Comparative Analysis of Corrugated Fillers and Molded Paper Packaging Solutions

A Case Study at IKEA

Rohan Dhanore and Deepen Kohli

DIVISION OF INNOVATION | DEPARTMENT OF DESIGN SCIENCES
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MASTER THESIS

Comparative Analysis of Corrugated Fillers and Molded Paper Packaging Solutions

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Preface

This thesis represents the culmination of an extensive research project undertaken as part of our Master's degree at Lund University. The research has helped us to widen our knowledge in the field of packaging & its interaction throughout the supply chain.

We extend our deepest gratitude to our supervisor, Daniel Hellström, for his unwavering guidance, support, and encouragement throughout this research. A special thanks to Diogo Figueirinhas for his assistance and support during challenging times. We also wish to acknowledge the support of our family and friends, whose encouragement and understanding have been instrumental in completing this thesis.

We would like to express our sincere gratitude to our supervisor at IKEA, Michal Zabka, for his active involvement and guidance throughout the thesis. We would also like to thank all the co-workers at IKEA whom we met during the thesis for their support and taking out their time to answer all our questions.

We hope our research offers practical insights for organizations seeking to optimize their supply chain operations through innovative packaging solutions.

Lund, May, 2024

Rohan Dhanore & Deepen Kohli

Abstract

Title: Comparative Analysis of Corrugated Fillers and Molded Paper Packaging Solutions: A Case Study at IKEA

Authors: Rohan Dhanore and Deepen Kohli

Supervisors: Daniel Hellström, Senior Lecturer & Head of Division at Packaging Logistics, Lund University, Sweden.

Michal Zabka, Engineering Manager -Workspaces, IKEA of Sweden, Älmhult.

Examiner: Henrik Pålsson, Professor, Packaging Logistics, Lund University, Sweden

Purpose: The main purpose of the research is the overall exploration, evaluation and comparison of the usage and efficiency of corrugated fillers and molded paper packaging solutions in supply chains.

Method: The research adopts a qualitative approach using a multiple case study approach using qualitative and quantitative data gathered through interviews, observations, literature, and documentation.

Conclusion: The findings reveal that molded paper packaging often results in packaging weight reduction, whereas volume efficiency showed slight variations across different products and suppliers. Molded paper packaging also demonstrated consistent efficiency gains in packing time, enhancing operational productivity and reducing labor costs. Slight lower cost was observed with molded paper in certain scenarios, primarily due to lower material costs, however molded paper involved significant tooling investment, varying across geographies and based on product, highlighting the need for detailed cost analysis. Quality performance with molded paper was more consistent, with lower defect rates reported, suggesting potential for higher customer satisfaction. However, the CO2 emissions for both corrugated filler and molded papers varied across different sources and concrete conclusions could not be made.

Keywords: Packaging, Supply chain, Corrugated filler, Molded paper, Comparative analysis, Case study

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1. Introduction

1.1 Background

Packaging is the key element in the modern consumer landscape, being the first point of contact between the products and the possible buyers (Yadav and Maheshwari, 2023). Over the years, packaging has undergone dramatic changes, from a mere container for goods to a key element in the logistics chain. Its significance is not limited to the idea of containment, but it also includes the aspects of protection, preservation, branding and sustainability (Mihindukulasuriya and Lim, 2014). The industries are constantly growing and changing, and in turn, the techniques and materials used in packaging systems are also changing (Rundh, 2013). An effective packaging helps to avoid product damage during transportation and handling processes, which in turn reduces the returns and losses. It not only brings significant benefits in optimizing logistics, but also improves load efficiency and in turn reduces transportation costs.

Packaging has now become a part of the overall supply chain planning which includes both operational efficiency and sustainability (McKinsey & Company, 2022). The companies are shifting to a holistic approach that takes into account the packaging design, material selection and the end-of-life disposal as part of their supply chain optimization. This approach involves working with suppliers, manufacturers, and logistics providers to develop packaging solutions that meet the performance requirements while at the same time reducing the environmental impact (AWLindia, n.d.). In addition, the regulatory compliance concerning the packaging waste and recycling requirements is having an impact on the packaging strategies globally.

The packaging innovation is a result of the consumer requirements changing, the technology development and the global market (Carbinato, Deryckere and Shiran, 2023). Companies are constantly searching for new materials, designs, and technologies that will enable them to achieve optimal packaging performance and address any customer-specific needs. Innovations such as smart packaging, which is composed of RFID tags and QR codes, improve the traceability and security of the products during the supply chain (Vijayaraman, Osyk and Chavada, 2008). Also, there has been the emergence of new materials through research in material science which has led to the development of lighter, strong and more versatile packaging materials. Sustainability has become a top priority in packaging, which is driven by increasing environmental awareness and regulatory requirements. The implementation of bioplastic and nanomaterials not only improves the package functionality but also matches the environmental objectives. This way, it will be possible to decrease waste, prolong the shelf life, and improve the whole customer experience (Stark and Matuana, 2021). While companies are constantly trying to keep up with the changes, packaging will always play a vital part in the improvement of operations and meeting the needs of the market.

1.2 Research problem

Many companies use molded paper and corrugated fillers for their packaging needs. The decision to select either molded paper or corrugated fillers is typically made during the product development stage, depending on the specific requirements of the product (Harris, 2021). Various products within a company's range may use molded paper, corrugated fillers, or a combination of both in their packaging systems. However, there is often a lack of comprehensive insight into the extent to which these two packaging solutions are utilized across different products.

Moreover, less data is available on the extent of molded paper and corrugated filler packaging solutions used. Key factors such as quality performance, sustainability, cost implications, and logistics efficiency are crucial for determining the optimal packaging solution. Such a knowledge gap can result in the use of poor packaging decisions that may not take the best out of each material. Addressing this problem requires a detailed comparative analysis of molded paper and corrugated fillers, evaluating their performance across various metrics within the supply chain. Such an assessment can be informative, and help companies to achieve more efficient and sustainable packaging solutions, thereby increasing efficiency and companies' environmental responsibility.

1.3 Objectives and Research Question

The main purpose of the research is the overall exploration, evaluation and comparison of the usage and efficiency of corrugated fillers and molded paper packaging solutions in supply chains. By addressing the following research question, this study seeks to contribute valuable insights to the existing body of knowledge regarding selection of packaging solutions and their implications for supply chain management:

Research Question 1 (RQ1): How efficient are corrugated fillers & molded paper packaging solutions in the supply chain?

This question relates to investigating the efficiency of both corrugated fillers and molded paper packaging solutions in terms of their quality performance, sustainability, cost implications, and logistics efficiency. The research will be conducted by selecting some of the products and gathering empirical data to evaluate the performance of the packaging within the supply chain. The research applies comparative analysis methods to identify the strengths and weaknesses of each packaging solution. This will assist in the decision-making process and provide the basis for continuous improvement initiatives.

1.4 Scope

The thesis is an in-depth study of packaging systems that use corrugated fillers and molded paper. The aim of the study is to examine packaging methods from various aspects, including utilization ratio, efficiency measures, cost implications, sustainability factors, and product quality. Through a combination of qualitative interviews, quantitative data, and case studies, the research aims to provide actionable insights for stakeholders that are related to packaging design, supply chain management, and sustainability.

In addition, the thesis aims to provide valuable contributions into the area of packaging systems and supply chain management by giving practical recommendations which can be used in the area of improving packaging performance, efficiency, and sustainability. Applying a case study will offer practical implications and best practices that will guide decision-making processes in the organization and other similar companies.

1.5 Outline of the Thesis

Chapter 1: Introduction

Introduction defines packaging systems in supply chain management as being of utmost significance. It focuses on the importance of studying packaging systems utilizing corrugated fillers and molded paper. The specific research objectives are stated, followed by the research question that are designed to answer the objectives.

Chapter 2: Literature Review

The literature review section gives an overview of packaging systems as a part of the supply chain management. It covers an in-depth discussion on corrugated fiberboard, including types, properties, manufacturing, and its uses. Further, the chapter discusses honeycomb cardboard, which consists of various types, manufacturing methods, and applications, followed by molded paper packaging, including its manufacture, characteristics, and advantages

Chapter 3: Methodology

This chapter explains about the research approach applied, along with the research methodology adopted. It explains the data collection methods such as qualitative interviews and quantitative analysis, as well as case studies. Further, the chapter also discusses the analytical methods used in data analysis and measures employed to ensure the quality and credibility of the research process.

Chapter 4: Case Study at IKEA

Chapter begins with an introduction to IKEA, its organizational structure, its flatpack packaging and its five dimensions for democratic design. The chapter goes on to outline the approach for the case study that is specifically for IKEA, and provides a detailed description of the two packaging solutions for the selected products.

Chapter 5: Results & Discussion

The chapter of results and discussion gives an overview of the main findings that arise from the study. It looks into the efficiency metrics such as the volume of the packaging, the weight of the packaging, container loadability, packing time and the cost implications. As well, it assesses product quality aspects closely related to packaging solutions and talks about the sustainability factors. The chapter finishes off with an analysis and evaluation of the findings and their relevance to the study objectives.

Chapter 6: Conclusion

The conclusion chapter presents a summary of the major findings obtained from our research, and it also explains how our research relates to the existing body of knowledge. In addition, it points out the limitations that were experienced during the research process.

Chapter 7: Recommendations & Future Research

This part of the report will focus on the practical solutions that improve packaging efficiency, sustainability, and performance which are based on the research findings. In addition, it points out some future research areas and chances for further exploration in the given field.

2 Literature Review

2.1 Packaging and logistics

Packaging is strategically important and can have a significant impact on the logistic performance of the supply chain (Pålsson, 2018). Packaging affects the costs and the environmental efficiency of logistics throughout supply chains; for instance, through packaging purchasing, packaging development, transportation efficiency and end-of-life handling (Ballou 2004; Bowersox, Closs and Cooper, 2009; Fernie and McKinnon, 2003). Packaging might not always be of great direct economic value, but the strategic value is high (Found and Rich, 2007). In global supply chains, Lancioni and Chandran (1990) argue that packaging is one of the most important areas in order to obtain smooth logistics operations. Packaging can also add value, for instance, in terms of sales, convenience or communication for several supply chain actors (Johnsson, 1998). From an environmental perspective, a recent analysis found that packaging initiatives inherit a great potential to reduce carbon emissions in supply chains (Doherty and Hoyle, 2009). Thus, an effective and efficient packaging selection approach should consider economic and environmental packaging requirements from several supply chain actors.

Given that the role of packaging has changed a lot, from just providing protective functions to being an important part of the supply chain, a large number of definitions exists for packaging.

F.A Paine (1981) states following definition of Packaging as

- "A coordinated system of preparing goods for transport, distribution, storage, retailing and end-use"
- "A means of ensuring safe delivery to the ultimate consumer in sound condition at minimum cost"
- "A techno-economic function aimed at minimizing costs of delivery while maximizing sales (and hence profits)"

The definition of packaging mentioned by the European Environment agency & in European Union directive as 'Packaging shall mean all products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer. Non-returnable items used for the same purposes shall also be considered to constitute packaging'.

2.1.1 Packaging System

Packaging can be classified to reflect its different levels as primary, secondary or tertiary packaging. Primary packaging is the one which is in direct contact with the product, while secondary packaging is designed to contain several primary packages. The primary packaging in many cases is also referred to as Consumer pack or sales pack. An assembly of a number of primary or secondary packages on a pallet or a roll container is defined as tertiary packaging (Pålsson & Hellström, 2016). The systems approach highlights the natural interaction between the different levels of packaging and facilitates an understanding of their interdependence. Packaging system performance is thus affected by the performance of each level and by the interactions between these levels (Hellström and Saghir, 2007). The different levels of packaging is shown in Figure 2.1.

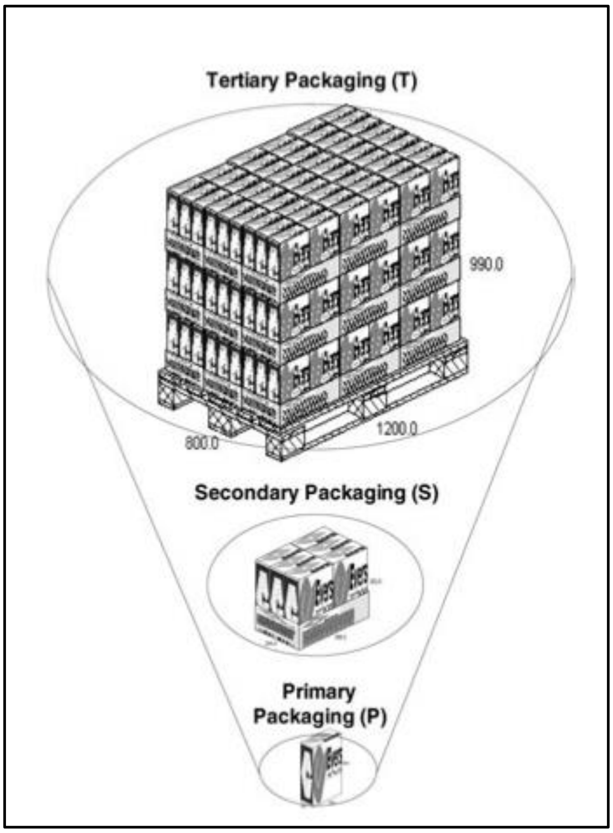


Figure 2.1 Packaging system Level (Hellström and Saghir, 2007)

Livingstone and Sparks (1994) mentioned about six functions that the packaging system should fulfill, namely

- Protection : to safeguard the content.
- Containment: to hold and maintain the content
- Apportionment: reduce large-scale and high-volume production to manageable size
- Unitization: to modularize the packaging levels to obtain material handling and transport efficiency. It means to fit a number of primary packaging into secondary packaging units, and a number of secondary packaging units into a tertiary packaging
- Communication: to identify the packaging in the supply chain and provide information
- Convenience: to simplify the use of products.

2.1.2 Packaging Logistics

Logistics may be defined as the design and operation of the physical, managerial and informational systems needed to allow goods to overcome time and space (Daskin, 1985). Logistics can also be defined as the process to plan, implement and control transport and stock keeping of goods from raw material to the end customer. (Aronsson et al., 2006)

According to the Council of Supply Chain Management professionals (2018), logistics management is defined as 'that part of the Supply chain management that plans, implements and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements.'

By combining the definitions of packaging and logistics, Pålsson (2018) defines packaging logistics as 'the interface between packaging and logistics throughout the supply chain, which demonstrates and supports the importance of viewing the physical flow of goods and its related information flow as one integrated system'.

Hellström and Saghir (2007) explain Packaging Logistic as "the synergies achieved by integrating logistics and packaging systems with the potential of increased supply chain efficiency and effectiveness, through the improvement of packaging and logistics related activities."

2.2 Corrugated Fiberboard

Corrugated fiberboard, also called corrugated cardboard, is a flexible packaging material that has a sandwich structure: two flat outer layers known as linerboard and a rippled inner layer known as the corrugating medium which is formed using heat, moisture and pressure. (Fadiji et al, 2018)

The sandwich can be formed in many ways, if one liner is used, the product is called as single faced (Figure 2.2a). When two liners are used on either side of fluting, then the product is called single-walled or double faced (Figure 2.2b). When two flutings and three facings are combined, the product is called as double wall (Figure 2.2c), and when three flutings and four facings are combined, then it is termed as triple wall (Figure 2.2d)

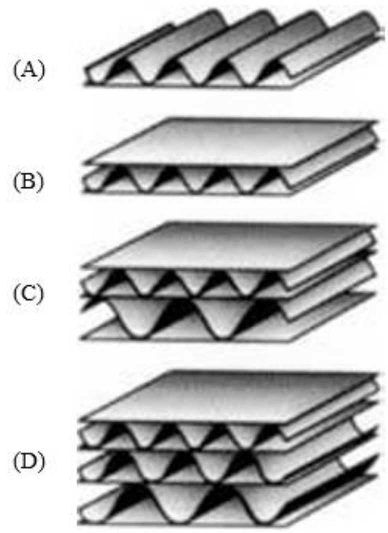


Figure 2.2 Corrugated board types (Twede and Selke, 2005)

Corrugated boards can be made from one of the nine flute sizes, i.e. A,B,C,D,E,F,G,K and O. The flute size can be defined by the number of flutes per unit length, the pitch, and the take-up factor. Pitch is defined as the distance between the two fluting tips, whereas take-up factor is the length of fluting material used in a corrugated fiberboard structure with the length of the facings (Poustis, 2005). The grade of corrugated board significantly affects the performance of the corrugated paperboard package in the distribution environment (Nordstrand, 2003)

Table 2.1 Corrugated flutes profiles (Poustis, 2005)

Flute	Average no. of flutes/m	Pitch (mm)	Take up Factor
D	75	14.96	1.48
K	95	11.70	1.50
A	110	8.66	1.53
C	129	7.95	1.42
B	154	6.50	1.31
E	295	3.50	1.24
F	310	2.40	1.22
G	350	1.80	1.21
O	360	1.25	1.14

Corrugated fiberboard packaging serves the same fundamental purpose as any other type of packaging which is protecting the products during transportation until they reach the end user. Palletization is increasingly being utilized in warehousing and distribution, and it requires corrugated boxes with good stackability. Corrugated board is a suitable material for achieving high stackability, creating a sturdy lightweight framework structure composed of liners separated by corrugated fluting papers. Another purpose of the package is to contain the products while they are being distributed. The ability to contain a product in the most cost-effective adaptation to logistics systems in packing and distribution are important factors in transport packaging design of corrugated boards.

2.2.1 Types of Corrugated Fiberboard

The most common type of corrugated fiberboard package used in the case (or box) with a rectangular cross section together with top and bottom flaps. This type of corrugated fiberboard box is also known as a rectangular slotted container (RSC) as shown in figure 2.3. Slots are cut between adjacent flaps in order to facilitate near folding when the box is closed. The manufacturer's joint can be taped, glued or stitched with staples.

