	3	0
Handling(M	0	0	7	1	2	0
Storage	0	2	0	0	0	2
Waiting	0	6	0	0	0	1
Transport	0	0	4	0	3	1

M4 — RPN correlation between Failure mode and product characteristics

Failure Mode (Cause)	Product Characteristics: Value	Size	Shape	Weight	Hardness	Pliability	Appearance	Fragility of product	Product likely to settle of shift	Sensitive to temperature	How many units of each package
item unidentify	7	0	0	0	0	0	0	0	0	0	0
tampered	6.7	0.15	0	0	0	0	0.4	0	0	0	0
drop	2.92	0.6	0.36	0.48	2.34	1.92	2.26	0.66	1.32	0	0
bend	4.8	0	2.7	3.6	3	4.7	0.1	0.1	0.2	0	0
bump /vibrate	3.3	0	0.45	0.6	3	2.45	0.85	0.85	1.7	0	0
contaminate	1.1	2.85	0	0	0.15	0.1	7.65	0.05	0.1	0	0

M5

Logistics Activities	Product Characteristics: Value	Size	Shape	Weight	Hardness	Pliability	Appearance	Fragility of product	Product likely to settle of shift	Sensitive to temperature	How many units of each package	Weighted RPN Score	Total RPN
Control/Va	14	0	0	0	0	0	0	0	0	0	0	4.535487	105.226805
Lablling	7	0	0	0	0	0	0	0	0	0	0	2.267743	
Filling(Auto	0	0	0	0	0	0	0	0	0	0	0	0	
Filling(Man	32.4	0	12.6	16.8	24	28.6	3.8	3.8	7.6	0	0	21.21105	
Handling(E	25.34	1.2	7.47	9.96	19.68	20.59	7.27	4.07	8.14	0	0	16.90121	
Handling(M	31.84	4.2	6.12	8.16	25.38	23.04	17.62	6.42	12.84	0	0	21.84689	
Storage	15.6	6	0	0	0.3	0.2	16.1	0.1	0.2	0	0	7.385877	
Waiting	41.3	3.75	0	0	0.15	0.1	10.05	0.05	0.1	0	0	14.82419	
Transport	22.68	5.25	2.79	3.72	18.51	15.13	19.24	5.24	10.48	0	0	16.25436	
Risk Weighting Factor	0.323963	0.034754	0.049371	0.065828	0.149954	0.149341	0.126205	0.033528	0.067055	0	0		

Figure 5.5 Evaluation Results for Reusable Packaging Solution

As shown in Figure 5.6, the RPN (Risk Priority Number) results transformed by the matrix from the operator scoring questionnaire reveal the same trend as the interviews and the historical data used previously for the calculation. The results indicate that the reusable packaging solution has a lower risk in delivering the worktop within the logistics setting in this case, and the major damage (breakage and scratch) potential is reduced over the logistic processes, which conforms to the comparison-of-damage ratio revealed by the trial operation of new packaging. The computation diagram also shows more of the details behind the damage: in the old cardboard box solution, the manual handling is with the highest RPN, and is significantly higher than other processes, and this is also the process that was tightly related to health and safety issues. The reusable packaging solution reduces the RPN for this process by 43%, meaning much lower delivery failure risk during this operation. And this conforms to the interview with the operator that the built-in handles significantly reduce the difficulties in manual handling of the worktop. Additionally, all top four risk issues with the cardboard are reduced in the reusable packaging solution, while other sub-RPNs almost remain the same, which is also confirmed by the interview to operational personnel that the features of reusable cover such as inbuilt corrugated PP sheet, anti-moisture coating, and Velcro closure make the performance better in manual filling, waiting, and transport processes. Because there is no auto-filling process in this case, the auto-filling sub-RPN is zero for both solutions.

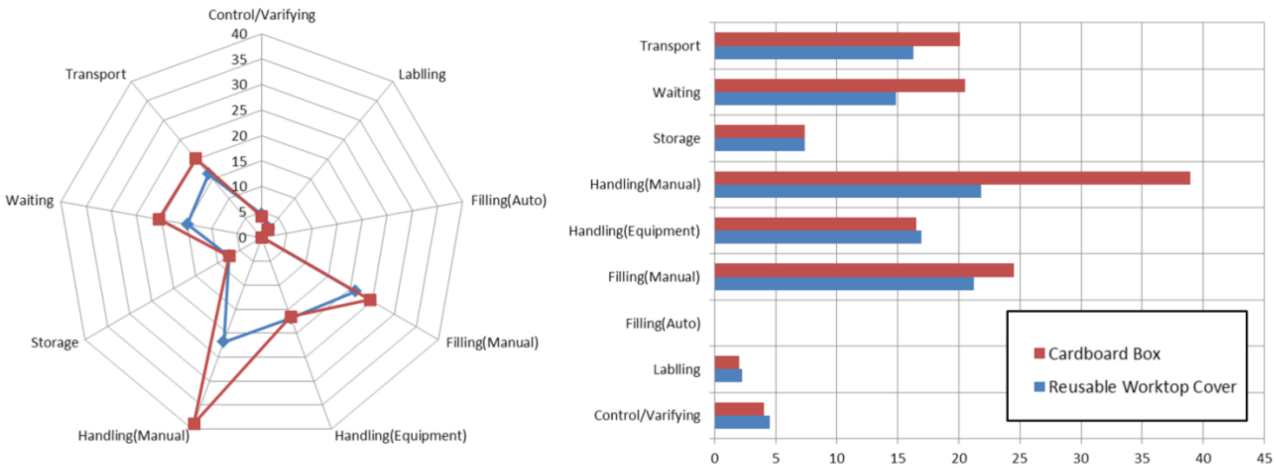


Figure 5.6 Comparison Result of the Two Packaging Solutions' Impact on Logistics Operation

Apart from major damage, the proposed matrix evaluation result also can be used to predict the near-miss events or minor defects that could potentially influence the end-user (accepted, but with less satisfaction), and the operator's feeling of difficulty with the process is also embedded into the survey (on their view of the probability of failure). And the RPN for each type of logistic process is useful as reference (clear design requirement input) when developing or continuously improving packaging or logistics operations, as the critical point for improvement can be revealed by the sub-RPN of each process. Also, for the processes already with low RPNs, reducing related packaging features can be a suggestion for improvement to avoid over-packaging, in order to make the system more sustainable.

5.1.5 Sensitivity Analysis of the Scoring Matrix

Because the assessment is based on human scoring of their views, the subjective result may not be perfectly accurate. Therefore, a simple sensitivity analysis for some main parameters during the scoring process is conducted to give a sense of how a possibly inappropriate judgment would affect the evaluation result and comparison.

The parameters tested are for the three processes with highest RPNs in the reusable packaging assessment result, including manual handling, manual filling (packaging), and equipment handling processes. For these chosen processes, different input parameters are tested to observe the variation in the evaluation result (change the range of critical scoring input to test its impact on analysis result). The sensitivity test and analysis results are shown in Figure 5.7 to Figure 5.13.

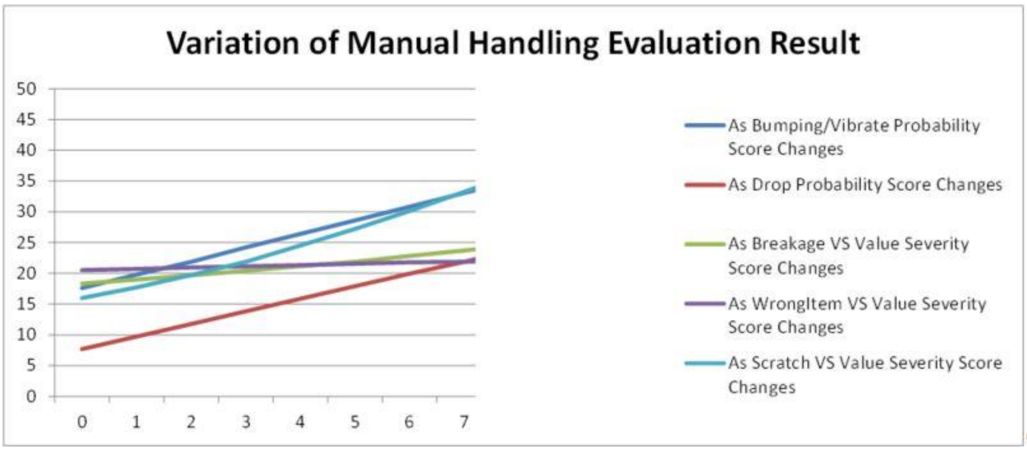


Figure 5.7 Variation of Manual Handling RPN as Input Parameter Changes

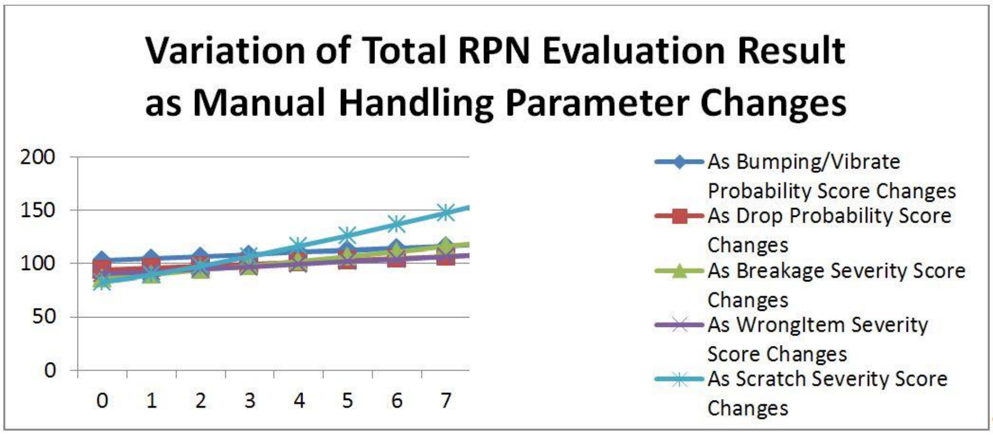


Figure 5.8 Variation of Total RPN as Manual Handling Parameter Changes

The Manual Handling process had the highest RPN in previous evaluation results. Figure 5.7 shows that this result changes as the main input scores change, but they are not significantly sensitive individually to the result; even for the most influential parameter (steepest curve in the diagram) for this process (Severity- Scratch vs Value), when the input score varies around 35% (from 2 to 4 on a range of 0 to 7) in its steepest section around the given scoring, this evaluation result changes less than 28%. And the reusable packaging solution performance will remain better in the solution comparison between the two if this score is not misjudged by 4 points or more. Which means the result is reasonably stable, the result is not heavily dependent to any single parameter, but, instead, is a comprehensive result that consolidates different related parameters, with proper safety margin for some bias or misjudgement when using human scoring process for the evaluation input. Aside from their influence on manual handling process, these manual handling-related parameters further indirectly impact the final RPN score, which is shown in Figure 5.8. This sensitivity result indicates that the variation of scratch severity in manual handling operation (input in Matrix 2) could influence the final RPN result more than other parameters; hence, this input should be considered and scored carefully in the evaluation.

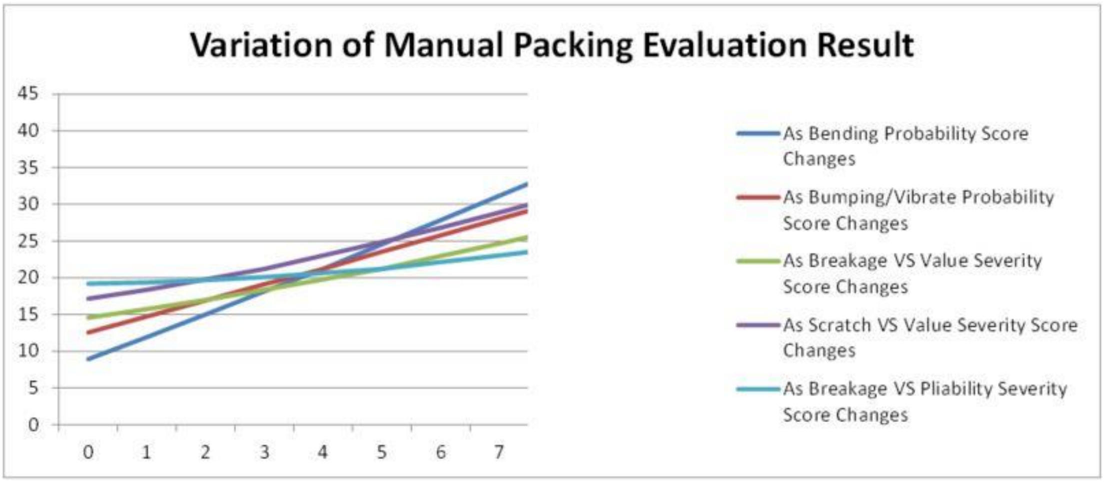


Figure 5.9 Variation of Manual Packing RPN as Input Parameter Changes

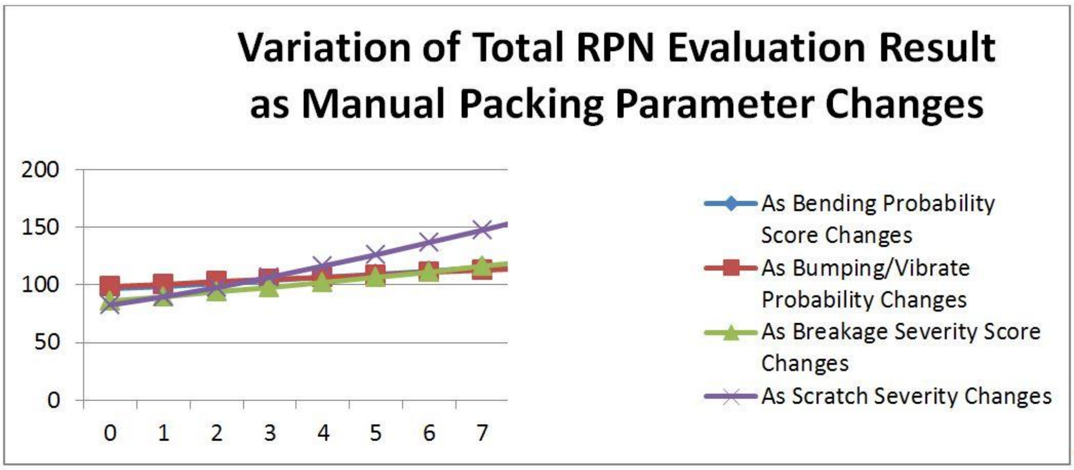


Figure 5.10 Variation of Total RPN as Manual Packing Parameter Changes

Another two key operations (scored second and third highest for reusable packaging solution) are Manual Packing and Equipment Handling processes. Similar to Manual Handling Process, Figure 5.9 and Figure 5.11 show the sensitivity analysis results for these two processes respectively. Some trends are found: for these two operation processes, parameters in Matrix 2 are found to be more influential, although still no single scoring input can act solely to significantly change the RPN result and the priority of the solution being evaluated. Sufficient safety margin is allowed for minor bias during subjective scoring input.

Figure 5.10 and Figure 5.12 illustrate how the Manual Packing and Equipment Handling related input influence the total RPN. The results show that the equipment handling related input has a higher safety margin for input bias, which are not sensitive to the total RPN calculation; similarly, in the manual handling process parameter analysis, the manual packaging process related scratch severity (in Matrix 2) is most sensitive to the total RPN score calculation.

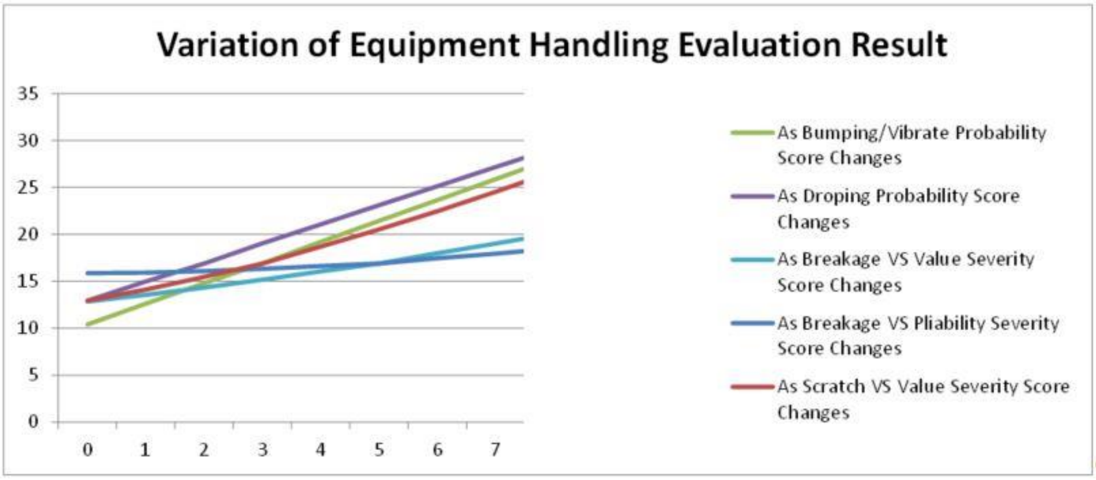


Figure 5.11 Variation of Equipment Handling RPN as Input Parameter Changes

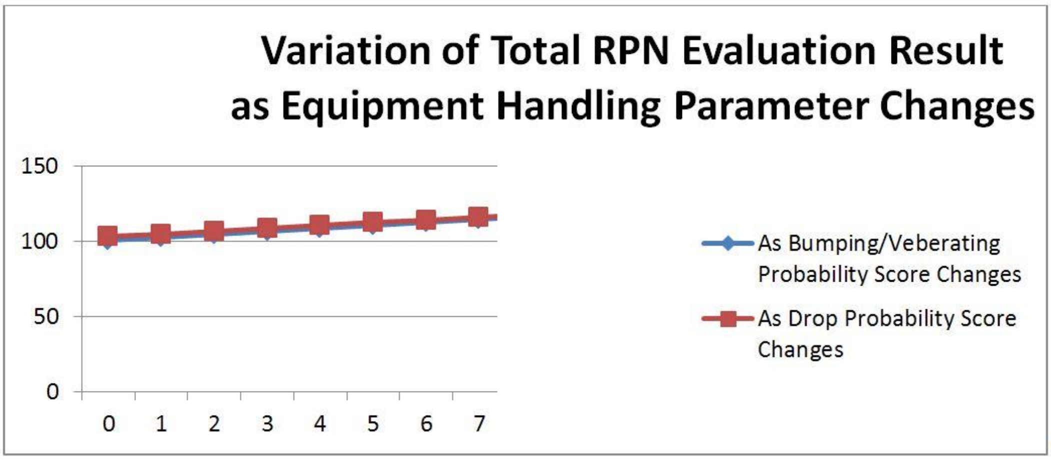


Figure 5.12 Variation of Total RPN as Equipment Handling Parameter Changes

Figure 5.13 shows the variation in weighted total RPN results when the key parameters change from a score of zero to a score of 7. Most parameters do not significantly change the final RPN result. The only one that is more sensitive to the result is 'Severity Score of Scratch vs Value'. Still, it allows more than 2 points of scoring (out of a 7-point scale) to keep the result constant when comparing with other packaging system evaluation results.

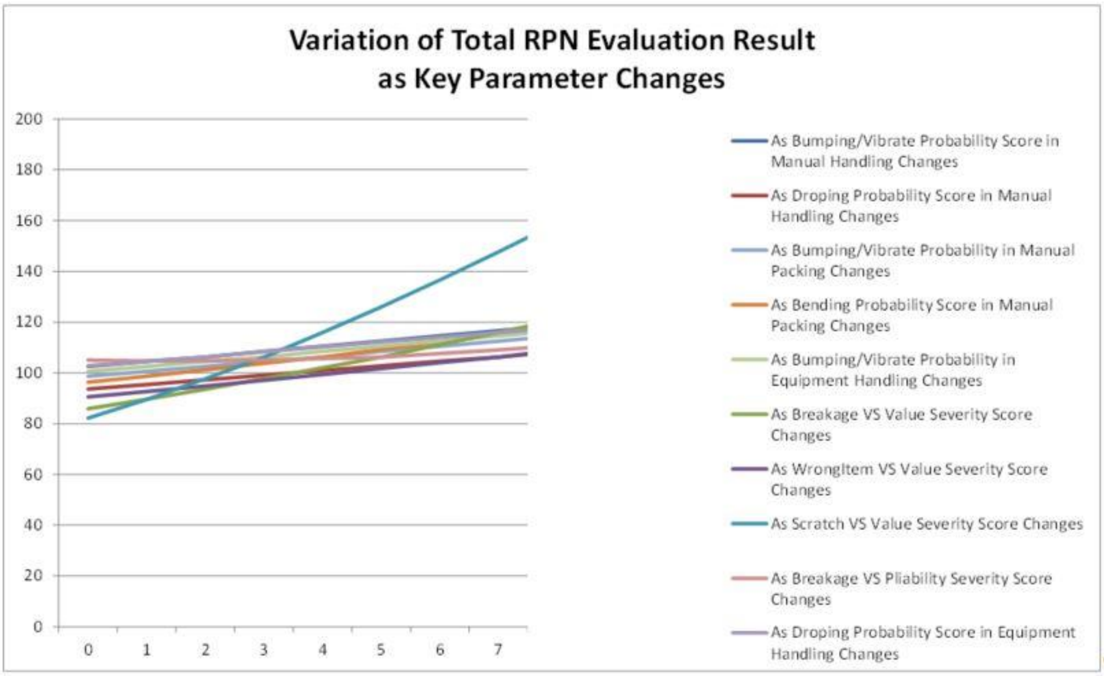


Figure 5.13 Variation of Weighted Total RPN

In summary, according to the sensitivity analysis, the proposed measuring tool has a reasonable safety margin for some input bias when collecting the data from related personnel. But Matrix 2, especially for the score of scratch failure severity, should be carefully considered and checked to improve the accuracy of the crucial operation identification and final RPN result for the solution being evaluated.

5.2 Case Study 2 – Upholstery Packaging in the Furniture Industry

Case study 1 illustrated the application of the proposed sustainable evaluation framework, as well as demonstrated the proposed risk impact evaluation matrix to estimate the impact from packaging logistics interactions for sustainability concerns when lacking of detailed numerical data on damages and risks. Case study 2 provides more examples (another three pairs) of packaging, in this case in the furniture industry rather than worktop packaging. But by only applying the evaluation matrix, this case study is used to illustrate the sole application of the proposed evaluation matrix for different phases of the supply chain when lacking detailed operation data at an early stage of packaging design and development, which reveals the packaging impact on supply chain structure in multi-phase scenarios. This case also provides a comparison between the packaging of different types of product in order to contribute to the packaging selection strategy in this industry.

Detail conduction process of case study 2 is shown in Figure 5.14. Similar to case study 1, once the packaging alternatives are identified, process and material flows need to be mapped; Then the evaluation matrix can be applied and the results can be interpreted.

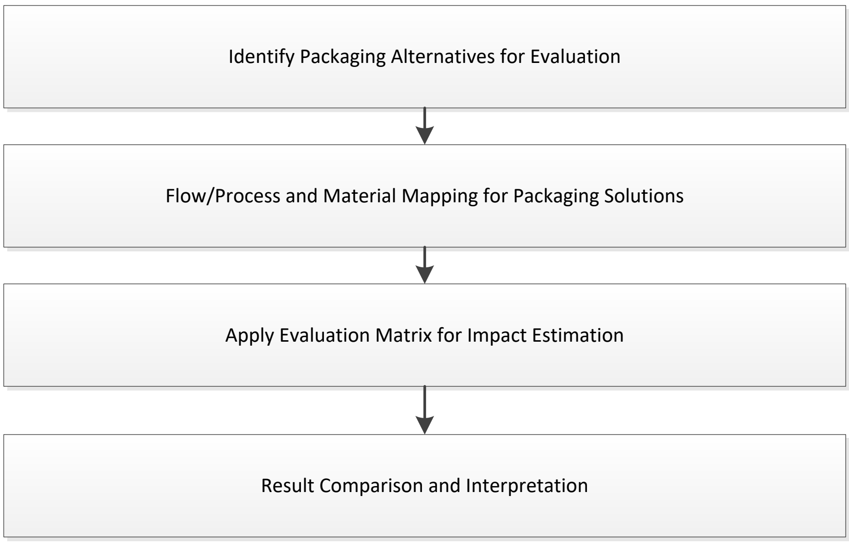


Figure 5.14 Conduct of Case Study 2

5.2.1 Differently Packed Products in Different Scenarios

In this case study, typical furniture packaging solutions in the supply chain of the upholstery industry are chosen to apply the proposed evaluation matrix. The chosen products include furniture with different product characteristics, different range of product value, and different levels of repacking requirement during the supply chain. Selected products also cover different supply chain scenarios with different logistics settings and different end-of-use scenarios, including such furniture products as worktops, mattresses, sofas, and headboards. The evaluation covered different types of packaging solutions for each chosen product along its supply chain.

