Lean Management Approach to Sustain Improvement of Customized Exhibit Packaging and Enhancing CSAT Scores

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THESIS

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LIST OF ABBREVIATIONS

AIAG	Automotive Industry Action Group
ASQ	American Society for Quality
ATA	Average Time to Assemble
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
COSO	Committee of Sponsoring Organizations
CSA	Compliance, Safety, Accountability
DFMEA	Design FMEA
DFSS	Design for Six Sigma
DMADV	Define, Measure, Analyze, Design, and Verify
DMAIC	Define, Measure, Analyze, Improve, and Control
ERP	Enterprise Resource Planning
FMEA	Failure Modes and Effects Analysis
GM	General Motors
ISO	International Organization for Standardization
KPI	Key Performance Indicator
MIT	Massachusetts Institute of Technology

LIST OF ABBREVIATIONS (continued)

MTBF	Mean Time Between Failures
MTTF	Mean Time to Failure
NPV	Net Present Value
PDCA	Plan Do Check Act
PDSA	Plan-Do-Study-Act
PFMEA	Process FMEA
QC	Quality Control
QFD	Quality Function Deployment
QMS	Quality Management System
r	Risk-free rate
RPN	Risk Priority Number
RRPE	Rate of Returns due to Packaging Errors
SDCA	Standardize-Do-Check-Act
SIPOC	Suppliers, Inputs, Process, Outputs, Customers
TER	Transport Efficiency Ratio
TPS	Toyota Production System
TQ	Total Quality
VoC/VOC	Voice of the Customer

SUMMARY

This thesis investigates the potential benefits and multifaceted impacts of packaging optimization within the visual communications industry. Using Orbus Exhibit and Display Group as a specific case study, the research aimed to address the prevalent customer dissatisfaction associated with the company's packaging methods and materials used for Customized Exhibit Structures, one of Orbus' main product categories.

The primary research objective was to alleviate customer difficulties experienced at exhibition sites due to inefficient packaging, subsequently aiming to increase the Customer Satisfaction Score (CSAT) related to packaging from a baseline of 76 to a target score of 86. To achieve these objectives, the study employed an integrative approach using Lean Management principles coupled with Design for Six Sigma (DFSS) methodologies.

A detailed application of the DMADV (Define, Measure, Analyze, Design, Verify) process was used to critically evaluate and redesign the existing packaging. This meticulous process culminated in an optimized packaging solution which offered marked improvements in several areas. These enhancements encompassed heightened durability of the packaging, refined item organization within the packaging, improved labeling for better identification, clearer and more straightforward packing instructions, and a strategic reduction in the external width of the crate to increase transport efficiency.

Key Performance Indicators (KPIs) were established to gauge the success of the project. The redesigned packaging solution delivered improvements in crucial KPIs, including the CSAT, Average Time to Assemble (ATA), Transport Efficiency Ratio (TER), and the Rate of Returns due to Packaging Errors (RRPE). The new packaging design not only ameliorated operational efficiency and customer satisfaction but also made a significant contribution to environmental sustainability. The latter was marked by a notable reduction in CO2 emissions per order by 43%, indicating the sustainable benefits of efficient design. In terms of financial implications, the study applied scenario analysis to evaluate the financial viability of the new packaging design. The results underscored the cost-effectiveness of the redesign, projecting an expected Net Present Value (NPV) of $5,220,617 over a six year period under realistic scenarios.

The primary objective of the study was successfully met, with the redesigned packaging resulting in an improved CSAT score of 88, surpassing the original target. However, the research also acknowledges its limitations, which include the relatively short Verify phase in the DMADV process and the potential inaccuracies in the financial data due to the monitoring system used by Orbus until June 2023.

This study provides substantial insights into how a combination of customer-centric design thinking, Lean Management principles, and DFSS methodologies can contribute significantly to the optimization of packaging within the visual communications industry. The outcomes reinforce the possibilities of enhancing customer satisfaction, reducing environmental footprint, and achieving substantial financial benefits simultaneously. The research concludes by highlighting the necessity of continuous improvement and further research to maintain and extend these benefits in the future.

CHAPTER 1

INTRODUCTION

1.1 Thesis Goals

1.1.1 Context and Issues

In today's dynamic and ever-changing business landscape, organizations continuously strive to optimize their operations and provide exceptional customer experiences. Among several factors influencing customer perception and satisfaction, companies have recognized the fundamental role of product packaging. Effective packaging solutions not only protect the products during transit but significantly contribute to customer convenience and overall satisfaction.

Orbus Exhibit & Display Group®, a renowned market leader in visual communications solutions for corporate interiors, retail environments, trade shows, and events, has established itself as the largest exhibit and display manufacturer and graphics producer in the United States. The company's commitment to delivering high-quality products and providing unparalleled customer service has been the bedrock of their success.

However, the firm has recently encountered some challenges regarding the packaging process of their Customized Exhibit Structures (Figure 1 and Figure 2). Despite their meticulous efforts to ensure product safety and durability, a noticeable decline has been recorded in the customer satisfaction scores, specifically tied to the packaging of these unique structures. This score is assessed through the General Customer Satisfaction Survey (1300 surveys collected in the last 3 years), conducted after every order exceeding $1000. The survey measures satisfaction across various aspects of the order experience, producing different Customer Satisfaction Score (CSAT) for each area.

Figure 1: Trade Show Booth of Nexen Tire

Figure 2: Trade Show Booth of Bank of America

From this point forward, for the sake of simplicity and clarity, the CSAT score related specifically to the packaging of Customized Exhibit Structures will be referred to as the *"Customer Satisfaction Score"* or *"CSAT"*.

In response to this challenge, the study's focus is to apply lean management principles to enhance the packaging process for these unique structures at Orbus Exhibit & Display Group®, without compromising product safety or customer satisfaction. The aim is to improve the Customer Satisfaction Score related to packaging and enhance the overall customer experience.

1.1.2 Components of a Customized Exhibit Structure

The intricacy and appeal of Customized Exhibit Structures rely heavily on their diverse components, each playing a unique role in creating an alluring and effective display. On average, a single structure requires approximately four crates for delivery, signifying the complexity and sophistication of these installations.

This section will delve into the details of these components, elucidating their purposes and contributions to the overall structure:

1. Graphics (Figure 3): The graphics are arguably the most noticeable component of the Customized Exhibit Structures. They are visually striking elements where images are printed, typically showcasing the brand's message or campaign, therefore playing a pivotal role in capturing the attention of onlookers and creating a memorable impression.

2. Acoustic Panels (Figure 4): Acoustic panels are another component where images are printed. Besides adding to the visual appeal, they also serve a practical function. They

help control the sound within the exhibit space, enhancing the overall auditory experience of the area.

Figure 3: Graphics

Figure 4: Acoustic Panels

3. Hardware (Figure 5): This category includes various smaller pieces like connectors, lights, and other related items. Despite their size, they are integral to the assembly and functionality of the structures. They ensure that the different components fit together securely and illuminate the structure to augment its visual appeal.

4. Metal Extrusions and Metalwork (Figure 6): Serving as the backbone of the Customized Exhibit Structures, the metal extrusions and other metalwork provide the much-needed

support and stability. They ensure that the structure stands tall and steady, capable of withstanding various environmental conditions while maintaining its shape and integrity.

5. Woodwork (Figure 7): Occasionally, woodwork also forms a part of these structures. These can be counters or other pieces, adding a touch of elegance and warmth to the overall design. Wood components contribute to the aesthetic diversity of the structure, enhancing its appeal and offering more design possibilities.

Figure 5: Hardware

Figure 6: Metal Extrusions

Figure 7: Woodwork

Each of these components is critical to the successful construction and visual impact of a Customized Exhibit Structure. Ensuring their safe and undamaged delivery through effective packaging solutions is therefore of utmost importance.

1.1.3 Lean Management Principles and Research Objectives

Lean management, well-known for its waste reduction, continuous improvement, and customer centric approach, offers valuable tools and strategies to streamline operations, increase efficiency, and exceed customer expectations.

The primary objective of this research project is to improve the quality and efficiency of the packaging process for Customized Exhibit Structures, ultimately enhancing customer satisfaction and increasing order frequency. To achieve this, the research methodology adopts the DMADV (Define, Measure, Analyze, Design, and Verify) approach, which aligns with the Design for Six Sigma (DFSS) framework. This strategic process emphasizes proactive design quality, aiming to create producible designs that precisely meet customer expectations of quality and performance.

1.1.4 Research Methodology

The research project begins with a comprehensive definition of the current packaging process for customized exhibit structures, meticulously identifying specific areas for improvement through robust data collection and analysis. Key performance indicators (KPIs) related to customer satisfaction scores and packaging efficiency metrics will be measured meticulously to ensure a precise assessment of the existing situation. The Voice of the Customer (VOC) approach will be utilized to capture valuable feedback and insights from consumers, ensuring their preferences and opinions are intricately integrated into the design process.

Drawing upon the analysis, a set of innovative proposed solutions will be meticulously developed, utilizing lean management tools. These transformative solutions aim to optimize the packaging process by reducing waste, streamlining flow, and maximizing value delivered to the customer. Through iterative testing and continuous refinement, the proposed solutions will be methodically implemented and meticulously evaluated to determine their effectiveness in meeting customer needs, enhancing overall packaging quality, and driving sustainable improvements.

The success of this research project will be measured by the ambitious goal of increasing customer satisfaction scores related to packaging by an impressive 10% by the end of Q3 2023. By effectively addressing specific challenges faced by Orbus's customers, this study aims to enhance the overall customer experience, foster increased customer loyalty, and drive sustainable business performance improvements.

Furthermore, this research endeavour contributes significantly to the field of industrial engineering by demonstrating the profound effectiveness of lean management principles in successfully tackling complex packaging challenges within the dynamic visual communications industry. The findings and recommendations arising from this study will not only benefit Orbus Exhibit & Display Group® but also provide valuable insights for other organizations aspiring to optimize their packaging processes, enhance customer satisfaction, and gain a competitive edge in the evolving marketplace.

1.2 Structure of the Research Works

This thesis is structured in six main chapters, each serving a distinct purpose in the exploration of packaging optimization in the visual communications industry.

Chapter 1: Introduction

This chapter serves as an introduction to the research project, providing an overview of the study's context within the dynamic business landscape of today. It emphasizes the significance of effective packaging solutions in influencing customer satisfaction and highlights the specific issues related to packaging that Orbus Exhibit & Display Group® has encountered. The chapter outlines the overall objectives of the study, with a particular focus on the application of lean management principles to enhance Orbus's packaging process for its customized exhibit structures.

Chapter 2: Literature Review

In the second chapter, an extensive review of the existing body of literature on lean management principles, Design for Six Sigma (DFSS), and the Voice of the Customer (VoC) approach is conducted. This chapter critically evaluates previous research, carefully assessing their methodologies, effectiveness, and relevance to the current study. Furthermore, it explores the theoretical foundations of these concepts, demonstrating their practical application in optimizing operations, improving efficiency, and enhancing customer satisfaction.

Chapter 3: Research Methodology and Case Study

This chapter presents the research methodologies and the real-world application of these methodologies to the case study at Orbus Exhibit & Display Group®. It begins with an overview of the research process, including the benefits and specifics of the interview process utilized for data collection. The chapter then moves into a deep dive into the initial phase of the study: defining, measuring, and analyzing the problem at hand. The researchers identify specific challenges and pain points in Orbus's existing packaging process, drawing from both customer and internal perspectives.

The application of the Define, Measure, Analyze, Design, Verify (DMADV) model forms the cornerstone of this chapter, beginning with the timeline of DMADV implementation. The study outlines the creation of customer requirements and design objectives for new packaging solutions, connecting customer dissatisfaction directly to inefficiencies in the packaging process. Key performance indicators (KPIs) are defined for tracking progress and ensuring the alignment of the solutions with set objectives.

The 'Design' stage of the DMADV model is then detailed, showcasing the development and iterative testing of innovative packaging solutions, including crate design optimization and user-friendly packaging instructions. Four prototypes are described, emphasizing the continual refinement of the design based on feedback and evaluation. This segues into the 'Verify' stage, where implemented solutions are scrutinized for their effectiveness. Recommendations for enhancing the packaging process are derived from these insights.

The chapter concludes with the evaluation of implemented solutions and the commitment to continuous improvement. It discusses the importance of regular monitoring and measuring of key performance indicators for the packaging process and includes the Failure Modes and Effects Analysis (FMEA) to evaluate the potential for failure. The necessity of continual refinement and improvement of packaging designs to meet evolving requirements and challenges is emphasized, underscoring the ongoing nature of process improvement.

Chapter 4: Market and Environmental Considerations

In this chapter, the study explores the influence of market trends, customer preferences, and environmental factors on packaging solutions design. It emphasizes how these factors were integrated into the design of Orbus's new packaging solutions and the importance of aligning packaging design with broader environmental sustainability goals.

Chapter 5: Evaluation and Results

This Chapter conducts a multifaceted evaluation of the new packaging strategy, examining its impact on customer satisfaction, cost-efficiency, and environmental footprint. The assessment commences by evaluating customer feedback to understand the enhancements to the user experience. This leads to an examination of the efficiency of the packaging redesign, looking closely at its financial implications through several lenses, including Net Present Value (NPV) and cost structures. It also considers different financial scenarios to ensure the robustness of the approach. Alongside this, the chapter delves into the environmental implications of the packaging changes, recognizing the growing importance of sustainability in business operations. The chapter's findings contribute to a well-rounded understanding of the successes and areas for future improvement in the new packaging strategy.

Chapter 6: Conclusions and Future Recommendations

The concluding chapter summarizes the key findings of the study, discussing their implications for Orbus and the broader visual communications industry. It acknowledges the study's limitations and provides recommendations for future research and potential improvements in packaging processes. The chapter emphasizes this research's significance in advancing industrial engineering, particularly in lean management and packaging design.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to the Literature Review

A comprehensive and well-executed literature review is essential for the coherence and success of any scholarly endeavor. Situated at the core of the research process, a literature review serves as a guiding compass, navigating the vast expanse of existing knowledge. In the case of this thesis, the literature review illuminates the path towards enhancing the packaging process at Orbus Exhibit & Display Group® by applying lean management principles, the Design for Six Sigma (DFSS) framework, and the Voice of the Customer (VoC) approach.

The purpose of this chapter unfolds through 2 integral parts. First and foremost, it aims to unearth, examine, and synthesize the extensive body of existing literature that is relevant to the research topic. This process lays the foundation for a comprehensive and holistic understanding of the principles, methodologies, and key concepts that underpin lean management, DFSS, and the VoC approach. In this context, the literature review serves as an intellectual bridge, connecting abstract theoretical concepts to the practical challenges faced in packaging design within the dynamic visual communications industry.

Secondly, an effective literature review acts as a catalyst for identifying potential gaps in the existing scholarship. Through critical analysis, this research project can pinpoint areas of the topic that necessitate further exploration, thereby providing an opportunity to contribute unique insights and extend the current body of knowledge. This process reinforces the academic value of the research, ensuring that it not only addresses a practical business problem but also enriches the theoretical landscape of lean management, DFSS, and customer-centric design.

The materials for the literature review are not confined to any single source or type of publication. Rather, they encompass a diverse range of scholarly and reputable resources, ensuring a comprehensive and robust collection of relevant information. These sources include peer-reviewed articles from academic journals, industry reports offering insights into current practices and trends, and textbooks providing in-depth explanations of key concepts and methodologies. By casting a wide net, the literature review ensures a comprehensive understanding of the research context, facilitating a robust, effective, and customer-centric approach to addressing the challenge at hand.

Furthermore, the review delves into the history and evolution of lean management and DFSS, tracing their origins, development, and application. This historical perspective enables an appreciation of how these methodologies have been adapted and refined over time to meet evolving business needs and customer expectations. Additionally, it explores how the VoC approach has revolutionized the dynamics of customer relationships, shifting the focus from product-centric to customer-centric business strategies.

In essence, this literature review forms the backbone of this research project. By connecting theoretical foundations to practical applications, it offers the knowledge and insights necessary to guide the strategic process of improving the packaging process at Orbus Exhibit & Display Group®. It underscores the need for a relentless commitment to continuous improvement, customer satisfaction, and exceptional business performance, aligning with the core principles of lean management.

2.2 Lean Manufacturing

2.2.1 Lean Overview

Lean methodology, also referred to as lean manufacturing, lean office, lean enterprise, lean production, or flexible mass production, has a rich historical background. Its origins can be traced back to the shipbuilding industry in 16th-century Venice [3], where the concept of flow production was first applied. In the 18th and 19th centuries, figures such as Matthew Boulton, John H Hall, Eli Whitney, Frederick Taylor, and Frank Gilbreth made significant contributions to the development of lean principles, focusing on efficiency, waste elimination, and the standardization of processes [4][5].

However, it was in the aftermath of World War II that the comprehensive philosophy of lean, as we know it today, emerged with the Toyota Production System (TPS). Influenced by quality gurus W. Edwards Deming and Joseph Juran [6], Toyota created an innovative approach to production that emphasized continuous improvement and the growth and development of all individuals within the organization. The TPS served as the foundation for lean thinking, fostering a culture of continuous improvement and waste reduction.

A notable example of the successful implementation of lean principles is the transformation of NUMMI [7][8], a joint venture between Toyota and General Motors. Through the application of lean principles, NUMMI went from being the worst-performing GM plant to one of the top performers within a short period, illustrating the transformative power of lean methodology.