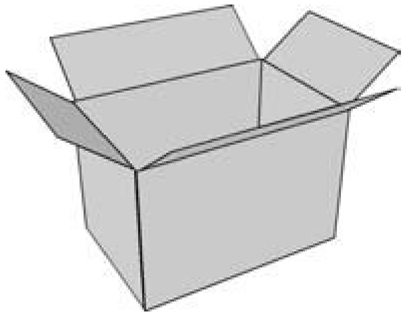


Figure 2.3 Regular slotted container. (Poustis, 2005)

Another type of box is a wraparound design, an alternative to RSC, where a flat blank is supplied to the packer by the manufacturer. This is then folded around the produced, and the overlap is then sealed, Figure 2.4.

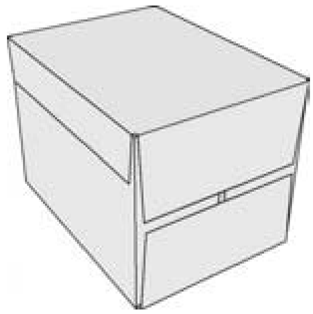


Figure 2.4 Wraparound case. (Poustis, 2005)

Product visibility is one of the important requirements for packs purchased by small shopkeepers in ‘Cash and Carry’ wholesaling, where the quantities directly supplied by the manufacturer do not justify the quantities purchased, and hence many packs still require a tray to contain the number of primary packs. The use of such shallow trays, shown in figure 2.5 also facilitates palletization.

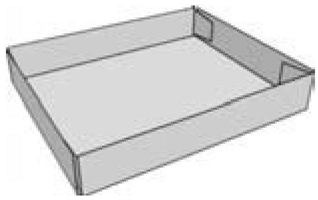


Figure 2.5 Corrugated fiberboard tray. (Poustis, 2005)

The tray can be used with the combination of a U-shaped fitting to provide increased stacking strength, as shown in Figure 2.6. This combination can be secured with a stretch or shrink wrapping.

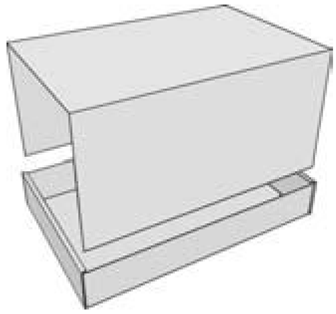


Figure 2.6 Tray with U-shaped fitting (Poustis, 2005)

Corrugated fiberboard can also be used as a shock absorber in different forms, for example as full-depth interlocking dividers or cells to protect bottles in a corrugated box. They are also used in the form of pads or fittings to restrict movement and protect product components which are prone to damage, as shown in figure 2.7.

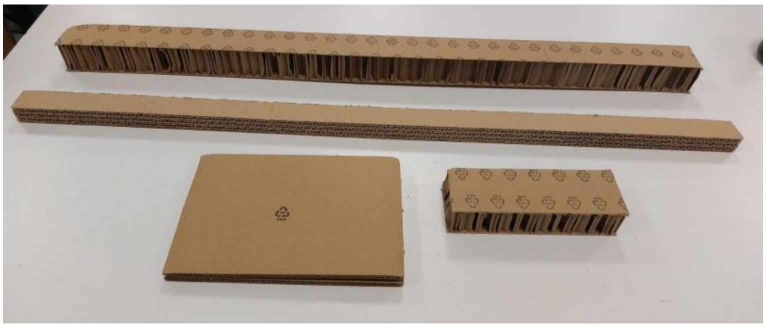


Figure 2.7 Corrugated cardboard used as fillers

2.2.2 Properties and Specifications of corrugated board

Weight per unit area (Grammage)

Grammage is defined as the weight of one square meter of corrugated board. The unit for grammage is g/m2 and measured under standard conditions 23 °C – 50% RH. For a single walled corrugated fiberboard, the grammage can be calculated by:

Grammage = L1 + (a ×F) + L2

Where L1 and L2 are the liners, F is the medium, and ‘a’ is the take-up factor, with all the measurements being made in g/m2.

Thickness (Caliper)

The average value of thickness is reported in Table 2.2. Thickness is measured under 20kPa pressure.

Table 2.2 Average caliper (thickness) for different corrugated board grades (Poustis, 2005)

Flute	Caliper thickness (mm)
D	8.0
K	6.5
A	4.8
C	4.2
B	2.8
E	1.7
F	1.2
G	1.0
O	0.7

Bursting Strength

Bursting strength is the most commonly used method to identify the quality of the corrugated board. The unit of bursting strength is kPa. Different qualities of burst strength are available based on the grammages and the nature of the liner, if they are made from recycled, virgin or the combination of both. The burst strength for a single wall corrugated fiberboard can be derived by,

Burst strength = L1 + L2 + 100

where L1 and L2 are the burst strengths of the liners in kPa.

Bending stiffness or Rigidity

Bending strength is defined as the force required to deflect a flat sample of corrugated board through a given angle. The standard unit of measurement for bending stiffness is newton meter (Nm). In general, C flute has higher bending stiffness than B flute, whereas corrugated board with kraft liner has a higher bending stiffness than the test liner for the same grammage. Also, the bending stiffness increases when the liner grammage is increased.

Edge Crush Test

The edge crush test (ECT) is used to determine the compression strength of the corrugated fiberboard. The unit of measurement for ECT is kilonewton per meter (kN/m)

Puncture

The energy required to penetrate the corrugated board can be determined through a puncture test. The unit of measurement is millijoule per meter (mJ/m).

Flat crash or hardness

The ability of the corrugated board to retain its geometry and structure is one of the main criteria for its stability. The flat crush test (FCT), as shown in figure 2.8, helps to classify and evaluate the performance of the fluting in accordance with its type and basis weight.

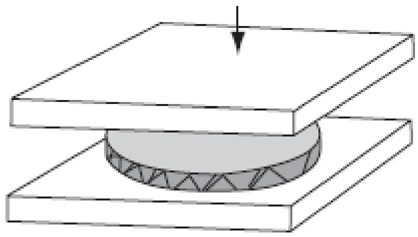


Figure 2.8 Flat crush corrugated board testing

Flute bonding and score cracking

The bonding between the flutes and the liners is evaluated through a pin-adhesion test (PAT). It measures the force required to separate the liner from the fluting, and is expressed in newtons per meter. Score cracking usually occurs in the corrugated board plants while converting the sheets. Moisture is one of the key parameters to influence the score cracking during the converting process of the corrugated board.

Moisture Resistance

Paper's sensitivity to moisture variations is an important factor, and the moisture content of a corrugated board is determined by the gravimetric moisture analysis by removing the water from weighted samples in an oven.

% Moisture = $(weight\ of\ moisture\ * 100)$÷ weight of wet sample

Paper Properties

The corrugated fiberboard is generally made of papers from wood fibers used to produce paper. Recycled fiber from recovered paper and board is a major source of fiber for the corrugating industry. Papers are identified from their mechanical properties, structural properties and their moisture sensitiveness. For corrugated fiberboard, the fluting medium comprises recycled or semi-chemical fibers whereas the liners consist of unbleached and bleached fibers (virgin or recycled). For satisfactory corrugated box performance, it is very extremely necessary to know the relative orientation of papers since the strength properties rely on the orientation: machine direction (MD) or cross direction (CD)

2.2.3 Manufacturing of Corrugated Fiberboard

The corrugated fiberboard plant comprises of a corrugated which produces flat sheets of corrugated fiberboard, and the converting equipment where the corrugated sheet is then converted into corrugated boxes by printing, cutting, creasing and gluing (or taping, stitching).

During the production of a single face corrugated fiberboard, the fluting medium is conditioned with steam and heat to ensure it is pliable enough to retain the shape of the fluting. The fluting medium is pressed into the medium either by using two profiled rolls or by using vacuum and forming the fluting medium on one profile roll, as shown in Figure 2.9. (Poustis, 2005)

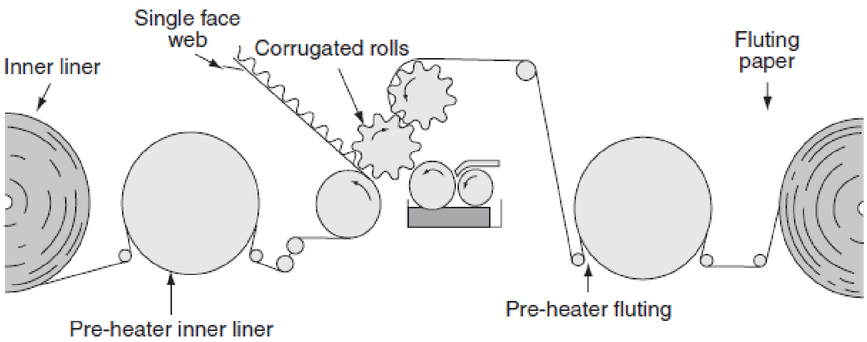


Figure 2.9 Production of single face corrugated board. (Poustis, 2005)

After that, starch adhesive is applied to the tips of the corrugations and the medium is then combined with the liner which has also been conditioned to bring it to the same temperature and moisture content as that of the fluting medium. To produce a double face or single wall corrugated fiberboard, a second liner is applied at the double backer as shown in Figure 2.10.

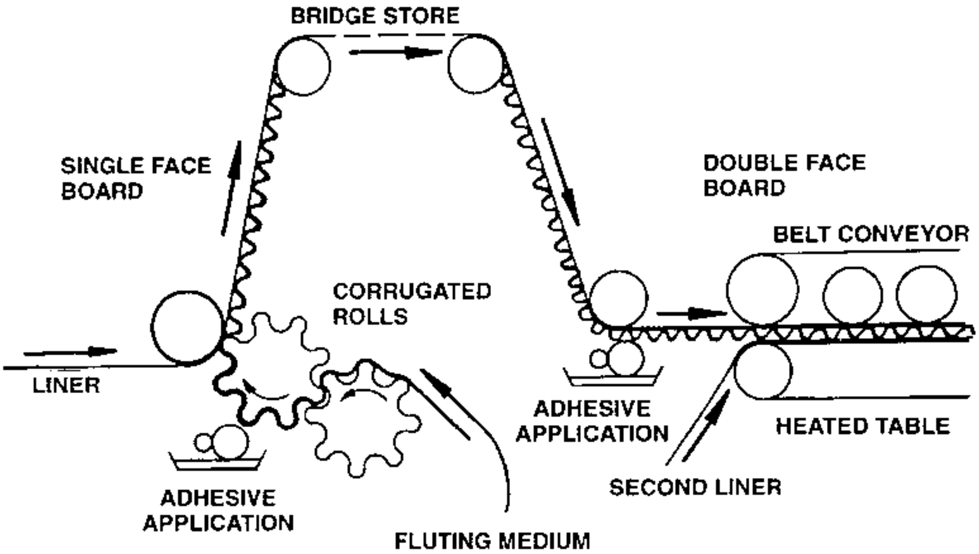


Figure 2.10 Production of single wall corrugated board. (Emblem and Emblem, 2012)

Once it is passed through the drying section, the board is cooled before being creased and cut to the required length and width. Fluting roll profiles (A,B,C etc.), roll temperature and pressure, adhesive viscosity, speed and pre-heat conditions of pre-heated inner liner and fluting medium are the key parameters of the corrugated fiberboard manufacturing process.

For manufacturing double walled corrugated fiberboard, additional sections would be incorporated in the machine as shown in Figure 2.11. In Zone 1, two single face corrugated webs are formed. In Zone 2, the flutes of Single Face 1 are glued to the liner of Single Face 2. A liner for the flutes of Single Face 2 is applied to the flutes of Single Face 2, and the combined board is then dried between the heating plates present in Zone C.

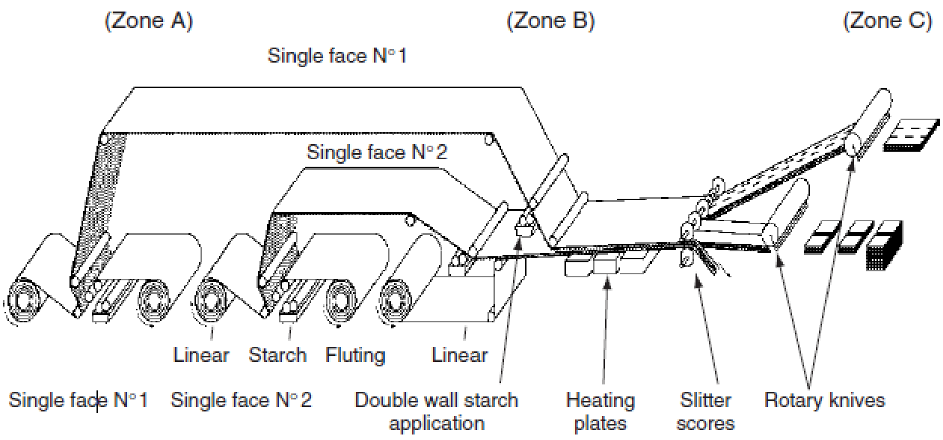


Figure 2.11 Production of double wall corrugated board. (Poustis, 2005)

2.2.4 Functions of Corrugated Fiberboard

Containability

The main function of the corrugated fiberboard box is to contain and protect the product during its transportation.

Box stackability

With the increasing use of warehousing and transporting, it is essential that the corrugated boxes have very good stability. Stackability is measured using a box compression test (BCT), where BCT is the top-to-bottom compression strength. Box dimensions play an important part in determining the box stability.

Protection

Corrugated board is a material which has a few energy absorption properties. The performance required from cushioning is to negate or minimize the risk of product damage arising due to vibration or impact. This can be done by spreading the forces on impact, localizing the force or absorbing it. Another important performance of the corrugated board is to protect the product when the box is dropped. Corrugated boxes can be damaged by puncturing, internally by product movement and externally by impact from any sharp objects. Protection against puncture can be achieved by quality of liners (kraft and test), the grammage of the corrugated fiberboard and the fluting profile (C or B flute)

Corrugated box packing line considerations

Corrugated boxes can be packed manually, automatically or semi-automatically depending on the product, the package and the line speed. In order to achieve packing line efficiency, the corrugated boxes should be able to meet requirements such as flatness, structural stability, and suitability for closure. Closure can be achieved by means of adhesive, tape, strapping or stitching. Adhesives can either by cold glues (examples PVA emulsions) or hot melt formulations.

Visual impact and Appearance

Mostly corrugated boxes are made in such a way so that some kind of information can be easily attached, pasted or printed on them. This information may include details about the contents, their owners, their respective manufacturers. Sorting instructions etc. Packaging materials are generally made with protection and storage in mind. However, their ability to make transport and sorting easier is also just as important (worldpackagingco.com, n.d.).

2.3 Honeycomb

Lightweight paper honeycomb is not a new structure as it has been used for a very long time for the manufacture of door leaves and also in the aerospace and automotive industry for decades (Pflug et al., 2004). In recent years, honeycomb cardboard has been widely used in the packaging industry for cushioning and shock absorbing applications, and has proven to be a more environmentally friendly alternative. Honeycomb is used in the packaging industry in boxes, pallets, crates and as a protective padding material. It is also used in the furniture industry for lightweight furniture components, shelves and partitions. Honeycomb paperboard's strength, versatility and environmental friendly nature make it popular among other industries such as construction, automotive, point of sale etc. Honeycomb cardboard has a very simple structure comprising of a honeycomb core which is sandwiched between surface of honeycomb paper bonded with adhesive as shown in Figure 2.12.

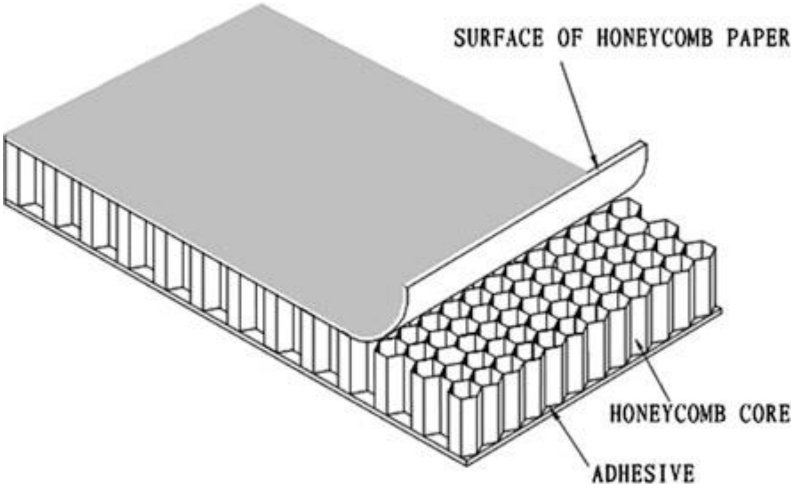


Figure 2.12 Honeycomb cardboard structure (S. Jiang et al.)

2.3.1 Types of Honeycomb Cardboard

Standard Honeycomb Cardboard

Standard honeycomb cardboard is made up of multiple layers of kraft paper sheets which are glued together in a honeycomb structure. Due to its lightweight properties & ability to provide cushioning and protection, it is mainly used in packaging applications. The hexagonal honeycomb structure distributes the weight evenly and offers high compression strength making it ideal for transportation applications (Gibson & Ashby, 1997). The standard honeycomb can be made from recycled paper as well.