5.2.2 Data Collection

Data used in the case studies came from the collaborated packaging providers' customer in the UK. The expert judgment scoring in this case study covers management and operation staffs in the packaging supplier and end-users. The sampling covers different phase and different level of people engaged in the supply chain that related to the packaging system being evaluated. Table 5.3 shows the details of personnel in the field where the input information resources come from.

Table 5.8 Personnel of Information Input for Packaging Data

Position	**Nature of Business/Organisation**	**Experience in the Field**
Production Manager	Packaging Provider - Supplier	High
Product Design and Development Director	Packaging Provider - Supplier	High
Production Operator	Packaging Provider - Supplier	Medium
Warehouse Operator	Packaging Provider - Supplier	Medium
Business Innovation Manager	Retailing Company - Depot	High
Operator	Retailing Company - Depot	Medium
Operation Manager	Retailing Company - Depot	High

5.2.3 Different Packaging Solutions and Logistics Processes

Different supply chain partners and different products with different packaging are involved in the case studies, which represent different packaging solutions and scenarios for the furniture supply chain in the UK upholstery industry. To identify different packaging materials and layers throughout the supply of furniture products, the packaging solutions in this case study are mapped out as in Table 5.9. Additionally, according to the difference in packaging and coverage of different supply chain partners, the supply chains are divided into different phases from manufacturer to retailer depots till end-users and reverse logistics provider.

Table 5.9 summarises the main packaging materials used for these furniture products at different supply chain phases, each with two different packaging solutions, referred to as 'one-off packaging solution' and 'reusable packaging solution'.

Table 5.9 Packaging Material for Furniture Products at Different Phases (phases shaded in green indicate retail-ready packaging)

	PHASE 1		PHASE 2				PHASE 3	
	Product Manufacturer	Overseas Shipping	Central Fulfilment Centre	Primary Transport Network	Regional Depot	Home Delivery Network	End-User	Reverse Transport
Worktop One-off Packaging	PE Film* Packaging Strap	PE Film Packaging Strap	PE Film Cardboard Box Packaging Strap	PE Film Cardboard Box Tape Barcode Sticker	PE Film Cardboard Box Tape Barcode Sticker	PE Film Cardboard Box Tape Barcode Sticker	PE Film Cardboard Box Tape Barcode Sticker	N/A
Worktop Reusable Packaging	PE Film Packaging Strap	PE Film Packaging Strap	PE Film Reusable Cover Packaging Strap	PE Film Reusable Cover Barcode Sticker	PE Film Reusable Cover Barcode Sticker	Reusable Cover Barcode Sticker	Reusable Cover Barcode Sticker	Reusable Cover
Mattress One-off Packaging	PE Film Cardboard Box Packaging Strap	PE Film Cardboard Box Packaging Strap	PE Film Cardboard Box	PE Film Cardboard Box Barcode Sticker	PE Film Cardboard Box Barcode Sticker	PE Film Cardboard Box Barcode Sticker	PE Film Cardboard Box Barcode Sticker	N/A
Mattress Reusable Packaging	PE Film Wooden Crate	PE Film Wooden Crate	PE Film Reusable Cover	PE Film Reusable Cover Barcode Sticker	PE Film Reusable Cover Barcode Sticker	PE Film Reusable Cover Barcode Sticker	PE Film Reusable Cover Barcode Sticker	Reusable Cover

Sofa One-off Packaging	HD PE Wrap ** Cardboard Box Corner Boards	HDPE Wrap Cardboard Box Corner Boards	HDPE Wrap Cardboard Box Corner Boards	PE Film Cardboard Box Barcode Sticker	PE Film Cardboard Box Barcode Sticker	PE Film Cardboard Box Barcode Sticker	PE Film Cardboard Box Barcode Sticker	N/A
Sofa Reusable Packaging	PE Film Wooden Crate	PE Film Wooden Crate Packaging Strap	PE Film Reusable Wrap	PE Film Reusable Wrap Barcode Sticker	PE Film Reusable Wrap Barcode Sticker	PE Film Reusable Wrap Barcode Sticker	PE Film Reusable Wrap Barcode Sticker	Reusable Wrap
Headboard One-off Packaging	PE Film Corner Boards Cardboard Box Packaging Strap	PE Film Corner Boards Cardboard Box Packaging Strap	PE Film Corner Boards Cardboard Box	PE Film Corner Boards Cardboard Box Barcode Sticker	PE Film Corner Boards Cardboard Box Barcode Sticker	PE Film Corner Boards Cardboard Box Barcode Sticker	PE Film Corner Boards Cardboard Box Barcode Sticker	N/A
Headboard Reusable Packaging	PE Film Corner Boards Packaging Strap	PE Film Corner Boards Packaging Strap	PE Film Corner Boards Reusable Sleeve Pallet	PE Film Corner Boards Reusable Sleeve Barcode Sticker	PE Film Corner Boards Reusable Sleeve Barcode Sticker	PE Film Corner Boards Reusable Sleeve Barcode Sticker	PE Film Corner Boards Reusable Sleeve Barcode Sticker	Reusable Sleeve

*PE = polyethylene; **HD PE = high-density polyethylene.

Due to different packaging systems applied in different scenarios, the different logistics processes related to the packaging were also described by mapping the operations in the supply chains. The packaging-related logistics process mapping covered the combination of general logistics processes that influence the packaging material in/output and physical flow of packed product from the filling or packing point at manufacturer, via retailer distribution centre, and down to the point of retailing shop or end-user's premises, and, when necessary, with customisation or repacking process during this flow.

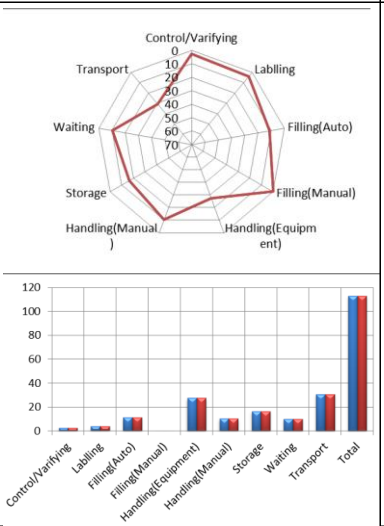
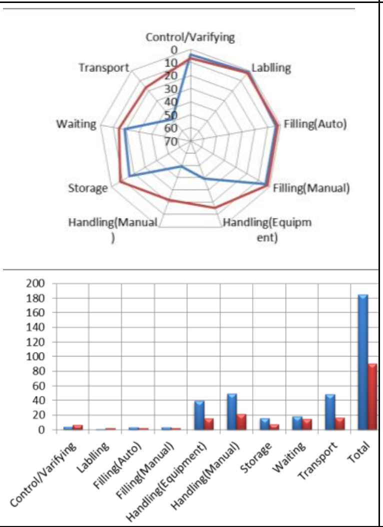
5.2.4 Applying Retail-Ready Packaging

The packaging-related processes of products' customisation also influence the overall impact. Notably, for different products and different packaging solutions in the case study, the forms of packaging are different during different phases of the supply chain. The products or transit packaging from the manufacturer sometimes are only for supply chain internal use, not 'ready' for retail use that meets the end-user's requirements. Specifically, some of the products that come with manufacturer transit packaging need a different level of re-processing or customisation after being shipped to the fulfilment centre and then repacked for a different customer; thus, the retail-ready packaging for different products in different scenarios is applied to products at different times during different supply chain phases. With different levels of ease for the reprocessing or repacking operations and different facilities for such operations, when and where to apply the final retail-ready packaging could have different levels of impact on the packaging logistics system's performance. As mapped in Table 5.9, the forms of retail-ready packaging are shaded in green, in contrast with manufacturer transit packaging, to indicate the location and phase in which the final retail-ready packaging is applied to the product, forming the final packed product that is ready to be delivered to retailing shops or end-users.

5.2.5 Result and Analysis

As with case study 1, the four pairs of packaging for different products all apply the proposed matrix evaluation, and the RPN results are listed in Table 5.10.

Table 5.10 Impact Evaluation for Different Furniture Products Packaging Systems (blue represents one-off packaging and red represents reusable packaging)

<table>
<tr><th></th><th>Phase1 Manufacturer</th><th>Phase2 Retailing Depots</th><th>Phase3 End-Users</th></tr>
<tr><td>Worktop</td>
<td>
</td>
<td>
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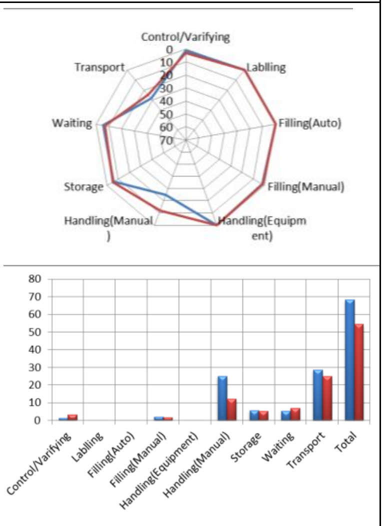
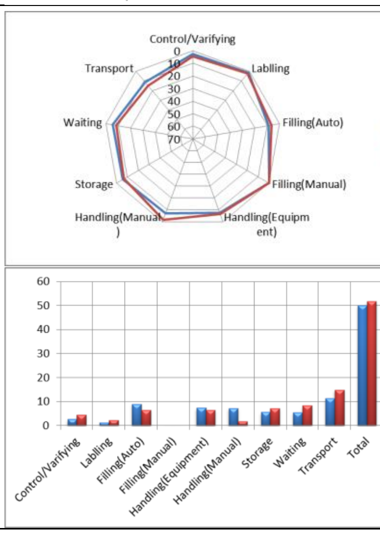
<td>
</td></tr>
<tr><td>Mattress</td>
<td>
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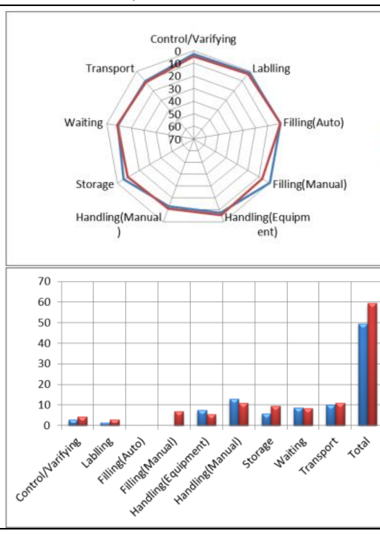
<td>
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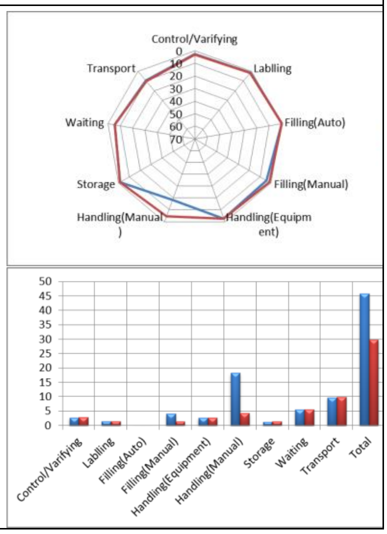
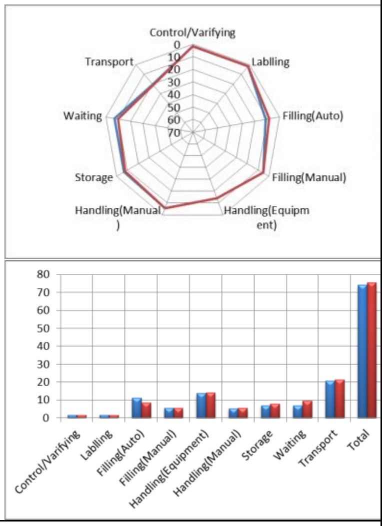
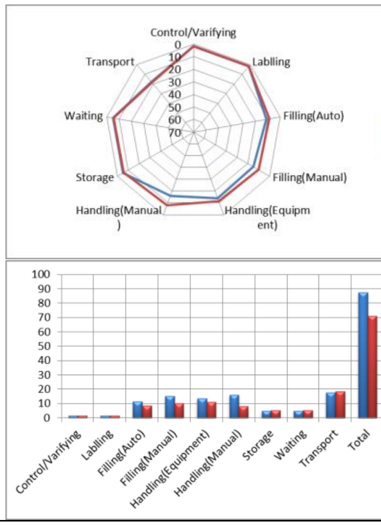
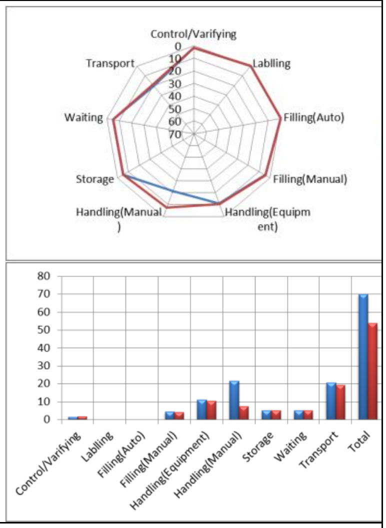
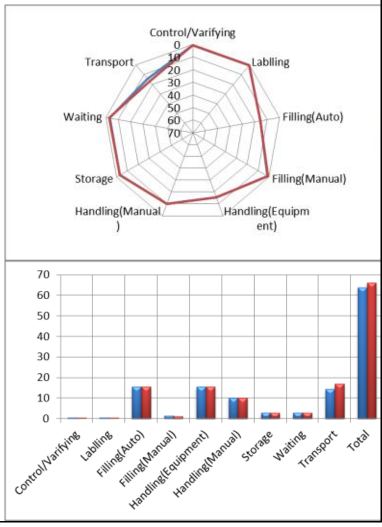
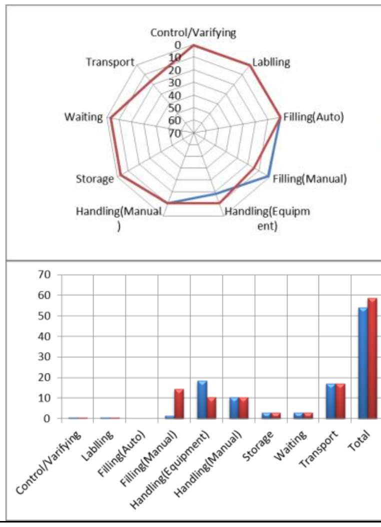
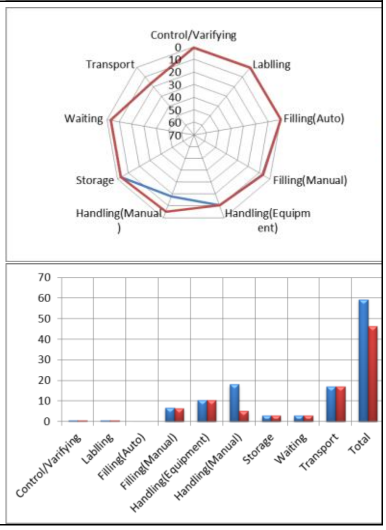
<td>
</td></tr>
</table>

Sofa			
Head-board			

As packaging decision-making support, implementation of this evaluation process helps with proper packaging selection by clearly identifying preferable packaging alternative according to priorities for each packed product in the case study. Shown in Table 5.10, the solution with lower RPN (better performance) for each product in each phase represents the more preferable solution as it reduces the risks for ope3rations and thus improve the performance in sustainability.

The results also reveal the different impact levels of different packaging system on different supply chain partners in different phases. It can be observed that the packaging's performance is different at different phase of the supply chain. Therefore, this tool can be used to help solving the challenge of imbalanced cost and benefit allocation for different supply chain partners.

At the same time, the comparison of different cases helps to cluster different types of products in the furniture industry according to the product characteristics and requirements on the re-packing of retail-ready packaging for packaging strategy decision-making support.

As shown in Figure 5.15, with the analysis of the furniture products in this case study, these products can be clustered into four different quadrants based on the two criteria related to the product characteristics: level of customisation or repacking requirement, as well as severity of operation failure consequence. The higher in operation failure severity, means the worse the impact on the product and supply chain partners when the packaging related logistic processes go wrong. The higher in customisation and repacking requirement, the more likely the packed products are unpacked, modified, or reprocessed and repacked into retail-ready packaging at certain points within the supply chain, due to different customer requirements.

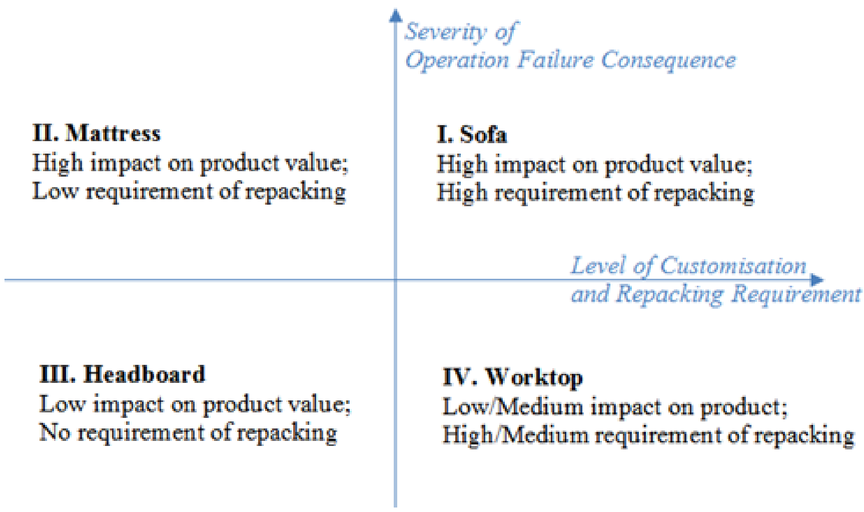


Figure 5.15 Classification of Furniture Products in this Case Study

With these clustering and impact evaluation results, different strategies on adopting reusable packaging can be developed for decision-making support. Details will be discussed in the discussion chapter as case study findings.

5.3 Case Study 3 – Sustainable Container Supply Chain Evaluation for Grain Distribution

This case study is conducted by applying proposed integrated simulation for sustainable container supply chain integrated decision making. In this case study, the application of proposed evaluation tool, and the triangulation between different container packaging scenarios provide support for the validity of the proposed evaluation.

The case study is based on a scenario in which dry grain product is supplied from Southern China to the UK. There are different solutions for the supply of this cargo; each solution is a unique combination of different packaging system and different route selection.

5.3.1 Case Scenario Introduction

- **Background Information**

The container shipping is rapidly increasing all over the world. At the same time, the containerisation is becoming a new trend for food and agriculture goods. McFarlane and Saul (2014) reveals the trend that more and more food companies shifting their shipping from dry bulk cargo ships to containers for agriculture goods – in year 2012, around 12 percent of global trade in agricultural goods (e.g., oilseed, grain, and sugar), which are traditionally shipped in bulk, were shipped using maritime container. For the majority of small growing businesses, the container shipping means much less pressure in working cash (compared to large trade to fill up bulk ship). Container shipping also provides more flexible options for these small exporters/importers (which is also an emerging trend for international business structure) by transporting those commodities in smaller shipment sizes with greater flexibility of cargo type (compared to bulk ship, very few types of goods can be shipped via one shipping journey) to quickly reach different locations for different customers.

The scenario chosen in the case study is grain product (rice) shipping from Southern China to Manchester UK in container supply chain, as illustrated in Figure 5.16. The selection of this case study on containerised dry agriculture goods shipment in intercontinental trading represents a very typical scenario and trend for container supply chain: containerised agriculture goods and flexible business mode, in which smaller trader in international trading with fulfilment demand on variety goods for different destinations with smaller shipment size.

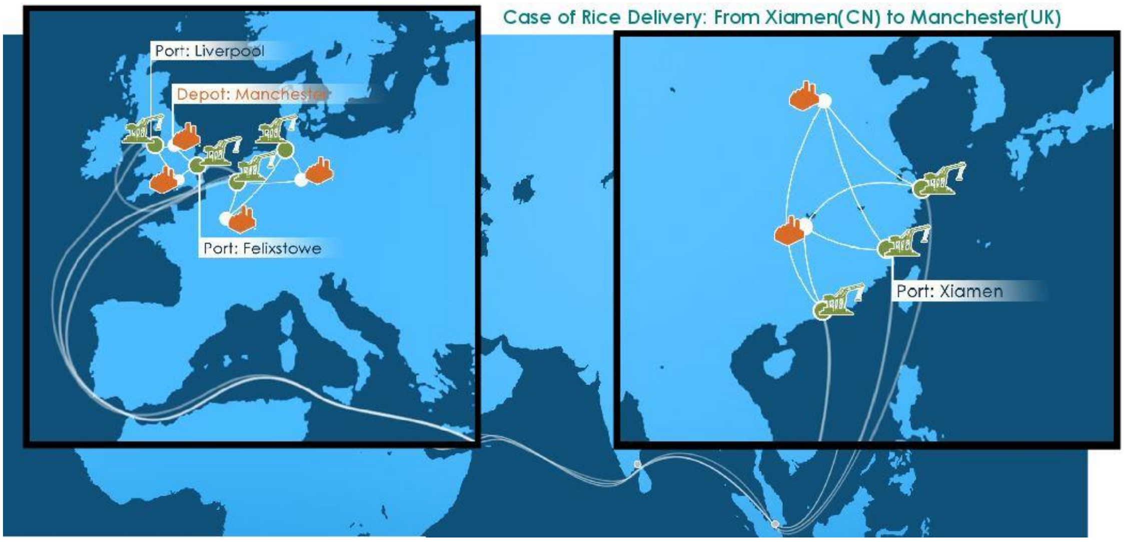


Figure 5.16 Container Shipping Scenario Setting in Simulation Model

- **Supply Chain Parties Information**

The supply chain partners in the case study mainly include the cargo owner (consigner), shipping line and packaging provider.

The consigner company C is a food provider that wholesaling and retailing food products in the UK. This company needs to import grain products for processing from oversea to its mill near Manchester, which is a fulfilment centre that supplies different regions in the UK. In this situation, there are different logistics solutions for the grain product supply from China to the UK via different routes and with different types of packaging.

Evergreen shipping line is able to take part in this supply chain for the grain product fulfilment by containerised shipping in this scenario. As one of the top 20 shipping companies in the world, Evergreen has resources of different lines operating between China and the UK; Specifically, in this case (as the client's depot based in Manchester), mainly two arrival ports (port of Felixstowe and port of Liverpool) with different supply chain structures are available for company C to choose from.

Weir & Carmichael is a UK based packaging supplier of wide range of industrial and commercial packaging products such as polypropylene products, polyethylene bags, and paper sacks etc. With rich experience in packaging industry, the company is the packaging supplier for company C for their packaging solution design and supply. As the consignment is originally dispatched from China, the packaging supplier is able to provide drop shipping from its China based OEM packaging supplier directly to the consignment sender to accommodate the cargo without sending the packaging from the UK to China before the cargo is packed into the container.

- **Operation Objective**

On making the container supply chain decision, apart from the different distance and cost for maritime shipping to different discharge port, the different road transportation distance and empty return journey between company C's mill and different discharge port needs to be considered. Also, different forms of packaging in the container are with different operation requirements and thus may fit different supply chain structure. Importantly, the selection of different solution leads to different performance on sustainability, including lead-time, business cost and environmental impact. Therefore, the options for company C's selection in this scenario is different combination of different supply chain structure and sub packaging in the container shipping. The aim of the case study is to provide decision making support to select the suitable or appropriate combination of container packaging and route for fulfilment of company C's demand, considering the impact on sustainability of chosen container supply chain.