In the late 20th century, the term "lean" was officially coined by James Womack and his team from MIT in their book, "The Machine That Changed the World" [9]. They used this term to describe the methods they observed during their study of Japanese manufacturing methods, particularly the Toyota Production System.

As we enter the 21st century, lean thinking continues to evolve and demonstrate its potential for improving various business sectors. Lean methodology goes beyond waste elimination; it encompasses a cultural shift towards continuous improvement, holistic development of individuals within an organization, and the reduction of non-value-added activities [10]. By embracing lean principles, businesses can enhance customer focus, reduce cycle time, and cut costs, leading to improved overall performance. Today, versions of TPS encompass lean thinking using the 8Ps: purpose, process, people, pull, prevention, partnering, planet, and perfection [1].

In lean methodology, value is defined by the customer's perception of a product or service's usefulness and necessity. Different customers have varying preferences and priorities, which influence their perception of value. For example, customers in the automotive industry may value quality, fuel efficiency, prestige, durability, or brand loyalty. Understanding customer-defined value helps shape the design and production processes to meet specific customer needs. Lean thinking distinguishes between value-added and non-value-added activities within a process. Value-added activities directly contribute to the product's transformation and are recognized by the customer. Non-value-added activities, on the other hand, do not alter the product's form, function, or value perception and are targeted for elimination.

Differentiating between value-added and non-value-added activities can be challenging in certain areas, such as inspection and testing. While some may argue that inspecting an incapable process is value-added as it prevents defective parts from progressing to downstream processes, most authorities argue that such inspections are non-value-added, and the focus should instead be on process improvement.

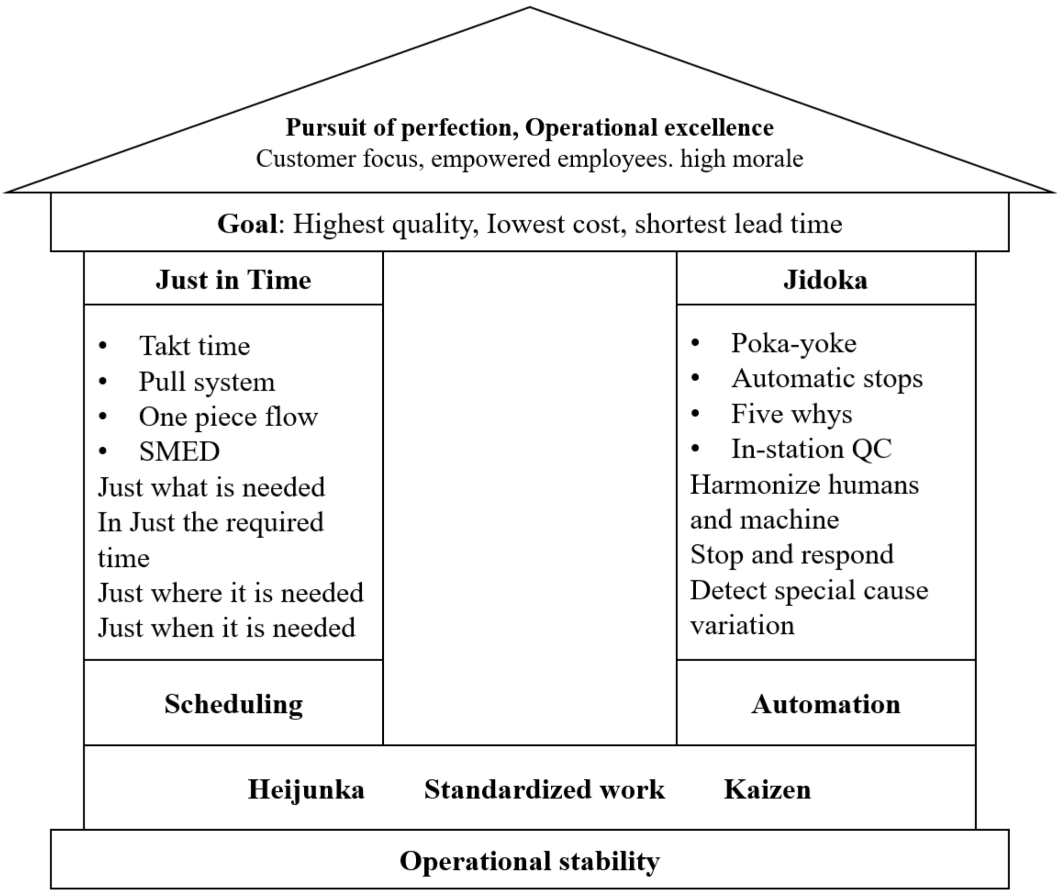


Figure 8: Lean Management House [1].

However, certain inspections or tests necessary for compliance, such as fire-testing each furnace by a gas furnace manufacturer to meet CSA requirements, are considered value-added as customers are willing to pay for the CSA listing. Studies have shown that a significant portion, approximately 95% [11], of lead time is consumed by non-value-added activities, often involving waiting time. Traditionally, efforts to reduce lead time have primarily focused on expediting value-added functions rather than minimizing or eliminating non-value-added functions. Lean challenges this approach by targeting non-value-added activities and waste for elimination.

In conclusion, lean principles embody a transformative philosophy that centers on creating customer-defined value and eliminating waste. This philosophy emphasizes a cultural shift towards continuous improvement, the holistic development of individuals within an organization, and a keen understanding and reduction of non-value-added activities.

2.2.2 Purpose of Lean

The central objective of lean is to enhance organizational performance through improved customer service. It achieves this by reducing and eliminating waste, minimizing cycle time, reducing errors, and promptly responding to customer needs. Cycle time, which encompasses the duration from the start to the end of a process, including any waiting time or delays, holds a crucial focus in the lean philosophy.

The effectiveness of lean lies in its ability to make processes more predictable, minimize changeover times, and decrease errors, resulting in significant reductions in cycle times. This is primarily accomplished through the elimination of waste, which refers to anything that does not add value to the product or service.

Within the lean philosophy, eight major categories of waste are recognized, with seven initially identified by the Japanese and an additional one identified by the Americans [12]. These wastes include transportation (unnecessary movement of products), inventory (excessive quantities), wasted motion (inefficient movement of people), waiting time (idle time for people, machines, or products), overproduction (exceeding customer requirements), overprocessing (performing more than necessary to meet customer needs), defects (errors requiring rework), and unused creativity and skills of employees.

An unwritten principle of lean is to involve every individual within the organization. This approach not only eliminates the waste of untapped skills and creativity but also serves as a powerful tool for transforming organizational culture. It enables the utilization of existing knowledge, fosters ownership of changes, and facilitates employee engagement. A staggering estimate suggests that approximately 95% [11] of a product's time in a manufacturing facility is spent on non-value-added activities. Through the reduction or elimination of the eight types of waste, lean methodologies dramatically decrease non-value-added time. Value-added steps are determined based on their importance to the customer and the necessity for the process to succeed. In addition to the eight wastes, redundant steps such as multiple approvals and unnecessary inspections are also potential areas of waste.

The implementation of lean philosophy, with the active involvement of everyone within the organization, leads to a significant cultural shift. Employees take ownership and become more engaged, fostering a collaborative teamwork environment while diminishing blame games as the focus shifts towards facts and data rather than subjective opinions. Over time, the mindset evolves from mere compliance to a relentless pursuit of excellence.

2.2.3 Wastes (Muda)

In the Lean methodology, the concept of waste, often referred to as "muda," holds significant importance. Typically, scholars and practitioners identify eight types of waste [13]: overproduction, excess motion, waiting, inventory, excess movement of material, defect correction (rework), excess processing, and lost creativity (underutilization of resource skills). Each type of waste has specific causes and impacts on the production process.

Overproduction occurs when more products are produced than needed or faster than required by the next process. This often leads to excessive work-in-process (WIP). Causes of overproduction include long setup times, unbalanced workload, and a just-in-case philosophy. In some cases, traditional accounting methods may incentivize overproduction to amortize machine costs. However, Lean thinking encourages ongoing evaluation of WIP to identify opportunities for reduction or elimination.

Excess motion refers to unnecessary movements in the workplace. It results from poor workplace layout and leads to ergonomic problems, wasted time in searching for or moving supplies or equipment, and a potential reduction in quality levels. Lean practices, such as Kaizen events involving short-term teams focused on specific areas, can help address and rectify these issues.

Waiting is a waste commonly caused by delayed shipments, long setup times, or absent personnel. It results in wasted resources and can demoralize the workforce. Lean methodology proposes solutions such as setup time reduction, total productive maintenance, and cross-training of personnel to mitigate the impact of waiting.

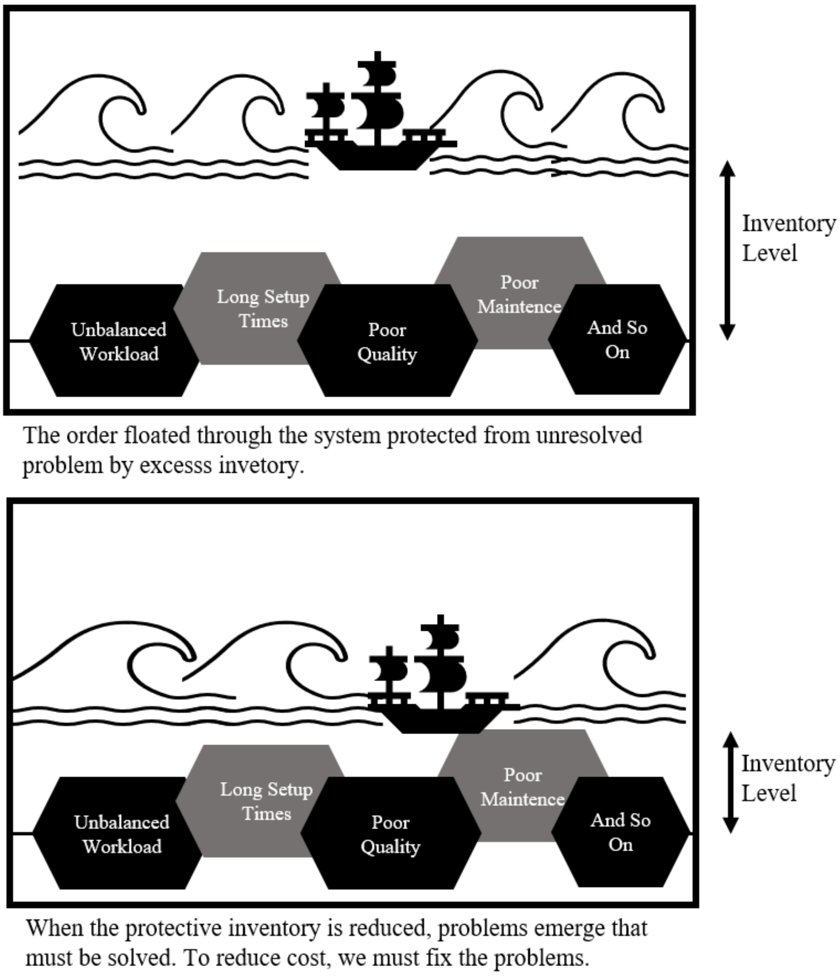


Figure 9: A Sea of Inventory often hides Unresolved Problems [1].

Excessive inventory incurs costs related to environmental control, record keeping, storage, and retrieval. These activities do not add value to the customer and are therefore considered wasteful in Lean thinking. Ideally, production should be synchronized with actual demand to avoid unnecessary inventory build-up.

Excess movement of materials or transportation adds complexity and cost to the production process. It can also have an impact on quality due to increased handling and storage. This waste is often attributed to poor plant layout, which Lean methodology aims to address by creating product or product-family-specific manufacturing cells.

Defect correction or rework is a non-value-added activity as customers are not willing to pay for the effort required to fix defective parts. Lean thinking emphasizes continuous efforts to reduce defect levels by addressing their root causes and implementing preventive measures. Excess processing or overprocessing can be challenging to identify but represents a significant waste. Entire steps in the value chain may be non-value-added and therefore wasteful. Lean methodology advocates for streamlining processes and eliminating unnecessary steps to mitigate this waste. In addition to the seven types of waste commonly identified, lost creativity represents a significant opportunity cost. Employees often possess ideas that can improve processes, but traditional organizational structures may hinder their contribution. Lean thinking calls for a cultural shift that empowers employees and fosters an environment where mistakes are viewed as learning opportunities, encouraging the exploration of new ideas.

The ultimate goal of eliminating waste, or muda, is to strive for perfection—a state where value-added activities are optimized, and waste is minimized. Achieving this perfection is not a one-time effort but a continual learning process that can lead to substantial tangible and intangible benefits.

2.2.4 Principles of Lean

The Lean methodology is guided by six principles designed to streamline operations, reduce waste, and increase value, all from the perspective of the customer [14][15][16]. These principles offer a systematic approach to enhancing efficiency and productivity, driving continuous improvement and fostering a culture of holistic participation in improvement processes.

1. Specify Value from the Customer's Perspective: This principle is the keystone of Lean thinking. No matter the excellence of your products or services, their true value is determined by the customer's perception and their willingness to pay for them. This value varies depending on the customer's needs and wants. Therefore, a key challenge for businesses is to identify and understand what their customers truly value, as well as the changes in their preferences over time.

2. Identify All Steps in the Value Stream: Recognizing every step in the value stream, extending from the suppliers' supplier to the customers' customer, is crucial in Lean thinking. These steps include all actions necessary to deliver your product or service to the customer, ranging from acquiring raw materials to after-sales customer service. The value stream does not confine itself within the walls of your organization; it integrates suppliers, distributors, direct and indirect customers. Using specialized process maps, particularly the value stream map, businesses can identify these steps, often uncovering a tremendous amount of waste in the process.

3. Flow: The principle of flow challenges the conventional batch-and-queue system. It proposes a shift towards continuous flow, where products are in constant motion, avoiding idle time or waiting periods. This approach necessitates a fundamental change in organizational thinking, often resulting in a refocus from functional efficiency to product or product-family efficiency. This might require physical layout modifications to facilitate a smooth, uninterrupted flow of goods.

4. Pull: Contrary to traditional push systems that rely on forecast-driven production, Lean methodology advocates for a pull system. In a pull system, production is initiated by actual customer demand, not by estimates or forecasts. The triggering of the production process in a pull system happens when a customer purchases a product, sending signals upstream. As a result, each process replaces what was used to fulfill the customer's order, effectively synchronizing production with actual demand. This way, inventory is kept at a minimum, and waste due to overproduction is significantly reduced.

5. Pursue Perfection Through Continuous Improvement: The Japanese call it "Kaizen," a principle that seeks perpetual refinement in all areas of the organization. The goal is to attain perfection, zero defects, one-piece flow, and so forth. Even as these objectives might seem unattainable, they serve as powerful motivators to continuously strive for improvement. Lean suggests a relentless pursuit of perfection; while your organization might be performing better than ever, there's always room for further enhancement.

6. Involve Everyone in Process Improvement: Lean is not merely a set of principles to be followed by top management; it's a culture to be adopted by everyone in the organization.

It calls for the involvement of all employees, at all levels, in the continuous improvement process. This democratic participation creates a sense of ownership among employees, fostering a holistic culture of constant learning and development.

Lean is a systematic and comprehensive approach to running an organization. Its implementation may be challenging, given the pull of tradition and cost-cutting focus, but its benefits are extensive. Lean proposes not merely a reduction in costs, but a better utilization of all resources to generate more value, serve more customers, and ultimately grow without incurring unnecessary expenditures.

When embraced fully, Lean transforms the organizational culture, propelling it towards efficiency, customer satisfaction, and continuous improvement. It ensures that value flows smoothly across the value stream, that production is pulled by genuine customer demand, and that every individual within the organization is an active participant in the never-ending journey towards perfection.

2.2.5 The Toyota Way

The five principles of Lean, namely value, value stream, flow, pull, and perfection, provide the philosophical groundwork for efficient and effective operation. Toyota, a pioneer in Lean manufacturing, has refined this philosophy into a set of 14 principles known as the Toyota Way [10].

These principles form a more granular and applicable blueprint for Lean implementation, focusing on long-term benefits, daily business management, respect for people, and a commitment to continuous improvement.

1. Base Management Decisions on a Long-Term Philosophy: The first and perhaps most challenging principle urges businesses to prioritize long-term success over short-term financial gains. While financial performance is essential, sustainable success lies in a strategic long-term vision that guides all decision-making processes. This foresight helps companies stay resilient amidst market fluctuations and prepares them for future growth opportunities.

2-8. Daily Process Management Principles: Principles two through eight are concerned with daily operational activities.

2. Create Continuous Process Flow to Surface Problems: By designing systems that create a continuous flow of work, bottlenecks and inefficiencies are made visible, allowing organizations to address them promptly.
3. Use Pull Systems to Avoid Overproduction: Following the Lean principle, a pull system is suggested, reducing waste by producing based on customer demand, not forecasts.
4. Level Out the Workload: Also known as "heijunka," this principle emphasizes workload balancing to avoid overburdening employees or resources and ensure smooth operations.
5. Build a Culture of Quality: Quality should never be compromised. Empower employees to halt production when they spot a quality issue, reinforcing a culture where getting quality right the first time is paramount.
6. Standardized Tasks: standardization provides clarity on job expectations and supports consistency, quality, and continuous improvement.