Aluminum Honeycomb Cardboard

Aluminum honeycomb cardboard consists of aluminum sheets bonded to the honeycomb core made of aluminum or paper. The aluminum sheets add strength and rigidity to the structure while maintaining a lightweight core. It is commonly used in industries like aerospace, marine, and automotive where a high strength-to-weight ratio is essential. It offers excellent durability and can withstand high impact and pressure, making it ideal for structural applications. (Fleck et al., 1994)

Moisture-resistant Honeycomb Cardboard

Honeycomb cardboard coated with water-resistant materials or treated to repel moisture and humidity serves as moisture resistant honeycomb cardboard. They are widely used for outdoor applications such as outdoor furniture, signages, as well as packaging in humid environments. The moisture-resistant properties help to prevent the cardboard from warping or deteriorating when they are exposed to moisture (Brown, & Sharma, 1987)

2.3.2 Manufacture of Honeycomb Cardboard

Honeycomb cardboard can be manufactured from two types of processes, the conventional expansion process and the traditional corrugation process. In the conventional expansion process, most honeycomb cores are adhesive bonded expanded cores (Bitzer, 1996). In the first step, the glue lines are printed on the flat sheets. And then a stack of many sheets is made and the glue is cured. In the third step, slices are cut from these bocks. In the last step, the sheets are pulled apart, expanding into a hexagonal honeycomb core, as shown in Figure 2.13. The residual stresses have to be relaxed after expansion of heat in paper honeycombs. (Pflug et al.,1999)

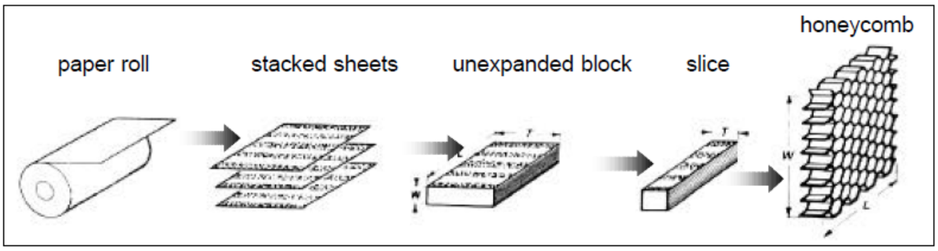


Figure 2.13 Expansion production process of conventional paper honeycombs (Pflug et al.,1999)

The primary reason for high costs of traditional expanded honeycomb cores is due to its batch wise nature of process. Honeycomb core production is very labor intensive and discontinuous. For low-cost applications, the degree of automation has surpassed the level reached in aerospace honeycomb production. However, the only drawback is that the cell size and core height for these low-cost paper honeycombs are usually above 10mm, due to the fact that the expansion step in the conventional honeycomb production process becomes very difficult at lower cell sizes.

The second production process for conventional honeycombs is the corrugation process. Due to more handling operations required for production of blocks & the difficulty in cutting off from the expanded process, this process is not often used and is more expensive. However, usage of inexpensive corrugated cardboard sheets can lead to the production of a low-cost honeycomb core, as shown in Figure 2.14. With a standard corrugated sheet process, a small cell size of 5mm can be achieved. (Paul and Klasmeier, 1997)

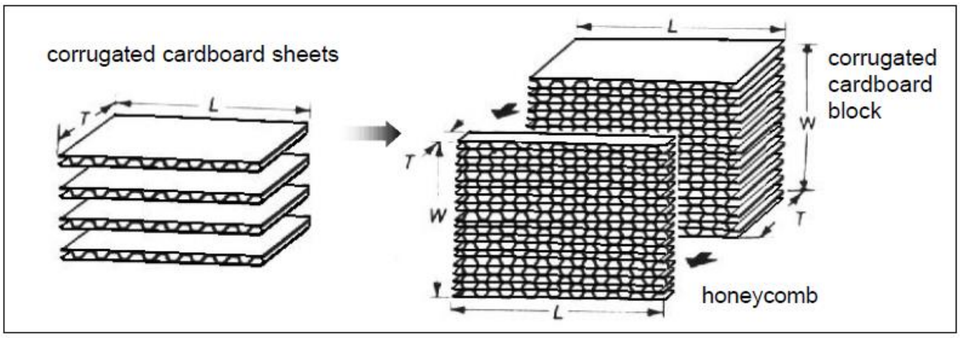


Figure 2.14 Manual production of corrugated cardboard honeycomb cores (Pflug et al.,1999)

With the increasing demand for low cost sandwich core materials and their highly advantageous mechanical properties have stimulated researchers to reduce the production costs of honeycomb cores produced from both paper as well as thermoplastic materials. Many expanded paper honeycombs are used in door filling and furniture applications. In packaging, these recyclable and biodegradable paper honeycombs materials are used as a substitute for foam products as inner packaging for a better crash absorption properties. Figure 2.15 below shows paper honeycombs in packaging applications.

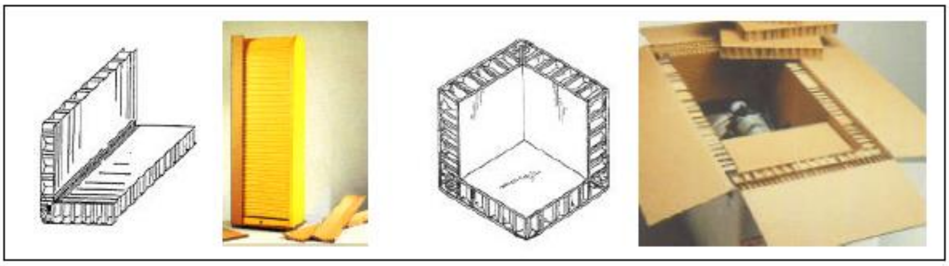


Figure 2.15 Inner packaging with paper honeycomb and edge elements. (Pflug et al.,1999)

2.4 Molded Paper

Molded paper, also referred to as molded pulp products or molded fiber products, were primarily used for packaging of food related products as containers or trays, eg: egg trays due to its geometry and aesthetic limitations (Wever & Twede, 2007). Due to environmental, social and economic concerns, a need for more sustainable products and industrial processes arises, and molded paper being made up of water and wood fibers, molded pulp is a renewable material and a sustainable solution. As the name suggests, molded paper is made from pulp which is molded into a shape designed to fold and protect the product which has to be packed. The primary function of molded paper packaging is to provide impact protection against breakage, chipping etc., which is achieved in the design, which locates and stabilizes the product. Due to its structural design, molded paper packaging also provides shock absorption.

Molded pulp product is produced by mixing water with either wood pulp or pulp made from recovered waste paperboard or paper to a consistency of 96% water and 4% fiber. A waterproofing agent can be added when required, such as rosin or wax emulsion, while dyes can be added to achieve specific colors. In most of the cases, fiber used is predominantly made from recovered paper and paperboard. However, virgin fiber can also be used. Baled recovered paper or pulp is hydro pulped and diluted to the correct consistency.

2.4.1 Manufacture of Molded Paper

There are different molded paper production techniques available based on conventional methods and newer processes. The molded paper production techniques can be divided into four different methods as described by Semple et al (2022)

One cast

One cast molding is the original 'plain molding' or 'thick wall' molding process where a relatively smooth surface is vacuum formed with the forming wire mesh on one side and very rough surface on the open side, before the web is deposited onto a conveyor for drying. The wall thickness achieved from the molding process is typically around 6-8, with the forming mold can be concave for heavy duty machine parts or furniture packaging. Recycled paper or paperboard are the most commonly used raw material for such applications.

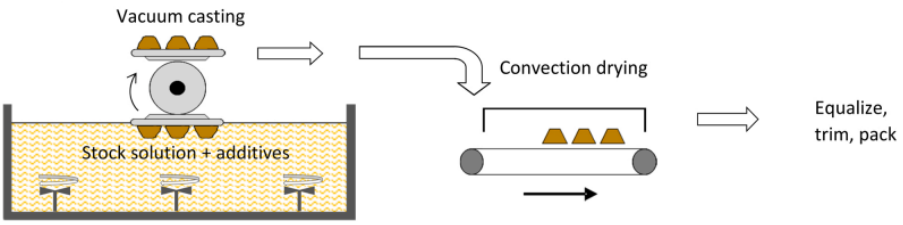


Figure 2.16 One cast molded paper processing technique (Semple et al., 2022)

Transfer Molding

In transfer molding, the cast is vacuum formed, dewatered and then removed from the forming mold to the transfer mold, before it is dropped off to a drying stage.The casts emerges with wire surface on the outside and a comparatively smoother surface than the single casts. The transfer molding process is suitable for high columns, easy to adapt, and can produce a wide range of 'light-duty' molded pulp packaging products. The wall thickness of products obtained from transfer molding are typically between 3-5mm. Applications for transfer molding can include a wide range of electronic, household and hardware packaging such as protectors, egg cartons, computers, cup holders, wine shippers etc. (Didone et al., 2017; Hogarth, 2005; Waldman, 2009).

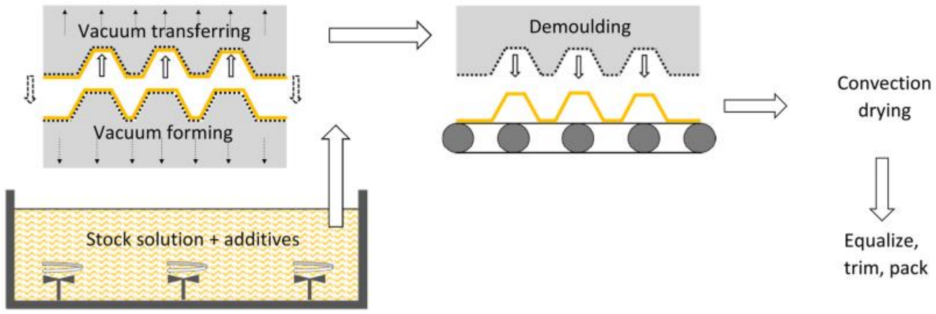


Figure 2.17 Transfer molding processing technique (Semple et al., 2022)

The dry web can then be transferred to a hot-press for further surface smoothening, embossing or printing any logo on the molded component. The temperature for hot press can be around 180 degrees Celsius with pressure of 10 kg/cm2. The raw material used in this process can be newspaper, tissue and corrugated board.

Three different types of quality surfaces can be achieved using the transfer molding process depending on the type of tools used during the production process. The first is the 'basic' quality surface, which is achieved by using only the forming and transfer tool. The molded part achieved is very rigid, of high compression strength and having a raw surface. The drawbacks with this quality type is that there is a possibility of partial shape deformation and low nesting, which can have a negative impact during storage and shipping of the molded products. The second is the 'Medium' quality surface which is achieved when an 'hot-press' is additionally used with the forming and transfer tools. This process provides a very smooth surface with precise shape and high nesting during shipping and storage. The third is the 'high' quality surface which is achieved by adding the edge cutting tool to the medium tooling setup. Along with precise shape and high nesting, it also yields precision in dimensions of the molded components.

Thermoforming

The process for Thermoforming starts in the same way as for the conventional process. The difference is during pressing and drying, the wet part is moved to heated mold. The part is compressed, and dried completely by two matches of a mold. The surface becomes relatively smooth and good dimensional accuracy is achieved. The pressing also improves the mechanical properties of the product adding high nesting for more efficient properties of the product. Then the edges are trimmed and all the scraps or rejected products are returned to the pulp mixture and re-used. The thermoforming molding process is shown in figure 2.18

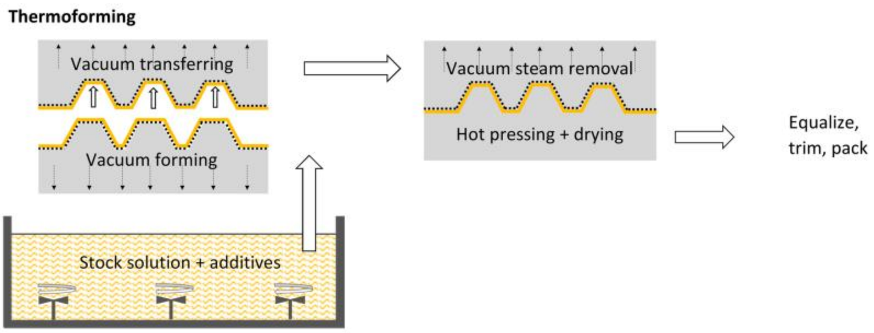


Figure 2.18 Thermoforming molding processing technique (Semple et al., 2022)

The thermoforming process is also called as 'precision molding' or 'thin-wall' process, as thermoforming eliminates convection drying of the cast to produce high precision, smooth, thin-walled casts whereby hot pressing, curing and drying take place in one step. The thermoforming process is comparatively faster and more process controlled, but the only drawback is that the production cost and energy consumption is relatively high, and is usually smaller in scale (Didone et al.,2017).The wall thickness achieved by this process is typically around 0.4 to 1.5 mm, and the applications include take-out food containers, smooth tableware, beauty products and high-end electronics packaging.

Dry Thermoforming

Dry thermoforming is a new technology, predominantly used for food and non-food packaging to adopt some of the process efficiencies of polymer or metal thermoforming and reduce water, drying time and energy usage. Defibrated cardstock or hot-pressed paperboard laminates are used by laminate thermoforming (Khakalo et al., 2017). Re-distributed into a thicker mat is done for mechanically separated fibers and then sprayed with a food-grade cellulose-compatible biopolymer such as gelatin or guar gum, lined top and bottom with thin tissue, forming a 3-layer composite which is then thermoformed to shape. Mechanical bi-axial compaction stressing with rubber sheeting to increase sheet extensibility and reduce anisotropy of the fiber network during thermoforming may be required for the whole paperboard. This helps to improve the tensile strength, stiffness, temperature and humidity stability. Overlaying and thermoforming thin treated papers can help to control the product thickness, network permeability/porosity, evenness of mat thickness and mechanical properties. The dry thermoforming process is shown in Figure 2.19

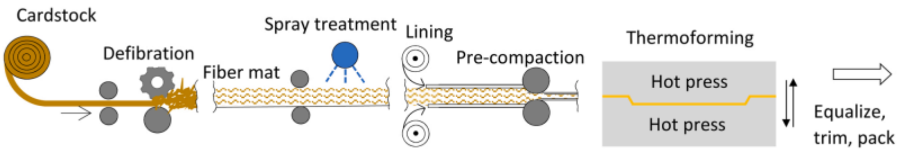


Figure 2.19 Dry thermoforming molding processing technique (Semple et al., 2022)

2.4.2 Key Characteristics of Molded Paper

Molded paper products offer a versatile, eco-friendly solution for various applications ranging from packaging to food industry like disposable tableware's key characteristics of molded paper are:

1. **Environmental Sustainability**

Molded pulp is environmentally friendly because it is made primarily from recycled materials, often post-consumer paper waste. This makes it biodegradable, compostable and recyclable, reducing the environmental impact of packaging materials.

2. **Protection and Cushioning**

Despite its environmental friendliness, the molded paper offers excellent protective properties. Its inherent shock-absorbing properties make it ideal for protecting the products during transport and storage, absorbing shocks and vibrations that could damage the goods.

3. **Lightweight**

Molded paper products being lightweight, make it easier for handling, storage and transportation.

4. **Customizability**

Molded pulp can be tailored to fit specific product shapes and sizes. It allows for customization, ensuring a tight and compact fit that securely holds the product in its place while providing adequate protection.

5. **Adaptability and Versatility**

The molded paper can be designed in various forms, ranging from simple shapes to complex structures, allowing for a wide range of applications across different industries.

6. **Recyclability**

Due to its composition of natural fibers, molded pulp breaks down easily when discarded, contributing to a circular economy by reducing waste and being recyclable or compostable in appropriate facilities.

3 Methodology

3.1 Research Approach

Research allows the discovery of new knowledge, helps organize new information, and helps in making informed decisions. The steps of the research depends on the type and purpose of research being conducted (Dubey, 2022). Based on the purpose of the study the research can be classified into four categories (Dubey, 2022)

Descriptive Study: The purpose of descriptive research is to collect data to describe a phenomenon, an event or how something works.

Analytical Study: This study involves the use of existing data and information to analyze and make critical examination of observations.

Evaluation Study: This study is conducted to examine or evaluate the impact of a particular parameter or decision.

Exploratory Study: This study is conducted when the information regarding the research area is limited and study needs to be conducted to develop understanding and formulate the problem.

3.1.1 Evaluation study

This research project aims to conduct a comparative analysis between two packaging systems, by evaluating and comparing their efficiency, effectiveness, and suitability within the supply chain. This study involves examining the impact of various parameters on the packaging, for this reason an evaluative study approach is most suitable for this objective. The study aims to provide a complete evaluation of the packaging systems by analyzing data related to the utilization, performance, cost implications, logistical efficiency, and sustainability of the two packaging systems. This will help in the decision-making processes of packaging selection.

The core of the research methodology will be mainly evaluation, where the impact of specific parameters or decisions related to packaging selection will be studied. However, some elements of other types of studies may also be included. For instance, descriptive aspects will be included to provide a detailed description of the characteristics and functionalities of each packaging system. Additionally, an exploratory approach will be adopted to address any gaps in understanding or to further develop insights into the factors influencing the effectiveness of packaging solutions within the supply chain.

3.1.2 Qualitative study

Once the purpose of the study is defined, the objective of the research should be stated. The objectives are developed by analyzing the purpose of the study and act as a guideline for the research in various steps. After defining the objective of the study, it is important to select a proper research approach. (Dubey, 2022) The basic research approaches are:

- Qualitative study
- Quantitative study
- Mixed study

More on the research approaches is available in Appendix A.

Table 3.1 Characteristics of the three research methods (Creswell, 2014)

Quantitative Methods	Mixed Methods	Qualitative Methods
• Pre-determined • Instrument based questions • Performance data, attitude data, observational data, and census data • Statistical analysis • Statistical interpretation	• Both pre-determined and emerging methods • Both open- and closed-ended questions • Multiple forms of data drawing on all possibilities • Statistical and text analysis • Across databases interpretation	• Emerging methods • Open-ended questions • Interview data, observation data, document data, and audio-visual data • Text and image analysis • Themes, patterns interpretation

For a comparative analysis of packaging systems, this study follows a qualitative method research approach while also incorporating quantitative data. This approach is recommended because it enables in-depth exploration and understanding, resulting in a more holistic view of different packaging methods.

The study is mostly qualitative and will explore the different packaging solutions and gain insight into differences between the packaging systems and how they vary from one another. Interviews, observations, and document analysis are used to learn about the packaging systems and user experiences. The quantitative component of the study will involve numerical comparisons of key metrics related to packaging systems, such as weight, volume, packing time, and cost. These data provide measurable comparison of the efficiency, performance, and economic parameters of different packaging methods.

3.2 Case Study Research Method

Once the research approach has been selected the researchers must select a research method to conduct their study. The objective of this thesis is to provide a comprehensive analysis of the two packaging systems from a variety of perspectives. Given the purpose of the study, the case study method is appropriate.