As stated in the evaluation framework and the principle of sustainable container management that the operation goal is to improve the operation performance of the whole container supply chain in terms of efficiency and effectiveness. The proposed simulation (with sustainability framework and risk impact estimation tool embedded) is applied to identify a most suitable solution of container packaging and route combination. Quantitatively, the objective can be described as minimise the cost and maximise the efficiency and effectiveness by controlling the environmental impact and service lead time in acceptable level.

- **Route and Supply Chain Structure Information**

The route is crucial for the container supply chain structure. As suggested by Evergreen the shipping line company, in order to deliver the grain product from China to Manchester UK, there are mainly two feasible destination ports for selection, namely Felixstowe (main UK hub port for ship routes from Asia, but far from Manchester) and Liverpool (a UK periphery port, but close to Manchester). For Liverpool route, there are also different devanning plans available: devanning the goods out of container at Liverpool port and transport the goods without container to the mill in Manchester; and devanning at Manchester, in which route the cargo will be transported to the mill in the container after arriving at the port, then discharged from container, and the empty container will travel back from Manchester to Liverpool port. For the Felixstowe solution, it would be easier to carry the cargo inside the container for such a long distance hinterland travel, so the devanning location is set to be in the client's mill in Manchester, but it also provides two different scenarios to be chosen from: after devanning the cargo, return the empty container back to Felixstowe which is a long empty container travel journey; or return the empty container to the shipping lines' closer container yard in Liverpool, with extra container repositioning fee or redeployment cost for the client. The 4 different route solutions are summarised in Table 5.11 for a clear overview of the route information in this case study.

Table 5.11 Summary of Different Route Solutions

Route	**Sender**	**Original Port**	**Arrival Port**	**Reciever**	**Empty Return**
1	Depot	Xiamen	Liverpool *	Manchester	Liverpool
2	Depot	Xiamen	Liverpool	Manchester*	Liverpool
3	Depot	Xiamen	Felixstowe	Manchester*	Felixstowe
4	Depot	Xiamen	Felixstowe	Manchester*	Liverpool
Note: * symble indicates devanning place for the conatiner freight					

- **Freight Consignment Information**

In this case study, the freight consignment is grain product: rice. This product is not seasonal, but for the UK market, it needs global sourcing, most of UK rice is imported from Asia and America. The country of origin for this consignment in this case study is southern China.

The consignment (rice) in this case study belongs to the grain product category. According to van der Vorst et al. (2009) and Bourlakis and Weightman (2004), following questions should be reviewed for the products' characteristics when considering the food supply chain:

(1) The seasonality and global sourcing requirement of the product;

(2) Any process impact on quantity and quality due to biological variations, seasonality as well weather, pasts or other random biological hazards;

(3) Any possible quality decay (or any quality constraints for raw material, intermediates and finished goods) as the cargo is processed through different operation along the supply chain, which may result to problems like volume and quantity shrinkage, stock-out and quality decline for out of best-before-date;

(4) Any special requirement or condition for operation environment (e.g. during transport, storage process);

(5) Any requirement or necessity for tractability of intermediate product for environment related quality monitoring.

Combine with the cargo category information and general risk factors summarised in Table 4.4and Table 4.5. The cargo should be regarded as A1 category (cereals and grains) cargo, the risk factors to be considered should include temperature (favourable temperature range 5°C to 25°C; 20°C to 30°C is optimum for molds growing and over 25°C will promote metabolic process for self-heating risk increase), humidity (maximum equilibrium moisture content 70%), ventilation (good surface ventilation is necessary), bio-activity (2nd order), odour (highly odour sensitive- passive behaviour), contamination (sensitive to dust, dirt fats and oil -passive behaviour), mechanical influences, toxicity (CO2 evolution), shrinkage and Insect infestation (especially storage pests infestation).

Table 5.12 Consignment Information (source: GDV. 2014)

Bulk Density	800kg/m^3
Key Transport Requirements	Vehicles and container for the transportation must be clean, sanitary for food grade products, dry and free of other contaminants
	During transport, the cargo must be fully covered, prevent from rain and sun
Key Storage Requirements	No open dump allowed, facility must be clean, dry, and ventilated
	To be placed more than 10cm from the ground, and at least 20cm away from any wall
	Wet, poisonous and spoilage items are prohibited to share the same warehouse section

The main characteristics and general requirement information of the consignment is identified in Table 5.12. The bulk density of rice produced in China is around 800kg/m^3 according to standard; it is not time sensitive perishable goods; but with sensitivities to temperature, humidity, odour, insects and contamination, thus with some requirement on storage and transportation environment. Some other key characteristics and requirement of the rice as cargo is listed in Table 5.12.

- **Packaging System Information**

Container Packaging Solution One: Container Liner

The first possible packaging solution is container rice liner, also called sea bulk liner or container bag, shown as in Figure 5.17. It is widely used for mining, chemical and various food industries. One container liner can be filled up with goods and fits in one 20ft maritime container. Compared with shelf-ready small woven bags, it is cheaper in terms of packaging (can be 50% cheaper than small woven bags), and with higher utility rate of the container (stock approximately 30% more products than small woven bags), but it requires special storage or unloading facilities (apart from general fork lift) for the loading and unloading. And the liner is not designed to be reused after end of use and cannot be used as storage equipment solely on its own, so that once it is disassembled from the container, the life cycle of this bag ends.

Figure 5.17 Different Solution Options for Sub Packaging in Container- Container Liner Solution

In this scenario, the technical specification of the container liner used in the supply is shown in Table 5.13. Made by degradable food grade Woven PP, each of this 4 panel liner bag with spout will fill up one 20ft container, and its SWL (safe working load) capacity also matches a 20ft container, which is capable of containing 22 tonnes of bulk cargo per bag.

Table 5.13 Technical Specification of Container Rice Liner

Container Bag Type	4 Panel with Discharge Spout
Overall Dimension	590cm * 230cm * 230cm (with margin to container size)
Construction Material	Heavy Density Polyethylene (HDPE) Fabric
Weight	10 kg
Safe Working Load	22 tonnes per bag

Container Packaging Solution Two: Industrial Bulk Bag

The alternative possible packaging system in this scenario is industrial bulk container bag (IBC), also known as tonne bag, shown as in Figure 5.18. The bulk bag can be filled with bulk goods and stacked on top of others with or without industrial pallet. It is a popular approach of moving quantities of aggregates, seeds, feeds, powers, minerals and large range of loose agriculture products. It is usually used as intermediate layer for container shipping and usually used within business flow. The feature of lifting loops enables it to be handled easily without pallet by general forklifts, cranes or even helicopters over many times. The capacity ranges from 500 to 2000kg depends on different design and material. It is also popular as it can also be storage unit after the cargo arrives at the receiver's warehouse before the goods being processed or delivered to end-user.

Figure 5.18 Different Solution Options for Sub Packaging in Container- Industrial Bulk Bag Solution

Table 5.14 shows the technical specification of the industrial bulk bag being compared as the packaging solution in the case study scenario. The bag is made up with degradable food grade woven PP fabric, with lifting features for forklift and spout for loading and sealing; it is sized to be fit on standard pallet for the convenience of stacking in the ware house and during transportation. Each bulk bag is capable of 500 to 2000kg capacity and flexible to meet different handling equipment and different delivery demand and plan.

Table 5.14 Technical Specification of Industrial Bulk Bag

Bag Type	4 Panel with 4 Lifting Loops and Top Spout
Overall Dimension	120cm * 100cm * 100cm
Construction Material	Coated UV Treated Food Grade Polypropylene (PP) Woven Fabric
Weight	2.5kg
Safe Working Load	1000kg per bag

- **Container Information**

The container is regarded as outer packaging for the packed cargo inside. It is with standard design and size for the cargo being transported in different transportation modes. The mostly widely used container for common goods nowadays is definitely the standard dry container, which is with two different sizes, namely standard 20ft and 40ft dry container as shown in Figure 5.19 (other dry container like 40ft 'high cube', smaller 8ft and 10ft container is far less popular as the two). The specification of container is shown in Table 5.15.

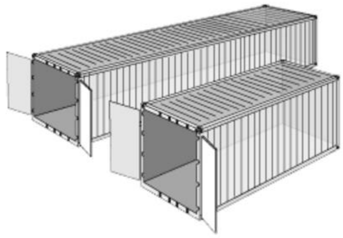


Figure 5.19 40ft and 20ft Dry Container

Table 5.15 Key Specification of Standard Dry Container

	20ft Dry Container		40ft Dry Container	
Tare Weight (Empty Weight)	2300 kg	5070 lbs	3750 kg	8270 lbs
Payload Capacity (General Container)	21670 kg	47774 lbs	26396 kg	58193 lbs
Payload Capacity (Overweight Container)	28280 kg	62347 lbs	26830 kg*	59150 lbs
Internal Length	5.91 m	19.4 ft	12.03 m	39.5 ft
Internal Width	2.34 m	7.7 ft	2.34 m	7.7 ft
Internal Height	2.40 m	7.9 ft	2.40 m	7.9 ft
Maximum Cubic Capacity (Internal Volume)	33 m^3	1165 ft^3	67 m^3	2366 ft^3

To be noted that the maximum load for 20ft overweight container is larger than the maximum load of 40ft container (indicated with * in the table), the reason is the larger container is physically with weaker point in the middle when handling by cranes hanging on four top corners, as the gravity centre is further to the hanging points than smaller container. To avoid the potential bending or breakage for safety operation, the load is with higher restriction for larger container.

5.3.2 Data collection

In this case study, both primary and secondary data are used. Primary data mainly includes freight consignment information, transport and operation conditions, operation processes; container packaging information, container specification and container related rate and fare; freight rate, delivery fare, fixed documentation cost, discharging and loading rate; maritime shipping time, container turnaround time, feasible route solution, operation risks and impact. Secondary data are used for carbon emission of transportation, environmental impact and charge of packaging material and logistics operation, and general cargo types in shipping industry.

In order to get the operation data and score information, the experts in container supply chain were contacted. The general information of experts is shown in Table 5.16, it includes professional in shipping lines, port operator, logistics provider and packaging provider to cover different aspects of the evaluation.

Table 5.16 Personnel for Data Collection in Container Shipping Supply Chain

Position	**Organisation**	**Nature of Organisation**
Project Logistics- Project Manager	COSCO Logistics Xiamen Co., Ltd.	Logistics Company
Market- Sales Manager	Evergreen Line Co., Ltd.	Shipping Line
Global Forwarding- Sales Manager	COSCO Logistics Xiamen Co., Ltd.	Logistics Company
Shipping	COSCO Container Lines Co., Ltd.	Shipping Company
Manager	Xiamen Port Development Co., Ltd.	Port Company
External Shipping Consultant	Weir and Carmichael Ltd.	Packaging Provider

Apart from the operation information such as lead-time, cost and carbon, the experts also provide the judgement on the importance of the different sustainable aspects for the AHP pair-wise comparison matrix establishment to work out proper weighting of the different criteria. Also, related research literature (Saaty, 1990; Harilaos & Christos, 2010; Song, 2011; Sarfaraz & Jurgita, 2012) is considered for the scoring of the comparison matrix and for the calculation of carbon emission.

5.3.3 Simulation Model Structure and Configuration

The simulation model is established using Anylogic software. As an agent base simulation model and configured for the given scenario of rice distribution, the interface is shown as the screenshot in Figure 5.16. For the stated business flexibility requirement for small international trader's characteristics, in the simulation model, standard 20ft container is chosen for analysis and comparison. For each supply chain route or structure scenario, two different types of inner layer packaging (A - container rice liner, and B - Industrial Bulk Bag) are considered and analysed.

- **Parameters Setting for Container Operation Rate**

The container information is used in the simulation model to consider the loading capacity, and container related fees and cost (collected from shipping line, and converted from CNY to GBP).

Table 5.17 Container Related Rates and Charges

		Dry Container Type	
		20ft Dry Container	**40ft Dry Container**
Fixed Cost (e.g. Entry Summary Declarations cost, document fee)		£94.15 per container	
Loading and Discharge Rate		£80.33 per container	£160.66 per container
Container Leasing Rate (in container yard)	1 to 7 days	£25 per day per container	£50 per day per container
	Over 7 days (Detention)	£40 per day per container	£80 per day per container
Container Leasing Rate (out of container yard)	1 to 7 days	£10 per day per container	£20 per day per container
	Over 7 days (Detention)	£24 per day per container	£48 per day per container
Alternative Return Location Charge		£58 per container	

The container related operation rates and fare are shown in Table 5.17. The fixed rate and loading/discharging rate is the same for different solution using 20ft container. The leasing cost is with first accumulated 3 days of container occupation free, after that, the days that the container is out of shipping lines control will be regarded as chargeable leasing days and the client is charged according to the situation of container's location and occupying days shown in the table.

- **Settings for Emission Factors**

The simulation model generates carbon emission information for transportation based on emission factors. The factors are set according to Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting (2012) as shown in Table 5.18.

Table 5.18 Freight Distance Conversion Factors for Carbon Emission

	HGV for Road Transportation	**Maritime Vessel (8000+TEU) for Container Shipping**
CO2 Emission **kg CO_2 per tonne km**	0.12168	0.001250
CH4 Emission **(equivalent kg CO_2 per tonne km)**	0.00008	0.00000
N2O Emission **(equivalent kg CO_2 per tonne km)**	0.00190	0.00010
Total Direct GHG Emission **(equivalent kg CO_2 per tonne km)**	0.12366	0.01260

In the model, the freight distance conversion factors are used together with travel distance and freight weight to estimate the carbon emission for different solution.

- **Distance Information**

The distance of different mode and route between the key transport nodes in the scenario is shown in Table 5.19 for reference. In the simulation model, the agent follows the GIS embedded in the tool.

Table 5.19 Distance Between Transport Nodes

Location 1	**Location 2**	**Distance**	**Transport Mode**
Liverpool Port	Liverpool Container Yard	0 km	Road
Liverpool Container Yard	Manchester Depot	58.5 km	Road
Felixstowe Port	Manchester Depot	367.5 km	Road
Xiamen Port	Felixstowe Port	21057.24 km	Ocean

- **Configuration for Route Scenario 1**

Illustrated in Figure 5.20, in this Scenario, the rice is produced in China, consolidated in depot of original, transported by road to Xiamen port, loaded onto vessel for maritime transport to Liverpool port, unloaded and de-consolidated at Liverpool yard, the product is then transported to cargo owner’s depot by road, leaving empty container at Liverpool yard.

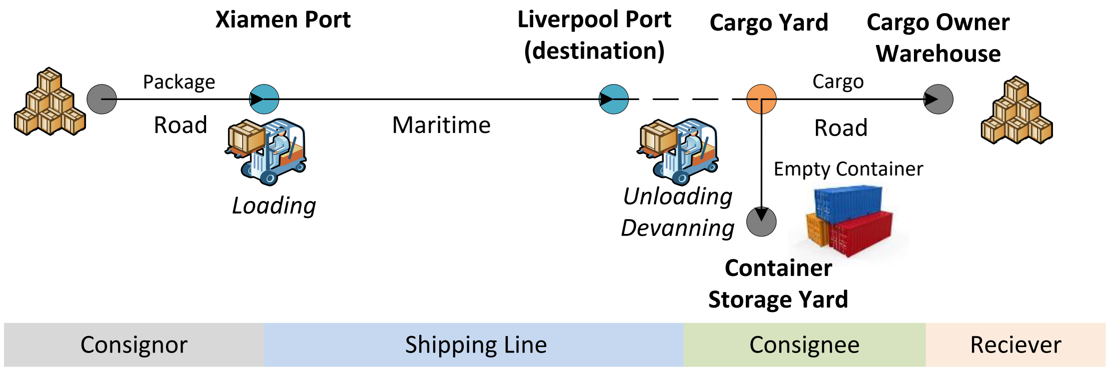


Figure 5.20 Route 1: Via Liverpool and Devanning at Liverpool

Solution 1 (Route 1 with Container Rice Liner)

For this combination of route scenario 1 and container packaging A (container rice liner), the settings for the simulation model is as follow:

1) Lead-Time

As the container is unstuffed on the arrival of destination port, therefore, the inland container turnaround time is 0, there will be no extra container leasing cost in this scenario. The service time is therefore the accumulation of ocean and inland transport time, waiting time in container yard and possible delay time if any failure occurs.

2) Cost

The cost of this solution is set in the simulation model being composite of:

Sea Fright Cost C_s- calculated using Sea Fright Rate P_s (£897.2 per TEU)

Inland Haulage Cost C_h- estimate based on Fuel Consumption Factor (6.2 mile per Gal), Fuel Price (£1.6 per Gal) and the one trip distance between Liverpool and Manchester.

Loading/Discharging Cost C_d-£80.3 per TEU

Container Packaging Material Cost – £120 per liner bag (per TEU)

Potential Risk Failure Cost C_r-Simulated by the simulation

Environmental Cost C_e-reflects on the packaging material recycling and reprocessing charge according to Packaging Recovery Notes Price as used in previous chapter, which is £17/tonne plastic material

$$C = C_s + C_h + C_d + C_p + C_e + C_f + C_r \quad (19)$$

Then the cost C is calculated to be absorbed by each weight unit (kg) of the product to represent the effectiveness. The unit equivalent cost C_u for every kg cargo product W_c is expressed as

$$C_u = \frac{C}{W_c} \quad (20)$$

Where cargo product W_c is subject to the type of container packaging. As one TEU contains one liner bag of 26.4 m^3 capacity (with safety margin to container internal volume), when fully loaded with rice (density of 800kg per m^3), and considering the maximum loading weight for 20 ft container, for this solution, when fully loaded with rice, W_c=21120 kg.

3) Carbon Emissions

The carbon emission considers the emission of transportation and the emission of the packaging material:

The packaging material emission is calculated using packaging material emission factor F_{pm} (for HDPE material F_{pm} =1.96kg CO2 per kg HDPE material) and the overall weight of the packaging material W_p =10 kg is used per TEU cargo in this scenario.

The transportation emission is estimated using the parameters of:

Consignment Weight W_i (including weight of cargo, packaging and container);

Travel Distance in each mode D_i- recorded in the simulation by cargo agent;

Maritime Shipping Freight Distance Conversion Factor EF_1 for maritime transportation efficiency - 0.0125 kg CO2 per tonne.km

HGV Freight Distance Conversion Factor EF_2 for inland transport efficiency- 0.12168 kg CO2 per tonne.km

$$E = E_t + E_m = \sum_{i=1}^{n} W_i \cdot D_i \cdot EF_i + F_{pm} \cdot W_p \qquad (21)$$

Same as the cost factor, the carbon emission will be converted into per kg goods equivalent emission using

$$E_u = \frac{E}{W_c} \qquad (22)$$

So that the emission factor represents emission performance for every unit weight cargo for easier comparison between solutions.

Solution 2 (Route 1 with Industrial Bulk Bag)

Combination of route scenario 1 and container packaging B (industrial bulk bags), the settings for the simulation model is similar to solution 1A:

1) Lead-Time

   Same as the solution 1, the lead time of this solution is based on the accumulation of ocean transport time, road transport time, waiting time in container yard and possible delay time if any failure occurs, but the unloading and loading for industrial bulk bags is slower than the container liner (as there are a batch of stacked bulk bags need to be loaded and discharge), therefore the lead time in this solution could be slightly longer than solution 1.

2) Cost

   The cost for this solution is configured as follow:

   Sea Fright Cost Cs- calculated using Sea Fright Rate Ps (£897.2 per TEU)

   Inland Haulage Cost C_h- estimate based on Fuel Consumption Factor (6.2 mile per Gal), Fuel Price (£1.6 per Gal) and the one trip distance between Liverpool and Manchester.

   Loading/Discharging Cost Cd-£80.3 per TEU

Container Packaging Material Cost – for every bulk bag unit in the container, £3.5 per bulk bag plus £4 per pallet (assume £20 pallet being used for 5 trips), then multiplied by the unit quantity in each container (in this case, 20 units)

Potential Risk Failure Cost Cr-Simulated by the simulation

Environmental Cost C_e- packaging material recycling and reprocessing charge according to Packaging Recovery Notes Price £17/tonne plastic material (2013 price)

$$C = C_s + C_h + C_d + C_p + C_e + C_f + C_r \quad (23)$$

The cost structure set in the simulation for this solution is similar to solution 1, as they share the same route for the distribution. But the parameters for the cost factors calculation are different for using different container packaging solution. For example, the bulk bags solution requires more than one bag inside the container. In order to fully utilise the container payload capacity, in this solution, the industrial bulk bags are filled with rice, placed on pallet individually and stacked as 2 layers inside the container (maximum 10 units per layer), as shown in Figure 5.21. Therefore, each container contains 20 bulk bag units.

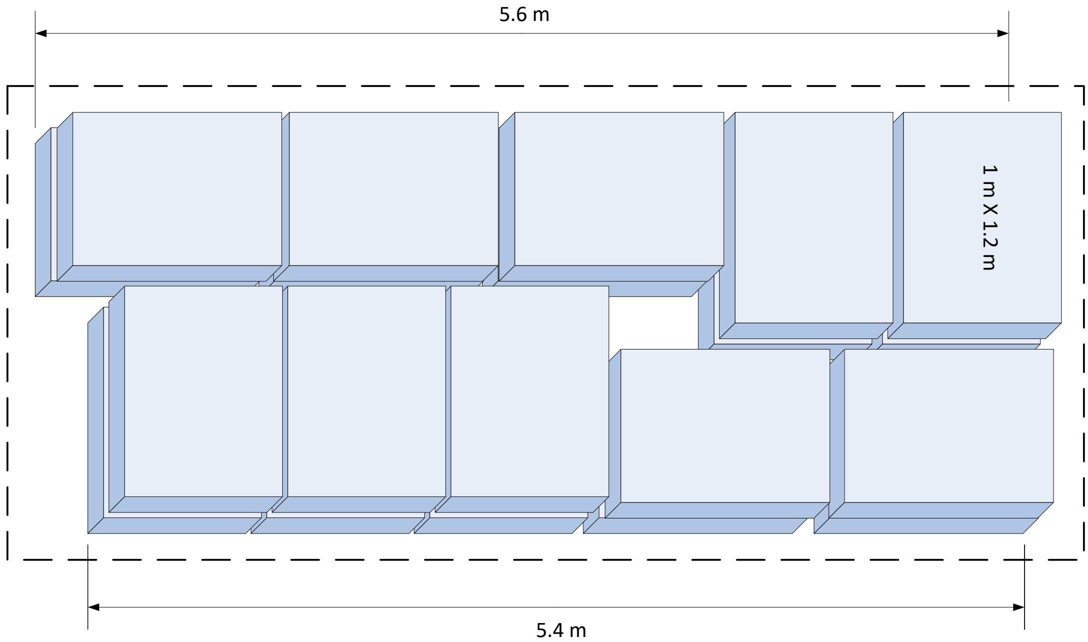


Figure 5.21 Fitting of Industrial Bulk Bags into 20 ft Container

This results in different cargo product capacity per container, different inland haulage impact due to different freight weight (product plus packaging), different container packaging material cost, and different amount of end of use packaging material.

When converting the cost C to unit cargo equivalent cost C_u for every kg cargo product using Equation 20.

$W_{c,}$ is calculated according to this container packaging solution: 20 bulk bag units with each capacity of 1.5m^3, loaded with 800 kg/m^3 density rice, considering the safety load of the bulk bag of 1 tonne, one 20 ft container can accommodate W_c=20000 kg cargo using this container packaging.

3) Carbon Emissions

Same as solution one, the carbon emission includes the emission of transportation and the emission of the packaging material:

$$E = E_t + E_m = \sum_{i=1}^{n} W_i \cdot D_i \cdot EF_i + F_{pm} \cdot W_p \qquad (24)$$

The main difference is the container packaging material impact and inland haulage loading weight.

The packaging material emission is calculated using packaging material emission factor F_{pm} ,different from solution one as different materials are used for these two container packaging materials (in this solution, for PP material F_{pm} =1.81 kg CO2 per kg HDPE material) and the overall weight of the PP packaging material W_p =50 kg (20 pieces of 2.5 kg bulk bag) is used per TEU cargo in this scenario.