7. Visual Controls: visual controls allows real-time tracking of performance and surfacing of problems.
8. Use Proven, Reliable Technology: Technology should support people and processes, not dictate them. Any technological investment should be carefully vetted for reliability and its ability to serve the needs of the process and the people involved.

9-11. People-Focused Principles: Principles nine through eleven delve into the organization's human aspects.

9. Grow Leaders: Toyota advocates for developing leaders who understand and embody the company's philosophy and can impart that wisdom to others.
10. Develop Exceptional People and Teams: Teams, rather than individuals, are the cornerstone of Toyota's operational approach. Employees are expected to embrace the company philosophy and work collaboratively.
11. Respect Suppliers: A successful business not only takes care of its internal stakeholders but also respects and supports its external partners. Toyota extends its culture of continuous improvement to its suppliers, challenging them and aiding their development.

12-14. Continuous Improvement Principles: The final set of principles reaffirms the Lean philosophy of relentless improvement.

12. Go and See for Yourself: Known as "Genchi Genbutsu," this principle encourages decision-makers to observe the actual process or problem firsthand, promoting informed, realistic decisions and solutions.

13. Make Decisions Slowly by Consensus, Implement Rapidly: A culture of consensus promotes collective intelligence, ensuring every decision considers all perspectives. Once a decision is reached, swift implementation prevents stagnation and keeps the organization moving forward.

14. Become a Learning Organization: Reflecting on processes and outcomes fosters learning, making the organization adaptable and capable of handling future challenges.

2.2.6 Kaizen & Kaikaku

At the heart of Lean manufacturing lies a simple but powerful concept – Kaizen [17][18][19]. Derived from Japanese, 'Kai' means change, and 'Zen' means good or for the better. When put together, Kaizen translates to "change for the better" or "continuous improvement". It encapsulates the philosophy of making small, incremental changes that, over time, result in significant improvements.

Kaizen is a reflection of a mindset or culture that permeates every level of an organization. It's the belief that there's always room for improvement, no matter how small, and that every member of the organization, from the shop floor worker to the CEO, has a role to play in making these improvements.

Understanding the concept of Kaizen necessitates a clarification of the distinct but interconnected aspects of continuous and breakthrough improvement. Kaizen primarily represents continuous, incremental improvement. This is where employees at all levels work together to achieve regular, minor enhancements to a process. These changes may seem insignificant in isolation, but when compounded over time, they can yield substantial performance increases.

The Japanese term for breakthrough improvement is 'Kaikaku' [20], representing more radical, substantial changes. These are often the result of focused efforts like Kaizen events or Kaizen blitzes, where a cross-functional team assembles for a set period (usually three to five days) to identify and implement significant process improvements. The goal of these events is to achieve a rapid, dramatic performance improvement, or 'breakthrough'.

This Kaikaku approach is primarily used in Lean implementation to expedite the results of the transformation. These events can focus on anything from a single process to an entire value stream, with the shared aim of reducing waste and improving efficiency.

However, it's important to highlight that while Kaikaku can provide rapid results, it requires a robust management support system. The time and resources invested in conducting a Kaizen event must be justified by the significance of the problem at hand. If a team cannot afford to dedicate three to five days to improve a process constraint, the issue may either be unimportant, or the organization may require a deeper cultural adjustment before implementing Lean.

In a Lean organization, Kaizen and Kaikaku are not mutually exclusive [21]; instead, they work hand in hand. Kaikaku can act as a catalyst, leading to significant leaps forward in a short time. Meanwhile, Kaizen ensures sustained long-term improvement by continually refining processes and reducing waste incrementally.

Despite the difference in their approach and scale, both Kaizen and Kaikaku share a common goal: the relentless pursuit of waste reduction and efficiency enhancement. They embody the principle of continuous improvement that is central to Lean manufacturing.

Moreover, both emphasize employee involvement and empowerment. Kaizen promotes a culture where every worker is not just allowed but encouraged to suggest improvements. Similarly, Kaikaku events capitalize on the collective knowledge and diverse perspectives of a cross-functional team to achieve breakthrough improvements.

In conclusion, Kaizen, with its dual facets of continuous and breakthrough improvement, represents the essence of Lean manufacturing. By fostering a Kaizen culture, organizations can drive efficiency, improve quality, and empower employees, leading to enhanced competitiveness and sustainable success in the long run.

2.2.7 Gemba

In the world of Lean Manufacturing, understanding and leveraging the concept of 'Gemba' is vital. Gemba is a Japanese term that translates literally to 'the real place'.

In a business context, it refers to the place where value is created: in manufacturing, this is the shop floor; in a hospital, the operating room; in a software company, the developers' desk. Simply put, it's where the action happens.

Gemba is founded on the belief that to truly understand a situation, one must go to the source. In Lean, it's where problems are found and solved, and improvements are made. This principle is often encapsulated in the phrase "Gemba walk" [22], which describes the act of walking around, being present where the work is done, and observing the processes in action.

Gemba walks serve a dual purpose. First, they provide first-hand knowledge of the actual processes, untainted by interpretation or hearsay. This enables leaders to identify issues that they might otherwise miss in reports or meetings. Secondly, Gemba walks show workers that management cares about their work and their challenges, leading to increased engagement and mutual respect.

A common misconception is that the purpose of Gemba walks is to catch mistakes or to find fault with employees' work. On the contrary, the true purpose is to observe, ask questions, and listen to the employees' insights. It's about understanding the process from the perspective of those who work on it daily, not about auditing or policing the workforce. To conduct an effective Gemba walk, managers and leaders should follow a structured approach. Before embarking on a Gemba walk, they should clarify their purpose – is it to understand a particular process better? Or to identify potential bottlenecks or waste? The specific objective will guide what to look for and which questions to ask.

Once at the Gemba, managers should focus on understanding the process and the challenges the workers face. This involves active observation, asking open-ended questions, and most importantly, listening to the answers. Remember, the goal is not to dictate solutions but to gain insights that will lead to process improvements.

After the Gemba walk, it's crucial to follow up on the insights gathered. If workers shared concerns or suggestions, these should be addressed promptly, or at least communicated if it will take time. This follow-up reinforces workers' belief in the Gemba process, demonstrating that their voices are heard and their inputs valued.

Embracing the Gemba concept is a powerful tool for Lean organizations. It connects leadership with the realities of the shop floor, fuels continuous improvement, and promotes a culture of mutual respect and engagement. By focusing on the place where value is genuinely created, organizations can drive efficiency, reduce waste, and ultimately deliver products that better meet their customers' needs.

2.2.8 Poka Yoke

In the realm of Lean Manufacturing, Poka Yoke [23], a Japanese term translated as "error-proofing" or "mistake-proofing," plays a significant role in optimizing processes and eliminating waste. The primary aim of Poka Yoke is to prevent errors from occurring in the first place, or to catch them as early as possible if they do occur. This proactive approach aligns seamlessly with the broader Lean Manufacturing goal of reducing waste and increasing efficiency.

Poka Yoke originated in the Toyota Production System, a precursor to Lean Manufacturing. Initially, the term was "Baka Yoke," which means "fool-proofing," but it was later changed to "Poka Yoke" to avoid disrespecting workers. This change reflects the principle that mistakes in production are not the result of foolish workers, but rather of processes that allow these errors to happen.

The practical applications of Poka Yoke in manufacturing are varied and can be ingeniously simple. They range from fixture designs that only allow parts to be assembled in one direction, to alarms and sensors that alert operators to abnormalities, or automated checklists that ensure all steps in a process have been completed before moving forward. No matter the specific implementation, the goal remains the same: prevent errors, and by doing so, prevent defects.

Implementing Poka Yoke techniques in a process involves several steps. Firstly, potential errors need to be identified. This is often done through methods such as Failure Modes and Effects Analysis (FMEA) or simply by soliciting feedback from workers, who, given their proximity to the work, are often the best at identifying where errors may occur. Once potential errors are identified, the next step is to design a Poka Yoke solution that either prevents the error from happening or detects it immediately after it occurs. It is important to note that the best Poka Yoke solutions are often the simplest ones. Complex solutions can introduce new potential sources of error and can be difficult for workers to adhere to.

Finally, after the Poka Yoke solution is implemented, its effectiveness should be monitored and adjusted as necessary. As with all Lean tools, the goal is continuous improvement, so even an effective Poka Yoke solution should be subject to periodic review and improvement.

2.2.9 Value to the Organization

Adopting Lean as an operational strategy can be transformative for an organization, leading to multiple benefits, some of which are often broad, indirect, and long-term. These benefits span different areas such as culture, efficiency, effectiveness, agility, and financials, all of which contribute to the overarching goal of creating sustainable value for the organization [24][25][26].

Customer Centricity: W Edward Deming, a prominent figure in the realm of quality management, emphasized the idea of creating customers for life. In Lean, the concept of 'value' is defined from the customer's perspective. It means that organizations should focus on continuously delivering products or services that meet customer needs and expectations, which, in turn, cultivates customer loyalty. It is typically more cost-effective to retain and satisfy existing customers than to acquire new ones, and loyal customers are more likely to become advocates, promoting the business to others, which can lead to business growth.

Cultural Transformation: One of the significant advantages of Lean is its potential to drive profound cultural change within an organization. Lean fosters a culture of continuous improvement, where everyone, from top management to frontline workers, is engaged in identifying and eliminating waste. This cultural shift can take time and requires commitment, but the transformation can be remarkable. Engaged employees, who understand their role in value creation and are empowered to make improvements, can drive increased productivity and innovation. This not only leads to higher employee satisfaction but also contributes to better customer experiences.

Increased Efficiency: Lean principles and tools aim to improve efficiency by streamlining processes, reducing waste, and better utilizing resources. Instead of adding more equipment or personnel, Lean seeks to maximize the existing capacity. This leads to cost savings and better throughput, allowing the organization to meet customer demand more effectively and efficiently.

Improved Effectiveness: Effectiveness in a Lean context refers to the ability of the organization to meet customer needs accurately. By focusing resources on value-adding activities and reducing non-value-adding ones, Lean organizations can enhance the quality of their products or services, leading to improved customer satisfaction.

Enhanced Agility: In today's rapidly changing markets, the ability to pivot quickly in response to customer and market needs is a crucial competitive advantage. Lean organizations, with their streamlined processes and continuous feedback loops, are well-equipped to adjust their operations and strategy swiftly and efficiently.

Financial Benefits: The financial benefits of Lean can be substantial, though they may not be immediately apparent or easy to measure. These include direct cost savings from reduced waste and more efficient use of resources, increased revenue from improved customer satisfaction and retention, and better cash flow from reduced cycle times and inventory levels. Furthermore, improved space utilization can defer or eliminate the need for capital investment in additional facilities.

In conclusion, the benefits of Lean are manifold and impactful. However, realizing these benefits requires a systemic and sustained effort, a commitment to long-term goals over short-term performance metrics, and a willingness to engage every member of the organization in the journey towards continuous improvement. By doing so, an organization can create a Lean culture that drives productivity, profitability, and customer satisfaction, contributing to sustainable success.

2.3 Six Sigma

2.3.1 Six Sigma Philosophy

Six Sigma [27] is a well-structured, data-driven methodology for eliminating defects, reducing process variability, and improving quality in processes, products, and services. It is primarily utilized as part of quality improvement but can also be integrated into quality planning, emphasizing strategic thinking.

This methodology, developed by Motorola in the early 1980s, utilizes a five-step model known as DMAIC: Define, Measure, Analyze, Improve, and Control. These steps provide a systematic approach to process improvement, emphasizing the use of statistical tools to reduce variation and enhance quality.

While Six Sigma and Total Quality (TQ) [28] share the overarching goal of quality improvement, they differ in focus and implementation. TQ, which echoes Deming's principles [29] and is reflected in the Malcolm Baldrige criteria [30], tends to concentrate on cultural transformation, empowering workers and teams to foster continuous improvement primarily within departments or functions. It typically employs simple but powerful tools for process improvement, highlighting that not all situations require complex statistical methods.

Conversely, Six Sigma focuses on high-level, cross-functional processes, requiring strong involvement from upper management and leaning on a cadre of experts for implementation. Its methodology incorporates advanced statistical tools to meticulously analyze and reduce process variation, striving towards virtually defect-free performance.

Despite these differences, Six Sigma and TQ can complement each other well. Combining the cultural emphasis of TQ with the rigorous, data-driven methods of Six Sigma can create a more holistic approach to quality and process improvement. Six Sigma is particularly oriented towards business outcomes, emphasizing benefits for the company, such as reduced costs, increased market share, and ultimately, higher profitability. By focusing on improving both the design and conformance quality, Six Sigma can enhance customer-perceived quality, leading to lower service costs, increased margins, and expanded market share.

However, successfully implementing Six Sigma requires a significant shift in mindset. Instead of being problem-driven, organizations need to become customer-driven. Rather than simply reacting to issues and dissatisfaction, they should proactively seek ways to prevent them. Under the Six Sigma philosophy, waste and rework aren't just problems to be fixed – they are opportunities for improvement, prevention, and reduction.

2.3.2 Significance of Six Sigma

The concept of Six Sigma is centered around reducing process variation and improving quality performance. This is exemplified through the expectation of a 1.5 sigma shift when comparing short-term and long-term performance in variation [31][32]. The shift represents a natural fluctuation in a process over time, and when considered, enables us to account for the practical reality of process performance.

While achieving a Six Sigma level of quality - that is, reducing defects to a staggering low of 3.4 per million opportunities - may seem a formidable task, it's essential to understand that substantial gains can be achieved at intermediate stages. As we move from one sigma level to the next, the defect reduction can be considerable, bringing significant improvements to process efficiency, product quality, and customer satisfaction.

One way to appreciate the potential of Six Sigma is by examining the curve of parts-per-million defects compared to sigma levels. Many processes utilized daily exhibit ample room for improvement, and the progression toward higher sigma levels can have profound effects on performance. When a process moves from a three-sigma to a six-sigma level, it signifies a reduction from 66,810 defects to merely 3.4 defects per one million opportunities - a testament to the transformative power of Six Sigma.

Organizations that consistently deliver products and services at the Six Sigma level are considered best-in-class. The benefit of reaching this level goes beyond mere process improvements. The financial implications are substantial, with significant savings from reduced waste and rework. Furthermore, achieving Six Sigma quality drastically reduces risk factors that can impact customer perception and harm a company's reputation.

To illustrate this, consider the quantifiable impact on various real-world examples [1]:

- In the healthcare sector, the implementation of Six Sigma could reduce wrong drug prescriptions from at least 200,000 each year to just 68 per year.
- In aviation, it could mean the difference between two short or long landings at major airports each day versus one such incident every five years.
- In surgical procedures, errors could drop from 5,000 incorrect procedures every week to only 1.7 per week.
- The postal service could reduce lost articles of mail from 20,000 per hour to just seven per hour.
- In terms of public utilities, unsafe drinking water could decrease from almost 15 minutes each day to one unsafe minute every seven months, and electrical outages could drop from almost seven hours each month to the same duration every five years.

These examples illuminate the profound impact of Six Sigma. Not only does it bring about substantial improvements in process efficiency and product quality, but it also enhances safety, reduces risk, and drastically improves customer satisfaction. Thus, Six Sigma represents a significant strategic tool for any organization seeking to excel in today's competitive marketplace.

2.3.3 Six Sigma History

Motorola introduced Six Sigma in 1986 [27] as a rigorous and systematic methodology for process improvement. Bill Smith and Mikel Harry, two pioneers in the field, initially developed the four-step Six Sigma stages: Measure, Analyze, Improve, and Control to effectively reduce defect levels. Their work set the groundwork for the development of Six Sigma as a means to improve quality performance within organizations.

Mikel Harry, often recognized as the primary architect of the Six Sigma movement, later co-founded the Six Sigma Academy in 1994 with Richard Schroeder [33], contributing to the spread of Six Sigma methodology across businesses and industries. The roots of Six Sigma can be traced back to a collective of knowledgeable individuals in the field of quality, each contributing their unique perspectives and methodologies to the discipline.

One of these influential figures is Dr. W. Edwards Deming, whose contributions to quality management principles have been fundamental. Deming's 14 points [34], for example, introduced the importance of a constancy of purpose towards improvement and a refusal to accept defects and errors as a normal occurrence. He underscored the significance of avoiding an exclusive focus on price at the expense of quality, championing instead a strategic balance of the two.

Deming was a staunch advocate for continuous improvement, promoting the significance of constant learning through on-the-job and cross-functional training. He highlighted the distinction between leadership and mere supervision, arguing for the elimination of fear in organizations to foster growth and development. Deming's approach focused on simplifying communication within organizations, breaking down siloes, and encouraging collaboration over competitiveness.

Similarly, Armand Feigenbaum [35] contributed distinct insights into quality control, extending its relevance beyond the manufacturing floor to design and delivery realms. He defined total quality control as a comprehensive system for integrating quality development, maintenance, and improvement efforts at the most economical levels.

Other noteworthy contributors to the Six Sigma process include Kaoru Ishikawa [36], known for his Fishbone diagram and the 5 Whys technique, and Joseph M. Juran [37], who developed Juran's Trilogy of quality planning, control, and improvement.

Dorian Shainin [38] further advanced numerous techniques revolving around principles of variance and statistical engineering, including the identification of a dominant variable or cause in many problems, a principle that later became known as the Pareto principle or the 80-20 rule.