A case study focuses on one instance of a phenomenon to be investigated, and it offers a rich, in-depth description and insight of that instance (Johannesson, 2016). A case study typically uses multiple methods and tools for data collection from a number of entities by direct observation in a natural setting. The methods and tools include both quantitative and qualitative approaches consisting of interviews, business plans, organizational charts, questionnaires, and observations of managerial or employee actions and interactions. The goal is to fully understand the phenomenon through different perspectives, accumulation of multiple entities as supporting evidence to assure that the facts being collected are correct (Meredith, 1998). Case studies are preferred strategies when "How" or "Why" questions are being posed, when the researcher has little control over events, and when the focus is on contemporary phenomenon within real-life context (Yin, 2009).

For conducting research with case study, five components of research study are important (Yin, 2009):

Study questions: A research study can address various questions, and depending on the questions a relevant research strategy is used. Case study is appropriate for 'how' and 'why' questions. The case study literature provides a framework for conducting a comparative analysis of the two different packaging systems. The methodology used in the study aligns closely with the fundamental principles discussed in the case study literature, ensuring a systematic approach to comparing the differences between corrugated filler packaging and molded paper packaging.

Study propositions: The second component determines the scope of the study. The research questions capture what the research will answer but propositions are needed to move in the right direction and point what should be studied. Following the guidance from case study literature, two products were carefully selected for investigation: chair packaging and storage packaging. These products are different and have different packaging requirements. This allows us to compare the effectiveness of corrugated filler and molded paper packaging solutions under varying conditions. Another reason for selecting these particular products is that, both chair and storage were available in both types of packaging: corrugated filler and molded paper. This selection of products and packaging solutions allows each type of packaging for both products to be considered as a separate case study.

Unit of Analysis: The unit of analysis in case study is related to a fundamental problem of defining what a ‘case’ is. Selection of appropriate unit of analysis is fundamental for conducting a case study. It ensures that the study remains focused and relevant to the research objectives. The unit of analysis in this thesis corresponds to each type of packaging for the selected products. By treating each packaging solution (corrugated filler and molded paper) for chair packaging and storage packaging as separate cases, we obtain four unique units of analysis. This approach allows detailed exploration of each packaging solution.

Linking data to propositions: Linking data to propositions in case studies involves connecting empirical observations to theoretical propositions or hypotheses. One approach for doing this is through "pattern matching," which is a technique of relating data to propositions. The comparison between corrugated filler packaging and molded paper packaging for chair packaging and storage packaging aligns with the principles of case study literature, which recommends the comparison of similar cases. By studying packaging solutions within the same product category, the study provides an apple-to-apple comparison on factors such as quality performance, sustainability, cost, and logistics efficiency.

Criteria for interpreting findings: Setting criteria for interpreting findings in case studies can be challenging, as there is often no precise way to determine the criteria for considering a match between data and propositions. In the absence of statistical tests, researchers must rely on the contrast between competing patterns or propositions to interpret their findings effectively. Key metrics were defined to collect relevant data, including the different packaging materials, quality performance, sustainability, cost, and logistics efficiency. For example, the packaging solution was evaluated based on factors such as weight and volume efficiency, packing time etc. Quality performance metrics measured the quality issues recorded for each solution. Sustainability indicators measured the packaging's carbon footprint throughout its lifecycle. Cost of packaging considered the material cost, operations cost, and transportation along with investment in tooling.

3.2.1 Case study design

Every research study follows a research design. The research design is a logical plan that guides the researcher in collecting, analyzing, and interpreting observations. The research design acts as a blueprint for the research (Yin, 2009). Case studies can be classified into two categories, single case and multiple case design. These case studies can have unitary unit (holistic) or multiple units (embedded) of analysis (Yin, 2009). See figure 3.1 below:

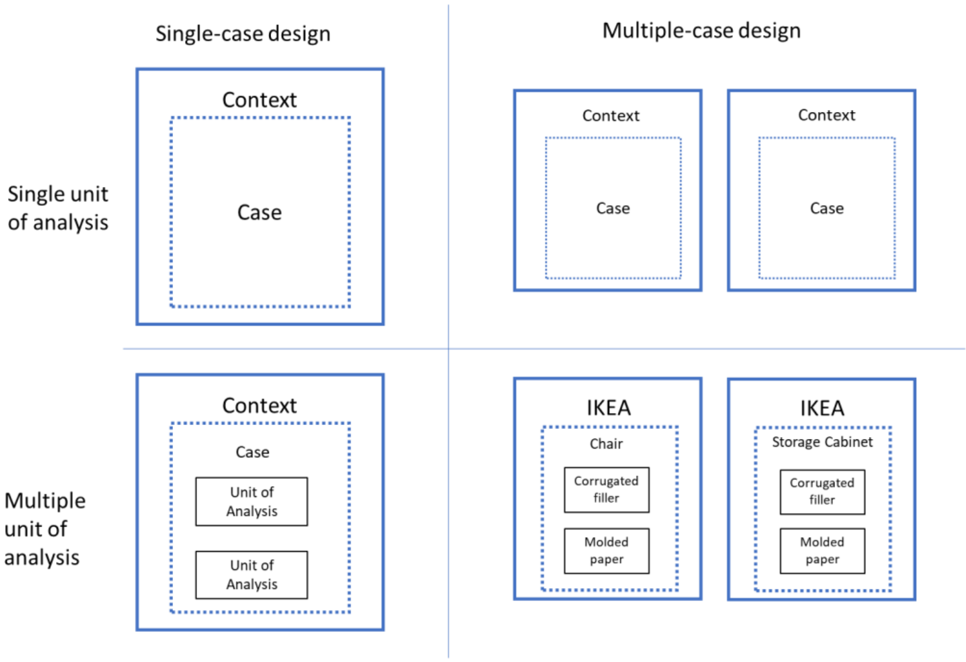


Figure 3.1 Basic types of design for case studies (adopted from Yin,2009)

The case study design in this thesis adopts a type 4 design, which involves multiple case studies with multiple embedded units of analysis, as described by Yin (2009). This research design was deliberately selected to provide greater depth to the investigation, as well as to enhance the generalizability of the findings.

The reason behind the multiple case study approach is because the packaging of a product is closely tied to the product's characteristics and requirements. By examining a diverse range of products, the research was able to develop a more comprehensive understanding of the complex relationship between packaging and the goods it contains.

Context of Case Study

Workspaces range area in IKEA has been working with different kinds of fillers in its packaging, ranging from corrugated fillers, honeycomb, molded paper, plastic fillers etc. Given the sustainability agenda of removing single use plastic in its packaging, IKEA is using a lot of paper-based packaging material in its packaging and thus the use of corrugated fillers, honeycomb and molded paper has increased in IKEA packaging.

IKEA had been working with filler solutions like corrugated filler and molded paper, where some cost comparison for the different types of packaging solutions was made by co-workers at IKEA of Sweden, but further investigations in how the different packaging solutions actually works in its supply chain in terms of quality, sustainability, logistics flow etc. haven't been conducted earlier. Molded paper packaging solution is believed to perform well in terms of quality in the Workspaces range area in the organization, and a shift was seen for some of the products from corrugated packaging to molded paper packaging.

However, in order to create good conditions for a successful shift, it is important to analyze the current situation i.e. knowledge of where the organization is today, and how a shift in packaging solutions can lead to improvements. IKEA never did this kind of analysis before and therefore a study felt accurate to analyze how efficient the different packaging concepts are today in IKEA supply chain.

Selection of Cases

IKEA workspaces have different ranges of products which are categorized based on the end use. These are Home-office desks, Home-office storage, Office-desks, Office-chairs, Office-storage, complementary workspaces items etc. IKEA is famous for its flat-packs, where the products are broken down into various components and packed in dis-assembled state in order to prevent shipping ‘air’ in the supply chain.

IKEA workspaces are working with two standard packaging solutions- corrugated fillers & molded paper solutions. To understand the efficiency and effectiveness of the two different packaging solutions, two products were chosen (see Figure 3.2 and Figure 3.3) in consultation with the Engineering manager, namely

1. Office Chair
2. Office Storage

Figure 3.2 Product 1- Office Chair (IKEA, n.d.)

Figure 3.3 Product 2- Storage Cabinet (Source IKEA, n.d.)

The above selected products were selected based on the complexity they provide in their packaging solution in terms of product weight, multiple number of components, different geographical manufacturing locations, and having multiple supplier bases. For the case study, each packaging solution was evaluated with the help of two suppliers for both the products, as shown in figure 3.4

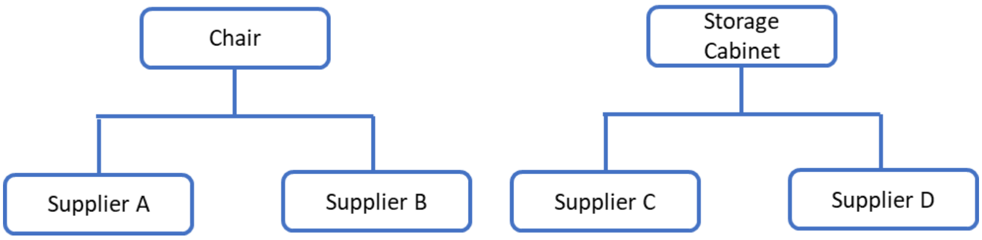


Figure 3.4 The selection of products and suppliers for the case

Both the supplies for the office chair product are located in Asia. The suppliers for office chairs will be referred as Supplier A and Supplier B respectively henceforth in the study, Whereas the office storage product is manufactured in Asia as well as Europe. The suppliers for office storage product will be refereed as Supplier C and Supplier D henceforth in the study.

3.2.2 Case Study Process

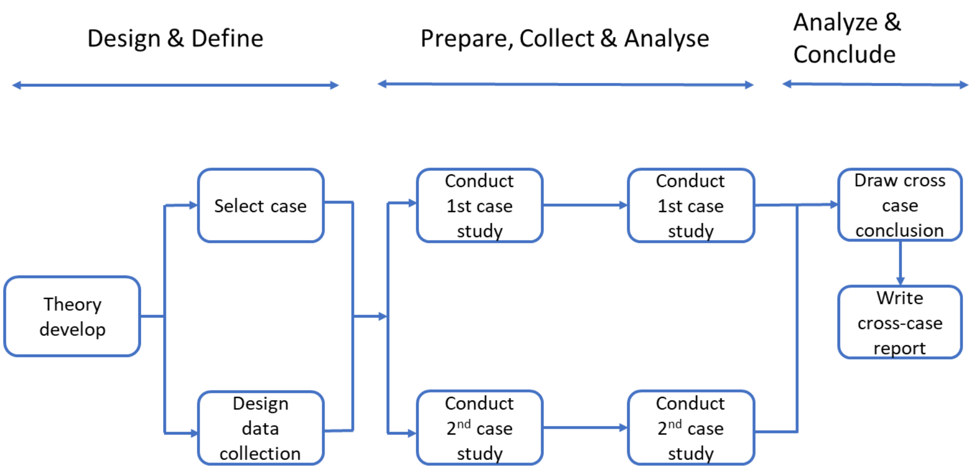


Figure 3.5 The case study method (adopted from Yin, 2009)

The process of conducting case study involves key steps, the figure shows the key steps involved in conducting a case study (Yin, 2009):

Theory Development: Researchers must formulate theoretical propositions or hypotheses that guide the investigation. A framework was established to study the effectiveness of corrugated filler packaging versus molded paper packaging in terms of cost, packaging quality, sustainability, volume, and weight efficiency.

Case Selection: The next step is the selection of cases for the research. Cases should be chosen strategically that are relevant to the research area and provide insights and contribute to the research topic. Chairs and storage packaging were selected for analysis since they were available in both corrugated filler and molded paper packaging.

Definition of Specific Measures: Once cases are selected, researchers define specific measures or variables to collect relevant data. This step ensures that the data collected aligns with the research objectives and theoretical framework. Specific measures or variables were defined to collect relevant data on cost, packaging quality, sustainability, volume, and weight efficiency

Individual Case Study: Each individual case study constitutes a "whole" study in itself. Researchers look for convergent evidence to support or refute the theoretical propositions within each case. Each individual case study focused on evaluating and comparing the packaging of chairs and storage units using both corrugated filler and molded paper packaging.

Replication of Conclusions: The conclusions drawn from each individual case serve as the information to be replicated by other cases. Researchers compare findings across cases to identify patterns or variations. Conclusions were drawn from cross-cases comparisons to identify trends and patterns.

Summary Report: Both individual cases and the collective results of multiple cases were included in the report. For each individual case, the results were discussed and across cases, the report highlights the replication of conclusions and discusses reasons for differences.

3.3 Data Collection

The data collection process was designed to gather both qualitative and quantitative data, ensuring a thorough exploration of the subject matter. The data collection approach used in this study was a combination of interviews, observation, and documentation, that allows for a complete exploration of the packaging systems and facilitates analysis and decision-making.

Interviews:

1. Company Manager: An interview was conducted with the manager at the company to gain insights into the organization's operations, requirements, and expectations regarding the thesis.

2. Packaging Engineer: Another interview was conducted with a packaging engineer to understand the workings of packaging design, materials, and considerations.

3. Production Engineer: Interviews were conducted with production engineers to gather supplier data related to packaging, including cost, dimensions, weight of packaging components, logistics data, and packing time.

4. Quality Engineer: Interview was conducted with quality engineer to gain information on the monitoring of packaging quality and insights into any quality issues associated with each type of packaging.

5. Sustainability Team and University Supervisor: Interviews were also conducted with the sustainability team at the company and the university supervisor to understand sustainability practices and gather data on carbon emissions for packaging materials.

A formal approach with a structured questionnaire was used for the interview conducted with the Production Engineer. The use of structured questionnaires made it easier to ask the same questions to multiple suppliers and also helped to gather specific information. The detailed interview questions with production engineers can be found in Appendix C. On the other hand, the Company Manager, Packaging Engineer, Quality Engineer, and Sustainability Team were interviewed in a less structured manner. This approach was more open and allowed for deeper discussions of various aspects of packaging materials, processes, and sustainability initiatives. The relaxed and conversational tone of these interviews allowed participants to give detailed answers and express their personal views and experiences.

Observation and Documentation:

1. Observation: Another way of data collection involved observing the packaging through unboxing processes and capturing pictures to document the physical properties and characteristics of the packaging materials.

2. System Drawings: Drawings from the system were collected to gain a better understanding of the packaging process and logistics involved, facilitating in the analysis of packaging efficiency and logistics performance.

3.4 Data Analysis

The data analysis phase of this study was instrumental in examining and interpreting the collected data related to packaging solutions, encompassing volume efficiency, weight analysis, packing time, cost implications, product quality, and sustainability considerations. The data analysis involved a systematic approach, integrating both quantitative and qualitative data to derive meaningful insights.

Comparative Analysis

A comparative analysis was conducted to identify patterns and trends between corrugated filler and molded paper packaging solutions. Comparisons were made within each product category (Product 1 and Product 2) and across different suppliers to determine any consistent patterns or supplier-specific variations. By dividing the analysis into specific areas allows covering all the necessary aspects of packaging solutions. It also assists in making decisions that are not only based on a single aspect but a broad perspective of all important factors. The structured figure 3.6 makes it easy to understand the various categories in which the analysis is done. Comparing data between different suppliers allows for identifying differences between suppliers. This can lead to more efficient supplier selection and negotiation practices to ensure the most cost-effective packaging solutions are used. This structured analysis provides deep insights that facilitate decision-making and assist in enhancing packaging solutions in terms of cost, quality, operations, and sustainability.

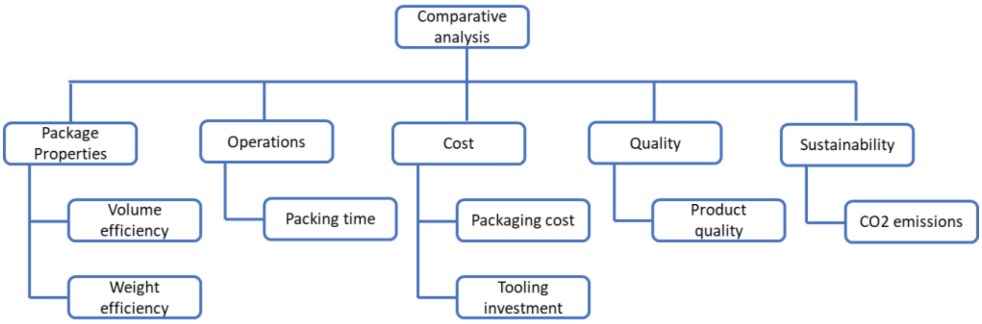


Figure 3.6 Comparative analysis structure

Volume Efficiency Analysis

The percentage change in volume efficiency between corrugated and molded paper packaging solutions was calculated for each product and supplier. The percentage change formula [(New Volume - Old Volume) / Old Volume * 100] was applied to determine the change in volume efficiency.

Weight Efficiency Analysis

Similarly, the percentage change in weight efficiency between corrugated and molded paper packaging solutions was calculated for each product and supplier. The percentage change formula [(New Weight - Old Weight) / Old Weight * 100] was utilized to determine the change in weight efficiency.

Packing Time Efficiency Analysis

The percentage change in packing time efficiency between corrugated and molded paper packaging solutions was calculated for each product and supplier. The percentage change formula [(New Packing Time - Old Packing Time) / Old Packing Time * 100] was applied to determine the change in packing time efficiency. Variations in packing time efficiency between packaging solutions for the same suppliers were analyzed to identify factors influencing packing time.

Cost Efficiency Analysis

The percentage change in cost efficiency between corrugated and molded paper packaging solutions was calculated for each product and supplier. The percentage change formula [(New Cost - Old Cost) / Old Cost * 100] was applied to determine the change in cost efficiency. For the purpose of data confidentiality of the company, the values used in the thesis are extrapolated by a factor.

Investment Cost Analysis

Investment costs associated with tooling for each packaging solution were analyzed and compared across suppliers and products.

Quality Defect Analysis

The percentage of quality defects for each packaging solution (Molded and Corrugated) was calculated for each year. The percentage of quality defects was determined using the following formula:

Percentage of quality defects = Number of quality defects / Total sales * 100

The quality defect percentages were then compared between the Molded and Corrugated solutions to assess their performance over the three-year period. Trends in the quality defect percentages for both packaging solutions were analyzed to identify any patterns over the three-year period.