The transportation emission is estimated using the parameters of:

Consignment Weight Wi (including cargo, packaging and container plus pallet weight);

Travel Distance in each mode D_i- recorded in the simulation by cargo agent;

Maritime Shipping Freight Distance Conversion Factor EF_1 for maritime transportation efficiency which is 0.0125 kg CO2 per tonne.km

HGV Freight Distance Conversion Factor EF_2 for inland transport efficiency- 0.12168 kg CO2 per tonne.km

- **Configuration for Route Scenario 2**

Shown in Figure 5.22, same as Scenario 1 for destination port, the rice is produced in China, consolidated in depot, transported by road to Xiamen port, loaded and transported by sea to Liverpool port, unloaded and de-consolidated at Liverpool yard. Then differently, the containerised cargo is unloaded but not de-vanned in the port cargo yard, instead, the whole package is transported to the Manchester mill by road for devanning, and the empty container is returned to Liverpool port by road transport.

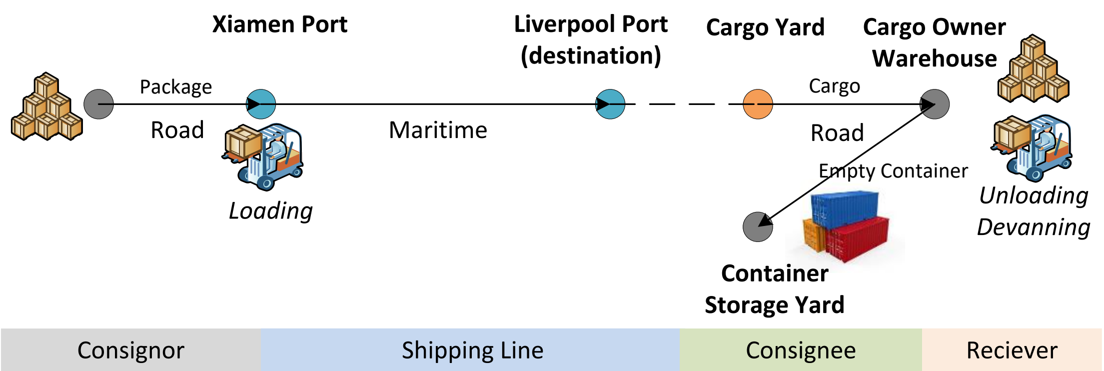


Figure 5.22 Route 2: Via Liverpool and Devanning at Manchester

Compared to Route Scenario 1, this route is different in the devanning location. As the container needs to be carried in inland transportation, the container leasing is added into consideration for both solution 3 and solution 4 using this route.

Solution 3 (Route 2 with Container Rice Liner)

For this combination of route scenario 2 and container packaging A (container rice liner), the settings for the simulation model is as follow:

1) Lead-Time

This route shares the same maritime transport and same destination port with route scenario 1 (solution 1 and 2). But differently, the devanning of container is not on the port yard as it arrives, instead, the container is transported to the customer's premises for un-stuffing. Due to potential waiting for devanning operation in the port due to operation capacity, stuffing at the customer's own premises is more likely to shorten the waiting time factor in the simulation, and the lead time could be slightly shorter. The inland container turnaround time is added into considered in this scenario as the container will be used outside the port for inland haulage, but the container turnaround (return) time is not recorded into lead time factor, as the lead time measures till the point customer receives and unloads the cargo from vehicles. Therefore the lead time factor is accumulated by sea transport time, inland transport time, waiting time and any potential failure induced delay.

2) Cost

The cost of this solution is set in the simulation model being composite of:

Sea Fright Cost C_s- calculated using Sea Fright Rate P_s (£897.2 per TEU)

Inland Haulage Cost C_h- estimate based on Fuel Consumption Factor (6.2 mile per Gal), Fuel Price (£1.6 per Gal) and twice trip distance between Liverpool and Manchester as the empty container needs to be returned.

Loading/Discharging Cost C_d-£80.3 per TEU

Container Packaging Material Cost – £120 per liner bag (per TEU)

Potential Risk Failure Cost C_r-Simulated by the simulation

Container Leasing Cost C_l- calculated according to the days that the container is occupied for transportation out of shipping line's control (generated by simulation), and the rate is £25 per chargeable day*.

Environmental Cost C_e- packaging material recycling and reprocessing charge using Packaging Recovery Notes Price £17/tonne multiplied by total packaging weight

$$C = C_s + C_h + C_d + C_p + C_e + C_f + C_l + C_r \quad (25)$$

The unit equivalent cost C_u is calculated using W_c =21120 kg for every TEU cargo packed in rice container liner in the container.

$$C_u = \frac{C}{W_c} \quad (26)$$

3) Carbon Emissions

The carbon emission considers the emission of transportation and the emission of the packaging material

$$E = E_t + E_m = \sum_{i=1}^{n} W_i \cdot D_i \cdot EF_i + F_{pm} \cdot W_p \quad (27)$$

Consignment Weight W_i includes two different phase, full load phase (W_1 and W_2) which is the weight sum of cargo, packaging and container, and empty container weight (W_3) for empty return journey;

Travel Distance in each mode D_i- recorded in the simulation by cargo agent, including empty container return trip;

Maritime Shipping Freight Distance Conversion Factor EF_1 for maritime transportation efficiency - 0.0125 kg CO2 per tonne.km

HGV Freight Distance Conversion Factor EF_2 (full load) and EF_3 (empty return) for inland transport efficiency-0.12168 kg CO2 per tonne.km

Packaging Material Emission Factor F_{pm} =1.96kg CO2 per kg HDPE material
Overall Weight of the HDPE packaging material W_p =10 kg per TEU cargo

Solution 4 (Route 2 with Industrial Bulk Bag)

Combination of route scenario 2 and container packaging B (Industrial Bulk Bag), the simulation model is configured for this solution as follow:

1) Lead Time

This route in this solution is the same as solution 3. The lead time is also accumulated by sea transport time, waiting time at container yard and any potential failure induced delay. Meanwhile, considering the fact that the unloading and loading for all 20 pieces industrial bulk bags takes longer time than the container liner in solution 3, the unstuffing time is set longer in the simulation model compared to solution 3 using container liner bag.

2) Cost

Same cost structure with the alternative solution in this route, but with different parameter value, the cost of this solution is set as: Equation 25.

Sea Fright Cost C_s- calculated using Sea Fright Rate P_s (£897.2 per TEU)

Inland Haulage Cost C_h- estimate based on Fuel Consumption Factor (6.2 mile per Gal), Fuel Price (£1.6 per Gal), one full load trip from Liverpool to Manchester and one empty container trip back to Liverpool yard.

Loading/Discharging Cost C_d-£80.3 per TEU

Container Packaging Material Cost – £150 per TEU (£3.5 per bulk bag plus £4 per pallet per trip, total 20 units in one container)

Potential Risk Failure Cost C_r-Simulated by the simulation

Container Leasing Cost C_l- calculated according to the days that the container is occupied for transportation out of shipping line's control (generated by simulation), and the rate is £25 per chargeable day*.

The unit equivalent cost C_u conversion is calculated using W_c =20000 kg for every TEU cargo packed in bulk bag container packaging in this solution using Equation 26.

3) Carbon Emission

Using Equation 27 for carbon emission calculation, Consignment Weight W_i including two different types, full load (W_1 and W_2) which is the weight sum of cargo, packaging and container, and empty container weight for empty return journey (W_3);

Travel Distance in each mode D_i- recorded in the simulation by cargo agent, including empty container return trip;

Maritime Shipping Freight Distance Conversion Factor EF_1 for maritime transportation efficiency - 0.0125 kg CO2 per tonne.km

HGV Freight Distance Conversion Factor EF_2 (full load) and EF_3 (empty return) for inland transport efficiency-0.12168 kg CO2 per tonne.km

Packaging Material Emission Factor F_{pm} =1.81 kg CO2 per kg PP material Overall Weight of the PP packaging material W_p =50 kg (20 pieces of 2.5 kg bulk bag used per TEU cargo) in this solution.

- **Configuration for Route Scenario 3**

Illustrated in Figure 5.23, in this scenario, the rice is produced in China, consolidated and transported by road to Xiamen port, loaded onto vessel for maritime transport to Felixstowe port, unloaded but not de-vanned at Felixstowe, the cargo with whole container is then transported by road to the mill in Manchester, unstuffed and return the empty container back to Felixstowe by road after that.

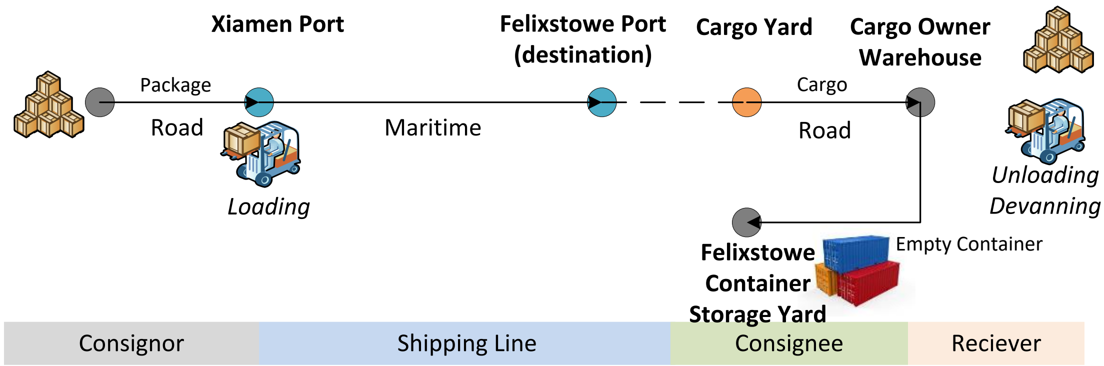


Figure 5.23 Route 3: Via Felixstowe and Return Empty to Felixstowe

The Felixstowe route is with different travel distance (both maritime and inland transport) and different container occupation period compared to Liverpool solutions. As the Felixstowe port is the main UK port, the charge of sea transport rate is lower than Liverpool according to shipping line's information. Also, the trunk route service to the main port is with shorter ocean shipping time compared to Liverpool solution. But the long container turnaround time contributes to higher container leasing fee.

<u>Solution 5 (Route 3 with Container Rice Liner)</u>

1) Lead-Time

It is accumulated by sea transport time, waiting time at yard, inland haulage time and any potential failure induced delay.

2) Cost

$$C = C_s + C_h + C_d + C_p + C_e + C_f + C_l + C_r \qquad (28)$$

Sea Fright Cost C_s- calculated using Sea Fright Rate P_s (£687.5 per TEU)

Container Packaging Material Cost – £120 per liner bag (per TEU)

Inland Haulage Cost C_h- estimate based on Fuel Consumption Factor (6.2 mile per Gal), Fuel Price (£1.6 per Gal), one full load trip from Felixstowe to Manchester and one empty container trip back to Felixstowe yard.

Container Leasing Cost C_l- calculated according to the days that the container is occupied for transportation out of shipping line's control (generated by simulation), and the rate is £25 per chargeable day*

Other fare and price parameters same to the Liverpool routes

To convert the cost to unit equivalent cost C_u, W_c =21120 kg is used for every TEU cargo packed in rice container liner in the container.

$$C_u = \frac{C}{W_c} \tag{29}$$

3) Carbon Emissions

Same as previous solution, the carbon emission considers the emission of transportation and the emission of the packaging material

$$E = E_t + E_m = \sum_{i=1}^{n} W_i \cdot D_i \cdot EF_i + F_{pm} \cdot W_p \tag{30}$$

Consignment Weight W_i includes two different phase, full load phase (W_1 and W_2) which is the weight sum of cargo, packaging and container, and empty container weight (W_3) for empty return journey;

Travel Distance in each mode D_i- recorded in the simulation by cargo agent, including one maritime journey from Xiamen to Felixstowe(D_1), one full load journey from Felixstowe to Manchester (D_2) and one empty container return trip from Manchester to Felixstowe (D_3);

Packaging Material Emission Factor F_{pm} =1.96kg CO2 per kg HDPE material
Overall Weight of the HDPE packaging material W_p =10 kg per TEU cargo

Other parameters setting refers to Solution 4

<u>Solution 6 (Route 3 with Bulk Bag)</u>

1) Lead-Time

This route in this solution is the same as solution 5. The difference in lead time mainly reflects on the difference in un-stuffing cargo from different container packaging, this operation time is set longer in the simulation model compared to solution 5 using container liner bag.

2) Cost

Same cost structure with solution 5 in the same route, but with different parameter value, the cost of this solution is set as Equation 28.

The difference compared to solution 5 mainly on

Container Packaging Material Cost – £150 per TEU (£3.5 per bulk bag plus £4 per pallet per trip, total 20 units in one container)

The unit equivalent cost C_u conversion is calculated using Equation 29, where W_c =20000 kg for every TEU cargo packed in bulk bag container packaging in this solution.

3) Carbon Emissions

Same as solution 5 in Equation 30, apart from the packaging material parameters

Packaging Material Emission Factor F_{pm} =1.81 kg CO2 per kg PP material Overall Weight of the PP packaging material W_p =50 kg (20 pieces of 2.5 kg bulk bag used per TEU cargo) in this solution.

- **Configuration for Route Scenario 4**

This scenario is similar to scenario 3 before the empty container is returned. Shown in Figure 5.24 the rice produced in China, is loaded into container, transported by road to Xiamen port, shipped to Felixstowe port by sea transport, then directly transported to mill in Manchester by road, de-vanned, then the empty container is returned by road transport to a nearby container yard in Liverpool to finish the whole distribution journey.

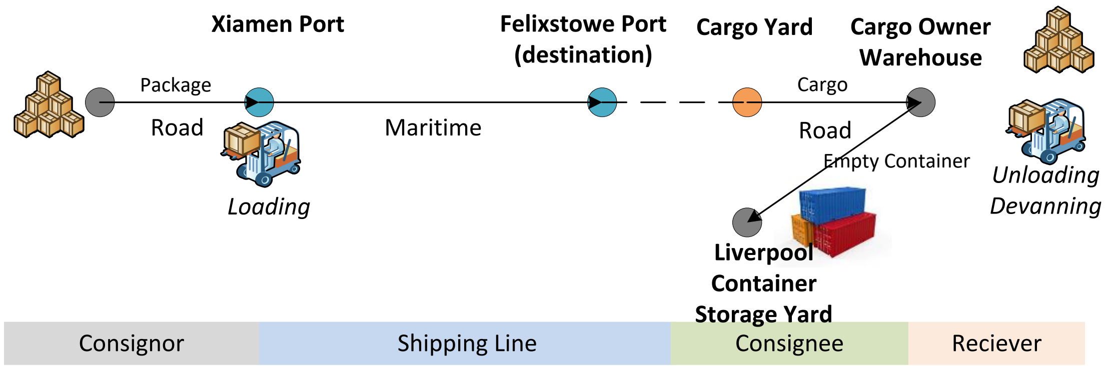


Figure 5.24 Route 4: Via Felixstowe and Return Empty to Liverpool

Same maritime route as route 3, but the difference in empty return location impact on the container turnaround time, container leasing and inland travel impact.

Solution 7 (Route 4 with Container Rice Liner)

1) Lead-Time

It is accumulated by sea transport time, waiting time at yard, inland haulage time and any potential failure induced delay. Same as route 2, the service lead time is calculated to the point the customer has the cargo un-stuffed in its premises before the empty container returns.

2) Cost

The cost of this solution is set in the simulation model being composite of:

$$C = C_s + C_h + C_d + C_p + C_e + C_f + C_l + C_{re} + C_r \qquad (31)$$

Sea Fright Cost C_s- calculated using Sea Fright Rate P_s (£687.5 per TEU)

Container Packaging Material Cost – £120 per liner bag (per TEU)

Container re-position/re-deployment fee C_{re} - £58 extra when returning the container to alternative location when agreed with shipping line

Inland Haulage Cost C_h- estimate based on Fuel Consumption Factor (6.2 mile per Gal), Fuel Price (£1.6 per Gal), one full load trip from Felixstowe to Manchester and one empty container trip back to nearby yard- Liverpool.

Other fare and price parameters same with Route 3

To convert the cost to unit equivalent cost C_u, W_c =21120 kg is used for every TEU cargo packed in rice container liner in the container.

$$C_u = \frac{C}{W_c} \tag{32}$$

3) Carbon Emissions

Same as previous solution, the carbon emission considers the emission of transportation and the emission of the packaging material

$$E = E_t + E_m = \sum_{i=1}^{n} W_i \cdot D_i \cdot EF_i + F_{pm} \cdot W_p \tag{33}$$

Consignment Weight W_i includes two different phase, full load phase (W_1 and W_2) which is the weight sum of cargo, packaging and container, and empty container weight (W_3) for empty return journey;

Travel Distance in each mode D_i- recorded in the simulation by cargo agent, including one maritime journey from Xiamen to Felixstowe(D_1), one full load journey from Felixstowe to Manchester (D_2) and one empty container return trip from Manchester to Liverpool (D_3);

Packaging Material Emission Factor F_{pm} =1.96kg CO2 per kg HDPE material
Overall Weight of the HDPE packaging material W_p =10 kg per TEU cargo

Other parameters setting refer to Route 3.

Solution 8 (Route 4 with Industrial Bulk Bag)

1) Lead-Time

This route in this solution is the same as solution 7. The difference in lead time mainly reflects on the difference in un-stuffing process in Manchester.

2) Cost

Same cost structure with solution 7 based on Equation 31. in the same route that also with container alternative return location charge. The difference compared to solution 7 mainly on

Container Packaging Material Cost – £150 per TEU (£3.5 per bulk bag plus £4 per pallet per trip, total 20 units in one container)

The unit equivalent cost C_u conversion is calculated using W_c =20000 kg for every TEU cargo packed in bulk bag container packaging in this solution, using Equation 32.

3) Carbon Emissions

Same as solution 7 based on Equation 33, apart from the different packaging material parameters

Packaging Material Emission Factor F_{pm} =1.81 kg CO2 per kg PP material Overall Weight of the PP packaging material W_p =50 kg (20 pieces of 2.5 kg bulk bag used per TEU cargo) in this solution.

5.3.4 Results and Analysis

- **Simulation Result of Sustainability Evaluation of the Solutions**

The result generated by proposed simulation is shown as Table 5.20, which considers the different criteria of sustainable measurement and the container packaging induced operation risks into the sustainable evaluation. General trend from this table will be explained and more detail discussion will be provided in sections of normalisation and sensitivity analysis. Decision making support on sustainable solution selection can be provided from the simulation.

The result 'service lead time' is a customer focus factor that represents the service time (effectiveness) from cargo consolidation and received by the consigner to the point when the cargo is received and de-vanned in the final receiver's premises, without the accumulation of empty container turnaround time. From the simulation result, it can be spotted that all the solutions are within the customer expected (consignee promised) service lead time to fulfil the demand. But the Liverpool solutions (solution 1 to 4) are generally few days slower than Felixstowe solutions, this could be caused by the different types of destination port as main hub port, Felixstowe has priority for shipping lines to calls to the port. And for every same route, the lead time of container liner bag solution is slightly shorter than the industrial bulk bag solution (under assumption that the facility of loading and unloading container liner is available in the operation premises), as the loading and loading unite per TEU is far less for container liner bag.

Table 5.20 Simulation Result for Different Scenario

		Lead-Time (days)	**Cost (£ per kg goods)**	**Carbon Emission (kg CO_2 per kg goods)**
Route1	**SOL1(LINER)**	42.78	0.060362	0.272392
	SOL2(IBC)	42.58	0.064888	0.273705
Route2	**SOL3(LINER)**	41.01	0.063905	0.281446
	SOL4(IBC)	41.69	0.068054	0.283214
Route3	**SOL5(LINER)**	34.83	0.074112	0.365929
	SOL6(IBC)	34.94	0.078507	0.375936
Route4	**SOL7(LINER)**	35.01	0.064319	0.32346
	SOL8(IBC)	35.41	0.067719	0.32951

In terms of 'cost', this is an essential factor that with the consigner's considerations. Usually, the cost used for the evaluation is total cost, TEU cost or weekly/monthly cost (van der Vorst et al., 2009), for operation decision making. But considering in this case, for different container packaging solution, the capacity is not the same, and as formerly discussed in packaging logistics objective, the main aim is to distribute the goods that packed inside the container, not about the transport of packaging or container. Therefore, for the validity of solution sustainability efficiency, the total cost for each TEU in each solution is converted into equivalent cost for distribution of each kg goods in the given settings. This provides different viewing angle compared to total cost, for example, some solution (e.g. solution 2 using IBC bag in route 1) is cheaper than certain solution (e.g. solution 3 using container liner bag in route 2) in terms of total cost (around £60 cheaper for each TEU transportation), but when the total is absorbed into per unit weight goods (per kg), due to the different capacity for the container packaging solutions, the distribution cost per kg goods order changes to solution 3 is in favour to solution 2. Generally, in the result, after converting the cost to per kg goods, all industrial bag solutions lost priority as its goods containment capacity is smaller than container liner solutions when absorbing the total cost for the scenario.

Same as cost factor, the carbon emission is also converted into kg CO_2 per kg goods, so that the evaluation can actually measure the environmental efficiency distributing the goods using different route and container packaging solutions. Although the maritime transport emission efficiency factor is as small as almost 1/10 of road transport emission, yet considering the very long haul ocean route from China to UK, the accumulated carbon emission of maritime transport has become dominantly large in each solution. Still, there is merely any difference between Liverpool and Felixstowe maritime route for carbon emission, therefore the main difference for carbon emission between solutions is the road transport route and its container packaging material. And for the same route, due to more packaging material needed and less goods capacity, the bulk bag solution is not in favour to the liner bag solution sharing the same route in terms of carbon emission performance.

After viewing the raw result of different solution evaluation, the result will be processed and integrated for better comparison in terms of sustainability in following sections.

- **AHP Pair Wise Comparison Result for Criteria Weighting**

As formerly stated, to integrate the sustainable criteria from different aspects, proper weighting is needed for different criteria. In order to address appropriate weightings for this case scenario, opinions of personnel working in this industry are collected, and research literature (Saaty, 1990; Harilaos & Christos, 2010; Song, 2011; Sarfaraz & Jurgita, 2012) is considered as stated in data collection section.

Among the sustainable criteria in the pair wise comparison C1 - Lead-time, C2 - Cost and C3 - Carbon Emissions, the judgement for the scenarios in this case study shows that:

Compare between C_1 lead time and C_2 cost, as in this scenario, the cargo is not very sensitive to transportation time and with very low perishability, and the cargo value is not very high to overlook the logistic cost. But consider the lead time relates to the stability of the business and would have further influence of downstream process and facility utilisation plan, the cost is essential important by not dominantly very vital. Therefore, C_2 is regarded essential important compared to C_1, so a_{12}=1/5;

Compare between C_1 lead time and C_3 carbon emission, not like some individual consumer that have clear demand on 'green' products, most of the container shipping business users are more about how to get the cargo delivered in time to keep their business stable and reliable rather than having the operation 'green' along the supply chain, although in this scenario, the lead time is also not crucially important due to the characteristics of the product and the business. So, C_1 is in slightly favour and judged to be moderate important compared to C_3, and the scored is therefore a_{13}=3;

Compare between C_2 cost and C_3 carbon emission, though the consumer's perception on 'green' product demand is rapidly growing nowadays, yet not like individual consumer or emerging new industries that can directly benefit from green enterprise image brought by green products and green operations, most of the traditional container shipping users (like the agriculture product business in this scenario) are still cost driven, always placing their main business goals of profitability (cost) in top priority, giving very little considerations on the greenness especially during the phases that not being seen by the end consumer. Therefore, C_2 is in very strong favour to C_3 for its very vital importance, and a_{23} is thus scored as $a_{23}=7$;

Therefore, the matrix for the three criteria can be established as:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} = \begin{bmatrix} 1 & 1/5 & 3 \\ 5 & 1 & 7 \\ 1/3 & 1/7 & 1 \end{bmatrix} \quad (34)$$

Follow the equations for normalisation introduced in section 5.2. The weighting vector of the criteria is calculated to be

$$W_i = \overline{W_i} \,/\, \sum_{i=1}^{3} \overline{W_i} \quad (35)$$

$$W = (0.1932, 0.7235, 0.0833)$$

And the consistency check is conducted for the judgement matrix using the method introduced in section 4.3.5, the consistency is calculated as:

$$\lambda_{max} = \sum_{i=1}^{3} \frac{[AW]_i}{nW_i} = 3.0658 \quad (36)$$

$$CI = \frac{\lambda_{max} - 3}{3-1} = 0.0329 \quad (37)$$

Knowing the Consistency Index (CI) combined with Random Consistency Index (RI) for n=3, checked in Table 4.8, RI=0.58; So the Consistency Ratio (CR) for the pair-wise comparison is:

$$CR = \frac{CI}{RI} = 0.0567 \quad (38)$$

The CR is smaller than 10%, which tells that the consistency meets the acceptable requirement for the comparison, therefore the weighing for the sustainable KPI- C_1 lead time, C_2 cost and C_3 carbon emission can be adopted from the comparison output which is 0.1932, 0.7235 and 0.0833 respectively.