Another luminary in quality circles, DH Stamatis [39], is particularly known for his foundational work in failure modes and effects analysis. Genichi Taguchi [40] also contributed significantly to the field of quality by emphasizing the initiation of quality at the engineering and design levels of the process. Lastly, Walter A. Shewhart [41] advanced the understanding of assignable and chance causes, a concept used in Statistical Process Control and the Plan-Do-Check-Act (PDCA) cycle.

2.3.4 PDCA

The Plan-Do-Check-Act (PDCA) cycle, also known as the Deming Cycle, is a fundamental tool in continuous improvement and plays a critical role in the application of Six Sigma. The cycle embodies the essence of Six Sigma by providing a structured approach to problem-solving and continuous improvement.

Figure 10: PDCA Cycle [1].

1. Plan: The first stage, 'Plan', involves identifying a problem and analyzing its causes. It requires a clear definition of the process or product to be improved and a deep understanding of customer needs and expectations. Data collection is an integral part of this stage, providing a factual basis for problem identification and subsequent analysis. In a Six Sigma context, this stage would involve defining the improvement project, its scope, objectives, and potential benefits. It aligns closely with the Define and Measure phases of the DMAIC (Define, Measure, Analyze, Improve, Control) cycle.

2. Do: The 'Do' stage involves developing and implementing solutions to address the identified problem or improve the process. It typically involves testing solutions on a small scale before full-scale implementation, reducing the risk of negative impacts from unexpected outcomes. In Six Sigma, this step parallels the Analyze and Improve phases of DMAIC, where potential solutions are evaluated and the best solution is implemented.

3. Check: The 'Check' phase involves monitoring the implemented solution to ensure that it is working as expected and making the necessary improvements. This phase requires an ongoing collection and analysis of data to evaluate the effectiveness of the solution. In Six Sigma, this corresponds with the Control phase of the DMAIC cycle, where the implemented changes are monitored to ensure they deliver the expected improvements.

4. Act: In the 'Act' phase, the improvements are standardized and the lessons learned are documented for future reference. If the solution implemented in the 'Do' phase has resulted in the desired improvement, the changes are standardized to ensure consistent

application across the process. This stage also involves planning for future PDCA cycles and Six Sigma projects based on the learning from the current project.

The PDCA cycle is a vital component of the Six Sigma methodology. It aligns well with the DMAIC cycle used in Six Sigma projects and reinforces the emphasis on continuous improvement and data-driven decision making. It underscores the iterative nature of improvement work, reinforcing the need for ongoing efforts to maintain and further improve quality and performance. Through its systematic, cyclical approach to problem-solving, the PDCA cycle contributes significantly to the successful implementation and sustainability of Six Sigma improvements.

2.3.5 DMAIC Model

The DMAIC model is a cornerstone of the Six Sigma methodology, driving the quest for process improvement and optimization. The acronym stands for Define, Measure, Analyze, Improve, and Control, each representing a phase in the project lifecycle. This chapter will delve into these stages in detail and their significance in Six Sigma, incorporating the data provided and pre-existing knowledge on the topic.

2.3.5.1 Define

The Define phase forms the foundation of any Six Sigma project. This phase is all about understanding the problem at hand from a customer satisfaction viewpoint, identifying the stakeholders, and understanding the process through tools like SIPOC (Suppliers, Inputs, Process, Outputs, Customers). In essence, it involves setting the project goals and boundaries. The significance of management commitment in this phase cannot be overstated. By initiating the project, outlining its scope, and establishing its objectives, management sets the tone for the ensuing stages. Tools like flowcharts and the five whys technique can aid in this endeavor.

2.3.5.2 Measure

In the Measure phase, the existing process is scrutinized to collect relevant data. This phase calls for precision and attention to detail, as the quality of data collected directly influences the effectiveness of the subsequent phases. A data collection plan is formulated, and statistical tools such as check sheets, histograms, Pareto charts, run charts, and scatter diagrams are used. Further, Measurement System Analysis (MSA) is employed to ensure that the data collection process itself is reliable. The data gathered helps in determining the process capability and identifying sources of variation.

2.3.5.3 Analyze

The Analyze phase involves scrutinizing the collected data to identify the root causes of the problem. This phase employs rigorous statistical analysis to delve into the process and data, identify trends, patterns, and relationships, and thereby highlight the reasons for variation and process inefficiencies. Advanced tools like the central limit theorem, geometric dimensioning and tolerancing (GD&T), and shop audits can be used here. The aim is to confirm the causes of issues and substantiate them with data.

2.3.5.4 Improve

In the Improve phase, the team focuses on mitigating or eliminating the root causes of the problem. This is where creative problem-solving skills come to the fore, as different solutions are brainstormed and tested. Techniques like Process Improvement, Variation Reduction, and

Design of Experiments (DOE) play crucial roles here. These strategies help devise process modifications that can substantially curb defects, improve process efficiency, and enhance customer satisfaction.

2.3.5.5 Control

The final phase, Control, is all about ensuring the gains achieved are sustained in the long run. Here, a Control Plan is developed and implemented to monitor the process closely and ensure it doesn't deviate from the updated process. Tools like Mistake-proofing and Process Behavior Charts are utilized to safeguard the process against future errors. Further, Management's role is crucial in consolidating the improvements and making sure the new methods are fully integrated into daily operations.

2.3.6 Navigating the Six Sigma Roadmap

The journey towards Six Sigma efficiency is one that demands discipline, commitment, and above all, a well-laid roadmap. The stages outlined provide a roadmap that charts the path from recognizing variation to celebrating success, incorporating a cyclical element of continuous improvement. In this chapter, we will discuss this suggested Six Sigma roadmap, blending the information provided with our knowledge of Six Sigma principles and practices.

Recognize Variation and Standardize Work: The first step in the Six Sigma journey is recognizing that variation exists in every process. To reduce this variability, it's crucial to standardize work. Standardization brings uniformity to tasks, making them easier to manage, measure, and control. It provides a consistent base from which one can observe variations and quantify them, thus setting the stage for improvement.

Understand Customer Requirements: Six Sigma is intrinsically customer-focused, and thus, the next step is identifying what the customer wants and needs. Understanding customer requirements allows for targeted reduction in variation that specifically enhances customer satisfaction. Using tools such as Voice of the Customer (VoC) can provide critical insights into customer expectations and needs.

Deploy Problem-Solving Methodologies: The third stage in the roadmap involves using a problem-solving methodology to plan improvements. Here, the focus shifts to identifying potential solutions to the issues uncovered in the preceding steps. Techniques like root cause analysis, brainstorming, and other problem-solving approaches are employed to devise potential solutions.

Implement the DMAIC Model: The DMAIC model is then used to deploy the improvement. This model – Define, Measure, Analyze, Improve, Control – provides a structured approach to process improvement, ensuring each step is underpinned by data and rigorous analysis. The model allows for targeted improvements, ensuring the solutions devised in the previous stage are effectively implemented.

Monitor with Process Behavior Charts: Once improvements are implemented, the next step is to monitor the process using process behavior charts. These charts provide visual cues about how the process is performing over time, making it easier to spot out-of-control conditions and react swiftly to maintain process stability.

Update Standard Operating Procedures: With the process stabilized and improved, the focus shifts to sustaining these gains. Standard Operating Procedures (SOPs) are updated to reflect the improved process, ensuring everyone in the organization is aware of the changes and can adhere to the new methods. Additionally, the lessons learned during the project should be documented and shared to encourage organizational learning.

Celebrate Successes: In the journey of continuous improvement, celebrating successes is a crucial aspect. It not only fosters a positive culture within the organization but also encourages the team to maintain their enthusiasm for continuous improvement.

Continual Improvement: Finally, the process starts over again in the spirit of continuous improvement. The PDSA (Plan-Do-Study-Act) or SDCA (Standardize-Do-Check-Act) cycles are employed to drive this continual improvement. The aim is not just to reach Six Sigma but to keep striving for improvement, even beyond it.

2.3.7 Cost – Benefit Analysis

In the world of Six Sigma, the Cost-Benefit Analysis is an indispensable tool, acting as the financial backbone that evaluates the efficacy of quality management efforts. It presents an in-depth look at the costs affiliated with quality, or the lack thereof, in the products or services. These costs typically manifest in four forms: prevention costs, appraisal costs, internal failure costs, and external failure costs.

Cost-Benefit Analysis, when applied to quality, aims to find a financial balance between the costs of improving quality and the benefits reaped from such improvements. It underscores the importance of understanding not only the visible costs of poor quality but also the concealed costs like rework, returns, and damaged reputation, all of which can heavily impact an organization's bottom line.

Prevention costs encompass expenses related to activities that are designed to prevent poor quality in products or services. These activities can include quality planning, training, and process control. Conversely, appraisal costs relate to the activities of inspecting, assessing, or auditing products or services to confirm their adherence to quality benchmarks and performance specifications. These can entail the inspection and testing costs, supplier performance evaluation, and the calibration of measuring and testing equipment.

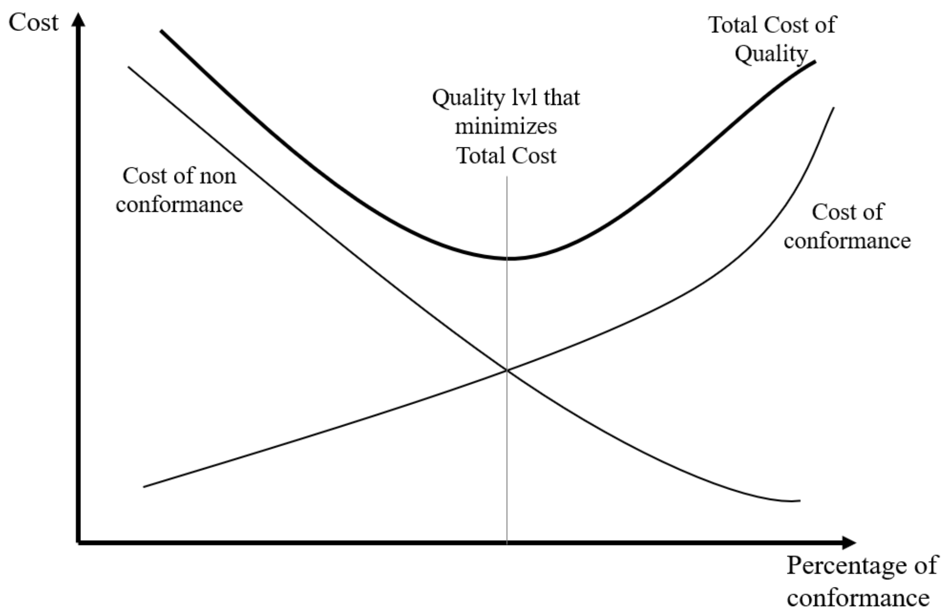


Figure 11: Traditional Quality Cost Curves [1].

Internal failure costs refer to the expenses involved in rectifying faults identified prior to the product or service being delivered to the customer. These expenses arise when outcomes don't meet the set quality benchmarks and are identified before being delivered to the customer.. Instances of these costs include rework, scrap, and corrective actions. Lastly, external failure costs are those related to defects found after the customer receives the product or service. Such costs occur when products or services don't meet quality expectations and this shortfall is not identified until after the product or service has been delivered to the customer. Examples include warranty claims, complaints, and returns.

A key feature of the Cost-Benefit Analysis in Six Sigma is its ability to track trends over time. The ultimate objective is to comprehend the total cost involved in providing your products or services to the customers. When the cost of quality is first calculated, many organizations find themselves surprised at the sheer amount of waste being produced.

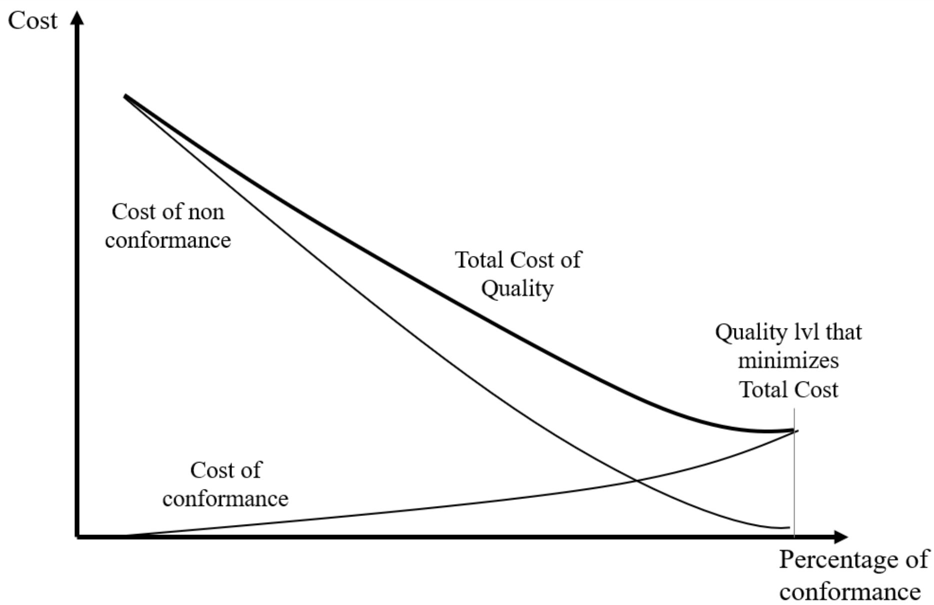


Figure 12: Modern Quality Cost Curves [1].

However, the true potency of the Cost-Benefit Analysis shines when organizations start focusing on reducing prevention and appraisal costs, leading to a decrease in failure costs both internally and externally. It's important to remember that this reduction won't happen overnight. In some stubborn cases, it may even take years for tangible improvements to surface as old products work their way out of the customer system.

The ultimate goal of the Six Sigma process is to transform the cost picture by constantly reducing the total cost of quality. This transformation can be achieved by creating a culture of continuous improvement, where all members of the team are actively involved in identifying and implementing ways to minimize quality-related costs.

A successful cost-reduction culture demands transparency. By making the results of the Cost-Benefit Analysis available to everyone, all team members can be motivated to generate ideas for improvement. As the old saying goes, "What gets measured gets done!" This visibility reinforces the importance of quality in the organization and assures everyone that management is keeping a keen eye on the numbers associated with the cost of quality, propelling improvements across the board.

2.4 Design for Six Sigma

Design for Six Sigma (DFSS) represents a paradigm shift in process and product design, marking a significant departure from conventional quality control methodologies. It's an integral part of Six Sigma, a strategy that, while resonating with the latter's core principles, uniquely concentrates on embedding quality right from the design phase.

When DFSS is implemented, it endeavors to prevent problems before they occur. This is a marked shift from traditional quality improvement methodologies, which focus on identifying and correcting defects in existing processes and products. The DFSS approach is proactive, dealing with potential issues during the design stage itself. This proactive approach to quality is key to mitigating risks, reducing costs, and improving efficiency.

DFSS follows a structured methodology that is reminiscent of the DMAIC process, but it is uniquely adapted for the design context. This methodology is typically denoted by the acronym DMADV, which stands for Define, Measure, Analyze, Design, and Verify. Each phase of this process focuses on a specific aspect of design, all working in harmony to deliver a product or process that not just meets but exceeds customer expectations.

While each project may demand specific tools and techniques in each phase, the universal spirit of DFSS is an undeterred focus on quality and customer satisfaction. In this era of global competition and increasing customer demands, DFSS serves as a potent tool for organizations striving to create superior products and services.

Integrating DFSS into an organization's culture is a transformative journey. It requires the instilment of a culture that esteems innovation, quality, and a relentless commitment to customer satisfaction. It's about cultivating an environment that values foresight and proactive action, where the identification of potential problems during the design phase is considered as important as solving current ones.

A distinct advantage of DFSS is its universal applicability. Whether it's a manufacturing company working on a new product, a service provider designing a new service, or an

IT company developing software, DFSS principles hold. This versatility makes it a valuable methodology for all sectors striving for excellence.

Adopting DFSS is often seen as a strategic decision. It aligns with an organization's long-term goals of reducing variation, minimizing waste, and enhancing customer satisfaction. DFSS is not just a set of tools or processes; it's a philosophy that guides an organization towards a vision of unblemished quality and customer satisfaction.

Moreover, DFSS is all about cost-effectiveness. By identifying and rectifying potential defects at the design phase, DFSS dramatically reduces the costs associated with late defect detection. It also brings down the overall development time, as fewer revisions are required once the product or process is rolled out.

The customer-focused nature of DFSS is another major benefit. By seeking to understand customer needs and expectations at the earliest stage of design, DFSS ensures that the end product or process is in perfect alignment with what the customer desires. This heightened customer alignment often results in enhanced customer loyalty, increased market share, and a stronger brand image.

Design for Six Sigma is an innovative methodology that is helping organizations across the globe to embrace a new level of quality and customer satisfaction. By putting quality at the heart of design, DFSS ensures that products and services are right the first time, every time. Its strategic, customer-centric, and cost-effective approach makes it an invaluable asset for organizations seeking to thrive in today's competitive marketplace. As we navigate the complexities of the 21st-century economy, the DFSS approach stands as a beacon, guiding us towards a future where excellence is not just an aspiration, but a reality.

2.4.1 DMADV

In today's competitive business environment, the emphasis on creating products and processes that meet and exceed customer and business requirements is more prominent than ever. One method that facilitates this proactive stance is the DMADV methodology, a core part of the Design for Six Sigma (DFSS) process.