CO2 Emissions

The CO2 emissions per unit for corrugated paper and molded paper were compared to assess their sustainability impact. Data from different sources, including research literature and industry sources, were analyzed to identify variations in emission factors. CO2 emissions for both types of paper materials were presented to highlight differences in their environmental footprint.

3.5 Research Quality

Ensuring the quality of data is critical in any research study, as it supports the credibility and reliability of the study's findings. The quality of the data that is collected needs to be as high as possible, and therefore the entire research process has to be planned with the quality aspect in mind before conducting the study. This section, we discuss the measures undertaken to enhance the validity of the data collected (Yin, 2009).

Internal Validity:

1. Triangulation: To support internal validity, we used triangulation by utilizing multiple researchers, sources of information, and methods to ensure a well-rounded perspective on the subject matter. This approach helped mitigate the risk of bias and ensure the robustness of our findings.

2. Control of Participants: Participants who provided information were given the opportunity to review and confirm data and improve mutual understanding. This ensured that the data accurately represented the perspectives of the participants.

External Validity:

1. Diverse Participants: To enhance external validity, diverse participants were selected, including multiple suppliers for the same product. This approach ensured that the findings could be generalized within the case study of the same product.

2. Comparative Analyses: Comparative analyses were conducted across multiple cases to assess generalizability of the findings. By studying variations across different cases, we aimed to strengthen the validity and applicability of our conclusions.

3. Replication Logic: The use of multiple case studies allowed the testing of theories. This was done by replicating the findings from one case study in another similar case study. This allowed us to provide strong support for the generalizability of our findings and contribute to the cumulative knowledge in the field.

4 Case Study at IKEA

4.1 About IKEA

IKEA was founded by Ingvar Kamprad in Småland, Sweden in the year 1943. The company was named after his initials (I.K), the farm he lived on (E.) and the parish he came from(A): Ingvar Kamprad Elmtaryd Agunnaryd.The trading company IKEA was registered on the 28th of July, 1943. In his early years as an entrepreneur, Ingvar Kamprad imported pens, watches and nylon stockings (IKEA, n.d.). The starting point of IKEA has always been curiosity about people's lives, needs, and dreams at home. IKEA has a unique heritage of 80 years of innovations, iconic products, solutions, and commitments to people and the planet. The brand is now represented in 62 markets with 462 IKEA touchpoints, 700 million physical customer visits, 2.6 billion online visits, and more than 20 million IKEA app downloads. The first IKEA store was opened in Älmhult, Sweden (IKEA, n.d.) The company's vision is to "to create a better everyday life for the many people" (IKEA, 2022).

4.1.1 The birth of Flat Packs in IKEA

IKEA flat packs have revolutionized furniture-making and home furnishing history. Today, most IKEA products come in flat packs that customers can easily transport everywhere.

Figure 4.1 Packing of parts inside the corrugated box (IKEA, 2023)

Gillis Lundgren is one of the people that made IKEA the brand it is today. He designed the BILLY bookcase as well as the IKEA logo. One of the many contributions of Lundgren in the organization started when he was tasked to deliver a table to a photo studio to be shot for the IKEA catalog. His car couldn't fit the table, so he thought to himself, "Why not take off the legs?" That little idea sparked big dreams not only for Lundgren but for all of IKEA. While Lundgren is not the inventor of flat-pack furniture, he's the person responsible for popularizing the idea. He revolutionized the industry by applying it on the IKEA range, advocating for the low-cost and convenient way of making furniture. Flatpacks have since become the cornerstone of the IKEA business model, influencing later designs.(IKEA, 2023)

The effects of IKEA flatpacks

Flatpacks are some of the reasons behind IKEA's global growth. Since the use of this idea, prices of furniture from the range have reached an all-time low in the industry. This also allowed more stocks to be stored in every store. Ease of transport is just another effect, conveniently moving products not only by the consumer but in bulk in between stores. Lastly, IKEA flatpacks encouraged designers to take the challenge of creating functional products that are also clean and minimalist.

Figure 4.2 showing IKEA flat packs

4.1.2 IKEA Organization

The IKEA retail business is operated through a franchise system with franchisees that are authorized to market and sell the IKEA product range within specified geographical territories. Inter IKEA Systems B.V. is the owner of the IKEA Concept and worldwide IKEA franchisor, who also assigns different IKEA companies to develop the product range, supply products and deliver communication solutions. Today, 12 different groups of companies have the right to own and operate IKEA sales channels under franchise agreements with Inter IKEA Systems B.V.

Inter IKEA Group includes Inter IKEA Systems B.V., IKEA of Sweden AB, IKEA Supply AG and IKEA Industry AB related businesses. Inter IKEA Holding B.V. is the holding company for the Inter IKEA Group (IKEA, n.d..)

IKEA of Sweden

IKEA of Sweden (IoS) is a part of the IKEA group located in Älmhult in Sweden. IoS is responsible for product development activities and is divided into different Range Areas each responsible for product development, packaging development and planning of a certain range of products.

4.1.3 Democratic Design

Democratic Design is at the core of each IKEA product. Democratic Design is IKEA's approach for designing, developing and evaluating IKEA home furnishing products to ensure that they integrate good function, beautiful form and long-lasting quality, while also securing sustainability and low prices. At IKEA, the development of a product goes through various phases, and one of the ways of identifying whether a product suits the range is with Democratic Design. It has five different dimensions—function, form, quality, sustainability, and low price. For IKEA, the design is considered to be democratic when there is balance between all the five dimensions.

Form	Beautiful products that people love
Function	Meaningful solutions to everyday needs

Quality	Products that last for long-term enjoyment
Sustainability	Products created with consideration to the boundaries of the planet
Low price	Truly affordable for the many people

The form is for beauty, it’s what attracts the eye, and the object has to be functional, otherwise it won’t be used. When objects and materials last over time, that’s quality. Being mindful of resources is something that has been with them since the start. IKEA doesn't like complicated solutions and wastefulness, as they consider it bad for everyone. Part of sustainability is about using exactly the right materials for the function, and using them sparingly, but sustainability also means taking responsibility all the way through a product’s life. It starts with how IKEA source materials, to the people who produce the product, all the way through to their clients.”(IKEA, n.d.)

Figure 4.3 Democratic design at IKEA (Adapted from IKEA internal)

4.2 Case study 1: Chair

4.2.1 Packaging of chair with Molded Paper

The primary packaging for the chair is a corrugated box that contains all the components of the chair. The molded paper fillers are placed on top and bottom to provide support and stability for the product components during their journey throughout the supply chain. These molded papers act as protective barriers, preventing the individual parts from shifting or colliding with each other, also absorbing shock due to external factors during transit. The product parts included in the packaging are backrest, seat, star base, gas cylinder, armrest, castors, Each component is positioned in a way that allows the molded paper cushions to support it on either side, minimizing the risk of movement and potential damage.

In addition to the molded paper inserts, a corrugated box is used to accommodate the fittings like screws, Allen keys etc. Also, a special corrugated insert (filler H) is used to restrict the parts movement inside the package and also to prevent the star base from damaging the seat. One of the drawbacks associated with using molded paper is generation of dust due to friction which settles on to the product. Since metal components are prone to scratches & dust accumulation, some metal parts are protected using plastic for scratches and dust. IKEA workspaces team is working on eliminating the use of plastic from its packaging as a part of their sustainability agenda. The corrugated box is then sealed with the help of a tape. The packaging process follows a specific, sequential order, as shown in the labeled figures 4.4 from a through f.

(a) (b) (c.)

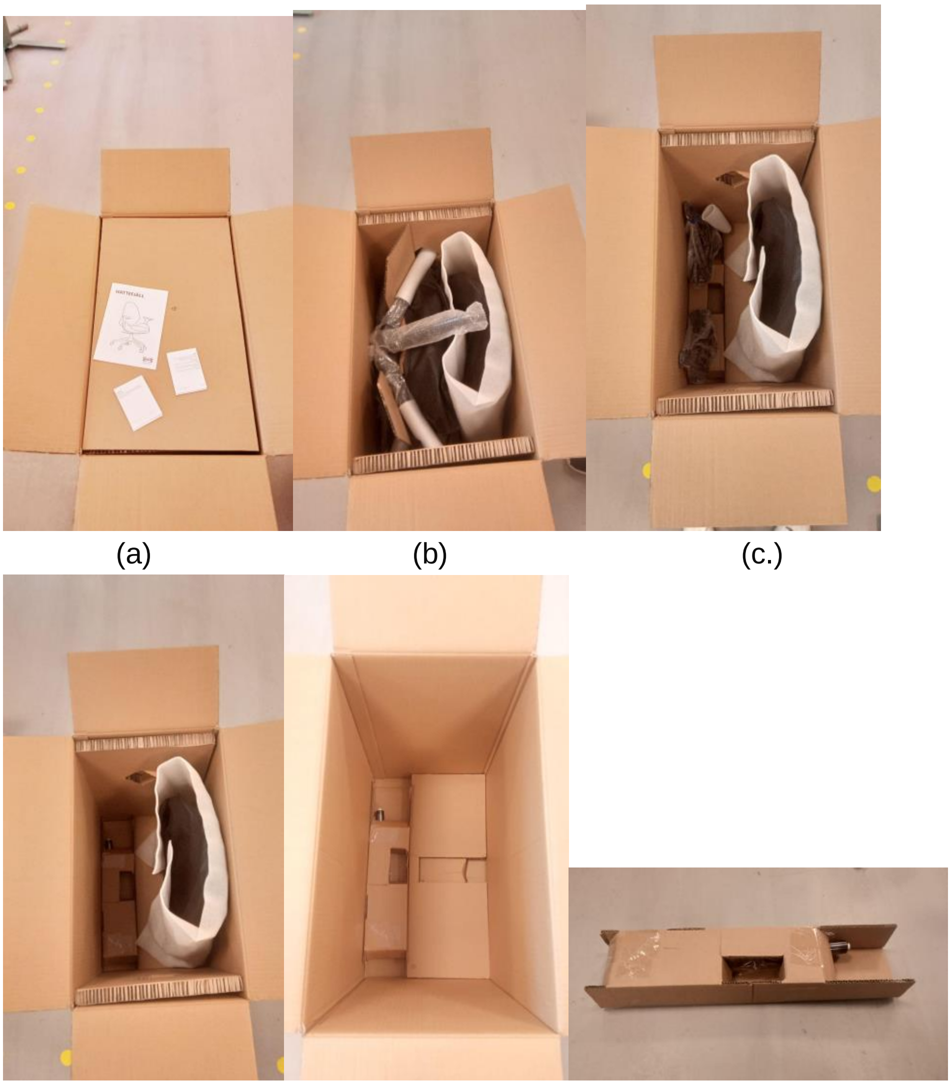
(d) (e) (f)

Figure 4.4 (a to f): Molded paper packaging solution for Chair

This ready package is termed as ‘Consumer Pack’ within IKEA. Many such consumer packages are placed on the paper pallet - which together is termed as ‘Unit Load’. The Unit Load is stretched wrapped for unitization with the help of plastic stretch film. Corner protectors are also used in the Unit Load to facilitate easy unitization & stacking. These Unit Loads are then loaded in a container and sent to the IKEA distribution centers or directly to retail stores.

4.2.2 Packaging of chair with Corrugated Fillers

The primary packaging for the corrugated filler solution is the same as used for molded paper, a double walled corrugated box. The components to be packed in the box are also the same, consisting of backrest, seat, gas cylinder, castors, star base and armrest. In this packaging solution, six different types of fillers are used of different dimensions and board thickness. These fillers are strategically placed in the box so as to restrict the parts movement inside the box and protect the parts from damage during the transit. In order to prevent the protect the seat & backrest from damage & also metal parts from scratches, plastic material is used to provide protection. Once all the parts are placed inside the package, a corrugated sheet is placed on top of all the parts along with Assembly instructions before sealing the box with the tape. The packaging process follows a specific, sequential order, as shown in the labeled figures 4.5 from a through f. These consumer packs are then placed on paper pallets to form a Unit load, and then sent to the distribution centers or stores.



(a) (b) (c.)

(d) (e) (f)

Figure 4.5 (a to f) : Corrugated filler packaging solution for Chair

4.3 Case study 2: Storage cabinet

4.3.1 Packaging of Storage Cabinet with Molded Paper

The primary packaging is a double walled corrugated box that contains all the parts and accessories. Inside the box, two molded paper are strategically placed on either side to provide support and stability for the product components. These molded papers act as protective barriers, preventing the individual parts from shifting or colliding with each other during transit.

The product parts included in the packaging are the top, bottom, left, right, and back panels, as well as the left and right doors, two shelves, and two legs. They are arranged neatly within the box. Each component is positioned in a way that allows the molded paper cushions to support it on both sides, minimizing the risk of movement and potential damage.

In addition to the molded paper inserts, soft paper spacers are placed between the product parts. These act as additional cushioning, creating barriers to prevent friction and scratches between the components. This ensures that the parts remain in perfect condition throughout the storage and transportation process.The packaging process follows a specific, sequential order, as shown in the labeled figures 4.6 from a through k.

(a)

(b)

(c.)

(d)

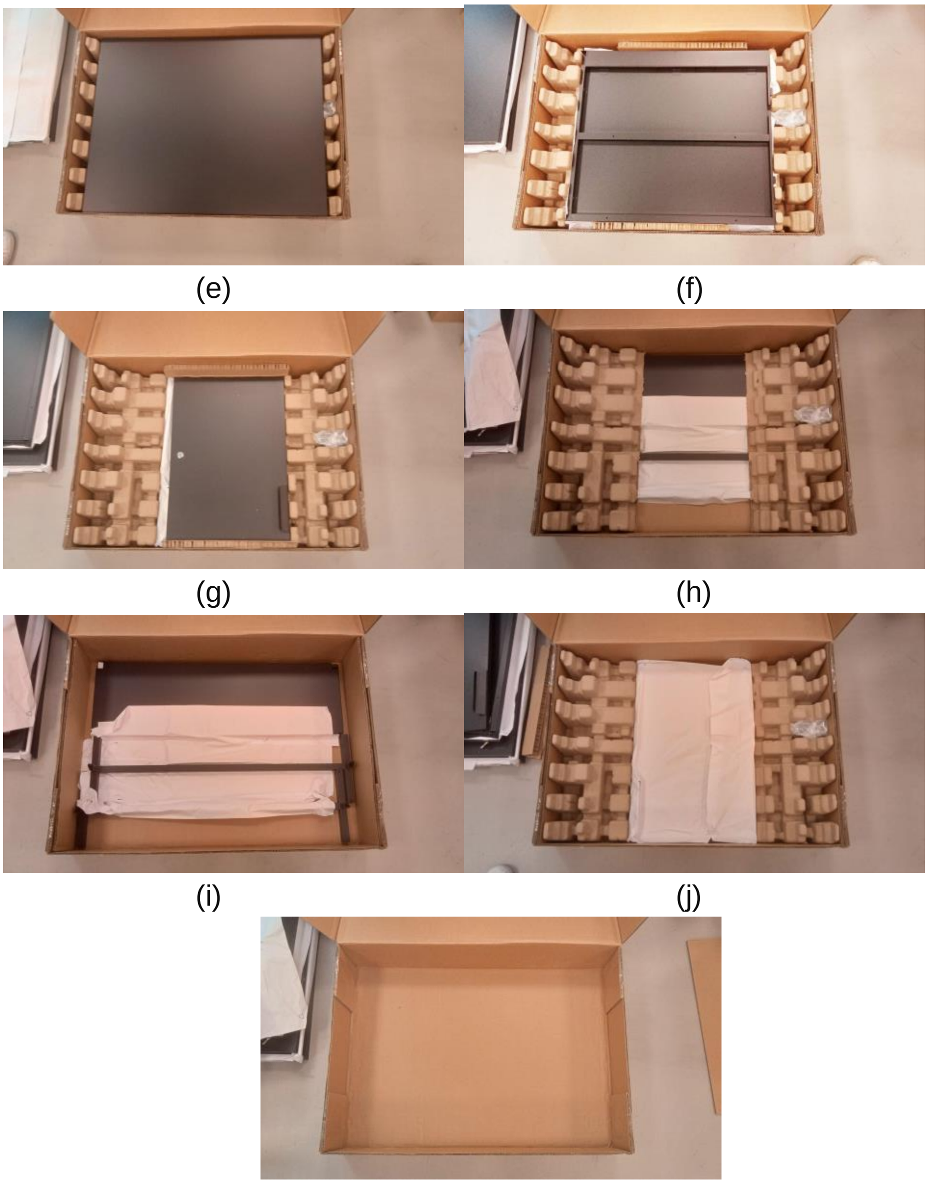


Figure 4.6 (a to k): Molded paper packaging solution for storage unit

4.3.2 Packaging of Storage Cabinet with Corrugated Fillers

A corrugated box is chosen as the primary packaging for packing the storage cabinet. All the product parts along with the packaging are placed inside the primary container. The product parts include panels (top, bottom, left, right, back), left and right doors, two shelves, and two legs, which are carefully arranged inside the corrugated box. Each component is positioned strategically to optimize space utilization. Soft paper inserts are placed between the product parts to provide an additional layer of protection. These inserts serve to cushion the components and prevent friction, reducing the risk of scratches or damage during handling.

Sixteen different types of fillers, with various dimensions, are selected to pack the product parts effectively. These fillers are strategically placed within the box to provide support to the flat components and prevent bending. By filling the gaps and voids, the fillers help restrict movement and ensure the stability of the packaged items. The packaging process follows a sequential order, as depicted in the labeled Figure 4.7 from a to m.


(a)

(b)


(c.)