- **Normalisation and Comparison**

After the weighting for different criteria is calculated, the preference on different sustainable criteria is identified for this case scenario. But as the measurement is with different unit that cannot be integrated, in previous research literature, the results from different aspects are compared respectively without integration together even they are different criteria that all measuring sustainability as final goal (van der Vorst, 2009). In this research, the result is normalised using feature scaling normalisation to be converted into the range of [0,1] for the ease of integrating criteria from different sustainable aspects and ease of comparison.

$$X' = \frac{X - \min(X_i)}{\max(X_i) - \min(X_i)} \qquad (39)$$

Where X is the original value, X' is the normalised value and X_i represents all the values within the same criteria of value X.

Table 5.21 Normalised Result and Weighted Index for Comparison

			Lead Time	Cost	Carbon Emission	Weighted Sustainable Index
LIV	**DEVAN LIV**	**SOL1(LINER)**	1	0	0	*0.1932
		SOL2(IBC)	0.974843	0.249405	0.01268	0.369841
	DEVAN MAN	**SOL3(LINER)**	0.777358	0.195273	0.08745	0.29875
		SOL4(IBC)	0.862893	0.423923	0.104521	0.482126
FLEX	**RETURN FLX**	**SOL5(LINER)**	0	0.757788	0.903364	0.62351
		SOL6(IBC)	0.013836	1	1	0.809473
	RETURN LIV	**SOL7(LINER)**	0.022642	0.218054	0.493203	0.20322
		SOL8(IBC)	0.072956	0.40546	0.55163	0.353396
Criteria Weighting			*0.1932*	*0.7235*	*0.0833*	

The normalised sustainable performance is shown in Table 5.21. Also, the normalised value is without unit, so that they can be integrated together; for each solution, the normalised sustainable performance value for different criteria are weighted summed into sustainable index using the criteria weighting that is calculated previously W= (0.1932,0.7235,0.0833).

When reading the results in Table 5.21, it should be noted that the measurements for time, cost and emission are all the smaller the better, therefore value '0' represents the best solution under that certain measurement criteria while value '1' indicates the worst performance among all solutions in this criteria.

In terms of service time, solution 5 (route 3 with container liner bag) is regarded to be the best solution though not very significant difference among all routes that travel through Felixstowe. While solution 1 (route 1 with container liner bag) is the worst in time performance.

Considering the cost criteria, for every weight unit goods being transported along the whole supply route, solution 1 (route 1 with container liner bag) is with highest preference; for the same route, the cost performance of solutions using container liner bag is better than bulk bag solutions; Although the ocean transport fare is lower for Felixstowe port, for the same container packaging solution, using route 3 (arrival Felixstowe and return empty container to Felixstowe) are with highest cost due to the long distance inland haulage and long container leasing period induced cost.

The carbon emission performance for every weight unit goods shows that when considering the emission, the route preference should be ranked as: route 1, route 2, route 4 and route 3 (comparing same container packaging among different routes), which indicates all Liverpool solutions are more environmental friendly than Felixstowe solutions in this case study scenario. It is also to be noticed that both solution using route 1 (via Liverpool port, unstuffing at Liverpool) perform significantly better than all other solutions.

As the solutions are with different priorities in different measuring criteria, to identify which one is the most sustainable solution in this scenario, the normalised performance value of different aspects are weighted summed for each solution using the AHP pair wise comparison weighting result (0.1932, 0.7235, 0.0833) to generate a sustainable index for easier comparison (the final weighted result shown in last column in Table 5.21). Same as individual criteria value, the smaller value of the index indicates better overall sustainable performance. For the criteria importance judgement in this case, solution 1 (route 1 with container liner bag) is with best sustainable performance index; on the contrast solution 6 (route 3 with industrial bulk bag) is the least preferable solution among all in terms of overall sustainable consideration in this case study scenario.

Not restricted to this result, in practice of different industry or scenario, when there are differences in business background, cargo types, market sector, detention penalties, stock out penalties, environment awareness level or environmental policy, the consignor will pay different level considerations on different sustainable criteria. Therefore, the following sensitivity analysis provides the alternative possibilities of 'what if' situations with different weightings that represents different business scenarios.

5.3.5 Sensitivity Analysis of Different KPI Priorities

Among the sustainable criteria being measured, environment is giving least importance in the case study scenario. But the environmental consideration can vary depending on person providing the judgement and the maturity of the industry and market. Also, considering the subjective judgement variations when calculating the weightings, in the sensitivity analysis, different weighting combinations for the three criteria are tested to discover the 'what if' situation for the container supply chain's sustainability evaluation.

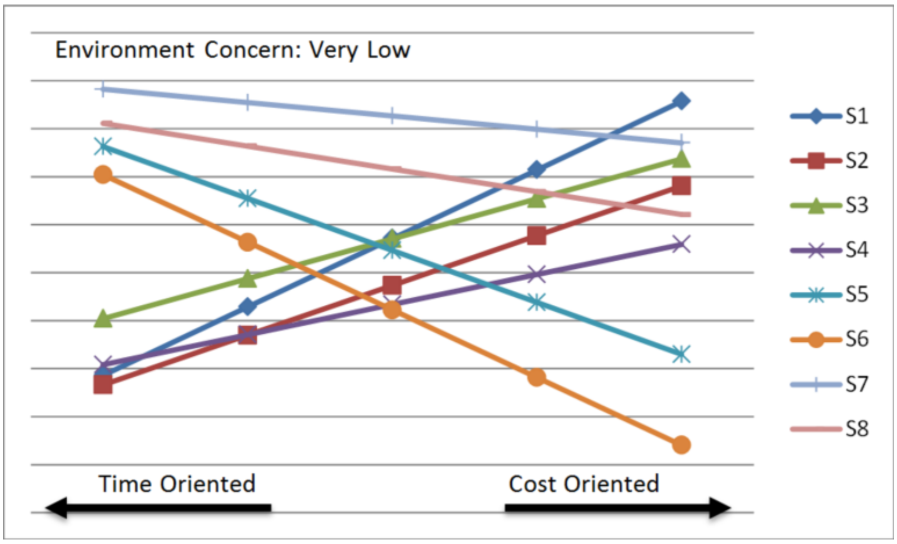


Figure 5.25 Sustainability Performance Variations in Very Low Environmental Concern Scenario

The sensitivity testing result for the variations are shown in Figure 5.25 to Figure 5.29. The figures are processed to be reverted from the previous sustainable index, so that the higher position in the figures indicates higher preference of the solution. The criteria importance is each tested by given different importance value from 1 (low importance) to 5 (high importance), then the weighting is applied on the normalised simulation result of the case study to explore the changes and trends.

Each of these figures represents a scenario with given environmental importance level. Towards left, the lead time importance is increasing which represent cargo or situations that with higher sensitivity to time (e.g. perishable products) or cargo with very high value compared to operation cost; while the cost importance is increasing towards right of each figure, representing goods with lower profit margin that the operation cost is essential.

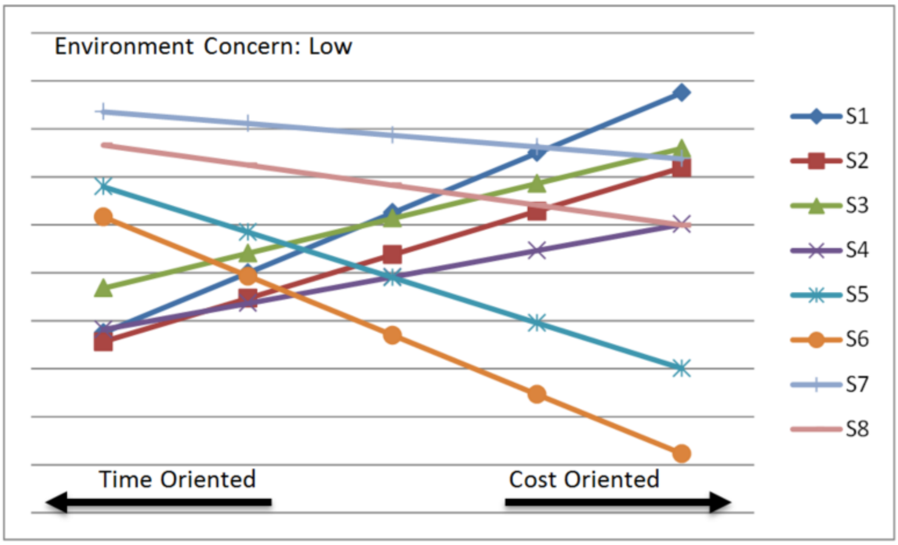


Figure 5.26 Sustainability Performance Variations in Low Environmental Concern Scenario

Starting from Figure 5.25, when the environment concern in the market is 'very low', and the time and cost are equally important, solution 7 (route 4 with container liner bag) and solution 8 (route 4 with bulk bags) are far more favourable than other solutions, but as the cost importance grows, solution 1 (route 1 with container liner bag) becomes the best solution. As the weighing shift just a little towards time criteria, all the Felixstowe solution are in favour to Liverpool ones, even the previous worst solution S7 becomes better than all Liverpool solutions in this scenario.

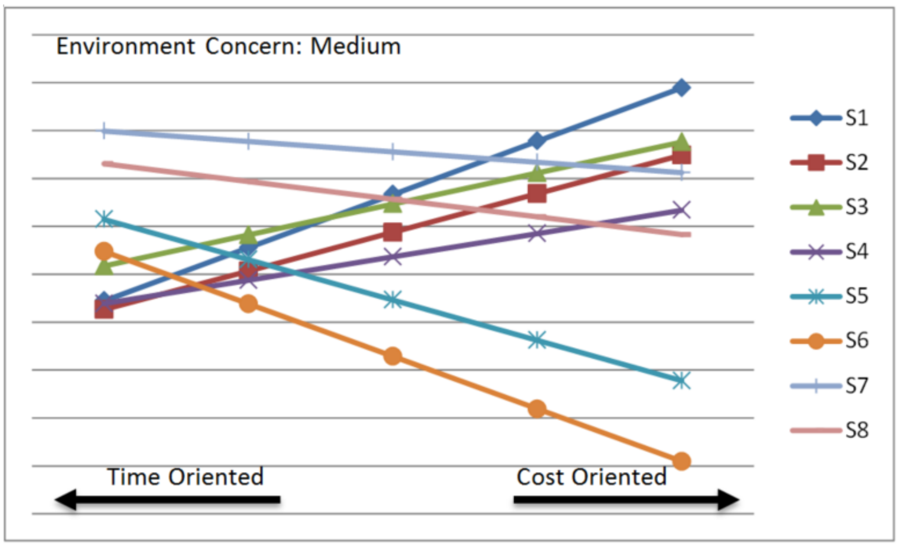


Figure 5.27 Sustainability Performance Variations in Medium Environmental Concern Scenario

As the environmental concern grows to 'low' as in Figure 5.26, when the time and cost are equally important, Solution 7 is still the best solution among all, but with much less superiority compared to 'very low' environmental concern scenario. When the time factor is dominantly important than cost, the Felixstowe solutions occupy a dominant position of top 4 best solutions.

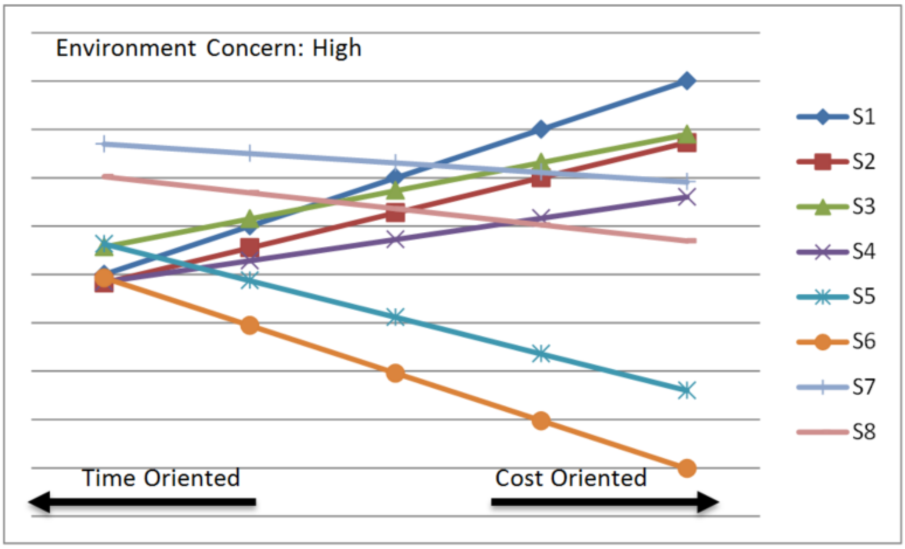


Figure 5.28 Sustainability Performance Variations in High Environmental Concern Scenario

In the 'medium' environmental concern situation (Figure 5.27), as the weighting shifts slightly from equally important to cost, solution 1 will replace solution 7 becoming the most favourable solution.

The same applies to 'High' environment awareness situation (Figure 5.28). Also this time, when the cost dominates the time criteria, most Liverpool solution comes prior to Felixstowe ones. And when the time and cost are equally important in this scenario, solution 1, 2, 3, 4, 7, 8 perform similarly to be chosen as sustainable feasible solution.

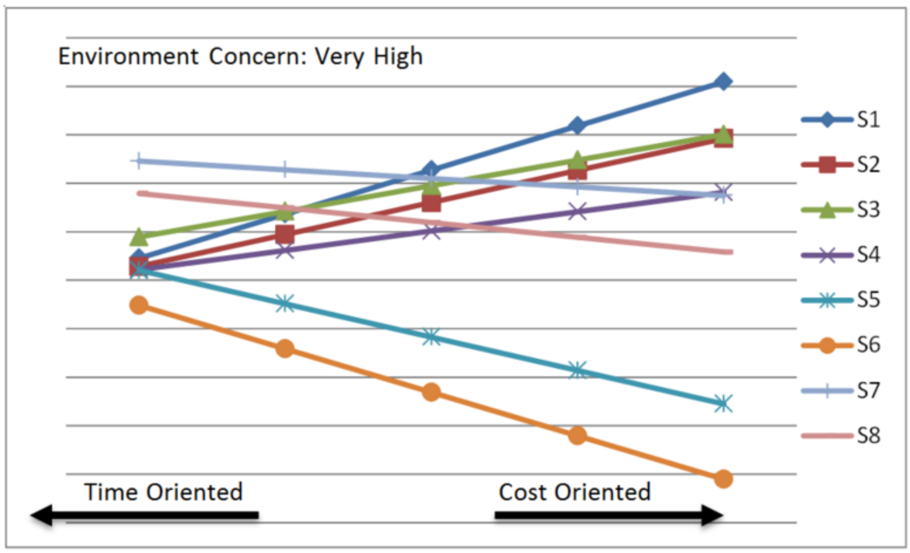


Figure 5.29 Sustainability Performance Variations in Very High Environmental Concern Scenario

As the environmental concern continue growing to 'very high' level (shown in Figure 5.29), only S7 and S8 can compete with Liverpool solutions when the time and cost balance is not on the cost side; solution 7 and 8 are with least preference no matter how the time and cost balance shifts under this setting; and as the cost get high importance in this scenario, the Liverpool solution dominant top 4 among all.

When considering all these figures together, the overall trend shows the Liverpool solutions get higher priority as environmental concern or environmental awareness grows; As the cost factor importance increase, Liverpool solutions receives higher preference and solutions using container liner perform more superior than bulk bag solutions, which indicate that Liverpool route is more suitable for cargo with lower profit margin (operation cost is relatively high compared to cargo value); Another trend shows that in time oriented situation, the Felixstowe solutions are more preferable, indicating that the time sensitive or high value cargo is recommended to use Felixstowe instead of Liverpool for the container shipping solution selection.

Chapter 6: Findings and Discussions

6.1 Findings from Case Studies

The case studies not only illustrate the application of proposed methods for support and validate purpose, but also reveal some useful findings that are useful for sustainable packaging and container shipping decision-making.

- **Findings from Case Study 1**

By conducting case study 1, it can be observed that the proposed matrix evaluation result of risk impact conforms to the trend of actual recorded failure risk impact. Therefore, it is useful for risk impact estimation when detailed data is not available in early design stage. According to sensitivity analysis, the proposed evaluation matrix is tested to be with proper safety margins when processing human judgement input, minimising potential human bias influence brought by the scoring process. The comparison between the results before and after consideration of operation risk impact largely varied, which emphasises that the packaging logistics interaction impact must not be overlooked when identifying sustainable packaging system (Saghir, 2004) .

- **Findings from Case Study 2**

As discussed in case study 2, the furniture can be clustered into four different quadrants based on the two criteria that related to the product characteristics, illustrated as Figure 5.15. This provides packaging selection strategy for different situation.

Figure 6.1 summarises the RPNs which presenting the impact of packaging solutions on the operation, for comparison of different packaging for different packed products located in different quadrant of Figure 5.15. According to Figure 6.1, the preferences between different solutions for different products in different scenarios were compared, following implications can be identified:

For the products with high reprocessing or customisation requirement that need to be unboxed, modified and repacked (quadrant I and IV), the reusable packaging solutions are significantly more preferable (with lower operation impact), performing better than traditional one-off packaging in securing the delivery of products along the supply chain. This mainly owes to the high customisation requirement induced repacking or additional packaging layers on top of original ones, for this, reusable packaging's features that are more operation friendly for processes like manual handling and packing.

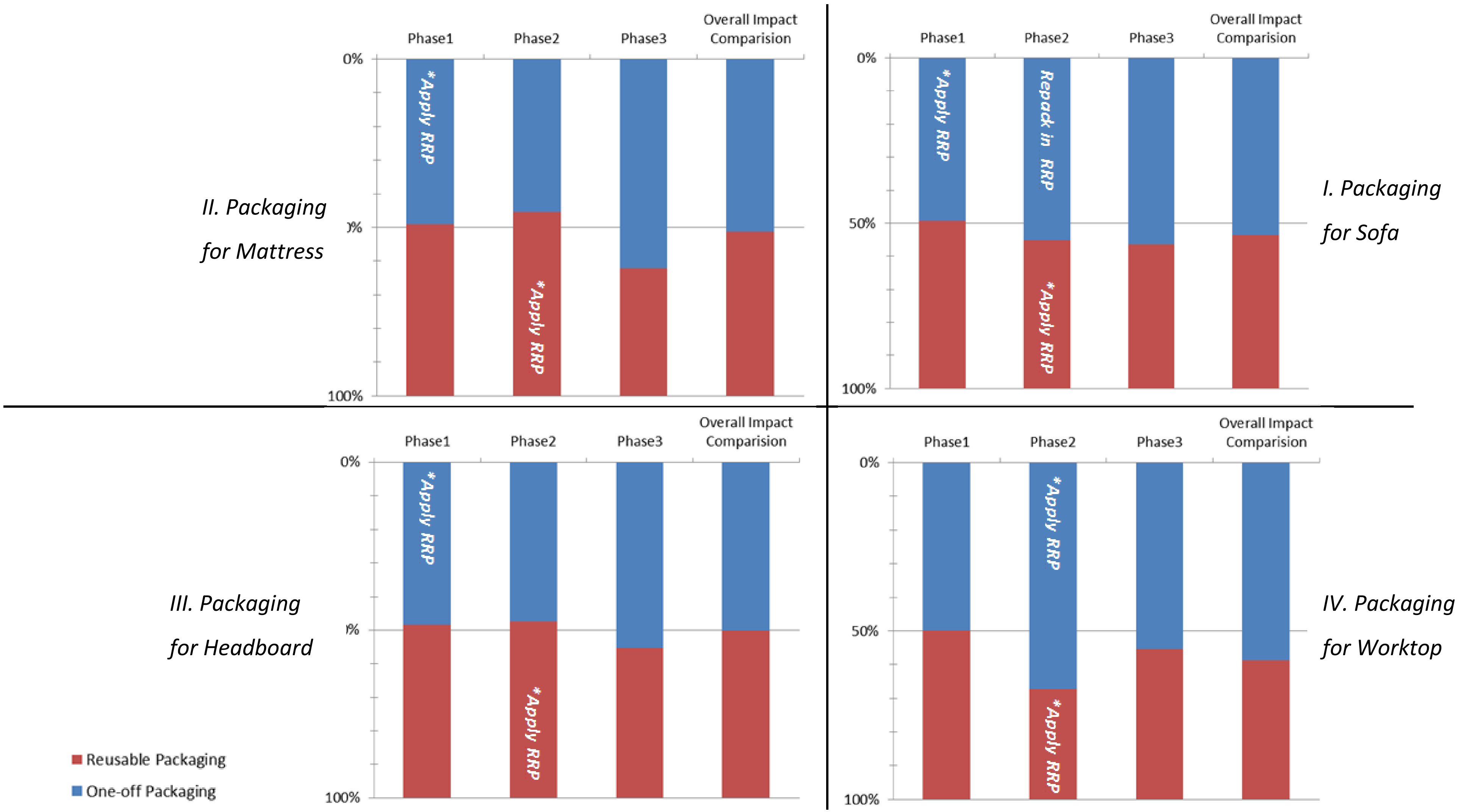


Figure 6.1 Summary of RPN Comparison Results of Different Packaging for Different Furniture Products

On the other hand, when looking at products with low or no requirement on customisation during supply chain (quadrant II and III), traditional one-off packaging system perform better than reusable packaging for its suitability of equipment filling or packing processes in phase 1 and phase 2 before heavy manual handling work involved. And also, they are suitable to have the final retail ready packaging applied by equipment in earlier phase of supply chain.

To consider the level of operation failure impacts, phase 3 in retail store or end-user's premises have shown clear differences between packaging solutions. For products with higher impact from operation failure, such as high in value, cleanness requirement or damage sensitivities (quadrant I and II), the reusable packaging is with much higher preferences for its features enabling easy manual handling processes to reduce the potential lost. And this improvement is more significant than products with lower impact severity (quadrant I and II).

Overall, traditional one-off packaging is more suitable for equipment packaging processes in large scale from manufacturer, especially for products with low customisation requirement and low value products like headboard in quadrant II; reusable packaging performs better in manual operations of handling and packaging, thus are suitable for products with repack, modification requirement during supply chain, and performs better when the final retail ready packaging is applied after completing the modification or customisation of the products, such as sofa and worktop in quadrant I and IV in this case study; for products with low customisation requirement but high impact from operation failure, like the mattress in quadrant I, the difference between one-off packaging and reusable packaging mainly reflects on the end-user phase, while the priority of reusable packaging is not shown in other phases and the overall performance for both packaging systems are very close to each other.

- **Findings from Case Study 3**

The sensitivity analysis shows for different market, goods and situation with different priorities for sustainable KPIs, the preference of container shipping solution shift from one to another. Therefore, there is no certain route/packaging combination always performs best in terms of sustainability, instead, the specific cargo characteristics and type (influence the weighting priority of sustainable KPIs) needs to be considered for different scenarios. And the proposed simulation is able to help with this task for considering complex interacted factors of the container supply chain to provide most preferable solution for decision making support. Additionally, by involving human soring process, the integrated simulation enables the estimation of sustainability evaluation without detail operation data, which help with the situation of new solution selection when the operation data does not yet exist or available.