DMADV, an acronym for Define, Measure, Analyze, Design, and Verify, is noted by Breyfogle [42][43][44] as the optimal methodology when either a new product or process needs to be developed, or when the existing one, despite optimization, does not meet customer or business needs. It is a data-driven approach aimed at aligning design objectives with final outputs, thereby reducing waste and increasing efficiency.

2.4.1.1 Define – Setting the Stage

The initial phase of DMADV, Define, sets the foundation for the entire project. In this crucial phase, the Six Sigma team works on evaluating and prioritizing the primary design objectives of the organization. The goals of the project, customer demands, and the requirements of the product or process are carefully defined. By targeting these priorities, the design efforts will have a profound impact on attaining Six Sigma targets. This phase sets the path for the forthcoming stages, ensuring that the team's focus aligns with the most significant areas of impact.

2.4.1.2 Measure – Recognizing What Matters

Following the Define phase is the Measure phase. Here, the team specifies the design criteria that are of most value to the customers and the industry at large. This stage requires a harmonious blend of technical expertise and competitive product management analysis. Additionally, expectations imposed by regulators, partners, and other stakeholders are identified and documented. This phase is pivotal, as it helps develop a deeper understanding of market dynamics and allows the team to measure essential metrics accurately.

2.4.1.3 Analyze – Making Informed Decisions

The Analyze phase comes next. Using the data gathered during the Measure phase, the team applies statistical and investigative methodologies to identify design priorities with significance and confidence. It uncovers potential risks, leading to more informed decision-making in the design stage. In essence, this phase serves as a guiding light, illuminating the direction in which the design efforts should be targeted.

2.4.1.4 Design – Creating with Intent

The Design phase in DMADV forms the practical heart of the process. It's where the insights generated in the Analyze phase start transforming into reality. This stage is more than just conceptualizing a product or service; it's about creating solutions that are efficient, customer-focused, and align with business goals. This chapter will delve deeper into the various objectives that guide the Design phase of DMADV, underlining the importance of each objective in shaping a successful design.

- Design for Cost (also known as Design to Cost): This approach ensures cost efficiency in the design process. Cost is a major consideration in many markets, and this principle encourages the constant pursuit of alternative processes, materials, and methods that can reduce cost while maintaining or enhancing quality. The design team may collaborate with cost accounting and purchasing departments to facilitate cost-effective design solutions.
- Design for Manufacturing/Producibility/Assembly: This concept focuses on subtle design modifications that streamline production and reduce manufacturing expenses. A good design, aligned with existing manufacturing capabilities, can yield significant savings in machining processes, tooling, and gauging. It also encourages reducing the number of parts in a product as a practical method of decreasing manufacturing costs.
- Design for Test (also known as Design for Testability): This principle stresses the importance of designing products that facilitate early-stage testing during the production process. Rather than relying entirely on functional tests of a completed assembly or subassembly, designing for testability means creating provision for performing tests earlier in the production cycle, thereby improving quality and reducing potential failures.
- Design for Maintainability: This is about ensuring the ease of maintenance. Designing products that require extended downtimes for diagnosis and repair can be detrimental to the user experience and, by extension, customer relations. Maintainability considerations include modularity, decoupling, and component standardization.
- Design for Robustness: This ensures the reliability and longevity of a product. Adequate time must be allocated during the design process to conduct life cycle tests of all parts,

subassemblies, and assemblies. It's also crucial to document the mean time to failure (MTTF) or mean time between failures (MTBF) for all products supplied.

- Design for Usability: The quality of a product is ultimately determined by its usability—the ease with which its intended users can operate it comfortably to obtain value. Hence, user-friendliness becomes an essential aspect of the design phase.
- Design for Extended Functionality: This encourages designs that transcend the initial vision, providing features applicable to a broader range of functions. This way, a product originally designed for a single purpose can be extended to meet evolving needs.
- Design for Efficiency: Efficiency in design is about developing a product or system that consumes minimal resources. This principle, though similar to design for cost, focuses more on resource consumption, including time, energy, and critical components.
- Design for Performance: This approach aims to design products that consistently achieve or exceed aggressive performance benchmarks. It is about pushing boundaries and innovating to meet ever-increasing customer expectations.
- Design for Security: As security threats grow in complexity and scope, ensuring product integrity, protecting intellectual property, and preserving user privacy become crucial design considerations. Design for security can significantly enhance a product's reputation and market acceptance.

- Design for Scalability: This involves designing products or systems capable of expanding or adapting to rapid market growth. This attribute prevents quality compromises when product usage increases dramatically.
- Design for Agility: In an age of rapid technological advancements, the ability to deliver customized solutions within a short time becomes a competitive advantage. This principle demands a flexible strategy for swift development, sturdy framework, and a diverse set of elements capable of enhancing the primary product with distinct characteristics.
- Design for Compliance: Given that every product must satisfy certain regulations to be marketed, the design phase needs to incorporate all such compliance requirements. Compliance could involve achieving specific product performance capabilities or demonstrating adherence to prescribed design processes.

In sum, the Design phase of DMADV requires not just technical acumen, but also a deep understanding of customer needs, market dynamics, and strategic business goals. Each of the design principles detailed above plays a vital role in creating products that are not just functionally superior but also economically viable, market-ready, and sustainable. This phase, therefore, remains the cornerstone of successful product development, driving both customer satisfaction and business growth.

2.4.1.5 Verify – The Final Check

The final phase, Verify, is the culmination of the entire DMADV process. The design, having been meticulously planned and executed, must now be validated to ensure that it fulfills the original design objectives. Verification can be demonstrated using a traceability matrix, which links the design objectives to the design outputs. This phase acts as a final checkpoint, ensuring that the entire DMADV process has been faithfully executed and that the final product or process aligns with the set objectives.

DMADV is an invaluable tool for businesses seeking to design or redesign their products or processes in a systematic, data-driven, and customer-centric way. By dissecting each phase of this methodology, we gain a deeper understanding of how this process works, thereby enabling us to better apply it in real-world scenarios.

2.5 FMEA

The practice of Failure Mode and Effects Analysis (FMEA) is fundamentally an exploration and assessment of risk. As a systematic and procedural approach, it has broadened to integrate various disciplines, becoming a crucial tool for diverse sectors ranging from engineering to health care and finance. The strength of FMEA lies in its potential to predict and mitigate risks before they materialize, enabling proactive control over unforeseen outcomes.

Risk is the inherent uncertainty of any event or action, carrying potential implications—positive or negative—that could impact the functioning of an organization or the performance of a product or service. The foundation of risk can be viewed through the lenses of three dimensions: severity (impact), frequency (occurrence), and detectability (event). The Risk Management Memory Jogger [45] lays out a Risk Road Map for ISO 31000:2009 of:

- Plan risk management
- Risk identification tools

- Analyze and evaluate risk
- Plan risk response
- Monitor and control risk

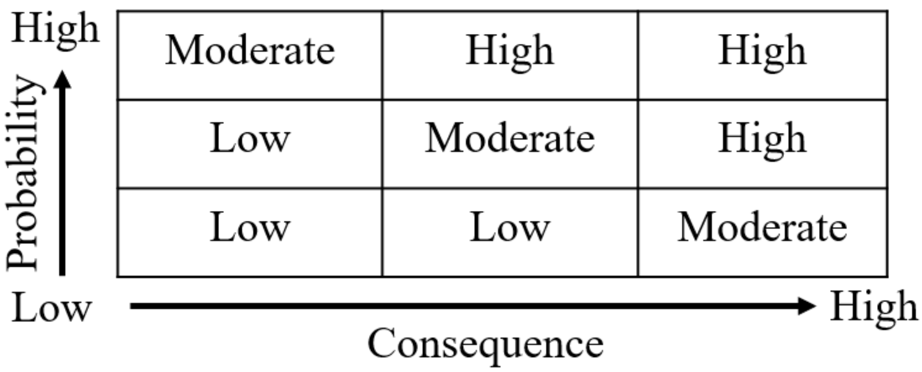


Figure 13: Simple Risk Matrix [1].

2.5.1 Evolution of FMEA

Initially, FMEA began as an informal process where inventors and product developers considered potential failure scenarios and implemented countermeasures in design and manufacturing processes. However, over time, FMEA has evolved and adapted to meet the increasing complexity of processes and products, culminating in a series of standards and procedures that shape its present form.

Noteworthy milestones in the development of FMEA include [1]:

- The U.S. Military first issues what we now know as FMEA on November 9, 1949—Military P-1629: Procedures for Performing a Failure Mode, Effects and Criticality Analysis. This led into the MIL-STD 1629 series of documents.
- NASA's Apollo space program uses RA-006-013-1A: Procedure for Failure Mode, Effects, and Criticality Analysis (FMECA), August 1966.
- Enterprise risk management (ERM)—in the early 1970s Gustav Hamilton of Sweden's Statsfoetag proposes the "risk management circle."
- Ford Motor Company starts using FMEA in the late 1970s after the Pinto issue.
- The NASA Challenger disaster on January 28, 1986, exposes a MortonThiokol O-ring FMEA in the resulting legal litigation.
- The Committee of Sponsoring Organizations (COSO) is organized in 1985. The full name is Committee of Sponsoring Organizations of the Treadway Commission, and their focus is on the financial aspects of risk management and fraud prevention.
- The Automotive Industry Action Group (AIAG) releases the first Big Three PFMEA in February 1993. (History: February 1993, February 1995, July 2001, fourth edition 2008.)
- SAE International releases SAE J-1739: Potential Failure Mode and Effects Analysis in Design (Design FMEA), Potential Failure Mode and Effects Analysis in Manufacturing and Assembly Processes (Process FMEA) 2009-01-15. (History: 1994-07-01, 2000-06-01, 2002-08-02, 2009-01-15.)

- ASQ publishes the first edition of D. H. Stamatis, Failure Mode and Effect Analysis: FMEA from Theory to Execution in 1995, second edition June 2003.
- AIAG releases FMEA for Tooling & Equipment (Machinery FMEA) November 1, 2001—second edition February 2012
- International Organization for Standardization (ISO) releases ISO 31000:2009 Risk management—Principles and guidelines.

The International Standard ISO 9001 was updated in 2015 to incorporate "risk-based thinking", further emphasizing the significance of risk management in quality systems.

2.5.2 Importance and Benefits of FMEA

The motivation behind FMEA is to foresee potential failure modes, analyze their impact, and determine the highest likelihood of their occurrence at different levels—be it concept, design, process, machinery, or system.

FMEA aids in recognizing and evaluating the potential failure of a product/process and the effects of that failure. The essence of FMEA lies in its ability to forecast the most probable risks that could occur, be it at the conceptual, design, process, equipment, or system stage. This philosophy can be encapsulated by the old adage "a stitch in time saves nine." By thoroughly visualizing the upcoming processes and documenting them meticulously either on paper or in a software system, the chances of predicting and preventing occurrences or situations that may cause unpleasant issues for the organization are significantly improved. It pinpoints measures that could eradicate or diminish the likelihood of a potential failure happening and plays a crucial role in recording the entire process. In essence, it is a significant step towards building a culture of risk-based thinking, vital to any robust Quality Management System (QMS).

Embracing a proactive approach to risk management, many organizations utilize the concept of a risk matrix to scrutinize potential issues within their operations. The automotive industry, through bodies such as the Automotive Industry Action Group (AIAG) and SAE International [46], has been instrumental in advancing this methodology.

The AIAG has defined FMEA as a succession of methodical actions aimed at identifying and evaluating the prospective failure of a product or process along with its impacts. Moreover, it spotlights measures that could feasibly eliminate or diminish the likelihood of such failures transpiring. As part of this systematic approach, the entire process is thoroughly documented.

Design FMEA (DFMEA) and Process FMEA (PFMEA) are two specific types of FMEA [47]. The aim of each is to comprehend the potential areas of failure and the effect of risks in a product or process design. The goal is to rank the risks and implement measures to remove or lessen the consequences of these risks. Thus, FMEA serves as a front-end tool. It's worth emphasizing that FMEA is not a one-time event, but rather an ongoing practice.

Teams involved in product and process development must regularly reassess and revise the potential modes of failure. During the initial phases of product or process development, risks are identified through data from analogous processes, collective expertise, and previous experiences. As the product or process is implemented, unanticipated risks and failures might surface. Therefore, continually reviewing the FMEA ensures the sustainability of the product's or process's success.

The control and documentation of FMEA revisions form a critical part of a well-designed Quality Management System (QMS). In this system, FMEA is associated with quality function deployment in the design and process "houses of quality," as well as control plans in the manufacturing house of quality. Since FMEA is viewed as a dynamic document, it should be adjusted as required, with revisions monitored to trace alterations over a period of time.

One of the remarkable aspects of FMEA as a risk management tool is its broad applicability. While it originated in the manufacturing industry, FMEA has also found effective application in areas like service and transactional procedures, software creation, the healthcare sector, among others.

Upon the completion of an FMEA analysis, a variety of benefits should become apparent. These include understanding the potential effects on all customers (internal and external), aiding in evaluating requirements and alternatives, identifying potential design or manufacturing issues, developing a prioritized list of actions, and helping validate the intended design or manufacturing process. Moreover, the FMEA process aids in recording the outcomes of the design or production process, and pinpointing established special traits that necessitate particular controls.

In practice, FMEA is utilized to address potential failures in various domains: product design is addressed by Design FMEA (DFMEA), process design by Process FMEA (PFMEA) [48]. Other variations like concept FMEA, machinery FMEA, and system FMEA still play essential roles in their respective areas. The critical understanding here is that FMEA, in all its forms, serves as an invaluable tool for the preemptive identification and mitigation of potential failures.

2.5.3 Steps in performing FMEA

Effective execution of a Failure Modes and Effects Analysis (FMEA) requires a systematic approach involving a collaborative, cross-functional team, well-defined scope, and a precise process flow.

Step 1: Form the FMEA Team

In the world of FMEA, a team approach is proven to be the most efficient. Therefore, the first critical step is assembling a diverse cross-functional team. This team should possess wide-ranging knowledge about the process, product, or service, and a deep understanding of customer needs. Essential roles frequently incorporated in the team include design, production, quality assurance, testing, reliability, maintenance, procurement (including suppliers), production workers, sales, marketing (including customers), and customer service.

Having process experts in design FMEA and design experts in process FMEA is crucial for providing valuable insights. Ideally, the team should comprise five to seven members to ensure effective interaction. If the FMEA requires additional expertise on safety, regulatory, or legal issues, such experts are incorporated as subject matter specialists.

Step 2: Define the FMEA Scope

The second step involves identifying the scope of the FMEA. The team should determine whether the FMEA is intended for a concept, system, design, process, or service. It's vital to establish boundaries, decide the depth of detail required, and outline the overall objective of the effort that the team will undertake.

Step 3: Follow the FMEA Process Flow

The next step involves adhering to a basic FMEA process flow, demonstrated by an FMEA flowchart. This flowchart outlines a three-step process for addressing the various aspects necessary when conducting an FMEA. It provides a schematic representation of how the team should approach the FMEA form.

While working through the form's different columns, the team should keep in mind that FMEA is not an absolute science. Disagreements might occur. In such cases, a consensus can be reached by adopting a middle-ground approach or making a note for further discussion. This strategy prevents the process from stalling and maintains progress.

With a clear understanding of these foundational steps, teams can perform an FMEA more effectively and efficiently, contributing to improved product quality and process reliability. This guide should serve as a roadmap for professionals seeking to utilize FMEA as a robust tool in their quality management system.

2.5.4 Severity, Occurrence, Detection & Risk Priority Number

FMEA involves evaluating each identified potential failure mode against three categories: severity, occurrence, and detection. These evaluations must be systematic and consistent, using pre-defined scoring tables appropriate for the industry and organization. It's critical that the tables used reflect the specific needs of the organization, which may require input from reliability or quality engineers using warranty data and other internal resources.

Severity is the rating of the potential impact or harm a failure mode could cause. This includes consideration of safety, customer satisfaction, and the financial implications of a failure. A high severity score (e.g., 9 or 10 on a 1-10 scale) is assigned to a failure mode that could cause significant harm to workers, customers, or the business, such as personal injury or extensive damage.

TABLE I: POSSIBLE SEVERITY EVALUATION CRITERIA [1].

Effect	Ranking
Hazardous without warning	10
Hazardous with warning	9
Very High	8
Low	5
Minor	3
None	1

Occurrence is the evaluation of how frequently a specific failure mode might happen, based on past data or predictive analysis. A failure mode that happens regularly, perhaps even daily, would score high (e.g., 8-10 on a 1-10 scale). In contrast, rare failure modes would have lower scores. The goal is to identify and focus on the most recurrent issues for improvement and prevention.

Detection scoring gauges the likelihood of identifying a failure before it impacts the product or process. This category is inverse to severity; the less likely a failure mode is to be detected, the higher its score. For instance, a failure mode that an operator could easily and consistently spot would receive a low score (e.g., 1 or 2), while a failure mode hidden within the system would have a high score.

TABLE II: POSSIBLE OCCURENCE EVALUATION CRITERIA [1].

Possible failure rates	Ranking
>100 per thousand vehicles/items	10
50 per thousand vehicles/items	9
5 per thousand vehicles/items	6
2 per thousand vehicles/items	5
1 per thousand vehicles/items	4
<0.01 per thousand vehicles/items	1

TABLE III: POSSIBLE DETECTION EVALUATION CRITERIA [1].