(d)


(e)


(f)

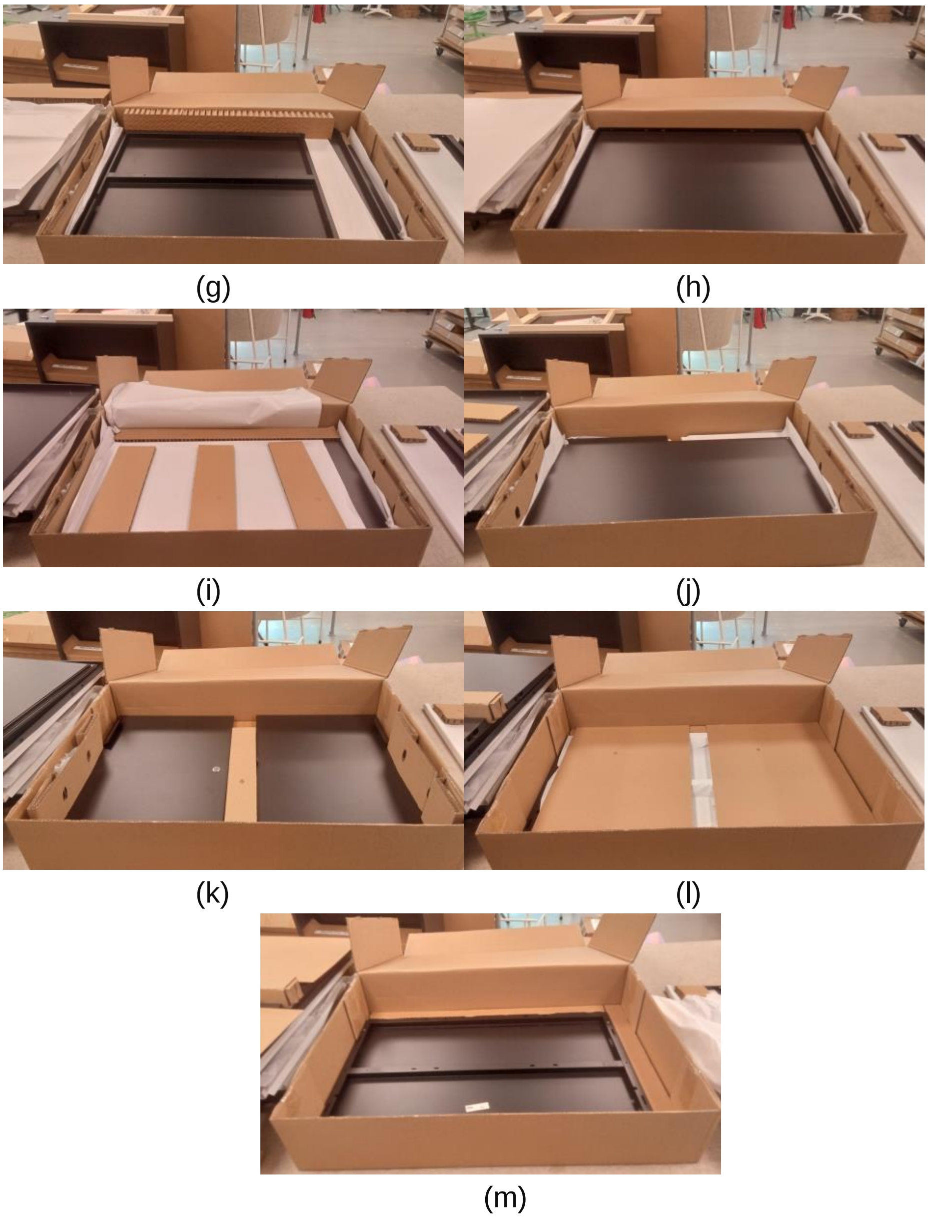


Figure 4.7 (a to m): Corrugated filler packaging solution for storage unit

5 Results & Discussions

5.1 Utilization of Fillers & Molded paper at IKEA Workspaces

The research conducted within IKEA workspaces department revealed that corrugated filler packaging was used on a greater extent than molded paper packaging. Proportionally, out of the total number of packages analyzed, corrugated filler packaging was used in 81.5% of the total, whereas molded paper packaging was utilized only in 18.5% of total. This suggests that corrugated filler packaging is the main type of packaging used in the IKEA workspaces in comparison to molded paper packaging.

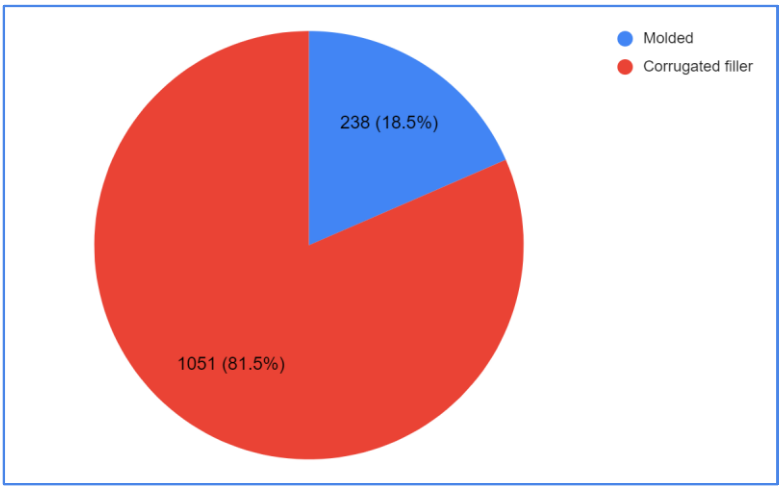


Figure 5.1 Utilization level of fillers and molded paper in IKEA packaging

5.2 Overview of Findings

Overall, the comparison between molded paper and corrugated fillers in packaging solutions reveals important information about their respective characteristics and performance across various parameters which was selected based on the Democratic design used by IKEA. In terms of packaging volume and weight, the results may vary depending on the specific product, supplier, and packaging design. However, molded paper packaging often shows advantages in weight reduction, potentially leading to cost savings and improved transportation efficiency. The data shows consistent efficiency gains in packing time when using molded paper packaging across different suppliers and products. This reduction in packing time can lead to improved operational productivity and throughput within the supply chain. Molded paper packaging demonstrates significant cost savings compared to corrugated fillers in certain scenarios. Across various products and suppliers, molded paper consistently shows lower material costs, contributing to potential overall cost reductions in packaging. However, tooling cost for molded paper is significant and can be more expensive than corrugated fillers. The cost is usually amortized over a certain period of time.

Quality analysis suggests that molded paper packaging may offer more consistent quality performance compared to corrugated fillers. While both solutions may experience fluctuations in quality defect percentages, molded paper generally maintains a lower defect rate, potentially leading to higher customer satisfaction and retention rates. In terms of sustainability, molded paper generally exhibits lower CO2 emissions compared to corrugated fillers. This indicates a potential environmental advantage for molded paper packaging, contributing to reduced carbon footprint. From a material perspective, both molded paper and corrugated fillers are made of paper and are easily recyclable. This means that both packaging materials offer similar end-of-life disposal options, aligning with circular economy principles and waste reduction efforts.

Figure 5.2 Overview of findings

A radar chart was created showing an overview of findings and the interaction between the parameters (figure 5.2). The weightage for the parameters is an assumption. However, this weightage will differ from company to company based on the company's vision, goals and priorities. The radar chart represents the better performing parameters with higher points while the lower performing parameters with lower points. The parameters were given points between 1-3, with 1 point given to a low performing solution and 3 points to a better performing packaging solution. 2 points were given when both the solutions performed equally for a parameter.

5.3 Case Findings

5.3.1 Package Properties

Packaging Volume Findings

An efficient packaging not only considers dimensions and weight, but also volume, as it directly impacts storage space utilization and transportation logistics. The formula for calculating volume of a pack is given in Appendix B. In our study comparing volume efficiency between corrugated filler and molded paper packaging solutions, we observed variations across different products and suppliers.

Table 5.1 Findings of Volume efficiency for Product 1

Volume (dm3)	Supplier A		% Change	Supplier B		% Change
	Corrugated	Molded		Corrugated	Molded	
Product 1	165,37	166,1	0,44	158,28	162,94	2,94

Table 5.2 Findings of Volume efficiency for Product 1

Volume (dm3)	Supplier C		% Change	Supplier D		% Change
	Corrugated	Molded		Corrugated	Molded	
Product 2	95,2	94,18	-1,07	NA	NA	NA

For Product 1, molded paper packaging showed a slight increase in volume compared to corrugated packaging, with a 0.44% change, whereas Supplier B reported a more substantial increase in volume efficiency for molded paper packaging, with a 2.94% change compared to corrugated packaging. However, for Product 2, in the case for both suppliers, exhibited a decrease in volume efficiency when using molded paper packaging compared to corrugated packaging. Supplier C reported a 1.07% decrease, while Supplier D did not provide volume data for Product 2.

Packaging Weight Findings

The weight of packaging materials plays a significant role in determining efficiency and cost-effectiveness within the supply chain. In our study comparing corrugated filler packaging with molded paper packaging, several observations were made regarding weight variations across different products and suppliers.

Table 5.3 Findings of Weight efficiency for Product 1

Weight (Kgs)	Supplier A		% Change	Supplier B		% Change
	Corrugated	Molded		Corrugated	Molded	
Product 1	3,87	3,51	-9,30	4,24	3,65	-13,92

Table 5.4 Findings of Weight efficiency for Product 2

Weight (Kgs)	Supplier C		% Change	Supplier D		% Change
	Corrugated	Molded		Corrugated	Molded	
Product 2	3,26	3,25	-0,3	3,26	3,24	-0,6

For Product 1, on an average, the weight of molded paper packaging was found to be lower compared to corrugated paper packaging solutions . For example, Supplier A reported a weight reduction of 9.30% when using molded paper packaging compared to corrugated packaging for Product 1. Similarly, Supplier B observed a weight reduction of 13.92% for the same product.

Contrary to the average weight comparison, the weight of molded paper solutions for Supplier C and Supplier D was almost similar to corrugated paper solutions for Product 2, showing negligible difference. This negligible difference can be attributed to the inclusion of corrugated fillers in the molded paper solution to protect the top component from denting due to its hollow surface.

Container Loadability

As there was no big difference in the dimensions and volume of the consumer pack, the number of consumer packs per pallet & the number of pallets loaded in the container remained the same for both the respective solutions for the Chair & Storage cabinet product.

5.3.2 Packing Time Findings

Efficiency in packing time is crucial for optimizing operational processes within the supply chain. Our study examined the packing time required for two products, sourced from different suppliers, using corrugated filler and molded paper packaging solutions.

Table 5.5 Findings of Packing time for Product 1

Packing time (s)	Supplier A		% Change	Supplier B		% Change
	Corrugated	Molded		Corrugated	Molded	
Product 1	360	300	-16.67	349	315	-9.74

Table 5.6 Findings of Packing time for Product 2

Packing time (s)	Supplier C		% Change	Supplier D		% Change
	Corrugated	Molded		Corrugated	Molded	
Product 2	NA	NA	NA	240	180	-25

For Product 1, Supplier A showed using molded paper packaging resulted in a 16.67% decrease in packing time compared to corrugated packaging. Similarly, Supplier B reported a 9.74% decrease in packing time for molded paper packaging compared to corrugated packaging. For Product 2, Supplier D reported a significant 25% decrease in packing time when using molded paper packaging compared to corrugated packaging. However, Supplier C did not provide data for packing time efficiency for Product 2.

5.3.3 Cost Findings

Packaging cost Findings

Cost efficiency is a critical consideration in packaging solutions, influencing overall operational expenses and profitability. Our study evaluated the cost implications of utilizing corrugated filler and molded paper packaging solutions for two products, sourced from different suppliers. To maintain the cost confidentiality, we have extrapolated all the material and investment actual cost by a certain factor.

For Product 1, in the case of supplier A, the cost of utilizing molded paper in packaging was 16.97% lower compared to corrugated packaging, representing a significant cost-saving opportunity in terms of packaging material cost. Similar cost-saving trends were observed at Supplier B, with molded paper packaging resulting in a 26.71% decrease in costs compared to corrugated packaging.

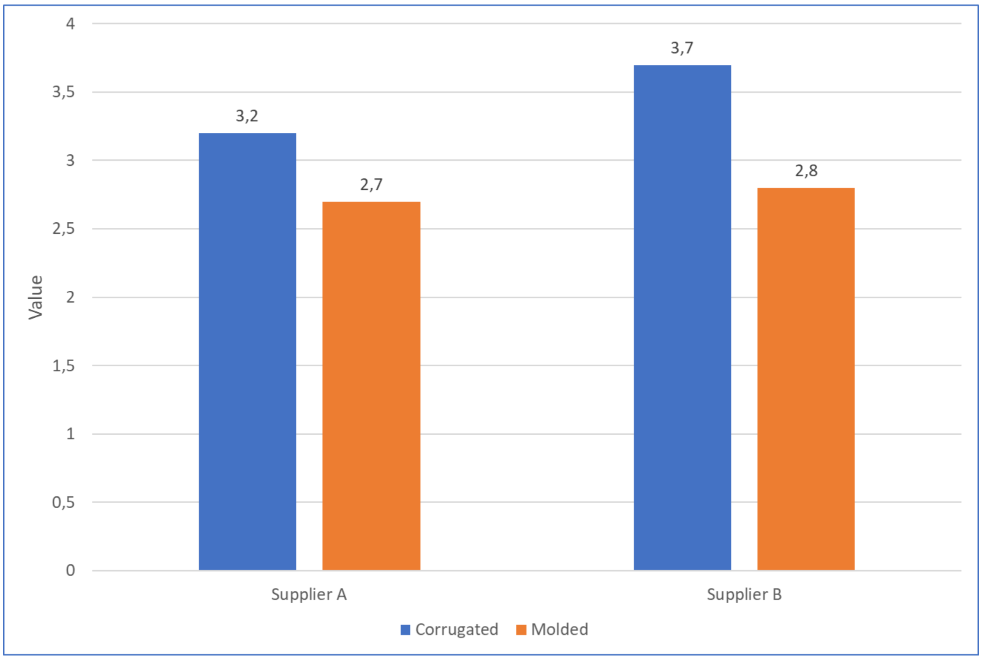


Figure 5.3 Packaging cost comparison between two suppliers for Product 1

For Product 2, Supplier C reported a 14.65% decrease in costs when utilizing molded paper packaging compared to corrugated packaging, showing a similar trend as observed in Product 1. However, for Supplier D, the cost of molded paper packaging was notably higher, with a 55% increase compared to corrugated packaging.

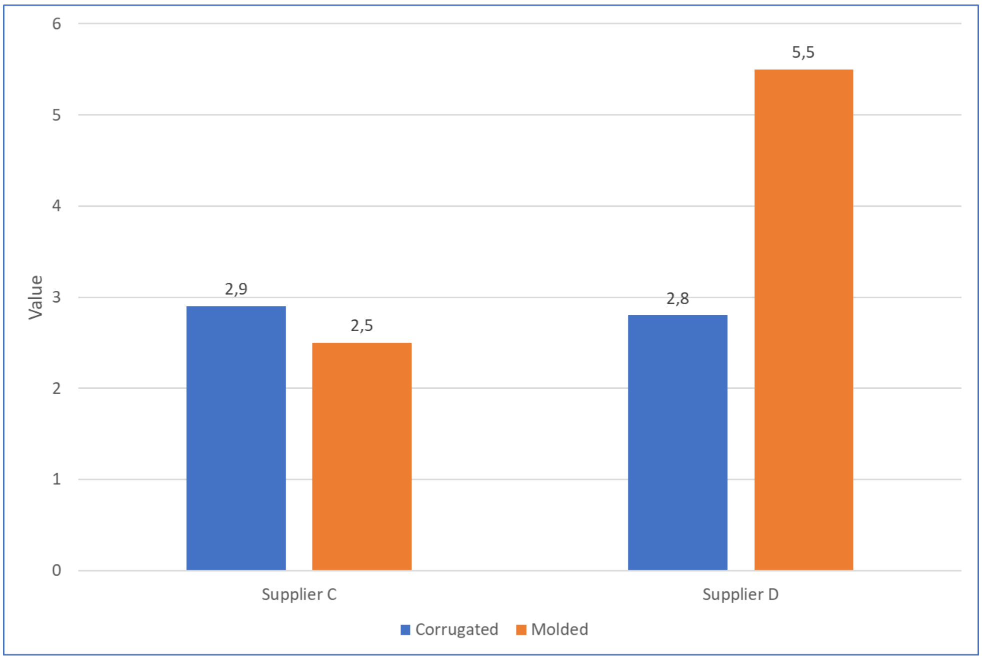


Figure 5.4 Packaging cost comparison between two suppliers for Product 2

Tooling Investment Cost Findings

Tooling investment costs play a crucial role in determining the feasibility and long-term viability of packaging solutions. This section provides a comparative analysis of the investment costs associated with corrugated and molded packaging solutions offered by respective suppliers, for Product 1 and Product 2.

Supplier A offers a molded packaging solution for Product 1, incurring an investment cost of value 1600. Meanwhile, Supplier B provides a molded packaging solution at a slightly higher investment cost of value 2000. No investment cost is incurred for the corrugated filler packaging solutions for both the suppliers.

Table 5.7 Tooling investment cost for Product 1

Investment	Supplier A		Supplier B	
	Corrugated	Molded	Corrugated	Molded
Product 1	0	1600	0	2000

Table 5.8 Tooling investment cost for Product 2

Investment	Supplier C		Supplier D	
	Corrugated	Molded	Corrugated	Molded
Product 2	0	2500	5100	12500

For Product 2, supplier C presents a molded packaging solution requiring an investment of value 2500, whereas supplier D shows a notable increase in tooling costs of value 12500. This tremendous increase in tooling cost can be attributed to factors such as material availability in the geography. Supplier D also had some investments for corrugated fillers as well. The tooling cost for supplier D are amortized in the per part cost and depreciated over time, whereas the tooling cost for all other suppliers are paid up-front.

5.3.4 Product Quality Findings

The quality data is obtained with the help of claims reported by the stores. The quality defects can be related to product, packaging, and other processes. These defects can occur either during receiving the product at/in store or when the customer returns the product back to the store. Quality issues reported against packaging are divided into five categories, namely defects due to handling damage, packaging & product damage, unsuitable handling aid, unsuitable packaging and damage by customer.