6.2 Contributions and Publications

6.2.1 Contributions to Knowledge

The contributions of this research can be concluded as follows:

1) This research further extended the concept of packaging logistics(Saghir,2002; García-Arca et.al., 2014) to include packed goods as a key consideration, providing in-depth understanding and quantified measures of how packaging logistics interactions with other factors impact sustainability. This study solved the research challenge to integrate different interacted factors into one general design and evaluation approach (Chonhenchob et al.,2008 ; Dobon et al., 2011; Robertson et al., 2014;) for sustainable packaging system.

2) The evaluation framework and evaluation method proposed for sustainable packaging provided a feasible and quantitative approach to identifying real, sustainable packaging along its life cycle from a holistic viewpoint to avoid sub-optimal and 'green-washed' packaging (Saghir, 2002; Nordin & Selke, 2010; Palsson & Hellstrom, 2016). Which changed the situations that most of existing research on sustainable packaging from holistic view are qualitative studies that provides only qualitative output for packaging system design (Saghir, 2004). At the first time, the proposed evaluation managed to quantitatively reflect the impact of packaging on logistics (Lockamy, 1995; Saghir, 2004) according to the characteristics of packaging products.

3) The evaluation matrix developed in this study can be used to estimate the impact of packaging logistics interactions, which solved the challenge that such interactions has not been investigated in a quantified approach(Saghir, 2004; Hellstrom & Saghir, 2007). It is also a generic design and evaluation tool for packaging evaluation when detailed data on operations is not available, reducing the data requirement and difficulties comparing to traditional Life Cycle based methods (Choi & Ramani; 2009, Grönman et al.,

2013; Molina-Besch, 2016) Which makes it useful especially in design stage when the lacking of full data.

4) The new evaluation method proposed by this research drew the concepts of FMEA and QFD together for packaging sustainability evaluation and design. Failure risk was re-contextualised for the consideration of packaging and logistics interaction. And the proposed approach simplified the evaluation process, compared to the traditional ETA method in packaging evaluation and traditional Risk Management methods (Pillay & Wang, 2003; Rausand & Hoyland, 2004). The combination of different methods provided a more holistic approach to bridging the limitations of different design tools (Ramani et al., 2010).

5) The proposed QFD-style evaluation enabled co-operation in performance of the assessment by decoupling the assessment into different matrices for personnel with different expertise in the supply chain to complete different parts according to their own expertise (Hauser & Clausing, 1988; Masui et al., 2003). The evaluation can also be used to analyse the different costs and benefits accruing to different supply chain parties by virtue of the balancing effect of the evaluation, solving the limitation of traditional QFD that 'lack consideration of the whole life cycle' (Bouchereau & Rowlands, 2000).

6) The research also bridged packaging logistics theory and container supply chain reality, which has not yet been done by previous research (Verghese & Lewis, 2007; Hellstrom & Saghir, 2007). By integrating different factors in container shipping context, and embedding the packaging evaluation into a simulation model, the simulation tool was proposed for sustainable container supply chain evaluation. In this evaluation tool, the container is no longer regarded as a 'black box' (Rogers et al., 2012; Lambert et al., 2011), but instead as an outer packaging layer that interacts with the inner packaging, packed cargo, and logistics operations.

7) The case studies provided in-depth analysis to reveal how the packaging and logistics interacts with packed cargo. Not only triangulated the proposed evaluation methods with practical examples, but also illustrated the decision-making support ability of the proposed method, showing how to support the packaging and container shipping decisions using the proposed integrated approach. Different from existing research on general design tools (Chonhenchob et al., 2008; Robertson et al., 2014; Prendergast & Pitt; 1996, Dobon et al., 2011), it integrated different factors related to packaging logistics systems and filled the gap of integrated design tool for sustainable packaging system.in supply chain.

6.2.2 Publications

As research outcomes at different stages, different part of this research has been put into conference and journal articles for publication by the author and in collaboration with other researchers. Conference and journal articles related to and derived from this research that are listed as follows:

Shi, J., Li, D., Shi, X. and Du, Q. (2015) Risk Evaluation for Sustainable Packaging Logistics Solution: A Quantitative Method and Case Study, *The 3rd International Conference on Transportation Information and Safety*. Wuhan, China.

Shi, J., Li, D., Zhou, Y., Dang, Shuo. (2016) An integrated Approach for Sustainable Container Supply Chain Design and Evaluation – A Simulation Approach with Case Study, *IEEE International Conference on Logistics, Informatics and Service (LISS 2016).* Beijing, China.

Fu, S., Yan, X., Zhang, D., Shi, J., Wan, C. and Song, Z. (2014) Use of FMECA Method for Leakage Analysis of LNG Fueled Vessels, *ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering (OMAE2014)*. San Francisco, CA, June 8-12,2014.

Wan, C., Zhang, D., Shi, J., Fu, S., Yan, X. and K.Y.Ng, A. (2014) Emerging LNG Fueled Ships in Chinese Shipping Industry: A Hybrid Analysis and Prospects, *International Association of Maritime Economists (IAME) 2014 Conference*. Norfolk, VA, USA.

Fu, S., Yan, X., Zhang, D., Shi, J., Wan, C. and Song, Z. (2014) Use of FMECA Method for Leakage Analysis of LNG Fueled Vessels, *ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering (OMAE2014)*. San Francisco, CA, June 8-12,2014.

Wan, C., Yan, X., Zhang, D., Shi, J. and Fu, S. (2014) Emerging LNG Fueled Ships in Chinese Shipping Industry: A Hybrid Analysis and Prospects. *International Journal of Performability Engineering (Special Issue on Dependability and Sustainability).*

Paper under review and revision with Production Planning & Control (PPC) journal: Evaluation for Sustainable Packaging Logistics Solutions in Supply Chain: A Case Study of Reusable Packaging in Furniture and Upholstery Industry.

6.3 Implications for Empirical Practice

Apart from the knowledge contributions summarised above, this research is also with following practical applications:

1) The proposed evaluation method can be used as tool by packaging supplier as it provides clear and quantified design requirement for packaging design project.

2) The proposed evaluation method for packaging and the simulation for container supply chain summarised common factors and operations, can be easily applied to any scenario in its field for the solution comparison without the need to build the criteria and failure causal chain from scratch for every case.

3) The simulation model is with flexibility in configuration which enables different scenario and different factors being considered.

With help of this study, the collaboration partner, packaging provider has developed and improved many features of its reusable packaging products based on the improvement point suggested by the proposed quantified evaluation.

The research has helped promoted the utilisation of sustainable reusable packaging for collaboration partners – the reusable packaging range has increased from 2 to 7 and the number of key customers of sustainable and reusable packaging has also largely increased. Within those newly developed or improved products utilising proposed design and evaluation approach (example shown in Figure 6.2), 2 newly developed packaging product features gained UK patent (pending) and several new reusable packaging designs secured design rights in the UK.

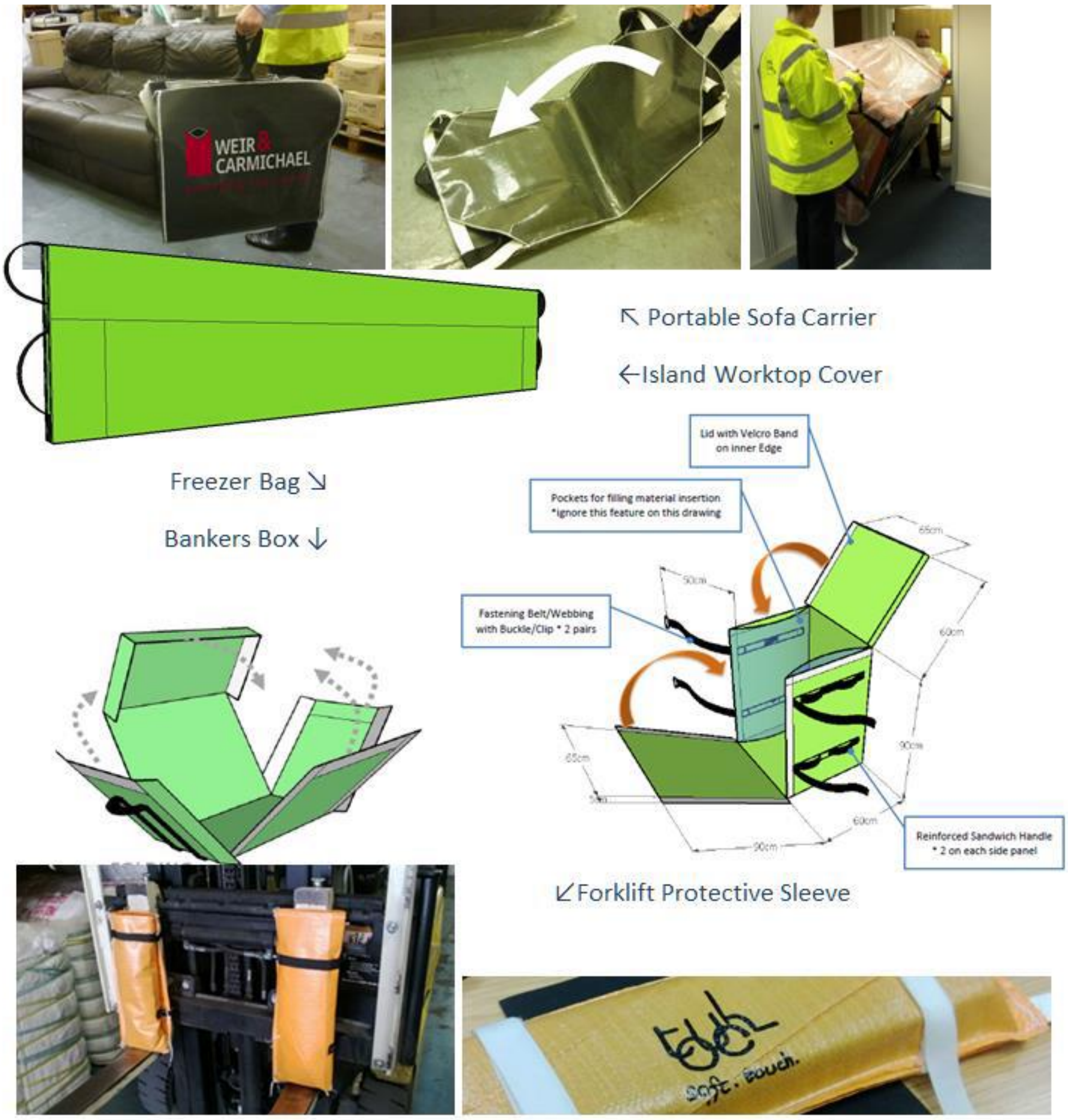


Figure 6.2 Examples of New Packaging Product Design and Development inspired by this Study

The proposed evaluation method is also adopted by the collaboration partner to integrated into design process for better understanding of the clients' requirement for new important packaging product design and development.

A letter states the impact of this research on the practice provided by the packaging collaboration partner is attached in appendix.

Chapter 7: Conclusions and Recommendations

7.1 Conclusions

After exploring the concept of ‘sustainable packaging’ and its relationship to the ‘container’ in container supply chain, this research proposed an evaluation framework and a generic tool for sustainable packaging design and evaluation, validated and supported by case studies. All the research elements arranged in the research map worked together to answer the research questions established for the research topic “design and evaluation of sustainable packaging in supply chain”.

In order to answer the 1st research question *“How is the impact of packaging on sustainability different from that of general product along life cycle, and from what perspective should the sustainability of packaging be evaluated?”* This research firstly explored the essence of “sustainable packaging”, by reviewing related literature on sustainability, sustainable design tools, packaging, packaging logistics and packaging in supply chain. Then, from the in-depth comparison between packaging’s and general products’ different impact on sustainability at different phases of the supply chain, and the comparison between different design tools from different viewing angle, the research summarised the special requirement for sustainable packaging design and evaluation consideration. Based on such difference, the research proposed the evaluation framework for sustainable packaging from a holistic viewing perspective, which combined both packaging designers’ and logistic specialists’ consideration.

To answer the 2nd research question *“What are the similarities and differences between packaging and container in terms of their role in risk minimisation, characteristics, impact on sustainable performance in supply chain and decision factors for their sustainability evaluation?”* This research not only employed literature review result to address the characteristics and impact factors of researched packaging and container packaging system, but also supported with semi-structured interview with experts in the field. By conducting such short interviews, the experts’ practical experience in the industry can be utilised to support the framework and evaluation tool that is proposed in this study. Also, the explanations and examples given by the interviewee's during the interview provided better in-depth understanding of how the decision factors impact the interactions between packaging system and logistic operations. The generic and easy to use design and evaluation tool was then proposed for packaging logistics interactions using the result of this phase. During the development of the tool, in order to promote co-operate between different experts and reduce human input bias, techniques like QFD and AHP were combined and used.

For the 3rd research question "How is the integrated sustainable evaluation to be applied in both packaging and shipping container scenarios- how does it help reducing packaging-related risks and waste, and support sustainability decision making? " By bridging packaging logistics theory and container supply chain reality, an integrated evaluation approach was proposed, altered for a container-shipping-specific context and integrated into a simulation model for sustainable container supply chain design and evaluation in this study. different case studies were conducted applying the tools for packaging system and container supply chain evaluation. The different case studies in different scenarios well illustrated the application of the proposed design and evaluation tool in industry, providing in-depth understanding of the impact of packaging logistics on sustainability supply chain, showing its decision making support function in sustainable packaging and container supply chain consideration in real practice. At the same time, different case studies triangulated with each other also provided support in validating the proposed design and evaluation tools.

In conclusion, following the roadmap of the research, all three research questions have been explored and successfully answered.

During the process answering the research questions, the aim of the research have been achieved: As the design and evaluation method for a sustainable packaging system and packaging logistics in container supply chain has been developed, providing decision-making support for sustainable packaging and container shipping business.

It is believed that this research -design and evaluation for sustainable packaging in container supply chain will help packaging suppliers and logistics providers to increase the sustainability of their packaging design and logistic services from a holistic view. The research also provided a useful container supply chain simulation platform and environment which imbedded failure risks into sustainability consideration in container shipping scenario. It is therefore useful for further studies and research on container supply chain planning and management.

7.2 Research Limitations and Implications

Subjective judgement used in sustainable packaging evaluation has embedded the respondent's psychological perception of the operation task's difficulty, which links to potential health and safety consideration. But the linguistic input may with bias, therefore, process of fuzzy logic or ANP is suggested to be added during the scoring process for more accurate result.

The environmental impact in the evaluation only considers the material and operation induced CO_2 emission and toxicity, lacking of considerations on other types of greenhouse gas emissions such as CH_4, N_2O (although they are significantly smaller than CO_2 factor in the case study), and emerging stricter Sulphur emission control, which can be a good supplement in sustainability consideration. By introducing these potential environmental policies induced charge, fare or costs can provide better decision making support for companies' future consideration under different 'what if' scenario.

Although the evaluation can show the cost and benefit for different supply chain parties, yet it cannot provide direct solution to optimise the balancing. As the link is built to bridge packaging logistics theory and container supply chain, the existing research in container supply chain such as gamming theory in container value recovery can be considered for appropriate pricing strategy of reusable packaging within different business models to better balance the cost and benefit between different supply chain parties, in order to promote the use of environmentally friendly packaging system.

The case study of container supply chain was also too detailed to be able to draw more general conclusion, so it could just be used to support the triangulation and validation of proposed evaluation tool. And the result was limited to given setting of supply chain and packaging solutions for certain type of goods. As summarised in the research, if different cargo in different sectors and more packaging combinations available for this case study, it could provide more general conclusions.

Currently, in the simulation model, the waiting time for each operation process in different location is estimated according to experts' experience and prediction, which is not dynamically changed. And the cargo risk factor is lacking of inter dependency consideration. To improve the simulation to be more realistic and more useful, risk factor interdependency can be considered to add in; and instead of estimate a static waiting time for each process, it would be better to generate large amount of cargo according to demand and let the cargo agent chooses the suitable route, and by their rational acts, the congestion and waiting can be simulated dynamically according to the cargo agent's density in different route and location. Other variables like the availability of container and packaging and availability of vehicles can also be considered into the simulation for a more realistic simulation model.

References

Abdelgawad, M, and Fayek, A. (2012) Comprehensive Hybrid Framework for Risk Analysis in the Construction Industry Using Combined Failure Mode and Effect Analysis, Fault Trees, Event Trees, and Fuzzy Logic, *Journal of Construction Engineering & Management*, 138, 5, pp. 642-651.

Accorsi, R., Cascini, A., Cholette, S., Manzini, R. and Mora, C. (2014) Economic and environmental assessment of reusable plastic containers: A food catering supply chain case study. *International Journal of Production Economics*, 152(0), 88-101.

Adams, W. M. (2006) *The Future of Sustainability: Re-Thinking Environment and Development in the Twenty-First Century*. Report of the Iucn Renowned Thinkers Meeting, 29-31 January 2006

Ageron, B., Gunasekaran, A. and Spalanzani, A. (2012) Sustainable supply management: An empirical study. *International Journal of Production Economics*, 140, 168-182.

Alejandro, S. M.-S., Esteban, E.-L., Felipe, G.-S. and Joan, G.-H. (2009) Tracking of Returnable Packaging and Transport Units with active RFID in the grocery supply chain. *Computers in Industry*. 60(3):161-171.

Alharbi, A., Wang, S. and Davy, P. (2014) Schedule design for sustainable container supply chain networks with port time windows. *Advanced Engineering Informatics*.

Alumur, S. A., Nickel, S., Saldanha-da-Gama, F. and Verter, V. (2012) Multi-period reverse logistics network design. *European Journal of Operational Research*, 220(1), 67-78.

Amin, S. H. and Zhang, G. (2013) A three-stage model for closed-loop supply chain configuration under uncertainty. *International Journal of Production Research*, 51(5), 1405-1425.

Anderson, D, SWEENEY, D, and Williams, T. (1994) *An Introduction to Management Science: Quantitative Approaches to Decision Making*, n.p.: St Paul (Minn.): West Publishing, 1994.

Armstrong, T. J. (1981) Packaging trends and implications in the container revolution. *Journal of Maritime Law & Commerce*, 12, 427-465.

Arugaslan, O. and Samant, A. (2014) Evaluating S&P 500 Sector ETFs Using Risk-Adjusted Performance Measures. *Journal of Finance, Accounting & Managemen*t, 5(1), 48-62.

Ayağ, Z., (2005) A fuzzy AHP-based simulation approach to concept evaluation in a NPD environment. *IIE transactions*, 37(9), pp.827-842.

Baines TS, Lightfoot H, Steve E, et al. (2007). State-of-the-art in product service-systems Proceedings of the Institution of Mechanical Engineers, *Part B: Journal of Engineering Manufacture*. Volume 221, Number 10, pp 1543-155.

Bergman, D (2012) Sustainable Design: A Critical Guide, n.p.: New York: Princeton Architectural Press, c2012.

Bernhofen, D. M., El-Sahli, Z., and Kneller, R. (2013) 'Estimating the effects of the container revolution on world trade'.[online] Available at: http://www.american.edu/cas/economics/news/upload/Bernhofen-Paper.pdf. [Accessed: 10 Dec 2015].

Bianchi, M., Campodall'Orto, S., Frattini, F. and Vercesi, P. (2010) Enabling open innovation in small and medium sized enterprises: how to find alternative applications for your technologies. *R&D Management*, 40(414-431).

Blackburn, W. A. (1992) Single-use vs. reusable personal protective equipment decisions involve more than pricing. *Hospital material management*, 17(7), 16-17.

Borshchev, A. (2014) Multi-method modelling: AnyLogic, 248-279.

Bouchereau, V., and Rowlands, H., 2000, ‘Methods and Techniques to Help Quality Function Deployment,’ Benchmarking: An International Journal, 7 (1), pp. 8–20.

Bourlakis, M.A. and Weightman, P.W.H., (2004) *Food supply chain management*. Oxford, UK: Blackwell Publishing.

Bovea, M. D., Serrano, J., Bruscas, G. M. and Gallardo, A. (2006) 'Application of life cycle assessment to improve the environmental performance of a ceramic tile packaging system', *Packaging Technology and Science*, 19, 83-95.

Breen, L. (2006) 'Give me back my empties or else! A preliminary analysis of customer compliance in reverse logistics practices (UK)', *Management Research News*, 29(9), 532-551.

Büşra, A., İsmail, S. B. and Bayındır, Z. P. (2001) Optimal pricing and production decisions in utilizing reusable containers. *International Journal of Production Economics*.

Byggeth S, Hochschorner E. (2006) Handling trade-offs in Ecodesign tools for sustainable product development and procurement. *Journal or Cleaner Production*.Vol. 14, No. 15-16, pp. 1420-1430.

Carlson, C. S. (2012) *Effective FMEAs*. John Wiley & Sons.

Carrasco-Gallego, R., Ponce-Cueto, E. and Dekker, R. (2012) Closed-loop supply chains of reusable articles: a typology grounded on case studies. *International Journal of Production Research*, 50(19), 5582-5596.

Carter, C, and Rogers, D (2008) 'A framework of sustainable supply chain management: moving toward new theory', *International Journal Of Physical Distribution & Logistics Management*, 38, 5, pp. 360-387

Chan, H. K., Yin, S. and Chan, F. T. S. (2010) Implementing just-in-time philosophy to reverse logistics systems: a review. *International Journal of Production Research*, 48(21), 6293-6313.

Chang, H.K., Liou, J.C. and Chen, W.W., (2012) Protection priority in the coastal environment using a hybrid ahp-topsis method on the Miaoli coast, *Taiwan. Journal of Coastal Research*, 28(2), pp.369-374.

Cheng, X. (2012) Functional requirements analysis-based method for product platform design in axiomatic design. *Journal of Digital Information Manage*ment, 10(5), 312-319.

Choi, J. K., and Ramani, K., 2009, 'A Quest for Sustainable Product Design: A Systematic Methodology for Integrated Assessment of Environmentally Benign and Economically Feasible Product Design', VMD, Saarbrucken, Germany.

Chonhenchob, V., Kamhangwong, D. and Singh, S. P. (2008) Comparison of reusable and single-use plastic and paper shipping containers for distribution of fresh pineapples. *Packaging Technology and Science*, 21(2), 73-83.

Christina Maria, D., Kim Hua, T. and Ming, L. (2013) Green as the new Lean: how to use Lean practices as a catalyst to greening your supply chain. *Journal of Cleaner Production*, 40, 93-100.

Clara, C. and Gian Paolo, M. (2012) Food-pack Waste Systemic Management: Alternative Ways to Reuse Materials and to Develop New Business, Products and Local Markets*. Procedia Environmental Sciences*, 16, 616-623.

Clarksons. (2015) Container Broking Service [Online]. Available at:
Http://Www.Clarksons.Com/Services/Broking/Containers/ [Accessed 5 March 2015].

Coates, J. F., (2000) 'Manufacturing in the 21 century', *International Journal of Manufacturing Technology and Management*, vol. 1, no. 1, pp. 42–59

Conrad, L. and Jessica, L. (2005) EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development. *Journal of Cleaner Production*, 14, 1396-1408.

Costa, C., Antonucci, F., Pallottino, F., Aguzzi, J., Sarria, D. and Menesatti, P. (2013) A Review on Agri-food Supply Chain Traceability by Means of RFID Technology. *Food and Bioprocess Technology*, 6(2), 353-366.

Crainic, T. G., Gendreau, M. and Dejax, P. (1993) 'Dynamic and stochastic models for the allocation of empty containers', *Operations Research*, 41(1), 102-126.

Creswell, J, and Plano Clark, V (2007). *Designing And Conducting Mixed Methods Research* / John W. Creswell, Vicki L. Plano Clark, n.p.: Thousand Oaks, Calif.; SAGE, c2007

Creswell, JW (2003) *Research Design: Qualitative, Quantitative, And Mixed Methods Approaches*, n.p.: Thousand Oaks, Calif.

Dangelico, R. M. and Pujari, D. (2010) Mainstreaming Green Product Innovation: Why and How Companies Integrate Environmental Sustainability. *Journal of Business Ethics*, 95, 471-486.