Detection	Ranking
Absolute uncertainty	10
Moderately high	4
Almost certain	1

After scoring for severity, occurrence, and detection (S-O-D), these values are multiplied together to yield the Risk Priority Number (RPN) [48]. The RPN serves as a quantitative indicator of risk, allowing the team to prioritize their efforts to address the most critical failure modes. The lower overall RPN indicates a lower risk. Each industry may have its specific guidelines on how to interpret and apply RPNs, so the team must be aware of these rules to use RPN effectively.

2.5.4.1 Continual Improvement and FMEA Updates

FMEA is a proactive, iterative process, not a one-time task. The team should continually work on reducing the RPNs by addressing identified failure modes. This approach requires maintaining an up-to-date FMEA that reflects ongoing efforts and the current status of design or process risks.

Regular team meetings and updates ensure that the FMEA is a living document, guiding continuous risk reduction efforts. FMEA training for all team members, utilizing the team approach, involving subject matter experts when necessary, and maintaining open communication with customers are also key strategies for a successful FMEA process.

2.5.4.2 Scoring Standardization and Cutoff

In FMEA, scoring standardization plays a significant role in creating a universal understanding of risks and ensuring valid comparisons between different FMEAs. The team must agree on a standardized scale for severity, occurrence, and detection, based on the nature and requirements of the business, rather than borrowing generic tables from other sources.

After initial RPNs are calculated, the team must decide on a cutoff score. This score helps determine which risks need immediate attention and resources. However, setting the cutoff score too high or too low can lead to overlooking significant risks or excessive resource allocation, respectively.

Therefore, the team needs to carefully review data and come to an agreement on an appropriate cutoff score.

Successful FMEA implementation is not just about compliance with procedures or standards but requires commitment and a proactive approach to risk management. With this mindset and a firm understanding of scoring mechanisms and risk prioritization, teams can harness the power of FMEA to reduce product or process risks and ensure quality and reliability.

2.5.4.3 Effective Practices for Successful FMEA Implementation

Do's:

- All FMEA team members should be given comprehensive training before their assignment. This training equips them with a detailed understanding of the FMEA process, thereby enhancing their contributions to the team. Alongside, always promote a team approach; it encourages diversity of thoughts and makes the process more robust and comprehensive.
- Sometimes, certain failure modes require specialized knowledge to comprehend fully. Don't hesitate to seek subject matter expertise in such situations. Additionally, engage with customers to understand how they intend to use the product. This insight will help you anticipate failure modes based on real-world usage.
- Standardizing scales for severity, occurrence, and detection is vital for consistent and comparable scoring. Remember, the scale should reflect your business nature and organization, rather than using a generic table. Also, it's essential to brainstorm all possible

failure modes, even those that might seem rare or trivial. This exhaustive approach ensures that no potential issue is overlooked.

- Always prioritize the risk with a higher severity rating when two risks have the same overall score. It ensures that the risks with potentially more damaging impacts are addressed first. And, as part of your continuous improvement efforts, ensure that your FMEA is periodically updated with new insights or discovered risks.

Don'ts:

- While it might be tempting to copy scales from another industry or organization, resist this urge. The scale levels and impacts may differ significantly based on industry or organizational specificities. Similarly, try not to force a 1-10 scale if your industry doesn't warrant it. A 1-5 scale might be more appropriate in certain contexts. Avoid customizing scales unless it's absolutely necessary; excessive customization could lead to inconsistencies or confusion.
- Engaging in disputes over minor rating differences, such as between 4 and 5, is counterproductive. If there is a significant divide in the team, for instance between ratings 4 and 7, thorough impact analysis is needed. Remember, the objective is to create a product or service with reduced risk, not just to score it.
- FMEA is a powerful business risk management tool, and it should not be performed merely to comply with procedures or standards. It requires genuine commitment from the team and management to make it work. When you face complex situations, like

multiple process steps for the product, divide the process into major blocks and perform FMEA for each block. Maintain a robust FMEA database; it saves time and aids in successful consecutive FMEAs.

- After tabulating the initial RPN scores, decide on a cutoff score. This score will determine which risks need immediate attention and resources. While a standardized cutoff score is common in most organizations, it's crucial to understand that one organization's cutoff score may not be suitable for another. A careful balance is needed; a low cutoff score might drain resources, while a high cutoff can overlook essential risks. Hence, management needs to review the data meticulously and agree on a suitable cutoff score.

2.6 VOC

An organization's success hinges on its ability to understand and fulfill its customers' needs. In a competitive marketplace, capturing and analyzing the Voice of the Customer (VOC) emerges as a crucial determinant of sustained business growth and customer loyalty.

Understanding customers and the markets in which an organization operates forms the cornerstone of its strategic goals. It is vital for a business to identify and comprehend the requirements, expectations, needs, and preferences of its customers and prospects. Equally important is the establishment of strong relationships with customers. These relationships allow a company to discern the factors that drive customer acquisition, satisfaction, loyalty, and retention. Such insights feed directly into strategies that fuel business expansion and sustainability.

The Voice of the Customer (VOC) [49][50] represents a comprehensive process that collects, analyzes, and acts on customer-related data. The purpose of VOC goes beyond merely reacting to customer feedback. It encompasses proactive and consistently inventive methods to apprehend both expressed and unexpressed customer requirements, needs, and wishes. Even anticipated customer needs—those not yet expressed by the customers themselves—are taken into account.

The ultimate goal of VOC is to promote customer loyalty and build lasting customer relationships. Therefore, it is an ongoing, dynamic process that evolves as market conditions and customer preferences change.

2.6.1 Customer Identification

At the heart of every project, there's an all-important question: who is the customer? Customer identification forms the initial phase of any project and informs the rest of the process, from data collection to final product delivery. In this context, customers can be either internal or external to the project, often referred to as 'internal customers' and 'external customers', respectively.

The first step in customer identification involves setting the boundaries of a project. This helps distinguish between internal and external customers. Internal customers are those who work within the process under study, while external customers are those beyond the boundaries of the project. At times, there might be individuals who fall outside the conventional definitions of internal and external customers. Such individuals, who nonetheless have a stake in the project's outcome, are considered stakeholders. Stakeholders can have a significant impact on the project and thus warrant consideration during the VOC process.

In the case of external customers, it's crucial not to overlook stakeholders outside your direct organization. These could include your company's board of directors, businesses purchasing your products or services, your local community, and governmental agencies at various levels. A useful approach to ensuring a comprehensive identification of external customers is considering your company's social responsibility towards society at large.

Identifying the customers of a project or process is essential, regardless of its maturity. Even if customers are ostensibly known, it is always beneficial to reassess and reaffirm using various tools and methods. These may include:

- Brainstorming: Generating ideas within a group setting to identify potential customers.
- SIPOC (Suppliers, Inputs, Process, Outputs, Customers): A visual tool that maps the flow of suppliers to customers in a process, aiding in the identification of potential customers.
- Marketing Analysis Data: Leveraging market research and data analytics to identify potential customers.
- Product or Service Tracking: Observing the path of a product or service from creation to delivery, identifying all the involved parties as potential customers.

Once internal and external customers are identified, they can be grouped into segments based on specific customer requirements. Common customer segmentation categories may include internal vs. external, age groups, geographical locations, and industry types. Creating a detailed listing of customers within a segment can further facilitate communication and customization efforts.

When proposing changes of any kind in a project, it's crucial to consider the views and concerns of all customers - internal and external. Engaging them in the process, or at least ensuring their concerns are represented, helps align project outcomes with customer expectations and ultimately strengthens the value and impact of the VOC process.

2.6.2 Customer Data

Understanding your customers' needs and wants is the key to successful project execution and product development [51]. A misconception often held by experts in their fields is the belief that their expertise equates to knowing what the customer wants.

One of the initial tasks after benchmarking process data should be to converse with the individuals directly involved in the work. Understanding their tasks and what could make their jobs easier can offer invaluable insights and help build support for the project.

Following these initial discussions, the conversation should be extended to individuals upstream and downstream of the target project area. What improvements could aid them in their work and have potential relevance to your project?

W. E. Deming, stated that some of the most critical numbers are unknown and unknowable, referring to intangibles like customer goodwill's financial value [1]. His point was that the significance of understanding and providing for customers' needs cannot be underestimated. There are several tools for capturing customer data. Among the most widely used are:

- Surveys: Structured questionnaires designed to collect specific data from a large audience.
- Quality Function Deployment (QFD): A structured method for converting customer needs into fitting company requirements at each phase, from innovation and development through to production and distribution.
- Interviews: Direct, one-on-one conversations to delve deeper into individual customer experiences and perceptions.
- Focus Groups: A style of in-depth research in which a collection of individuals are queried about their perspectives, views, convictions, and reactions regarding a product, service, concept, or thought.

Statistically, collecting customer data would ideally involve randomly selecting a large group of customers and obtaining complete, accurate data from each one. In practice, however, this approach is often unfeasible, leading to the application of various other methods, each incorporating statistically valid procedures in its way.

The collected data should be objective and capable of illuminating customer requirements. To achieve a comprehensive understanding, it is advisable to use multiple independent resources to gather this information. The resulting data can then be cross-analyzed to identify patterns of reinforcement or contradiction in conclusions.

Once collected, the accuracy and consistency of the data should be verified. Any conflicts or ambiguities in the data should be resolved to ensure the findings' validity and reliability.

2.6.3 Critical to Satisfaction

Critical to Satisfaction (CTS) measures are key outputs derived from our analysis of the Voice of the Customer (VOC). These essential measures can span various domains, such as quality, design, cost, and process, among others. The identification of these critical measures can significantly shape and influence the design, process, or product to better serve our customers, satisfy their needs, and ultimately delight them.

The journey of developing CTS metrics begins with the voice of the customer. Analyzing customer feedback, you look for common themes, recurring topics, and specific comments that help explain the reasoning behind a customer's purchase decision or the failure to purchase. The insights drawn from the VOC are instrumental in defining and influencing any aspect that can impact a CTS metric. These influential aspects can emanate from any part of the organization.

Tools such as affinity diagrams and tree diagrams can be invaluable in organizing your ideas and findings. They help in grouping and sub-grouping ideas based on repeatedly asking 'why'. This recursive questioning allows for a deeper exploration of the root causes that affect customer satisfaction.

At times, additional follow-ups with customers might be necessary to gain more comprehensive insights. As you collate the insights, look for any gaps, and strive to fill them as required.

CTS metrics play an essential role. Intriguingly, if we consider the equation 'outputs as a function of inputs', the Critical to Quality (CTQ), Critical to Delivery (CTD), or Critical to

Cost (CTC) characteristics represent the CTS metric or the dependent variable. On the other hand, the process characteristics represent the independent variables, or the inputs.

The management and attention given to CTS metrics help ensure that projects align with customer needs and deliver value. A project lacking in CTS metrics is inefficient and lacks a clear purpose that can be directly tied to the needs of the customer. By effectively leveraging CTS measures, organizations can not only enhance their products and services but also foster a culture that truly values and prioritizes customer satisfaction.

2.6.4 Quality Function Deployment

The ideal design of processes and products is one that meets or surpasses customer requirements at the most economical cost. Achieving this involves linking customer requirements to product and process features, designing products and processes for optimum quality at minimal cost, and utilizing design tools that foster innovative problem-solving strategies. Quality Function Deployment (QFD) [52], also known as the 'House of Quality', is an instrumental tool for these purposes. It is a systematic process that translates customer needs (Voice of the Customer, or VOC) into technical requirements. QFD aids in planning new or redesigned products and services by organizing customer requirements and linking them to specifications.

The QFD matrix comprises several components. While there's no standard format, a typical QFD matrix includes:

1. Customer Requirements: Derived from the VOC analysis, these highlight what the customer wants from the product or service. This segment typically encompasses a scale that represents the significance of individual prerequisites.

2. Technical Requirements: These are established in response to the demands of the customers.. Symbols on the top line indicate whether lower, higher, or target is better. A circle signifies that target is better.

3. Relationship Area: Displays the link between technical and customer requirements, employing diverse symbols to indicate the intensity of the relationship.

4. Comparison with Competition: These areas, which are not included in all QFD matrices, evaluate how the customer and technical requirements stack up against competitors.

5. Improvement Activities Index: This documents any actions taken to improve the product or process.

6. Target Values: This area lists the target values for the technical requirements.

7. Co-relationships: Indicate the interconnections among the technical requirements. A positive correlation suggests that enhancements in both technical requirements can be achieved concurrently, whereas a negative correlation implies that improvement in one will lead to a deterioration in the other.

The QFD matrix can function as an all-inclusive repository for product development, a base for strategizing product or process enhancements, and an indicator of prospects for deploying fresh or revised products or processes.

In the QFD context, customer requirements represent the "what" aspect, while the technical requirements correspond to the "how" aspect. An effective QFD procedure incorporates matrices for strategizing the components that constitute the product and the processes that will manufacture these parts.

QFD is adept at identifying key links and tracking relationships to determine Which customer preferences coincide with a particular design strategy. These relationships are categorized based on technical significance to pinpoint opportunities and areas to concentrate on for enhancement or innovation.

In a staged environment, QFD proves invaluable in incorporating client requirements at the initial phases and funneling the acquired data to the following stages. This approach ensures no gaps in customer satisfaction.

To summarize, QFD supports the adoption of customer value within the product, connecting customer desires and anticipations to technical specifications and approval standards. This ensures a robust design that accurately defines the terms of product development, delivery, maintenance, and fulfillment. In essence, QFD champions customer-driven quality and the total customer experience, making it an indispensable tool in the VOC process.

CHAPTER 3

RESEARCH METHODOLOGY AND CASE STUDY

3.1 Overview of Research Methodology & Data Collection

Orbus Exhibit & Display Group® has established a comprehensive evaluation process to understand their customers' satisfaction levels. For every order exceeding $1000, an online survey, referred to as the General Customer Satisfaction (CSAT) Survey, is sent to the customer. This survey covers several aspects of the order, including packaging, responsiveness, quality of graphics, and more.

Customers are invited to score each category on a scale from 1 to 5. Orbus then transforms these scores into a scale of 1 to 100, which facilitates a more nuanced understanding of customer satisfaction. The average of all customer scores is computed to derive the overall CSAT score for each category.

In addition to the scoring, customers are also encouraged to provide written feedback about their experiences at the end of the survey. This qualitative data is particularly insightful as it provides specific comments and suggestions, enhancing the effectiveness of the feedback process.

The Operations Manager at Orbus is responsible for sending out these surveys and monitoring the responses. The Manager also oversees the calculation of the CSAT scores and the analysis of the written feedback, ensuring that the customer's voice is heard and incorporated into their continuous improvement efforts. In the last 3 years, over 1300 surveys were collected.

The Operations Manager pointed out the issue that, With an average score of 76/100, the packaging of Customized Exhibit Structures had the lowest rating among all assessed areas in the CSAT survey. This result highlighted an urgent need for improvement in this particular aspect.

Reacting to this concern, the Continuous Improvement Manager convened a dedicated team to focus on enhancing the CSAT score related to packaging. The team initiated a comprehensive feedback collection process. Four main customers were chosen for personal interviews, and their insights turned out to be a wealth of understanding on the customer perspective and identification of improvement areas.

Once the feedback was gathered, it was scrutinized in a team meeting involving the Continuous Improvement Manager and the engineers. The goal was to identify the specific shortcomings in the packaging that led to the sub-optimal customer ratings.

Following this review, the engineers commenced an iterative design process to address these identified issues. Four different prototype models were developed in succession. Each iteration was an enhancement over the previous, incorporating learnings and improvements. Each of these prototypes was brought to life in the woodshop for testing.

The prototypes were then put through rigorous tests to assess their robustness against the physical forces exerted during transit, and their effectiveness in preserving the integrity of the Customized Exhibit Structures. Each test provided practical insights and informed the design process of the subsequent model. Through this iterative and customer-centric approach, the team aimed to augment the packaging design to improve the CSAT scores, thereby ensuring higher customer satisfaction in the future.

3.1.1 Introduction to the Research Process

For the express purpose of enhancing the Customer Satisfaction (CSAT) score specifically tied to the packaging related to the Structures at Orbus Exhibit & Display Group®, a meticulous research methodology was designed. This methodology was derived from the theories and concepts presented in Chapter 2, including the Voice of the Customer (VoC), Critical to Satisfaction (CTS) elements, and the application of the DMADV methodology.

The foundation of the research methodology lay in qualitative data collection. Singular, detailed interviews with key customers served as the conduit for extracting the VoC. Here, the VoC extended beyond simple feedback, incorporating the customer's expectations, preferences, and critiques of the packaging process.

The interviews conducted were insightful and encompassed various facets of the packaging process, such as the state of the product upon receipt, ease of locating items within the crates, adequacy of external and internal labeling, trade-off between packaging cost and durability, comparison with other custom packaging systems, problem areas in the current packaging, and suggestions for crate design and packing material. Furthermore, the interviews also considered elements like packaging sequence, unpacking convenience, clarity of packing slips and labeling, packaging durability vs. cost considerations, observations about other successful custom packaging, as well as pain points and improvement suggestions for the current crate design and packing materials. These elements were reviewed to attain a comprehensive understanding of the factors contributing to customer satisfaction and dissatisfaction regarding packaging.

Customers were then requested to assign a CSAT score, ranging from 1 to 100, specifically for packaging. This Customer Satisfaction (CSAT) scoring was derived from the customers' collective experiences with our products and packaging.

This research initiative began with an existing packaging-specific CSAT score of 76, which served as a crucial benchmark for gauging the effectiveness of any improvements made to the packaging process post research.