Customer Returns due to ‘packaging & product are damaged’ are used when a product has been damaged during delivery to a customer, either by IKEA or by another Service Partner. Customer Returns due to ‘product being damaged during handling/delivery’ are used when a product or package has been damaged by IKEA or a customer. Internal Damages in Store due to ‘unsuitable packaging’ is used when goods are damaged in the store. Poor packaging increases the risk that goods are damaged. Internal Damages in Store due to ’unsuitable handling aid’ is used when goods are damaged in the store. Unsuitable handling aids increase the risk that goods are damaged. It’s also important to educate staff, forklift drivers etc, about how to handle goods in order to keep the damages down. Internal Damages in Store due to ‘damage by a Customer’ is used when goods are damaged by customers in the store. Examples are ripped up packaging, unpacked/assembled products and misplaced products that have been damaged in the process.

Quality data for Product 1:

In 2022, no quality defects data was available for Molded solution, however, in 2023, the number of quality defects increased to 91, with total sales reaching 15,186 units. This led to a quality defect percentage of 0.60% for that year. By 2024, the number of quality defects further increased to 232, with sales totaling 37,475 units. Consequently, the quality defect percentage slightly increased to 0.62% for that year.

Table 5.9 Quality data for Product 1 with Molded paper packaging

Year	Quality defects	Sales (Pcs.)	% Quality Defects
2022	0	0	0
2023	91	15186	0.60
2024	232	37475	0.62
Grand Total	323	52661	0.61

In contrast, the Corrugated solution showed quality defects 73 reported quality defects, with sales amounting to 10,950 units, resulting in a quality defect percentage of 0.67% for the year 2022. The number of quality defects increased to 102 in 2023, with sales reaching 16,188 units. However, the quality defect percentage decreased slightly to 0.63%. By 2024, the number of quality defects decreased to 32, with sales totaling 4,657 units. Despite the reduction in defects, the quality defect percentage rose to 0.69% for that year.

Table 5.10 Quality data for Product 1 with Corrugated Filler packaging

Year	Quality Defects	Sales (Pcs.)	% Quality Defects
2022	73	10950	0.67
2023	102	16188	0.63
2024	32	4657	0.69
Grand Total	207	31795	0.65

Quality data for Product 2:

For molded paper packaging, for In 2022, the data revealed 178 quality defects out of 34,104 units sold, resulting in a defect rate of 0.52%. In 2023, the defect rate improved to 0.45%, with 170 defects out of 38,137 units sold. The most significant improvement occurred in 2024, with the defect rate dropping to 0.30%, based on 64 defects out of 21,630 units sold. Overall, the total for the three years indicates 412 quality defects out of 93,871 units sold, leading to an average defect rate of 0.44%. This trend shows a steady improvement in the quality performance of Product 2 with molded paper packaging, as shown below in table 5.11.

Table 5.11 Quality data for Product 2 with Molded paper packaging

Year	Quality defects	Sales (Pcs)	% Quality defects
2022	178	34104	0.52
2023	170	38137	0.45
2024	64	21630	0.30
Grand Total	412	93871	0.44

On the other hand, for corrugated paper packaging, In 2022, there were 349 quality defects reported out of 33,928 units sold, resulting in a defect rate of 1.03%. The following year, 2023, saw a slight increase in the defect rate to 1.06%, with 324 defects out of 30,499 units sold. However, in 2024, the defect rate significantly improved to 0.64%, with only 104 defects out of 16,183 units sold. Overall, the grand total for the three years shows 777 quality defects out of 80,610 units sold, yielding an average defect rate of 0.96%. This data indicates an overall improvement in the quality performance of Product 2 with corrugated filler packaging over the observed period. (See Table 5.12)

Table 5.12 Quality data for Product 2 with Corrugated paper packaging

Year	Quality defects	Sales (Pcs)	% Quality defects
2022	349	33928	1.03
2023	324	30499	1.06
2024	104	16183	0.64
Grand Total	777	80610	0.96

5.3.5 CO2 emission Findings

From a material perspective, both corrugated fillers and molded paper are made up of paper and can be easily recycled again with recycling capabilities available throughout the globe. However, the two packing materials can differ in terms of CO2 emitted during the production, transport The analysis of carbon dioxide (CO2) emissions associated with the production of paper packaging materials reveals significant variations depending on the type of paper used. The following results summarize the findings:

Corrugated Paper

The average CO_2 emissions associated with the production of corrugated paper are approximately 1.01 kg CO_2 eq per unit. This value is based on data obtained from research literature, reflecting the emissions generated throughout the manufacturing process. An alternative source provides a slightly higher average CO_2 emission value of 1.14 kg CO_2 eq per unit for corrugated paper. The corroborates the emissions data obtained from previous research literature, further emphasizing the carbon footprint associated with corrugated paper production.

Molded Paper

Molded paper demonstrates comparatively lower CO_2 emissions, with an average of 0.85 kg CO_2 eq per unit. This value is obtained from IKEA, indicating the emissions attributed to the production of molded paper packaging materials used in their supply chain. Dry molded paper exhibits a higher CO_2 emission rate, with an average of 1.5 kg CO_2 eq per unit. Wet molded paper demonstrates relatively lower CO_2 emissions compared to dry molded paper, with an average of 1.1 kg CO_2 eq per unit. This data was sourced from research conducted in China.

The data regarding carbon dioxide (CO_2) emissions associated with the production of paper packaging materials exhibits inconsistencies across different sources. While some values are derived from research literature, others are obtained directly from industry sources like IKEA. These disparities suggest variations in methodologies, geographical locations, and production processes among the sources.

5.4 Discussions

When it comes to selecting the best packaging solution, there are many factors that have to be taken into consideration and these factors are often correlated and may depend on each other. For instance, package properties like weight and volume density are not only vital in minimizing the cost of transportation but also in the achieving of sustainability goals. This is because using lightweight materials will reduce the costs of shipping as well as the amount of fuel used and emissions produced. However, there are some factors which should be considered including the quality of the product and defects which may lead to extra costs and losses. Furthermore, the environmental factor of the packaging, including the carbon footprint and the recyclable nature of the packaging, is also linked to the cost and quality of the packaging. Organic and recycled materials and methods may be expensive at the initial stage but they are cheaper in the future because they help in reducing wastage, and enhance the image of the company. Therefore, it also implies that the packing time is also related to cost, environmental concerns, and product quality. Therefore, these dimensions should be considered in order to design packaging strategies and solutions that can be cost effective, productive, ensure product quality and promote sustainability.

5.4.1 Package properties analysis

Volume Efficiency

The volume difference in molded paper packaging and corrugated paper packaging is small and does not affect the pallet and container loadability. Based on the analysis of volume efficiency for molded paper and corrugated filler packaging companies should consider the following strategies:

Supplier Collaboration: Even though it might be small, the differences in volume efficiency between suppliers indicates that collaboration with the suppliers to optimize packaging design can lead to quite a considerable benefit. Collaboration with suppliers on the packaging design and sharing of best practices can help in improving volume efficiency and lessen the overall logistics costs.

Evaluation of Trade-Offs: Although molded paper packaging can be environmentally friendly and cost-effective, companies should do a comparative analysis of these benefits against the possible reduction in volume efficiency. A robust analysis of all the packaging parameters like environmental impacts, cost, durability, and volume efficiency will help in making smarter and more informed decisions.

Weight Efficiency

Based on the analysis of weight efficiency for molded paper and corrugated filler packaging companies should consider the following strategies:

Cost Savings Through Weight Reduction: The weight reduction noticed with molded paper packaging for product 1 shows a possibility of large cut in the transportation costing. Manufacturers should think about fitting molded paper packaging to products where weight efficiency can be up to the maximum, hence, the shipping cost will be reduced and the logistics performance will be improved.

Product-Specific Packaging Design: The difference in weight efficiency between the product and the supplier makes it clear that the packaging solution must be custom designed according to the specific product needs. The packaging designs that are customized to each product based on the specific characteristics of each product can optimize weight efficiency and improve overall performance.

5.4.2 Packing Time Analysis

The analysis of packing time efficiency between molded paper and corrugated filler packaging provides several strategic improvements:

Operational Productivity: The observed high reduction in packing time with molded paper packaging across multiple suppliers shows that there is a clear benefit in terms of operational productivity. Companies may consider to opt for molded paper packaging if possible, to reduce packing time and increase the output.

Cost Savings: A decrease in the packing time can result in lower labor costs as well as higher overall cost efficiency. The time savings can result in reduced overtime expenses and the possibility of processing more volumes without additional labor costs. Companies need to calculate the possible cost savings that are coming from faster packing processes and take this into account when devising their packaging strategy.

5.4.3 Cost Analysis

Packaging Cost Analysis

The results of the study show that, while molded paper packaging can be beneficial by providing cost savings and operational efficiencies, the benefits are not universal and highly dependent on supplier-specific factors. In order to optimize packaging costs, companies should consider the following strategies:

Supplier evaluation: Conduct detailed cost analyses for each supplier to understand the financial aspect of the changeover to molded paper packaging. This should include reviewing the initial investment, material costs and forecasting of long-term savings.

Tailored packaging solutions: Create packaging strategies that are tailored to the various product types, which could be the molded paper or corrugated fillers, along with the supplier capabilities and cost considerations.

Continuous improvement: Conduct continuous monitoring and evaluation of packaging solutions to determine the best areas for cost reduction and efficiency, and make sure that goals are aligned with the overall business objectives.

Tooling investment

The results suggest that the molded packaging options could be cost-effective in the long run, but the initial investment costs are really a major problem for its adoption. To optimize tooling investments and overall packaging costs, companies should consider the following strategies:

Supplier negotiations: Engaging with the suppliers to find out the opportunities of reducing tooling investment costs as through bulk purchasing agreements or long-term contracts that could amortize the initial investments through a longer period.

Local Sourcing: Analyze regional factors, like material availability and economic conditions, that influence tooling costs. Supplier identification in areas with lower tooling costs is a way to obtain useful savings.

Phased implementation: Consider a step-by-step rollout of the packaging solutions by the suppliers or the regions where the costs of the investment are more affordable. This method provides a smooth transition between the old and new systems while monitoring the effect on the overall cost and sustainability objectives.

5.4.4 Product Quality Analysis

The product qualities are compared by determining the defect rates that are linked to the two types of filling materials that are used in the packaging. Since each packaging has only one filling material, the comparison is made based on the defect rates of the packaging that use these materials in order to determine which material has lower defect rates and hence provides better quality products. While both solutions experienced fluctuations in quality defect percentages, the consistent reduction in defect rates over time highlights the effectiveness of molded paper packaging in providing better protection and durability.

Product-Specific Performance: The quality defects observed in both packaging and for both products are relatively low. However, molded paper packaging performs a little better than its corrugated filler packaging counterpart. In addition, the performance of molded paper in product 2 is better than product 1. This suggests that the benefits of molded paper packaging might be more pronounced for certain products, possibly due to differences in product dimensions, weight, or handling requirements.

5.4.5 Sustainability Analysis

The data on CO2 emissions are not consistent across various sources due to differences in the techniques used, the regions covered, and the production systems. For example, IKEA reported lower emissions for molded paper while studies from China reported higher emissions for dry molded paper. These inequalities show the importance of using consistent metrics and reporting methods for comparison purposes.

Some sources indicate that Molded paper packaging generally has lower CO2 emissions than corrugated fillers. The average CO2 emissions for molded paper are around 0. 85 kg CO2 eq per unit compared with 1 kg CO2 eq per unit for corrugated paper. 1 kg CO2 eq per unit. This also shows that molded paper is a better alternative as far as emissions are concerned.

But there are other factors that affect the environmental sustainability of molded paper, such as whether it is dry or wet. Dry molded paper produces more CO2 emissions 1.5 kg CO2 eq per unit than wet molded paper 1.01 kg CO2 eq per unit.

The difference in the production method shows that the means of production is a significant contributor to the carbon footprint of molded paper packaging.

6 Conclusion

6.1 Summary of Findings

The study revealed that corrugated filler packaging was used for 81.5% of the articles, while the molded paper packaging solution was used for almost 18.5%. However, since both types of packaging solutions are used at IKEA, both the types should be considered for evaluation. Therefore, while corrugated filler packaging dominates in terms of usage, molded paper packaging still has a notable presence within IKEA workspaces.

The purpose this master thesis was,

How efficient are molded paper and corrugated filler packaging solutions in supply chain?

The research has provided a comprehensive examination of molded paper and corrugated filler packaging solutions within the context of IKEA's democratic design principles. Through an extensive analysis of various parameters like packaging volume and weight, packing time efficiency, cost implications, quality performance, and sustainability, we have found some important information regarding the performance and implications of these packaging materials across different suppliers and products, which is summarized in Table 6.1

Table 6.1 Overview of the case findings

Parameters	Corrugated Filler	Molded Paper
Volume Efficiency	Parity	Parity
Weight Efficiency	Low	High
Packaging Cost	High	Low
Tooling/Investment Cost	Low	High
Packing Time	High	Low
Quality Defects	High	Low
CO2 Emission factor	High	Low

Molded paper packaging often resulted in weight reduction, potentially leading to cost savings and improved transportation efficiency. While slight variations in volume efficiency were observed across different products and suppliers, molded paper consistently showed lower weights compared to corrugated fillers. In case of packing time, molded paper packaging demonstrated consistent efficiency gains in packing time across various suppliers and products. This reduction in packing time can lead to improved operational productivity and throughput within the supply chain and also result in less labor cost.

Molded paper packaging generally showed significant cost savings compared to corrugated fillers in certain scenarios, primarily due to lower material costs. However, variations in significant tooling investment costs among suppliers shows the importance of cost analysis for informed decision-making. In terms of quality performance, molded paper packaging exhibited more consistent quality performance compared to corrugated fillers, with lower defect rates reported across various suppliers and products. This suggests the potential for higher customer satisfaction and retention rates with molded paper packaging solutions. Molded paper packaging demonstrated lower CO_2 emissions compared to corrugated fillers, aligning with efforts to reduce carbon footprint. Both packaging materials offered recyclability, contributing to waste reduction and circular economy principles. However, the data about carbon emission factors were obtained from multiple sources and showed variations

In summary, our results show that packaging material choice is a complex issue with many aspects affecting the operational efficiency, cost-effectiveness, quality, and sustainability in the supply chain. Based on the findings, IKEA should use molded paper packaging for high-volume products sourced from Asia, where economies of scale can be maximized, and environmental impact minimized. Thus, this strategy should be preferred where IKEA can amortize the tooling investment cost over a period of time. Conversely, corrugated filler solutions can be implemented where the volumes are low and the lead time for the packaging manufacturing is low. However, the study's limitations must be acknowledged. The analysis was limited to only two products, constraining the generalizability of the findings across IKEA's entire product range.

6.2 Research contribution

Our research contributes to the existing knowledge of choosing the right packaging material by highlighting the different aspects that are taken into account. Through a systematic evaluation of the performance of molded paper and corrugated filler packaging for different parameters, the stakeholders were provided with actionable insights, which, in turn, empowers them to make logical and informed decisions.

The study offers a complete overview of packaging solutions, by considering not only traditional metrics such as cost and efficiency but also quality performance and sustainability. This provides a holistic view of packaging material selection and helps to reveal the complexities and the trade-offs that are involved. By examining the performance of packaging solutions across different suppliers and products, the analysis shows that the outcomes vary depending on supplier behaviors, product features, and regional standards. This shows the importance of supplier collaboration and the design of unique packaging for optimal response to diverse customer needs.

From our study, we can help the stakeholders to make strategic decisions, which they can use to align the packaging material choice to the organizational objectives, whether they be cost reduction, operational efficiency improvement, quality enhancement, or sustainability initiatives. Finally, our research serves as a useful tool for all those who take part in a packaging material selection, primarily in the packaging department, but also within the supply chain. The objective can be achieved utilizing the outcomes of this research into packaging decisions thus setting the foundation for reduction of packing costs, improving quality and sustainability.

6.3 Limitations

The first limitation observed in the study was the selection of only two products for the analysis, creating a small sample size, which is an obstacle to the generalization of the comparison between molded paper and corrugated filler packaging solutions in IKEA. While the knowledge derived from the study can be useful for choosing a packaging material for strategic planning, it is possible that by having more products in the analysis, a wider range of product types within the department would have been covered, thus leading to generalizing the findings for the entire product range.

Another limitation was concerning data accuracy from the suppliers, the risk of getting partial or biased information. The suppliers may have their own interests in promoting some materials over others, which could affect the data they provide. Moreover, the supply chains for packing materials are complex and thus, they introduce chances of inaccuracies or errors in data transmission. Factors such as dissimilarities in manufacturing processes, sourcing of raw materials, and regional differences in regulations may be the cause of data inconsistencies.

The study also had a limitation which was a detailed comparison of the two packaging solutions from a sustainability point of view. The carbon emission factors were gathered from several sources and there were some differences in the carbon emission factors available from different sources.

7 Recommendations & Future Research Areas

During the investigations at IKEA we have found various factors which will enable co-workers in IKEA to work in a more efficient way. This chapter will discuss recommendations and areas which should be further researched in order to more exactly determine how efficient are corrugated fillers and molded paper packaging solutions in IKEA workspaces supply chain.

7.1 Recommendations

Based on the findings and insights generated in the study, we would recommend IKEA to explore below possibilities in order to be more efficient while developing and choosing packaging solutions. By implementing these recommendations, IKEA can enhance its competitive advantage, strengthen its commitment to sustainability, and drive positive environmental impact throughout its supply chain.

Utilize Molded Paper Packaging for Suitable Volumes and Asian Sourcing: Molded paper packaging offers several advantages, including its eco-friendly nature, lightweight properties, and versatility in design. The recommendation to use molded paper packaging when volumes are substantial and sourcing is from Asia stems from a strategic perspective. Given that IKEA has a global presence and a well-established supply chain network in Asia, using molded paper packaging for products sourced from that region can bring many advantages. Firstly, utilizing molded paper packaging for high-volume products can drive economies of scale, potentially reducing costs associated with packaging materials, transportation, and tooling investment cost. IKEA's sustainability targets and the company's effort in reducing the negative impact on the environment, which helps in building the company's image. This recommendation emphasizes the importance of aligning packaging choices with regional sourcing strategies to optimize efficiency, sustainability, and cost-effectiveness.