DEFRA, (2012). *Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting.* in: UK Department for Environment, Food & Rural Affairs

Dharmadhikari, S. (2012) Eco-Friendly Packaging in Supply Chain. IUP *Journal of Supply Chain Management*, 9(2), 7-18.

Dhillon, B, and Rayapati, S (1988) 'Reliability Analysis of Mechanical Devices', *International Journal Of Quality & Reliability Management*, 5, 4, p. 17

Dobon, A., Cordero, P., Kreft, F., Østergaard, S., Antvorskov, H., Robertsson, M., Smolander, M. & Hortal, M. (2011a). The sustainability of communicative packaging concepts in the food supply chain. A case study: part 2. Life cycle costing and sustainability assessment. International Journal of Life Cycle Assessment, 16, 537-547.

Dobon, A., Cordero, P., Kreft, F., Østergaard, S., Robertsson, M., Smolander, M. and Hortal, M. (2011b) The sustainability of communicative packaging concepts in the food supply chain. A case study: part 1. Life cycle assessment. *International Journal of Life Cycle Assessment*, 16(2), 168-177.

Dominic, C. (2013) Supply and Demand Chain Integration: A Case Study Conducted in the Packaging Industry. *Packaging Technology & Science*, 26(1), 51-63.

Dong, J.-X. and Song, D.-P. (2012) Lease term optimisation in container shipping systems. International Journal of Logistics: *Research & Applications*, 15(2), 87-107.

Dowlatshahi, S. (1999) A modeling approach to logistics in concurrent engineering. *European Journal of Operational Research* (115), 59-76.

Drewry (2009) *Risk Management in International Transport and Logistics*. London: Drewry Shipping Consultants Ltd.

El korchi, A. and Millet, D. (2011) Designing a sustainable reverse logistics channel: the 18 generic structures framework. *Journal of Cleaner Production*, 19(6-7), 588-597.

Elmore, B. J. (2012) The American Beverage Industry and the Development of Curbside Recycling Programs, 1950-2000. *Business History Review*, 86(3), 477-501.

Eurostat. (2016) Packaging waste by waste operations and waste flow. [online] Available at:
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waspac&lang=en

Fleischmann, M., Bloemhof-Ruwaard, J. M., Van Der Laan, E., Van Nunen, J. A. E. E., Dekker, R. and Van Wassenhove, L. N. (1997) Quantitative models for reverse logistics: A review. *European Journal of Operational Research*, 103(1), 1-17.

Fransoo, J, and Lee, C 2013, 'The Critical Role of Ocean Container Transport in Global Supply Chain Performance', *Production & Operations Management*, 22, 2, pp. 253-268

Fraser Johnson, P. (1998) Managing value in reverse logistics systems. *TRANSPORTATION RESEARCH PART E LOGISTICS AND TRANSPORTATION REVIEW*, 34(3), 217-228.

Frota Neto, J. Q., Bloemhof-Ruwaard, J. M., van Nunen, J. A. E. E. and van Heck, E. (2008) 'Designing and evaluating sustainable logistics networks', *Economics*, 111(2), 195-208.

Fu, S., Yan, X., Zhang, D., Shi, J., Wan, C. and Song, Z. (2014) Use of FMECA Method for Leakage Analysis of LNG Fueled Vessels, *ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering (OMAE2014)*. San Francisco, CA, June 8-12,2014.

Fu, X., Ng, A.K.Y and Lau, Y.Y. (2010) 'The impacts of maritime piracy on global economic development: the case of Somalia', *Maritime Policy and Management*, 37(7), pp. 677-697.

García-Arca, J., Prado-Prado, J. C. and Garrido, A. T. G.-P. (2014) "Packaging logistics": promoting sustainable efficiency in supply chains. *International Journal of Physical Distribution & Logistics Management*, 44(4), 325-346.

GDV, G. d. D. V. e. V. (2000-2014) *Cargo information, 2000-2014.* [Online]
Available at: http://www.tis-gdv.de/tis_e/ware/inhalt.htm [Accessed.5 March 2015]

Gerard Prendergast, L. P. (1996) Packaging, marketing, logistics and the environment: are there trade-offs. *International Journal of Physical Distribution & Logistics Management,* 26(6), 60-72.

Glock, C. H. and Kim, T. (2014) Container management in a single-vendor-multiple-buyer supply chain. *Logistics research*, 7(1), 1-16.

GLOGOWSKA, M (2011). 'Paradigms, pragmatism and possibilities: mixed-methods research in speech and language therapy (English)', *International Journal of Language & Communication Disorders (Print),* 46, 3, pp. 251-260

Gnoni, M. G., De Felice, F. and Petrillo, A. (2011) A Multi-Criteria Approach for Strategic Evaluation of Environmental Sustainability in a Supply Chain. *International Journal of Business Insights & Transformation*, 3(S3), 54-61.

Goellner, K. and Sparrow, E. (2014) An environmental impact comparison of single-use and reusable thermally controlled shipping containers. *International Journal of Life Cycle Assessment*, 19(3), 611-619.

Govindan, K., Palaniappan, M., Zhu, Q. H. and Kannan, D. (2012) Analysis of third party reverse logistics provider using interpretive structural modelling. International *Journal of Production Economics*, 140(1), 204-211.

Gu, Q., Ji, J. and Gao, T. (2008) Pricing Management for A Closed-Loop Supply Chain. *Journal of Revenue & Pricing Management,* 7, 45-60.

Guide, V. D. R. and Van Wassenhove, L. N. (2002) 'The reverse supply Chain', *Harvard Business Review,* 18(2), 25-26.

Guide, V. D. R. and Van Wassenhove, L. N. (2009) 'The Evolution of Closed-Loop Supply Chain Research', *Operations Research*, 57(1), 10-18.

Guirong, Z. and Zongjian, Z. (2012) Green Packaging Management of Logistics Enterprises. *Physics Procedia, 24(Part B),* 900-905.

Guo, Y. and Ma, J. (2013) Research on game model and complexity of retailer collecting and selling in closed-loop supply chain. *Applied Mathematical Modelling*, 37(7), 5047-5058.

Gustafsson, K., Jonson, G., Smith, D. and Sparks, L. (2008) *Retailling logistics & Fresh Food Packaging*, London: Kogan Page Limited.

Gwanpua, S. G., Verboven, P., Leducq, D., Brown, T., et al. (2015) The Frisbee Tool, A Software for Optimising the Trade-Off Between Food Quality, Energy Use, And Global Warming Impact of Cold Chains. *Journal of Food Engineering*, 148, 2-12.

Hall,R (2012) Mixed Methods: In Search of a Paradigm. *International Conference: Innovative Research in a Changing and Challenging World,* Australian Multicultural Interaction Institute, Tasmania, Australia

Harilaos, P.N. and Christos, K.A. (2010) 'Balancing the economic and environmental performance of maritime transportation', *Transportation Research Part D*, 15, pp. 458–462.

HAUSER, J, and CLAUSING, D (1988) 'The House of Quality', *Harvard Business Review*, 66, 3, pp. 63-73

Healy, M. and Perry,C. (2000). ‘Comprehensive criteria to judge validity and reliability of qualitative research within the realism paradigm’, *Qualitative Market Research: An International Journal*. 3,3, pp.118-126

Hellström, D. and Nilsson, F. (2011) Logistics-driven packaging innovation: a case study at IKEA. *International Journal of Retail & Distribution Mana*gement, 39(9), 638-657.

Hellstrom, D. and Saghir, M. (2007) Packaging and logistics interactions in retail supply chains. *Packaging Technology and Science,* 20(3 (2007-05-01)), 197-216.

Hoffmann, P., Schiele, H. and Krabbendam, K. (2013) Uncertainty, supply risk management and their impact on performance. *Journal of Purchasing & Supply Management*, 19(3), 199-211.

Hofmann, E. and Locker, A. (2009) Value-based performance measurement in supply chains: a case study from the packaging industry. *Production Planning and Control* (1), 68.

Hosseinzadeh, M. and Roghanian, E. (2012) An Optimization Model for Reverse Logistics Network under Stochastic Environment Using Genetic Algorithm. *International Journal of Business & Social Science*, 3(12), 249-264.

Huang, D.; Chen, T.; Wang, MJJ, (2000) ‘A fuzzy set approach for event tree analysis’, *Fuzzy sets and systems*, 118(1), pp. 153-165.

International Maritime Organization (IMO). 2014. Third IMO GHG Study 2014. [online] Available at: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Greenhouse-Gas-Studies-2014.aspx

Islam, S. and Olsen, T. (2014) Truck-sharing challenges for hinterland trucking companiesA case of the empty container truck trips problem. *Business Process Management Journal*, 20(2), 290-334.

ISO (2005) *'Information technology – unique identification – Part 5: unique identification of returnable transport items (RTIs)'*, ISO/IEC 15459-5

J. Wang, J. B. Yang, P. Sen, (1996) Multi-person and multiattribute design evaluations using evidential reasoning based on subjective safety and cost analyses, *Reliability Engineering and System Safety*, vol. 52, no. 2, pp. 113–128.

Jedlička, W. 2015. Packaging Sustainability: Tools, Systems and Strategies for Innovative Package Design. Somerset: Wiley.

Jesús, G.-A. and José Carlos Prado, P. (2008) Packaging design model from a supply chain approach. *Supply Chain Management*, 13(5), 375-380.

Ji-Feng, D. and Chien-Chang, C. (2013) An Evaluation Model of Quantitative and Qualitative Fuzzy Multi-Criteria Decision-Making Approach for Location Selection of Transshipment Ports. *Mathematical Problems in Engineering*, 1-12.

Johansson, G., 2002, "Success Factors for Integration of Eco design in Product Development," Environ. Manage. Health, 13 (1), pp. 98–107.

Jönson, G. (2000) *Packaging Technology for the Logistician*, 2nd edition. Lund University.

Kaplan R, Norton D. The Balanced Scorecard – Translating Strategy into Action. Harvard Business School Press: Boston, MA, 1996.

Karkkainen, M. A.-R., T; Herold, M. (2004) 'Managing the rotation of reusable transport packaging- a multiple case study', in *Thirteenth International Working Seminar on Production Economics*, Igls/Innsbruck, February 16-20,

Kemme, N. (2012). *Design and operation of automated container storage systems*. n.p.: Springer Science & Business Media.

Khan, F. I., Sadiq, R., and Veitch, B., 2004, "Life Cycle iNdeX(LInX): A New Indexing Procedure for Process and Product Design and Decision-Making," J. Cleaner Prod., 12 , pp. 59–76.

Khanlarzade, N., Yegane, B. Y. and Nakhai, I. (2012) Genetic algorithm to optimize two-echelon inventory control system for perishable goods in terms of active packaging. *International Journal of Industrial Engineering Computations*, 3(2), 103-114.

Koffler, C., Krinke, S., Schebek, L., and Buchgeister, J., 2008, 'Volkswagen slimLCI: A Procedure for Streamlined Inventory Modeling Within Life Cycle Assessment of Vehicles,' Int. J. Veh. Des., 46, pp. 172–188.

Kotler, P. and Keller, K. L. (2006) *Marketing management* / Philip Kotler, Kevin Keller, 12th ed. edition. Upper Saddle River, N.J.: Pearson Prentice Hall.

Kroon, L. and Vrijens, G. (1995) Returnable containers: An example of reverse logistics. *International Journal of Physical Distribution and Logistics Management*, 25(2), 56-68.

Kumar, V. V. and Chan, F. T. S. (2011) A superiority search and optimisation algorithm to solve RFID and an environmental factor embedded closed loop logistics model. *International Journal of Production Research*, 49(16), 4807-4831.

Lacasa, E, Santolaya, J & Biedermann, A. 2016. 'Obtaining sustainable production from the product design analysis', Journal of Cleaner Production, 139, pp. 706-716.

Lado Cousté, N., Martos-Partal, M. and Martínez-Ros, E. (2012) The Power of a Package. *Journal of Advertising Research*, 52(3), 364-375.

Lai, K.-h., Ngai, E. W. T. and Cheng, T. C. E. (2002) Measures for evaluating supply chain performance in transport logistics. *Transportation Research: Part E*, 38(6), 439.

Lam, J. S. L. (2014) Designing a sustainable maritime supply chain: A hybrid QFD–ANP approach. *Transportation Research Part E.*

Lam, J. S. L. and van de Voorde, E. (2011) Scenario Analysis for Supply Chain Integration in Container Shipping. *Maritime Policy and Management*, 38(7), 705-725.

Lambert, S., Riopel, D. and Abdul-Kader, W. (2011) FOR IS:A reverse logistics decisions conceptual framework. *Computers & Industrial Engineering*, 61(3), 561-581.

Lange, J., Bergs, F., Weigert, G. and Wolter, K. J. (2012) Simulation of capacity and cost for the planning of future process chains. *International Journal of Production Research,* 50(21), 6122-6132.

Lee, C. K. M. and Lam, J. S. L. (2012) Managing reverse logistics to enhance sustainability of industrial marketing. *Industrial Marketing Management*, 41(4), 589-598.

Lee, Y. J., Baker, T. and Jayaraman, V. (2012) Redesigning an integrated forward–reverse logistics system for a third party service provider: an empirical study. *International Journal of Production Research*, 50(19), 5615-5634.

Lee, Y.M. and Yun, W.Y. (2011) 'Optimal inventory control of empty containers in inland transportation system', *Int. J.ProductionEconomics*, pp. 451-457.

Lehr, C. B., Thun, J.-H. and Milling, P. M. (2013) From waste to value – a system dynamics model for strategic decision-making in closed-loop supply chains. *International Journal of Production Research*, 51(13), 4105-4116.

Li, C. (2013) An integrated approach to evaluating the production system in closed-loop supply chains*. International Journal of Production Research*, 51(13), 4045-4069.

Li, L., Wang, B. and Cook, D. P. (2014) Enhancing Green Supply Chain Initiatives via Empty Container Reuse. Transportation Research: Part E: Logistics and Transportation Review, 70, 190-204.

Li, X, Zhu, Y, and Zhang, Z n.d., (2010) 'An LCA-based environmental impact assessment model for construction processes', *Building And Environment*, 45, 3, pp. 766-775

Lindfors L-G, (1995) *Nordic guidelines on life-cycle assessment*, Nordic Council of Ministers, Copenhagen

Ling, D., Huang, H.-Z., Song, W., Liu, Y. and Zuo, M. J. (2012) Design FMEA for a diesel engine using two risk priority numbers. *2012 Proceedings Annual Reliability & Maintainability Symposium, 1.*

Lockamy Iii, A. (1995) A Conceptual Framework For Assessing Strategic Packaging Decisions. *International Journal of Logistics Management*, 6(1), 51-60.

Logsa 2004. Choose To Reuse. Superintendent Of Documents.

Lu, L. Y. Y., Wu, C. H. and Kuo, T. C. (2007) AHP: Environmental principles applicable to green supplier evaluation by using multi-objective decision analysis. *International Journal of Production Research*, 45(18/19), 4317-4331.

Luttropp, D. C., and Lagerstedt, J., 2006, 'EcoDesign and the Ten Golden Rules: Generic Advice for Merging Environmental Aspects Into Product Development,' J. Cleaner Prod., 14 , pp. 1396–1408.

MA, X. & MOULTRIE, J. (2017) 'What Stops Designers from Designing Sustainable Packaging? -A Review of Eco-design Tools with Regard to Packaging Design.' Sustainable Design and Manufacturing 2017. SDM 2017. Smart Innovation, Systems and Technologies, vol 68. Springer, Cham

Manzini, R. and Accorsi, R. (2013) The new conceptual framework for food supply chain assessment. *Journal of Food Engineering*, 115(2), 251-263.

Manzini, R., Accorsi, R., Ayyad, Z., Bendini, A., Bortolini, M., Gamberi, M., Valli, E. and Toschi, T. G. (2014) Sustainability and quality in the food supply chain. A case study of shipment of edible oils. *British Food Journal*, 116(12), 2069-2090.

Marcoulides, GA (1998) *Modern Methods For Business Research*, Mahwah, NJ, US

Marjudi, S., Sulaiman, R. and Amran, M. F. M. (2012) Designing Computer Aided Design for Malaysia SMEs Food Packaging (PackCAD) using Quality Function Deployment (QFD). *International Journal of Computer Applications*, 41(16), 16-19.

MarketLine (2014) *Containers & Packaging Industry Profile: United Kingdom. Containers & Packaging Industry Profile: United Kingdom*, 1-32.

Martin, C. (2014) The Packaging of Efficiency in the Development of the Intermodal Shipping Container. *Mobilities*, 9(3), 432-451.

Masui, K., Sakao, T., Kobayashi, M., and Inaba, A., 2003, ‘Applying Quality Function Deployment to Environmentally Conscious Design,’ Int. J. Qual. Reliab. Manage., 20, pp. 90–106

Mavi, R. K., Kazemi, S., Najafabadi, A. F. and Mousaabadi, H. B. (2013) Identification and Assessment of Logistical Factors to Evaluate a Green Supplier Using the Fuzzy Logic DEMATEL Method. *Polish Journal of Environmental Studies*, 22(2), 445-455.

McFarlane, S. and Saul, J. (2014) *Food importers shift from dry bulk cargo ships to containers, 2014.* [Online] Available at:
http://www.reuters.com/article/agri-container-idUSL5N0LF3MZ20140214
[Accessed. 5th April 2016].

Meisel, F., Kirschstein, T. and Bierwirth, C. (2013) Integrated production and intermodal transportation planning in large scale production-distribution-networks. *Transportation Research Part E*.

Minami, C., Pellegrini, D. and Itoh, M. (2010) When the Best Packaging Is No Packaging. International Commerce Review -- *ECR Journal*, 9(1/2), 58-65.

Mininni T. (2007) ‘Packaging that works for the planet’. *Brandweek 2007*; 48(17): 20.

Ministry of Housing. 2000. Eco-indicator 99Manual for Designers. Ministry of Housing, Spatial Planning and the Environment, Netherland.

Ministry of Housing. 2000. Eco-indicator 99Manual for Designers. Ministry of Housing, Spatial Planning and the Environment, Netherland.

Mishra, H. G. and Jain, D. (2012) Impact of Packaging in Consumer Decision Making Process of Namkeen Products. *Journal of Marketing & Communication*, 7(3), 48-63.

Mishra, P. and Sharma, P. (2012) Green Marketing: Challenges and Opportunities for Business. *Journal of Marketing & Communication*, 8(1), 35-41.

Molina-Besch, K., 2016. Prioritization guidelines for green food packaging development. British Food Journal, Vol. 118 Iss: 10, pp.2512 – 2533.

Möller, B, and Beer, M. (2004) *Fuzzy Randomness: Uncertainty In Civil Engineering And Computational Mechanics*, n.p.: Berlin : Springer, 2004.

Mont, O, Tukker, A. 2006. Product-service Systems: reviewing achievements and refining the research agenda. *Journal of Cleaner Production*. Vol. 14, No 17, pp. 1451-1454.

myEcoCost. 2012. Forming the nucleus of a novel ecological accounting system. [online] Available at: http://www.myecocost.eu/

Noda, S. (2004) 'Container shipping and security issues: the carriers' responsibility in the fight against terrorism', *Maritime Economic and Logistics*, 6, pp.157-186.

Nordin, N. and Selke.S (2010)'Social Aspect of Sustainable Packaging', *Packaging Technology And Science*, 23, 6, pp. 317-326

Olander Roese, M. and Olsson, A. (2012) Challenging the strategy paradigm within the paper packaging industry. *International Journal of Business Science & Applied Management*, 7(2), 1-12.

Olander-Roese, M. and Nilsson, F. (2009) Competitive Advantage Through Packaging Design - Propositions for Supply Chain Effectiveness and Efficiency, *International Conference on Engineering Design*, ICED09. Stanford.

Olsmats, C. & Dominic, C. 2003. Packaging scorecard - a packaging performance evaluation method, Packaging Technology and Science, Vol. 16 No. 1, pp. 9-14.

Omar, M. W., Fadzil, M. I., Ali, M. N. M. and Shaharudin, M. R. (2011) The Effectiveness of Bumiputra SME Food Product Packaging in the Malaysian Customer's Preception. *Canadian Social Science*, 7(2).

O'Neill, B. (2007) Tips for Sustainable Packaging Programs. *Flexible Packaging*, 9(11), 31-32.

Orita, A. and Draghici, G. (2010) Improvement of QFD with a Quality Plan. *Proceedings of The 21st International Daaam Symposium*, 2010 Vienna, Austria. Daaam International, 1513-1514.

Özkır, V. and Başlıgıl, H. (2012) Modelling product-recovery processes in closed-loop supply-chain network design. *International Journal of Production Research*, 50(8), 2218-2233.

PackagingResourcesActionGroup (2009) *An Introduction to Packaging and Recyclability,* [Online]. Available at: Http://Www.Recycle-More.Co.Uk/Images/Static/Household/Prag_Packaging_And_Recyclability_Guide.Pdf [Accessed June 10 2013].

Paine, F. A. (1981) *Fundamentals of packaging*, Leicester: Brookside Press.

Paksoy, T., Pehlivan, N. Y. and Özceylan, E. (2012) Application of fuzzy optimization to a supply chain network design: A case study of an edible vegetable oils manufacturer. *Applied Mathematical Modelling*, 36(6), 2762-2776.

Palsson, H. & Hellstrom, D. 2016, Packaging logistics in supply chain practice - current state, trade-offs and improvement potential. International Journal of Logistics Research and Applications, Volume 19, 2016 - Issue 5.

Park, H, Um, J, Woo, I, and Kim, J (2012) 'Application of fuzzy set theory to evaluate the probability of failure in rock slopes', *Engineering Geology*, 125, pp. 92-101,

Pham, J, Kim, G, Natterman, J, Cover, R, Goeschel, C, Wu, A, and Pronovost, P n.d., (2010).'ReCASTing the RCA: An Improved Model for Performing Root Cause Analyses', *American Journal Of Medical Quality*, 25, 3, pp. 186-191

Pillay, A, and Wang, J. (2003) 'Modified failure mode and effects analysis using approximate reasoning', *Reliability Engineering and System Safety*, 79, pp. 69-85.

Prendergast, G. and Pitt, L. (1996) Packaging, marketing, logistics and the environment: Are there trade-offs? *International Journal of Physical Distribution & Logistics Management,* 26(6), 60.

Pullman, M. E., Maloni, M. J. and Dillard, J. (2010) Sustainability Practices in Food Supply Chains: How is Wine Different? *Journal of Wine Research*, 21(1), 35-56.

Ramani, K., Ramanujan, D., Bernstein, W., Zhao, F., Sutherland, J., Handwerker, C., Choi, J., Kim, H. and Thurston, D. (2010). Integrated Sustainable Life Cycle Design: A Review. Journal of Mechanical Design, 132(9), p.091004.

Rausand, M. and Hoyland, A. (2004) *System reliability theory: Models, Statistical Methods, and Applications.* 2nd edn. WILEY-INTERSCIENCE.

Reddon, T. (2013) "Special" Loads Deserve Extra Smarts. *Material Handling & Logistics*, 68(6), 33-36.

Reznik, L, Dimitrov, V, and Kacprzyk, J 1998, *Fuzzy Systems Design: Social And Engineering Applications*, n.p.: Studies in Fuzziness and Soft Computing, vol. 17.

Robertson, K, Garnham, M, & Symes, W 2014, 'Life cycle carbon footprint of the packaging and transport of New Zealand kiwifruit', International Journal Of Life Cycle Assessment, 19, 10, pp. 1693-1704

Robertson, K., Garnham, M. & Symes, W. 2014. Life cycle carbon footprint of the packaging and transport of New Zealand kiwifruit. International Journal of Life Cycle Assessment, 19, 1693-1704.

Robertson, K., Garnham, M. & Symes, W. 2014. Life cycle carbon footprint of the packaging and transport of New Zealand kiwifruit. International Journal of Life Cycle Assessment, 19, 1693-1704.

Routroy, S. (2009) Antecedents and Drivers for Green Supply Chain Management Implementation in Manufacturing Environment. ICFAI *Journal of Supply Chain Management,* 6(1), 20-35.