The adopted methodology combined qualitative customer insights with quantitative ratings, aligning with both the theoretical underpinnings of VoC, CTS, and DMADV, and practical necessities. The dual approach of qualitative customer interviews and quantitative CSAT scoring ensured a thorough, data-driven understanding of the packaging experience. This in turn facilitated the identification of key areas for improving the packaging-specific CSAT score at Orbus Exhibit & Display Group®.

3.1.2 Interview Benefits

Interviews provide a highly valuable tool for collecting customer feedback, offering distinct advantages over other methods of data collection. They foster a deeper, more personal engagement between the company and its customers, paving the way for more comprehensive insights.

1. Depth and Detail: Unlike surveys or feedback forms, interviews allow for open-ended responses and follow-up questions. This depth of conversation provides a detailed un-

derstanding of customer experiences, attitudes, and opinions, which can reveal nuanced insights about the customer's interaction with the product or service.

2. Flexibility: An interview can be adapted in real-time to explore interesting or unexpected avenues that may come up during the conversation. This flexibility allows the interviewer to probe more deeply into specific areas of interest or concern, uncovering rich data that may not have been revealed in a more structured format.

3. Contextual Understanding: Through interviews, you can gather contextual data that can provide greater insight into the circumstances or situations surrounding the customer's feedback. This context can add depth to the data and help companies better understand and address customers' needs and pain points.

4. Establishing Trust: By engaging customers directly, interviews can help build trust and strengthen relationships. Customers who feel their voices are genuinely being heard are likely to have a more favorable view of the company, which can positively affect loyalty and brand image.

5. Non-Verbal Cues: In face-to-face or video interviews, observing body language and emotional reactions can give additional insights that are not possible through written feedback. These non-verbal cues can provide invaluable information about the customer's feelings towards the product or service.

6. Immediate Clarification: Any misunderstanding or ambiguities in the customer's responses can be immediately addressed in an interview setting. This immediacy ensures that the information collected is as clear and accurate as possible.

3.1.3 Interview Process and Questions

The feedback collection process included in-depth interviews with four key customers, each representing different areas of the United States. Each customer provides distinct perspectives and insights based on his unique experiences and requirements. The interviews were conducted in person at the Orbus site in Woodridge, Chicago, facilitating a direct and immersive feedback gathering process.

The purpose of each question used in the interview was designed to gather specific insights into customer experiences, perceptions, and preferences. Below are the questions along with their individual purposes:

1. Do you find any damaged items when you receive our product?

   This question assesses the quality and durability of the packaging during shipping. Understanding the extent of damage upon receipt can help identify if improvements are needed in packaging or shipping procedures.

2. Are items easy to locate within the crates for setup?

   This question is designed to understand the user experience during the setup process. Easy location of items can lead to faster setup times and overall customer satisfaction.

3. Is external labeling of the items shipped adequate?

   The purpose here is to gather feedback on the clarity and effectiveness of external labeling. Adequate labeling can significantly ease the setup process and prevent confusion or delays.

4. Is labeling of the individual items shipped adequate?

Similar to the previous question, but focusing on individual items, it aims to assess if customers can easily identify each item in the package, which is crucial for efficient setup and usage.

5. Are you more concerned with the cost of the packaging or the durability of the material?

   This question seeks to understand customer priorities between cost and durability. The answer can guide decisions about materials used for packaging, offering a balance between cost-effectiveness and robust protection.

6. Have you come across other custom packaging that you think would work better than what we provide?

   This question is an open invitation for customers to provide feedback based on their experiences with other companies. Their responses can serve as valuable input for future improvements.

7. What aspect of our custom packaging causes you the most trouble?

   The purpose is to identify specific pain points with the current packaging system. Addressing these issues directly can lead to more satisfied customers and improved efficiency.

8. What recommendations would you have for our crate design?

   This question seeks actionable suggestions for improving the crate design. Customer recommendations can provide practical insights from the user's perspective, which can be instrumental in guiding design revisions.

9. What recommendations would you have for our packing material?

This question aims to gain insights into potential improvements for packing material from the user's viewpoint, which can enhance product safety during shipping and ease of use during setup.

10. Do you have any other concerns we have not covered so far?

    This open-ended question allows customers to express any additional concerns or suggestions that were not addressed in the previous questions, ensuring that the interview captures a comprehensive range of customer feedback.

Through these questions, the interview process seeks to understand the strengths and weaknesses of the current packaging and labeling system, collecting customer perspectives and ideas for improvement. This feedback is invaluable in driving enhancements that can lead to increased customer satisfaction and loyalty.

3.2 Define, Measure, Analyze

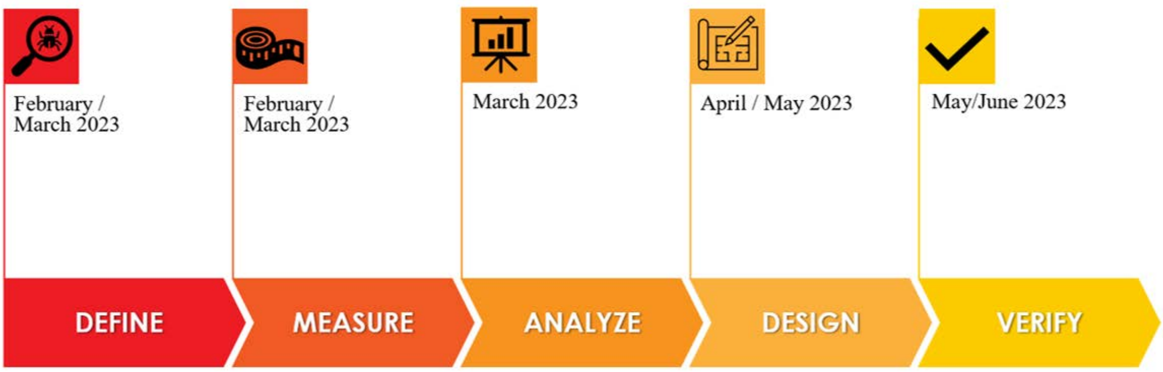


Figure 14: Timeline of the Project

3.2.1 Analysis of Current Packaging at Orbus

3.2.1.1 Packaging Process

Orbus's exhibition structures are complex, usually necessitating an average of four crates for packaging. The journey of each structure begins as it arrives at the designated packaging area.

In this area, the structure undergoes assembly, a process meticulously handled by experienced operators. They use a standard set of instructions as a foundation, which guides them through the assembly process. However, the nature of a customized offerings means that each structure has its unique quirks and requirements. Therefore, these instructions are not a rigid blueprint but a flexible guide that operators adjust based on the specificities of each custom structure. This fluid approach ensures that every structure is assembled optimally, according to the client's specific needs.

Figure 15: Image showing a Crate filled by Layer

After the structure has been successfully assembled, a rigorous quality control process takes place. Every component of the structure - the graphics, extrusions, laminates, and monitors - is scrutinized for any possible defects. It's a meticulous process that typically takes about three hours.

The next phase commences once the structure has passed the quality control stage and the assembly instructions have been modified to reflect the nuances of the customized structure. Here, the structure is carefully disassembled, and the packing into crates begins.

Figure 16: Cardboard Sheet Dividers

Figure 17: Cardboard Sheet Dividers

At present, there isn't a rigid logic dictating the sequence in which pieces are placed within a specific crate. Generally, the heaviest components, such as the extrusions, are placed at the bottom of the crate. They're separated by a layer of cardboard, which serves as a buffer to prevent potential friction during transit, thus avoiding damage. The filling of the crate proceeds in stages, with each stage involving the addition of progressively lighter pieces.

Figure 18: External Label

To further safeguard each component, each layer in the crate is separated by a cardboard sheet. An additional security measure taken is the capturing of a photograph at each layer. This provides a visual record that can be referred to in the unlikely event that a customer reports a missing piece.

Once the crate is satisfactorily filled, it is sealed. The door is securely fastened with eight bolts 18-thread, each 6.5 inches long, and a 5/16 fender washer. These bolts guarantee the overall security and structural integrity of the crate, preventing any unintended opening during transportation or storage.

Finally, upon the crate's closure, it's labelled. A barcode is applied to facilitate the identification of the shipment. This barcode contains crucial information, including the customer details, the destination, and the specific number of the crate within the total number of crates for the shipment (e.g., '1 of 3') (Figure 18). This detailed, carefully orchestrated process ensures that the products reach the customers in the best possible condition, accompanied by comprehensive information for a seamless assembly process.

3.2.1.2 Crate Design

The packaging process of Exhibit Structure at Orbus primarily involves the use of rectangular crates, designed to ensure safe transit of exhibition structures. The specific design details of these crates are detailed below.

The crate features rectangular dimensions of 101 inches in length, 49 3/4 inches in height (feet included), and 53 inches in width (Figure 19).

Figure 19: Old Crate

All panels of the crate, except the base, are made from a 0.5-inch thick CDX plywood layer. The base stands out with its robustness, being a solid 3/4-inch thick CDX plywood panel (Figure 23). Internally, each panel is lined with grey tweed fabric. This specific type of felt material is chosen for its protective properties, shielding the contents of the crate from potential damage during transit.

The crate stands on eight trapezoidal feet, each measuring 4.5 inches in height, 3.5 inches in thickness, and 20 inches in length. Their arrangement sees three parallel to the crate's longer side, three at the two ends, and two centrally positioned (Figure 23). Every panel, except the base, is reinforced with rectangular wooden bars known as 2 by 4s. Each of these bars is 1.5 inch in height and 3 inches in width, with the length corresponding to the dimensions of the panel they support. At every joint where the 2 by 4s meet, a gusset with a thickness of 0.5

inches, also made of CDX, is placed for added structural integrity. Both 2 by 4s and gussets are secured to the structure using screws (Figure 21).


Figure 20: Front View of the Old Crate


Figure 21: 2 by 4 and Gusset


Figure 22: Closing Bolts


Figure 23: Base of the Crate

The crate door shares the same structural components as the other panels, with 2 by 4s and gussets, again made of CDX. This door is attached to the rest of the crate using eight 18 thread bolts, each 6 1/2 inches in length, with the support of 5/16 fender washers. Two bolts are positioned on the left side, while two are located on the right side, ensuring a secure closure from both directions. Additionally, three bolts are strategically placed on the top of the crate, providing extra protection and ensuring a tight seal when the door is closed (Figure 20).

The interior dimensions of the crate measure 48 inches in width, 96 inches in length, and 42 inches in height. The internal volume is 193536 cubic inches. The total volume of the crate is 266312 cubic inches.

The packaging process at Orbus is characterized by the use of sturdy, carefully designed crates. Each component contributes to the crate's overall integrity, ensuring the safe and secure transportation of the exhibition structures

3.2.2 CTS: Specific Challenges and Pain Points faced by Customers

A thorough examination of the customer interviews revealed a variety of specific challenges and pain points associated with our current packaging system. These insights helped us identify Critical to Satisfaction (CTS) factors, which are fundamental elements of our product and service that significantly influence customer satisfaction.

Challenge 1: Item Damage

While the majority of customers, reported receiving products without damage, one of them brought to our attention that the durability of certain items like laminated pieces and counters could be improved. Over time, edges of these items often get caught, leading to chips and damage. An additional issue identified was a yellow cast appearing on the laminate, which they suspected might be a result of the padding inside the crate. This challenge calls for a thorough examination of the materials used in our packaging system and potential improvements to protect products better during transit.

Challenge 2: Locating Items within Crates

Across all interviews, customers mentioned the difficulty in finding items within the crates, especially in larger orders. The sequence of packing appears to exacerbate this issue, as items required early in the setup process often get packed at the bottom of the crate. This arrangement leads to time-consuming and inefficient unpacking and sorting processes, delaying the overall setup. There is a clear need to reconsider our packing methodology to enhance the setup experience for our customers.

Challenge 3: Labelling Adequacy

Customers identified problems with both external and internal labelling. mentioned the need for better labels and multiple packing slips for improved order tracking. On the other hand, other customers pointed out inconsistencies and inadequacies in the labelling of individual items, causing confusion during setup. Feedback indicates that a more comprehensive and coherent labelling system could significantly improve the unpacking and setup process.

Challenge 4: Packaging Preferences

Customers' preferences between cost and durability of packaging material was another critical challenge. The overall sentiment leaned towards durability, emphasizing the importance of protecting the products effectively rather than cutting costs on packaging materials. One customer suggested the return of layered packing as it is less time-consuming compared to unwrapping each individual item.

Challenge 5: Crate Design

Customers expressed several concerns regarding crate design. Some of these included outdated designs, poor construction leading to damage, and the need for lighter, more efficient crate designs. To address these concerns, customers suggested improvements like more durable crate designs, smart packing to protect contents, and detailed lists of crate contents.

Challenge 6: Packing Instructions

Several customers expressed frustration over the lack of repacking instructions. This omission often led to difficulties when preparing products for return shipment or storage after use. The feedback strongly suggests that including clear and comprehensive repacking instructions would greatly improve the user experience and efficiency.

Challenge 7: Additional Concerns

In addition to the above challenges, customers mentioned several additional concerns such as missing parts, durability issues with specific products (Hybro Pro 01 Counter), and problems with graphic imprinting. Notably, a customer pointed out quality control issues with graphics needing reprinting and inaccurate mock-ups confusing the setup team.

The Kano model is a helpful tool to distinguish between the different types of customer requirements and their impact on customer satisfaction. Here is how the attributes of the packaging crate could fit into this model:

Must-Have Attributes: These are the basic expectations that need to be fulfilled to ensure customer satisfaction. Any failure in these areas can lead to significant dissatisfaction.

- Item Durability: The crate should ensure that items arrive undamaged.

- Clear Labeling: Both the external and internal labeling should be accurate and comprehensive to avoid confusion during unpacking and setup.
- Quality Control: There should be no missing or incorrectly labeled parts, and all components should match their specifications.
- Durability of Packaging Material: The material of the crate needs to be sturdy and durable to protect the contents during transit.

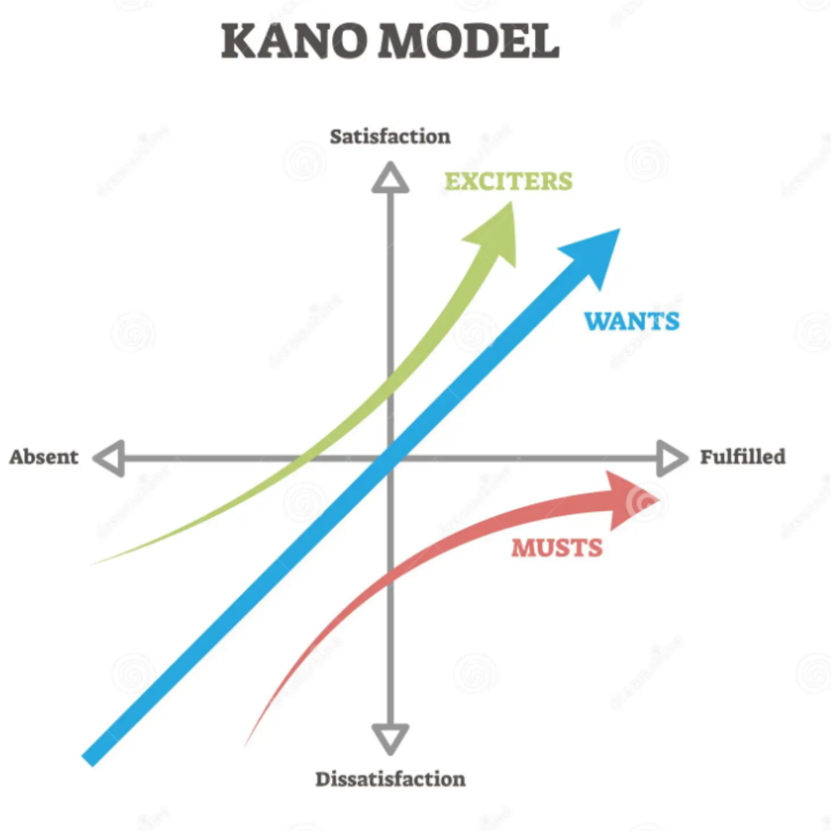


Figure 24: Kano Model.

Performance Attributes: These are features where the degree of implementation is proportional to the customer's level of satisfaction. The better these features are implemented, the higher the customer satisfaction.

- Efficient Packing Methodology: The ease of finding items in the crate, the logic of the packing sequence, and the convenience of unpacking all contribute to customer satisfaction.
- Optimized Crate Design: A well-designed crate that is easy to handle, offers efficient space utilization, and has a lightweight yet durable construction can significantly enhance customer satisfaction.

Delighters or Exciters: These are the unexpected features that can pleasantly surprise the customer, leading to higher satisfaction.

- Clear Packing and Repacking Instructions: Though not always expected, providing comprehensive and easy-to-follow instructions for packing and repacking can greatly enhance the customer's experience and satisfaction.
- Special Protection Measures: Additional protection for delicate items like laminated pieces or counters, such as individual packaging or protective layers, can exceed customer expectations.
- Easy-to-Replace Components: Designing the crate with replaceable parts, such as latches, can be a delighter attribute. If a part breaks, the customer can easily replace it, ensuring the longevity of the crate.

3.2.3 Defining Customer Requirements and Design Objectives

The detailed customer feedback acquired through the interviews provided valuable insights into the customers' needs and challenges. The experiences and perspectives shared by key customers from different regions in the US have greatly influenced the design objectives for improving the product. This chapter will delineate those customer requirements and outline the corresponding design objectives.