Encourage Supplier Collaboration: Collaboration with packaging material suppliers is essential for driving innovation, optimizing packaging solutions, and enhancing supply chain resilience. IKEA can also strengthen its ties with its suppliers to look for possible collaborations and co-creation in the field of packaging materials and processes. Using the competence and the facilities of the suppliers, IKEA can identify innovative packaging solutions that align with its sustainability objectives, cost considerations, and logistical requirements.

Invest in Tooling and Infrastructure: Investing in tooling and infrastructure is crucial for adoption of molded paper packaging within IKEA's operations, especially in the European region where the tooling cost and lead time is significantly higher than Asia. IKEA can explore opportunities to invest in the best production facilities, tooling technologies and automation solutions to simplify the molded paper manufacturing process and make it more efficient. Through investing in the latest infrastructure, IKEA can effectively overcome the obstacles of molded paper packaging, such as upfront capital costs and production complexity. Moreover, IKEA can be partnered with suppliers and industry partners to discover ways of investing in tooling and infrastructure together, which would allow them to benefit from economies of scale and gathering of expertise, and therefore, would lead to reduction of costs and faster adoption of molded paper packaging in the company’s product portfolio.

Invest in Research and Development (R&D): Research and development is a critical factor for the drive of continuous improvement, innovation, and sustainability in packaging solutions. R&D investment can be used to facilitate the development of improved materials, manufacturing processes, and design innovations that are designed to decrease the environmental impact and cost of renewable energy. IKEA can create special R&D divisions or cooperate with outside research organizations, industry partners and sustainability professionals to promote packaging technology development more quickly. Besides, R&D investment can also facilitate the exploration of the new trends and technologies, for example, bio-based materials, circular economy principles, and digital packaging solutions, which are the potential for the revolution of the packaging landscape. Through the continuous application of cutting-edge technologies and sustainability tendencies, IKEA can remain as a leader in sustainable packaging innovation and differentiate itself by doing so on the market.

7.2 Future Research Areas

This study provides valuable insights into the decision-making process for selecting between molded paper and corrugated filler solutions. However, there are several areas for future research that could further enrich our understanding of packaging material selection within the supply chain.

Long-term sustainability analysis: Since, this research could not provide concrete findings on sustainability for the packaging material, future research could explore the long-term sustainability implications of molded paper and corrugated filler packaging solutions, considering factors such as life cycle assessments, end-of-life disposal options, and environmental impact mitigation strategies.

Consider various product types & categories: As discussed in the study previously, variations are observed depending on the product. Thus, an extensive study can be conducted taking products of various types from various categories in the Workspaces area. This will help to increase the sample size of the study as well as include all the product types, which can help to generalize the findings.

Our research serves as a foundation for future studies aimed at further understanding the complexities of packaging material selection within the supply chain and identifying strategies to optimize efficiency, cost-effectiveness, quality, and sustainability.

8. References

Ballou, R.H. (2004), Business Logistics/Supply Chain Management: Planning, Organizing, and Controlling the Supply Chain, 5th ed., Pearson Prentice-Hall/Pearson Educational International, Upper Saddle River, NJ.

Bitzer, T. N., Recent Honeycomb Core Developments, Proceedings of the 3. Sandwich Construction conference, Southampton 1995, page 555-563, edited by H.G. Allen, 1996

Bowersox, D.J., Closs, D.J. and Cooper, M.B. (2002), Supply Chain Logistics Management, 1st International ed., McGraw-Hill/Irwin, New York, NY.

Brown, R. H., & Sharma, M. M. (1987). Moisture diffusion in honeycomb sandwich panels. Journal of Composite Materials, 21(1), 30-50.

Carbinato, D., Deryckere, M. and Shiran, Y. (2023). Sustainable Packaging: What Consumers Want Next from the Paper and Packaging Industry. [online] Bain. Available at: https://www.bain.com/insights/sustainable-packaging-paper-and-packaging-report-2023/.

Creswell, J. W. (2014). Research design: Qualitative, quantitative, and mixed methods approaches (4th ed.). Thousand Oaks, CA: Sage Publications.

Creswell, J.W. (2017). Research design: Qualitative, quantitative, and mixed methods approaches. 4th ed. London: Sage Publications Ltd.

Daskin, M.S., 1985. Logistics: an overview of the state of the art and perspectives on future research. Transportation Research Part A: General, 19(5-6), pp.383-398.

Didone, M., Saxena, P., Brilhuis-Meijer, E., Tosello, G., Bissacco, G., Mcaloone, T. C.Howard, T. J. (2017). Moulded Pulp Manufacturing: Overview and Prospects for the Process Technology. Packaging Technology and Science, 30(6), 231–249. https://doi.org/10.1002/pts.2289.

Doherty, S., and S. Hoyle. 2009. Supply Chain Decarbonisation: The Role of Logistics and Transport in Reducing Supply Chain Carbon Emissions. Geneva: World Economic Forum.

Emblem, A. and Emblem, H. (2012). Packaging technology: Fundamentals, materials and processes

Fadiji, T., Berry, T.M., Coetzee, C.J. and Opara, U.L. (2018). Mechanical design and performance testing of corrugated paperboard packaging for the postharvest handling of horticultural produce. Biosystems Engineering, Vol. 171, pp.220–244. doi:https://doi.org/10.1016/j.biosystemseng.2018.05.004.

Fernie, J. and McKinnon, A.C. (2003), "The grocery supply chain in the UK: improving efficiency in the logistics network", The International Review of Retail, Distribution and Consumer Research, Vol. 13 No. 2, pp. 161-74.

Fleck, N. A., Mullin, T., & Ashby, M. F. (1994). Honeycomb structures: a review of materials, manufacturing and optimization. Journal of Sandwich Structures & Materials, 4(1), 3-35.

Found, P. A., and N. L. Rich. 2007. "The Meaning of Lean: Cross Case Perceptions of Packaging Businesses in the UK's Fast Moving Consumer Goods Sector." International Journal of Logistics Research and Applications 10 (3): 157–171.

Gibson, L. J., & Ashby, M. F. (1997). Cellular solids: structure and properties (2nd ed.). Cambridge University Press.

Greene, J. C., & Caracelli, V. J. (1997). Defining and describing the purposes of mixed-method evaluation. In J. C. Greene & V. J. Caracelli (Eds.), Advances in mixed-method evaluation: The challenges and benefits of integrating diverse paradigms (pp. 5-17). New Directions for Evaluation, 74. San Francisco, CA: Jossey-Bass.

Harris, S. (2021). The Importance of Packaging Design: Ultimate Guide. [online] Print Bind Ship. Available at: https://printbindship.com/the-importance-of-packaging-design/.

Hellström, D. & Saghir, M. (2007) Packaging and Logistics interaction in retail supply chains. Packaging Technology and Science Vol.20, No.3, p 197-216.

Henrik Pålsson & Daniel Hellström (2016) Packaging logistics in supply chain practice – current state, trade-offs and improvement potential, International Journal of Logistics Research and Applications, 19:5, 351-368, DOI: 10.1080/13675567.2015.1115472

Hogarth, C. (2005). Moulded Pulp Packaging. Paper and Paperboard Packaging Technology(pp. 414–422). John Wiley & Sons, Ltd.,. https://doi.org/10.1002/9780470995877.ch14

Jason, L. and Glenwick, D. eds., 2016. Handbook of methodological approaches to community-based research: Qualitative, quantitative, and mixed methods. Oxford university press.

Johannesson, P. (2016). Introduction To Design Science. Springer International Pu.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. Educational Researcher, 33(7), 14-26.

Johnsson, M. (1998) Packaging Logistics – a value added approach. Department of Engineering Logistics, Lund University. Lund.

Khakalo, A., Kouko, J., Filpponen, I., Retulainen, E., & Rojas, O. J. (2017). In-Plane Compression and Biopolymer Permeation Enable Super-stretchable Fiber Webs for Thermoforming toward 3-D Structures. ACS Sustainable Chemistry and Engineering, 5(10), 9114–9125. https://doi.org/10.1021/acssuschemeng.7b02025

Lancioni, R.A. and Chandran, R. (1990), “The role of packaging in international logistics”, International Journal of Physical Distribution & Logistics Management, Vol. 20 No. 8, pp. 41-3.

Livingstone, S. and Sparks, L. (1994), “The new German packaging laws: effects on firms exporting to Germany”, International Journal of Physical Distribution & Logistics Management, Vol. 24 No. 7, pp. 15-25.

McKinsey & Company (2022). Sustainable packaging: Five key levers for impact | McKinsey. [online] www.mckinsey.com. Available at: https://www.mckinsey.com/industries/industrials-and-electronics/our-insights/sustainability-in-packaging-five-key-levers-for-significant-impact.

Meredith, J. (1998). Building operations management theory through case and field research. Journal of Operations Management, 16(4), pp.441–454. doi:https://doi.org/10.1016/s0272-6963(98)00023-0.

Mihindukulasuriya, S.D.F. and Lim, L.-T. . (2014). Nanotechnology development in food packaging: A review. Trends in Food Science & Technology, [online] 40(2), pp.149–167. doi:https://doi.org/10.1016/j.tifs.2014.09.009.

Nordstrand, T. (2003). Basic testing and strength design of corrugated board and containers. Doctoral dissertation. Lund University.

Paine, F. A. (1981) Fundamentals of Packaging. Brookside Press Ltd. Leicester.

Pålsson, Henrik, 2018. Packaging Logistics, Understanding and managing the economic and environmental impacts of packaging in supply chains.

Paul, R, and W. Klusmeir Struchthan. 1997. A composite with a future. Status report. Bayer AG. Leverkusen.

Pflug, J., Verpoest, I., Vandepitte, D., 2000, "Folded Honeycomb Cardboard and Core Material for Structural Applications", Proceedings of the 5. Sandwich Construction conference, Zürich.

Pflug, J.; Vangrimde, B.; Verpoest, I.; Bratfisch, P.; Vandepitte, D. Honeycomb Core Materials: New Concepts for Continuous Production. Sampe J. 2003, 39, 22–30.

Poustis, J. (2005). Corrugated FiberboardPackaging. In Paper and Paperboard Packaging Technology, M.J. Kirwan (Ed.). https://doi.org/10.1002/9780470995877.ch11

R. Wever and D. Twede, "The history of molded fiber packaging; a 20th century pulp story," in Proceedings of the 23rd IAPRI symposium on packaging, 2007

Rundh, B. (2013). Linking packaging to marketing: how packaging is influencing the marketing strategy. British Food Journal, 115(11), pp.1547–1563. doi:https://doi.org/10.1108/bfj-12-2011-0297.

Semple, K.E., Zhou, C., Rojas, O.J., Nkeuwa, W.N. and Dai, C. (2022). Moulded pulp fibers for disposable food packaging: A state-of-the-art review. Food

Packaging and Shelf Life, 33, p.100908. doi:https://doi.org/10.1016/j.fpsl.2022.100908.

Stark, N.M. and Matuana, L.M. (2021). Trends in Sustainable Biobased Packaging Materials: A Mini Review. Materials Today Sustainability, [online] 15, p.100084. doi:https://doi.org/10.1016/j.mtsust.2021.100084.

Vijayaraman, B.S., Osyk, B.A. and Chavada, D. (2008). An Exploratory Study of RFID Adoption in the Paperboard Packaging Industry. Journal of technology management & innovation, 3(4). doi:https://doi.org/10.4067/s0718-27242008000200008.

Waldman, E. H. (2009). Po through Pu. The Wiley Encyclopedia of Packaging Technology(pp. 1044–1047). John Wiley & Sons, Ltd.,. https://doi.org/10.1002/9780470541395.ch16

Yadav, A. and Maheshwari, H. (2023). Development & Function of Packaging in The Marketing of Consumer Product: (With Special Reference to Himalayas). International Journal for Multidisciplinary Research, [online] 5(3). Available at: https://www.ijfmr.com/papers/2023/3/3042.pdf.

Yin, R.K. (2009). Case study research: Design and methods. 4th ed. Los Angeles: Sage Publications.

Websites:

1. IKEA. (n.d.). IKEA 80th anniversary - IKEA Global. [online] Available at: https://www.ikea.com/global/en/newsroom/corporate/ikea-80th-anniversary-assembling-a-better-future-together-230728/

2. IKEA (2022). IKEA culture and values. [online] www.inter.ikea.com. Available at: https://www.inter.ikea.com/en/how-we-do-business/ikea-culture-and-values

3. IKEA. (n.d.). IKEA 80th anniversary - IKEA Global. [online] Available at: https://www.ikea.com/global/en/newsroom/corporate/ikea-80th-anniversary-assembling-a-better-future-together-230728/.

4. about.ikea.com. (n.d.). Democratic Design. Making great design available to everyone. [online] Available at: https://www.ikeasocialentrepreneurship.org/sitecore/content/nl/aboutikea/home/life-at-home/how-we-work/democratic-design?sc_lang=en.

5. IKEA (2023). The history of the revolutionary IKEA flatpacks. [online] www.ikea.com. Available at: https://www.ikea.com/ph/en/this-is-ikea/about-us/the-story-of-ikea-flatpacks-puba710ccb0

6. www.awlindia.com. (n.d.). India's Leading Logistics Companies Service Provider - AWL India. [online] Available at: https://www.awlindia.com/blog-role-of-packaging-in-supply-chain-management.

7. www.worldpackagingco.com. (n.d.). *Functions of Corrugated Shipping Boxes and Other Packaging Materials*. [online] Available at:http://www.worldpackagingco.com/functions-of-quality-corrugated-shipping-boxes-and-other-packaging-materials.html [Accessed 20 May 2024].

8. IKEA (n.d.). *The road from trading pens to furniture - IKEA Museum*. [online] WordPress på Azure. Available at: https://ikeamuseum.com/en/explore/the-story-of-ikea/the-birth-of-ikea/.

9. Appendix

A. Types of research studies

Qualitative study

Qualitative research is a valuable research methodology that provides insights and perspectives that complement quantitative approaches. It involves a smaller, non-probabilistic sample of individuals and focuses on descriptive data, primarily reported in words or pictures rather than numerical figures (Jason & Glenwick, 2016). Qualitative research seeks to understand multiple realities and the unique context in which they unfold. It plays a pivotal role in generating hypotheses for further investigation and providing a foundation for subsequent quantitative studies (Creswell, 2017). In essence, qualitative research enriches our understanding of complex phenomena by capturing the depth and richness of human experiences within their natural contexts .

Quantitative study

Quantitative research is a type of research that uses numerical data to answer questions. It is often used in the social sciences. There are many different methods to collect quantitative data, including surveys, interviews, and experiments. Once data has been collected, it needs to be analyzed using statistical methods. Quantitative research can be a powerful tool for answering questions about the world, but it has some limitations, such as the difficulty of generalizing results to a larger population and the expense and time-consuming nature of the research (Creswel, 2014).

Mixed Study

Mixed research is a comprehensive approach that combines both quantitative and qualitative methods to gain a deeper understanding of a phenomenon. This approach is particularly useful when researchers seek to explore complex research questions by leveraging the strengths of both quantitative and qualitative data (Creswell, 2014). There are various ways to conduct mixed research, such as the sequential design and the concurrent design (Greene & Caracelli, 1997). Despite its potential benefits, mixed research presents certain challenges, such as integrating quantitative and qualitative data and analyzing mixed data. However, when conducted effectively, mixed research can offer valuable insights into complex research questions. (Johnson & Onwuegbuzie, 2004).

Single Case study

A single case study is used when the objective of research is in-depth examination of a single entity, such as an individual, group, organization, event, or phenomenon. This approach allows researchers to thoroughly investigate the complexities of the case, providing detailed insights into its characteristics and context. Single case studies are particularly useful when testing an existing theory, case is unique, unusual, or represents an extreme or critical case. (Yin, 2009)

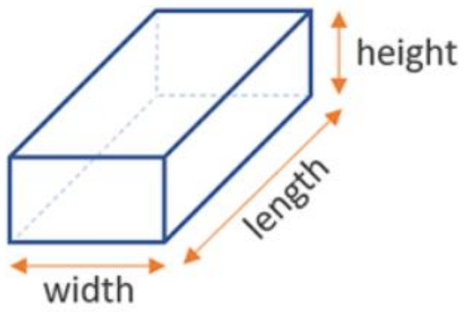
Multiple Case study

On the other hand, multiple case studies involve the comparative analysis of two or more cases within the same study. This approach enables researchers to identify patterns, similarities, and differences across cases. Multiple case studies are preferred as they allow generalization of findings. Multiple case studies are valuable for exploring variations across similar cases, testing hypotheses across different cases, and enhancing the validity and reliability of research findings through replication. (Yin, 2009)

B. Calculating volume of box

The volume for the box is calculated by using the three dimensions of the box, namely length, width and height.The formula is given as:

$$Volume = Length \times Width \times Height$$



C. Interview questions with Production Engineers

Structured interviews were conducted with Production engineers of each product and each packaging solution in order to obtain data regarding the cases.

1. Corrugated Filler and Molded Paper Cost:

- Parts per article
- Weight
- Cost per piece
- Tooling cost (investment)

2. Overall Cost of Product:

- With corrugated filler packaging (PUA Price)
- With molded paper packaging (PUA Price)

3. Packing Process:

- Is the packing process automatic or manual?
- Time required for packing products with corrugated filler solution
- Time required for packing products with molded paper solution
- Labor cost for packing products with corrugated filler
- Labor cost for packing products with molded paper

4. Logistics:

- Type of container used for shipping products to DC (20ft /40ft/HQ)
- Number of unit loads shipped per container (including top filling)
- Number of consumer packs shipped per container
- Logistics cost (cost of one container) for shipping products with corrugated filler packaging

5. Packaging Material Supplier:

- CO_2 Emission factors for corrugated filler
- CO_2 Emission factors for molded paper
- Energy utilization for producing corrugated filler
- Energy utilization for producing molded paper
- Distance of corrugated material supplier from Hisense
- Distance of molded paper material supplier from Hisense
- How packaging material (corrugated filler & molded paper) is shipped from material manufacturer to Hisense (In container/truck)