Saaty, T. L. (1990). How To Make A Decision: the Analytic Hierarchy Process. *European Journal of Operation Research*, 48(1), 9-26.

Saaty, T.L., (1980) *The Analytic Hierarchy Process*. Mcgraw-Hill, New York.

Saghir, M. (2002) *Packaging Logistics Evaluation in the Swedish Retail Supply Chain* Lund University, Lund.

Saghir, M. (2004) The Concept Of Packaging Logistics. *The Second World Conference On Pom And 15th Annual Pom Conference*. Cancun,Mexico.

Saghir, M. and Jönson, G. (2001) Packaging handling evaluation methods in the grocery retail industry. *Packaging Technology and Science*, 14(1), 21-29.

Sarfaraz, Z.H. and Jurgita, A. (2012) 'Team Member Selecting Based on AHP and TOPSIS Grey', Inzinerine Ekouomika-*Engineering Economics*, 4 (23), pp. 425-434.

Schultmann, F., Zumkeller, M. and Rentz, O. (2006) Modeling reverse logistic tasks within closed-loop supply chains: An example from the automotive industry. *European Journal of Operational Research*, 171(3), 1033-1050.

Shammot, M. M. (2011) Green Marketing and Jordanian Consumer Behavior. Research *Journal of International Studies*, 20, 30-36.

Shang, J.S., Tjader, Y. and Ding, Y., (2004). A unified framework for multicriteria evaluation of transportation projects. *IEEE transactions on engineering management,* 51(3), pp.300-313.

Sharma, R, and Sharma, P (2010) 'Methodology and theory: System failure behavior and maintenance decision making using, RCA, FMEA and FM', *Journal Of Quality In Maintenance Engineering*, 16, 1, p. 64-88

Sherwin, C., and Bhamra, T., 1999, 'Beyond Engineering: Ecodesign as A Proactive Approach to Product Innovation,' Proceedings of the IEEE International Symposium on Environmentally Conscious Design and Inverse Manufacturing Conference , Tokyo, Japan, pp. 41–46.

Shi, J., Li, D., Shi, X. and Du, Q. (2015) Risk Evaluation for Sustainable Packaging Logistics Solution: A Quantitative Method and Case Study, *The 3rd International Conference on Transportation Information and Safety*. Wuhan, China.

Sii, H.S. and Wang, J., 2003. A design—decision support framework for evaluation of design options/proposals using a composite structure methodology based on the approximate reasoning approach and the evidential reasoning method. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, 217(1), pp.59-76.

Silva, D. A. L., Renó, G. W. S., Truzzi, O. M. S., Sevegnani, G. and Sevegnani, T. B. (2013) Comparison of disposable and returnable packaging: A case study of reverse logistics in Brazil*. Journal of Cleaner Production*, 47, 377-387.

Simms, C. D. and Trott, P. (2014) Barriers to the upgrade cycle in a commodity process industry: evidence from the UK packaging industry. *R&D Management*, 44(2), 152-170.

Song, D.-W. and Panayides, P. M. e. (2012) Maritime Logistics: A Complete Guide to Effective Shipping and Port ManagementLondon and Philadelphia:Kogan Page; distributed by Ingram Publisher Services, La Vergne, Tenn.

Soroka (2002) *Fundamentals of Packaging Technology*, Institute of Packaging Professionals

Srivastava, S. (2008) Network design for reverse logistics☆. *Omega*, 36(4), 535-548.

Stamatis, D. H. (2003) *Failure Mode and Effective Analysis: FMEA from Theory to Execution*. ASQ Quality Press.

Statista (2010) Estimated value of international seaborne trade in 2010, [Online]. Available at: Http://Www.Statista.Com/Statistics/254067/Value-Of-International-Seaborne-Trade/ [Accessed 18 September 2015].

Stefan, M. (2001) Strategic safety stocks in reverse logistics supply chains. *International Journal of Production Economics*, 71, 417-428.

Sustainable Packaging Alliance (SPA). (2005) Defining sustainable packaging. [online] Available at:
http://www.sustainablepack.org/research/subpage.aspx?PageID=10&id=7

Sustainable Packaging Coalition (SPC). (2011) Definition of Sustainable Packaging. [online] Available mat: http://www.sustainablepackaging.org/content/?type=5&id=definition-of-sustainable-packaging

Svanes E, Vold M, Møller H, Kvalvåg Pettersen M, Larsen H, Jørgen Hanssen O. (2010). Sustainable packaging design: a holistic methodology for packaging design. *Packaging Technology and Science*. Vol. 23. No 3, pp. 161–175.

Tanik, M. (2010) Improving "order handling" process by using QFD and FMEA methodologies: A case study. International *Journal of Quality and Reliability Management,* 27(4), 404-423.

Tao, Y. and Yin, Z. (2014) Reverse logistics network: A literature review. *Journal of Chemical & Pharmaceutical Research,* 6(7), 1916-1921.

Tay, K. M. and Lim, C. P. (2008) 'On the use of fuzzy inference techniques in assessment models: part II: industrial applictions'. *Fuzzy optimization and Decision making.* 7(3), pp. 283-302.

The World Bank. (2016) Container port traffic. [online] Available at: http://data.worldbank.org/indicator/IS.SHP.GOOD.TU?end=2014&start=2000&view=chart

Ting, S. L., Tse, Y. K., Ho, G. T. S., Chung, S. H. and Pang, G. (2014) Mining Logistics Data to Assure the Quality in a Sustainable Food Supply Chain: A Case in the Red Wine Industry. *International Journal of Production Economics*, 152, 200-209.

Tseng, W.J., Ding, J.F., Chou, C.C., Hsu, F.T., Wang, Y.M., Liu, Y.N., Chang, N.W., and Wu, Y.W. (2012) 'Risk analysis of cargos damages for aquatic products of refrigerated containers: shipping operators' perspective in Taiwan', *Information Management and Business Review*, 4(2), pp. 86-94.

TTClub (2010) *Container Loss. Stop Loss, 7.* [Online]Available at: http://www.ttclub.com/fileadmin/uploads/ttclub/Publications___Resources/Stop%20Loss%2007%20-%20English.pdf [Accessed. 5 May 2013]

Tuzkaya, G., Gulsun, B. and Onsel, S. (2011) A methodology for the strategic design of reverse logistics networks and its application in the Turkish white goods industry. *International Journal of Production Research*, 49(15), 4543-4571.

Twede, D. and Clarke, R. (2004) Supply Chain Issues in Reusable Packaging. *Journal of Marketing Channels,* 12(1), 7.

Twede, D. and Parsons, B. (1997) *Distribution Packaging for Logistical Systems: A literatureReview.* .Pira, UK.

Ugboma, C., Ugboma, O. and Ogwude, I.C., (2006) *An analytic hierarchy process (AHP) approach to port selection decisions–empirical evidence from Nigerian ports. Maritime Economics & Logistics,* 8(3), pp.251-266.

UK Environment Agency. 2015. 2010 to 2015 government policy: waste and recycling. [online] Available at: https://www.gov.uk/government/publications/2010-to-2015-government-policy-waste-and-recycling/2010-to-2015-government-policy-waste-and-recycling#appendix-7-packaging-waste-producer-responsibility-regimes

UK-P&I-Club (2000) *Container Matters, 2000.* [Online] Available at: www.ukpandi.com/loss-prevention/books-pamphlets-library/
[Accessed.27 May 2013]

Ullman, D. G., 1997, 'The Mechanical Design Process', 2nd ed., McGraw-Hill, New York.

United Nations Environmental Program (2013). *"Guidelines for National Waste Management Strategies Moving from Challenges to Opportunities"*

Vadde, S., Kamarthi, S. V. and Gupta, S. M. (2007) Optimal pricing of reusable and recyclable components under alternative product acquisition mechanisms. *International Journal of Production Research*, 45(18-19), 4621-4652.

van der Vorst, J. G. A. J., Tromp, S.-O. and Zee, D.-J. v. d. (2009) Simulation modelling for food supply chain redesign; integrated decision making on product quality, sustainability and logistics. *International Journal of Production Research*, 47(23), 6611-6631.

Van Ewijk, S, and Stegemann, J (2016) 'Limitations of the waste hierarchy for achieving absolute reductions in material throughput', *Journal of Cleaner Production*, 132, pp. 122-128

Verghese, K. and Lewis, H. (2007) Environmental innovation in industrial packaging: a supply chain approach. *International Journal of Production Research*, 45(18/19), 4381-4401.

Vidal, J. (2008) *True scale of CO_2 emissions from shipping revealed*, the Guardian. UK2008

Vieira, D, Calmon, J, and Coelho, F (2016) 'Review: Life cycle assessment (LCA) applied to the manufacturing of common and ecological concrete: A review', *Construction And Building Materials*, 124, pp. 656-666

Waage S. (2007). Re-considering product design: a practical "roadmap" for integration of sustainability issues. *Journal of Cleaner Production*. Vol. 15, pp. 638-649.

Wan, C., Yan, X., Zhang, D., Shi, J. and Fu, S. (2014) Emerging LNG Fueled Ships in Chinese Shipping Industry: A Hybrid Analysis and Prospects. *International Journal of Performability Engineering (Special Issue on Dependability and Sustainability).*

Wan, C., Zhang, D., Shi, J., Fu, S., Yan, X. and K.Y.Ng, A. (2014) Emerging LNG Fueled Ships in Chinese Shipping Industry: A Hybrid Analysis and Prospects, *International Association of Maritime Economists (IAME) 2014 Conference*. Norfolk, VA, USA.

Wang, Y. M., Liu, J., and Elhag, T. M. (2008) 'An integrated AHP–DEA methodology for bridge risk assessment', *Computers & industrial engineering*, 54(3), pp. 513-525.

Ward, J. (2010) Is sharing a box worth it? *Automotive Logistics*, 13(3), 26-32.

Wei, L., Huan, X. and Xin, Z. (2009) *AGILE SERVICE ORIENTED SHIPPING COMPANIES IN THE CONTAINER TERMINAL.* Konteinerių terminalai ir laivų kompanijos - lankstaus ir greito aptarnavimo organizavimas., 24(2), 143-153.

Williams, H (2011). *'Food Packaging for Sustainable Development',* Karlstad University Studies,

Williams, H. & Wikström, F. (2010) Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items, Journal of Cleaner Production, Vol. 19, pp. 43-48.

Woo, S., Park, Y. and Park, S. (2013) Comparative quality evaluation of king oyster mushroom as affected by unit packaging method during simulated export shipment. *Korean Journal of Horticultural Science & Technology*, 31(2), 186-193.

World Business Council for Sustainability (WBCSD). 2008. Sustainable Consumption Fact and Trends From a Business Perspective. [online] Available at: http://www.wbcsd.org/Clusters/Sustainable-Lifestyles/Resources/Sustainable-consumption-facts-trends

Yan, N.-N. and Sun, B.-W. (2012) Optimal Stackelberg Strategies for Closed-Loop Supply Chain with Third-Party Reverse Logistics. *Asia-Pacific Journal of Operational Research,* 29(05), 1250026.

YANG, C.-S., LU, C.-S., XU, J. and MARLOW, P. B. (2013) Evaluating Green Supply Chain Management Capability, Environmental Performance, and Competitiveness in Container Shipping Context. *Journal of the Eastern Asia Society for Transportation Studies,* 10(0), 2274.

Yang, T., Lee, R.S. and Hsieh, C. (2003). Solving a process engineer's manpower-planning problem using analytic hierarchy process. *Production Planning & Control,* 14(3), pp.266-272.

Yang, Z, Wang, J, Bonsall, S, Yang, J, and Feng, Q (2005) A Subjective Risk Analysis Approach for Container Supply Chains, *International Journal of Automation and Computing ,* vol 1, pp. 85-92

Yang, Z. L., Bonsall, S., and Wang, J. (2010) ‘Facilitating uncertainty treatment in the risk assessment of container supply chains’, *Journal of Marine Engineering & Technology,* 9(2), pp. 23-36.

Yasutaka, K. and Nobuhiko, T. (2006) A Multiple Attribute Utility Theory Approach To Lean And Green Supply Chain Management*. International Journal of Production Economics*, 101, 99-108.

Yiangkamolsing, C., Bohez, E. L. J. and Bueren, I. (2010) Universal design (UD) principles for flexible packaging and corresponding minimal customer requirement set. *Packaging Technology and Science*, 23(5), 283-300.

Young, R. R., Swan, P. F. and Burn, R. H. (2002) 'Private railcar fleet operations: the problem of excessive customer holding time in the chemicals and plastics industries', *Transportation Journal, Fall*, 51-59.

Young, S. 2010. Packaging and the Environment: A Cross-Cultural Perspective. *Design Management Review,* 19(4), pp.42-48.

Yu, S., Kato, S., and Kimura, F., 2001, ‘EcoDesign for Product Variety: A Multi-Objective Optimization Framework,’ Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing

Appendix I – Letter of Implication for Packaging Practice

Letter from packaging supplier on impact of research

Impact of Research Project – Weir and Carmichael

WEIR & CARMICHAEL
packaging your world

TO WHOM IT MAY CONCERN

In collaboration with University of Liverpool via ERDF funded CGE project, Jing's research on sustainable packaging has helped Weir and Carmichael in environmental-friendly reusable packaging range design and development. We gained economic and environmental benefit from the research outcomes. We are happy to see the increasing number of clients opting to our green reusable packaging range as a result of a number of new sustainable packaging design, development and improvement with the help of this collaboration project.

Jing's research in this project enables us improving our packaging design and development process. By better understanding the customer needs and better identifying improvement area of current packaging products, the design and evaluation tools adopted from Jing's research have helps us with design improvement, product range extension and new product development for green packaging.

With help of Jing's research work in this project, we managed to secure 2 patent (pending) for useful protective packaging features addressing the critical operation problems identified from the evaluation tool and analysis derived from the research. At the same time, 3 new design rights for new reusable packaging products have been approved, 5 new ranges of reusable packaging have been developed and under trial process of potential clients.

As a result of this collaboration project, our key reusable packaging product range has been improved and extended during the project period. The number of clients purchasing has greatly boosted and the monthly sales of this product range have largely increased by around 390% in purchasing quantity.

Apart from domestic market, we also start to receive oversea contracts from American and Canadian clients on our new reusable packaging products developed in this project. We believe this is a prime step of our green packaging expansion to international market.

For long term environmental impact, this project helped out client and users in emission and waste reduction. Estimated by CGE environmental impact assessment report, just for our key clients opt to reusable protective cover from one-off packaging for furniture, our clients can save over 108 tonnes of GHG emission and reduce over 1400 tonnes of packaging material for each key client each year.

For all positive impact mentioned above, we are very happy to engage in this collaboration project with university researchers.

Mr. Dean Alexander
Product Development and Production Manager
Weir and Carmichael

ACS REGISTRARS ISO 9001 | ACS REGISTRARS ISO 14001 | ACS REGISTRARS ISO 18001

WEIR & CARMICHAEL LTD 100-130 ST JOHN'S RD BOOTLE LIVERPOOL L20 8BH
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Appendix II – Questionnaire for Packaging Evaluation

Please firstly provide basic information about the supply chain using this packaging.

>Please indicate what packaging you are evaluating in this form. e.g. worktop cover, mattress cover, headboard cover, TV cover or other packaging product

( )

>What product is this packaging used for? ( )

>What's your organisation's role/position in the supply chain of this product? e.g. Manufacturer, Distributor, Retailer, End-user, Packaging Provider or Other

( )

>The fleet for the product delivery belongs to which supply chain partner(s)? e.g. Manufacturer, Distributor, Retailer, End-user, Packaging Provider or Other

( )

>Which supply chain partner(s) cover the initial cost of this packaging?

( )

>Which supply chain partner(s) manage the reuse (e.g. collecting back, sorting, inspection, cleaning, maintenance and record) of the reusable packaging (if applicable)? ( )

>Which supply chain partner(s) cover the cost of the reuse process/operation?

( )

>How many days does it take for a closed-loop delivery cycle for the reusable packaging? (from the day the packaging with product goes out from your warehouse to the day the empty packaging comes back to your warehouse) ( )

>What's your job position in your organisation? (optional) ( )

I. Please evaluate the *probability* of each failures occurrence within each logistic process. Score the probability range from *1 to 7*, where *(1) is 'almost never'*, *(4) is 'moderate'* and *(7) is 'almost certain'*, or input *N/A* where the failure is *not applicable* for such logistic process.

1.1 During 'scanning' process, how likely does each of following situation occur to the product?

Not identified( ); Tampered( ); Dropped( ); Bended( ); Bumped( ); Contaminated( )

1.2 During 'labelling' process, how likely does each of following situation occur to the product?

Not identified( ); Tampered( ); Dropped( ); Bended( ); Bumped( ); Contaminated( )

1.3 During 'manual packing' process, how likely does each of following situation occur to the product?

Not identified( ); Tampered( ); Dropped( ); Bended( ); Bumped( ); Contaminated( )

1.4 During 'auto packing' process, how likely does each of following situation occur to the product?

Not identified( ); Tampered( ); Dropped( ); Bended( ); Bumped( ); Contaminated( )

1.5 During ‘manual handling’ process, how likely does each of following situation occur to the product?

Not identified( ); Tampered( ); Dropped( ); Bended( ); Bumped( ); Contaminated( )

1.6 During ‘equipment handling’ process, how likely does each of following situation occur to the product?

Not identified( ); Tampered( ); Dropped( ); Bended( ); Bumped( ); Contaminated( )

1.7 During ‘storage’ process, how likely does each of following situation occur to the product?

Not identified( ); Tampered( ); Dropped( ); Bended( ); Bumped( ); Contaminated( )

1.8 During ‘waiting’ process, how likely does each of following situation occur to the product?

Not identified( ); Tampered( ); Dropped( ); Bended( ); Bumped( ); Contaminated( )

1.9 During ‘transport’ process, how likely does each of following situation occur to the product?

Not identified( ); Tampered( ); Dropped( ); Bended( ); Bumped( ); Contaminated( )

II. Please give the *percentage of the possibility* of *failure consequence* caused by each failure. (Add up to 100% for each line).

2.1 When the item is 'not identified', what's the percentage of following consequences happen?

__%Wrong Item delivered __%Item Lost __%Breakage __%Scratch __%Dirty

2.2 When the item is 'tampered', what's the percentage of following consequences happen?

__%Wrong Item delivered __%Item Lost __%Breakage __%Scratch __%Dirty

2.3 When the item is 'dropped', what's the percentage of following consequences happen?

__%Wrong Item delivered __%Item Lost __%Breakage __%Scratch __%Dirty

2.4 When the item is 'bended', what's the percentage of following consequences happen?

__%Wrong Item delivered __%Item Lost __%Breakage __%Scratch __%Dirty

2.5 When the item is 'bumped', what's the percentage of following consequences happen?

__%Wrong Item delivered __%Item Lost __%Breakage __%Scratch __%Dirty

2.6 When it comes to 'contamination', what's the percentage of following consequences happen?

__%Wrong Item delivered __%Item Lost __%Breakage __%Scratch __%Dirty

III. Please describe the characteristics of the content product that is delivered, from following aspects (instead of accurate value, you can also use linguistic description in your convenience):

Value: Size: Weight:

Shape: Hardness: Pliability:

Appearance/finishing: Fragility:

Stability against sliding: Sensitivity to temperature:

Product quantity per package：

IV. Please score the impact of each product characteristics on each failure consequence severity, score from 1 to 7, where (1) is 'almost no impact, (4) is 'moderate impact' and (7) is 'very high impact', or put N/A where the characteristic is not applicable for the impact on the failure consequence.

4.1 How the '<u>incorrect item</u>' severity is impacted by each following characteristics of the product?

Value ( ) Size ( ) Shape ( ) Weight ( ) Hardness ( ) Pliability ( )

Appearance ( ) Fragility ( ) Stability against sliding ( )

Sensitivity to temperature (   )   Product   quantity

per pack (   )

4.2 How the 'item lost' severity is impacted by each following characteristics of the product?

Value (   )   Size (   )   Shape (   )   Weight (   )   Hardness (   ) Pliability (   )

Appearance (   )   Fragility (   )   Stability against sliding (   )

Sensitivity to temperature (   )   Product   quantity

per pack (   )

4.3 How the 'breakage' severity is impacted by each following characteristics of the product?

Value (   )   Size (   )   Shape (   )   Weight (   )   Hardness (   ) Pliability (   )

Appearance (   )   Fragility (   )   Stability against sliding (   )

Sensitivity to temperature (   )   Product   quantity

per pack (   )

4.4 How the 'scratch' severity is impacted by each following characteristics of the product?

Value (   )   Size (   )   Shape (   )   Weight (   )   Hardness (   ) Pliability (   )

Appearance (   )   Fragility (   )   Stability against sliding (   )

Sensitivity to temperature ( ) Product quantity per pack ( )

4.5 How the ‘dirty’ severity is impacted by each following characteristics of the product?

Value ( ) Size ( ) Shape ( ) Weight ( ) Hardness ( ) Pliability ( )

Appearance ( ) Fragility ( ) Stability against sliding ( )

Sensitivity to temperature ( ) Product quantity per pack ( )

V. Please give your *overall opinion* *(tick the answers)* on how the packaging and packaging system performs within this certain logistics setting.

5.1 How would you agree on ‘This packaging is suitable for packing this product’?

Strongly Disagree Disagree Neutral Agree Strongly Agree

5.2 How would you agree on ‘The logistics process is suitable for delivery of this product’?

Strongly Disagree Disagree Neutral Agree Strongly Agree

5.3 How would you agree on ‘This packaging and the logistics operation is suitable for each other’?

Strongly Disagree Disagree Neutral Agree Strongly Agree

5.4 Are you satisfied with the cost-efficiency of the packaging (including service cost on maintaining reusable packaging)?

Very Dissatisfied Dissatisfied Neutral Satisfied Very Satisfied

5.5 Overall, what do you think of the packaging and delivery system for this product?

Very Poor Poor Fair Good Very Good

=== Here is the end of this questionnaire, thank you very much for your time =====

Appendix III – Template for Semi-structured Interview

PART I
What's your position in your organisation and how long have you worked in this industry?
How well are you familiar with the reusable packaging used in your organisation? And which reusable packaging your organisation is using currently?
Would you please briefly describe the operations related to packaging in your organisation? Can the process be summarised into combinations of general logistic operation types: Verification, Labelling, Filling, Handling, Storage, Waiting, Transport, or other logistic activity (if "other activity" is named, ask for explanation)

PART II
What do you think are the key characteristics of a product that is influenced by the packaging and logistic activities? (if outside the range from literature findings, ask for example on how they are related)
PART III
What are the usual operation failure that related to the packaging? (if possible, please give simple examples to show how it happened and what consequence if the failure)
We've listed the general types failure cause and consequences for the packed product (on the literature finding list). According to your experience, can they cover the most of the operation failure that happen in your organisation when using the reusable packaging?(ask for examples on how the failure mode linked to the effect, and ask for explanation if more failure mode or effect is addressed

Appendix IV – Packaging Evaluation Paper Abstract (under review and revision)

Evaluation for Sustainable Packaging Logistics Solutions in Supply Chain: A Case Study of Reusable Packaging in Furniture and Upholstery Industry

Abstract

This study provided an integrated approach to packaging solution evaluation and selection problem for greener reusable packaging system adoption. Reusable packaging, part of reverse logistics, has gained attention in supply chain management as a vital element of achieving sustainable supply chains in different industries. But reusable packaging initiatives were affected by the challenges and barriers including imbalanced cost and benefit for different supply chain partners, waste reduction with extra logistics operations. Importantly, the impact from packaging system not only limited to packaging itself, it is also a result of combination that interacted between packaging layers, logistic processes and packed products, as different combinations of these contributed to different impact on the supply chain sustainability. However, this influence from packaging logistics has hardly been quantitatively measured. In the approach proposed by this article, from the view of packaging logistics, different effects and impacts were considered and evaluated for different packaging systems under different logistics settings when distributing different products in the supply chain. Case studies were conducted using proposed approach for typical furniture products in upholstery industry, illustrating the application of proposed approach for packaging system selection when adopting reusable packaging for different types of products in this industry.

Keywords: Packaging logistics; Packaging evaluation; Sustainable; Risk analysis