Customer Requirements:

- Durability: Customers require the packaging crate and its contents to remain undamaged during transit and handling.
- Ease of Locating Items: It is important for customers to be able to quickly and easily locate items within the crates during setup.
- Effective Labelling: Customers require clear, comprehensive labelling on both the crate exteriors and individual items inside. This aids in order tracking and streamlines the setup process.
- Packaging Efficiency: Customers value efficient packing that prioritizes the order of setup and minimizes the unpacking effort.
- Instructions: A prominent requirement emerging from the feedback was the need for clear packing and repacking instructions to simplify on-site tasks and reduce setup time.
- Optimized Crate Design: Customers expressed a need for crate designs that are lightweight yet robust, secure, and designed with their specific needs in mind.

Design Objectives:

- Enhanced Durability: The design should ensure that the crate and its contents are adequately protected during transit and handling. The crate's design should incorporate measures to safeguard fragile items, particularly laminated pieces and counters.
- Improved Item Organization: The design should incorporate an efficient packing methodology, possibly with a packing list per crate, ensuring that items are easy to find, and the order of setup is logical.
- Comprehensive Labelling: The design should include a comprehensive external and internal labelling system that clearly indicates the contents of the crate and their respective locations.
- User-Friendly Packing Instructions: The design should include comprehensive, easy-to-follow packing and repacking instructions. This may include diagrams or color-coded guidelines to simplify the process.
- Crate Design Optimization: The crate design should prioritize lightweight materials without compromising durability. The design should protect important elements such as latches and should not lead to crate damage when stacked.

Addressing these requirements effectively will result in a product that not only satisfies customer needs but also enhances their overall experience. In the next stage of the project, these design objectives will guide the development and evaluation of potential solutions.

3.2.4 Mapping Customer Dissatisfaction to Packaging Process Inefficiencies

Customer satisfaction extends beyond the point of sale and often relies heavily on the unboxing experience. This element carries significant weight in the case of Orbus' complex exhibition structures that require meticulous assembly. Instances of customer dissatisfaction at Orbus have been recognized and upon examination, a correlation emerges between these instances and certain aspects of the current packaging process.

The prevailing method for packing the crates at Orbus is stratified, with the heaviest components situated at the bottom and lighter ones positioned progressively upwards. While this approach might appear logical initially, it is potentially contributing to a series of issues.

Difficulties in component identification and location within the crate have been reported by customers. Every layer inside the crate is photographed as a reference, however, the absence of a defined packing order often necessitates a tedious and potentially frustrating search for specific parts. This challenge can be exacerbated for customers assembling an exhibition structure for the first time.

A further source of dissatisfaction stems from the absence of packing instructions specifically tailored to the unique structure of each customer. The assembly instructions provided typically represent a modified version of the standard instructions, adapted based on the customization of the structure. Considering the wide range of possible customizations, these instructions might not be entirely clear or accurate, potentially leading to confusion during assembly.

Damage to certain components has been reported, with a plausible link to the current packaging process. Although cardboard separators are used to reduce friction during transportation, varying component weights and shapes can still result in some parts experiencing excessive pressure or movement, leading to potential damage.

While the current packaging process at Orbus reveals a methodical approach, several improvement opportunities exist that could enhance the customer experience substantially. Addressing these issues could not only streamline the process but also contribute to a notable increase in customer satisfaction.

3.2.5 Other Internal Design Objectives

Another critical objective that Orbus has set internally is to redesign the crate to reduce its external width from 53 inches to 50 inches, without affecting the internal volume. This adjustment aims to allow two crates to fit side by side within a standard shipping truck, thereby optimizing the utilization of transport space.

The standard shipping truck used for this purpose has dimensions of width: 106.25 inches, height: 106.25 inches, and length: 435.5 inches, which yields a total volume of 4,916,387 cubic inches. Considering the current crate volume of 266,312 cubic inches, and given that a truck is capable of accommodating three crates, the Transport Efficiency Ratio, defined as the utilized volume (volume of three crates) to the total truck volume, equates to approximately 16.3%.

This seemingly minor reduction in size can bring substantial advantages, as outlined below:

- Improved Transport Efficiency: By reducing the crate's width, Orbus can fit more products into a shipping truck. This adjustment not only optimizes the use of space but also reduces the number of trucks needed for transportation, thereby decreasing logistics costs.

- Increased Environmental Sustainability: By decreasing the number of trucks needed for transport, Orbus reduces its carbon footprint, aligning with broader societal and corporate sustainability goals. A reduction in transport requirements equates to less fuel consumption and fewer carbon emissions.
- Potential Cost Savings: A decrease in the number of shipments results in cost savings that may extend to customers. Lower transportation costs can improve Orbus' competitiveness, making their products more attractive to potential customers.
- Enhanced Operational Efficiency: The new crate size could lead to operational efficiencies, including ease of handling and manoeuvrability. The smaller size may also facilitate easier storage, both within Orbus facilities and at customer sites.
- Maintained Product Safety: Importantly, despite the external reduction in size, the internal volume of the crate remains unchanged. This ensures that the capacity to securely pack and transport items is not compromised, continuing to meet customer requirements for product safety and integrity.

It is worth noting that while the decrease in size presents numerous benefits, careful consideration must be given to the crate redesign to ensure that product protection and durability are not compromised. The challenge is to achieve the objective without altering the crate's ability to protect the packed items effectively. Hence, this internal design objective, while presenting potential advantages, also requires careful implementation to ensure successful execution.

3.2.6 KPIs

- Customer Satisfaction Score (CSAT): This score measures customer satisfaction with the company's packaging. The actual score is 76 and the objective would be to improve the current CSAT score to 86. This KPI is assessed by incorporating a question related to packaging in the General Customer Satisfaction Survey.
- Average Time to Assemble (ATA): This metric measures the average time it takes for customers to assemble the products once received. A reduction in ATA would indicate an improvement in packing instructions and overall packaging design, contributing to a more efficient assembly process. The actual ATA is 27 and the objective would be to improve the current score to 20. This KPI is assessed by incorporating a question related to the average assembly time in the General Customer Satisfaction Survey.
- Transport Efficiency Ratio (TER): TER evaluates the utilization of transport space. It's calculated by comparing the volume of products shipped to the total volume of the shipping vehicle. An increase in TER indicates more efficient use of transport space, reflecting the success of the crate size optimization. The actual TER is 16.3% and the objective would be to improve the current score to 30%. This KPI is measured by calculating the ratio of the total volume of the crates to the total volume of the truck.
- Rate of Returns due to Packaging Errors (RRPE): This KPI tracks the number of returns that occur due to errors in packaging or damaged items due to the packaging methods, over the total number of orders shipped. A decrease in RRPE would signify that the new packing instructions and improved item organization are effective in minimizing errors.

The actual RRPE is 1.2% and the objective would be to improve the current score to 0.5%. This KPI is measured by calculating the proportion of returned orders due to packaging errors out of the total orders shipped.

Each of these KPIs provides a means to objectively measure the success of the improvements in packaging and crate design, thereby helping to maintain the highest standards of customer satisfaction at Orbus.

3.3 Design: Designing & Development of Solutions using DMADV Model

3.3.1 Crate Design Optimization

Here the attention is turned towards the optimization of crate design. The focus of the improvements was not only on enhancing the structural robustness of the crates, but also on ensuring the safety and integrity of the items packed within. The chapter provides an overview of all the prototypes designed, explaining the elements introduced and the rationale behind them, highlighting the efforts in marrying functionality with customer satisfaction.

3.3.1.1 First Prototype

The initial concept for the crate redesign was primarily driven by the idea of swapping the crate's height and width dimensions, without modifying both the internal and external volume or the structural elements of the crates. The intention behind this modification was to reduce the overall width of the crate to 47 inches, accounting for an internal width of 42 inches (42 inches interior + 2.5 inches layer per side).

Although this notion presented a potentially innovative shift in design strategy, it was promptly ruled out. The main issue was that the narrowed internal width of 42 inches posed a substantial problem when it came to accommodating many items within the crate.

The proposed design was developed only in Solidworks, a solid modeling computer-aided design (CAD) and computer-aided engineering (CAE) program. Further development was not pursued due to the limitations discovered in the initial testing phase.

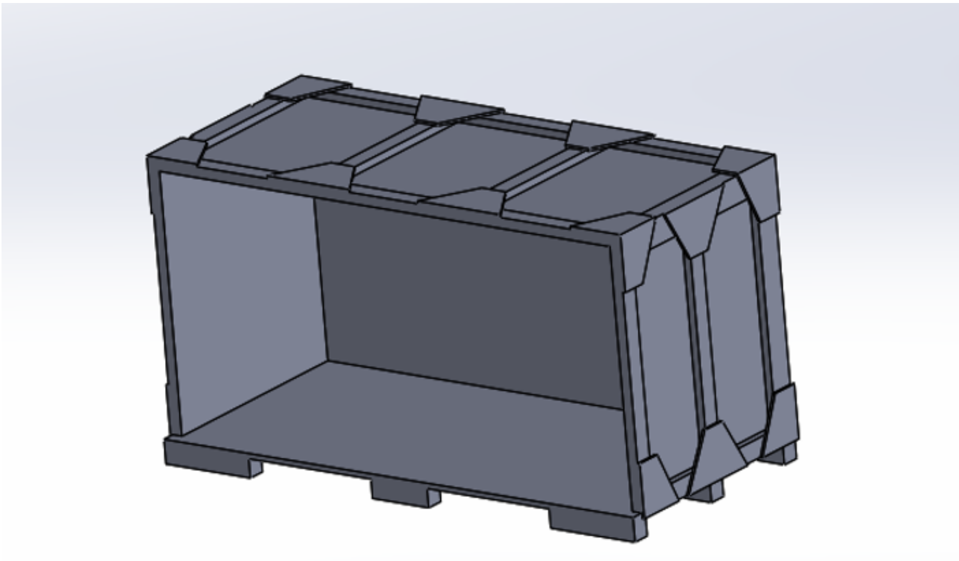


Figure 25: First Prototype

This prototype iteration and the insights gleaned from it served as a stepping stone in the ongoing process of crate redesign.

3.3.1.2 Second Prototype

In the development process, the second prototype presented a series of modifications to the original design. The crate underwent a modification of its closure system, replacing the initial bolts with latches. The number and positioning of these latches, totaling eight, were retained as in the previous design.

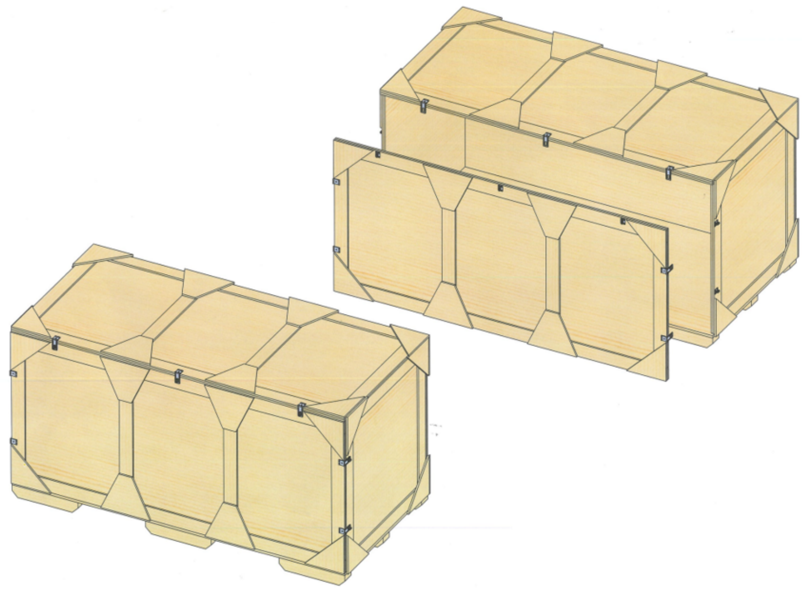


Figure 26: Second Prototype

Other defining characteristics such as the grey tweed fabric panels and gussets remained unchanged. However, the thickness of the reinforcing 2 by 4s was reduced from 1.5 inches to a mere 0.5 inches. The feet of the crate underwent a minor alteration, with their height being reduced from 4.5 to 3.5 inches to provide additional stability, while other measurements were maintained.

The dimensions of the crate were adjusted. The internal height was increased to 47.25 inches, and the internal length was extended to 99 inches, while the internal width decreased to 46 inches. The external dimensions stood at a height of 53 inches, a length of 102 inches, and a width of 49 inches. This resulted in an internal volume of 219627 cubic inches and a total volume of 262674 cubic inches.

Despite adhering to the dimension constraints, this design iteration was ultimately unsuccessful. While the reduced width of 46 inches was sufficient to accommodate the items within the crate, it did not provide adequate protection for the parts. Furthermore, the latches implemented in this design were found to be less reliable as a door closure method and prone to damage, which compromised the overall functionality of the crate.

3.3.1.3 Third Prototype

The third prototype saw a return to the traditional bolt system for closure, utilizing eight bolts placed in the identical locations as the existing crate. The grey tweed fabric panels were also incorporated into this design, providing an assured sense of consistency.

The crate's structural integrity was further enhanced with the introduction of metal gussets, significantly stronger than the previous CDX ones. Despite their minimal thickness, their impact on the crate's overall strength and durability was remarkable.

Modifications were made to the 2 by 4s, which now had a thickness of only .5 inches, while the crate feet were reduced in height from 4.5 inches to 3 inches for improved stability, with other dimensions remaining unchanged.

Internally, the height was increased to 48 inches, while the width and length remained at 48 inches and 96 inches respectively. The external dimensions were adjusted to a height of 53 inches, a length of 98 inches, and a width of 50 inches. The result was a total external volume of 259,900 cubic inches and an internal volume of 221,184 cubic inches.

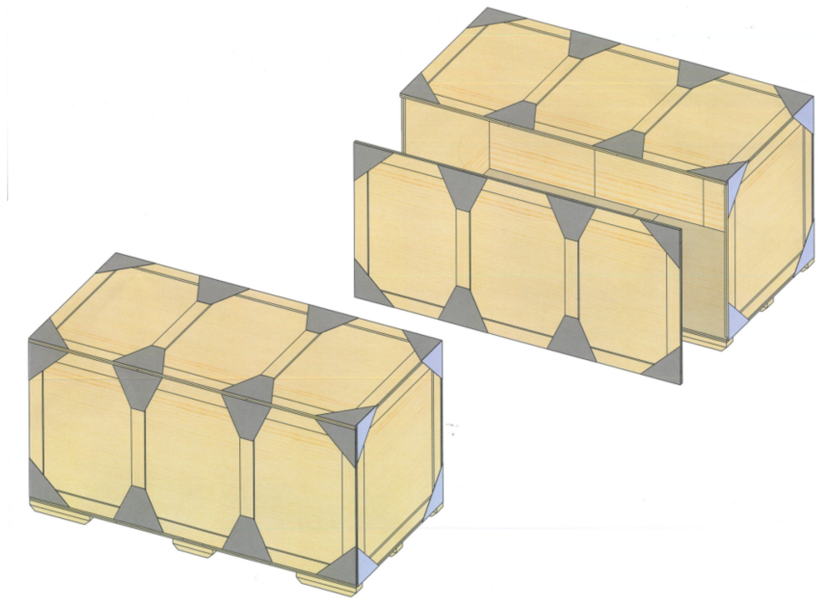


Figure 27: Third Prototype

Despite the design fulfilling all targeted objectives, it was ultimately deemed unsuccessful. The primary reasons for its failure were the significant increase in the crate's weight and, more importantly, the substantial hike in its cost, which proved to be prohibitive for practical implementation.

3.3.1.4 Final Fourth Prototype

In the fourth and final prototype, an innovative approach to interior organization was introduced.

Figure 28: New Crate filled with a Structure

Integrated with cardboard dividers, vertically placed 0.5-inch CDX panels lined with grey tweed fabric were used. This not only added robustness but also significantly enhanced the protection of the items within the crate.

With a view to simplifying construction, gussets were eliminated from the design. Instead, an increased number of nails were used to hold the panels together, and two metal connector plates were introduced in the lower rear corners. Despite their structural importance, these connector plates had a negligible thickness, so they didn't impact the overall measurements of the crate.

Figure 29: New Crate Empty

The 2 by 4s were reduced to a thickness of .5 inches, and the height of the crate feet was lowered to 3 inches, while other dimensions of the feet remained unchanged. The closure was performed using the reliable bolt system, with eight bolts located in the same positions as in the existing crate.

The internal dimensions of the crate were adjusted to a height of 48 inches, maintaining the length and width at 96 inches and 48 inches respectively. The external dimensions were measured as 53 inches in height, 98 inches in length, and 50 inches in width, resulting in a total external volume of 259,700 cubic inches and an internal volume of 221,184 cubic inches (same as third prototype).


Figure 30: .5 inches 2 by 4


Figure 31: Metal Connector Plate


Figure 32: Crate Width


Figure 33: Crate Door

This final prototype achieved the desired success. It satisfied all the objectives, increased the cost per crate by only $9, and maintained an acceptable weight. This prototype was a triumph in balancing cost-efficiency, enhanced protection, and space optimization, marking a successful conclusion to the crate design development process.

3.3.2 User-Friendly Packaging Instructions

This chapter explores the transformation of assembly guidelines into more intuitive, user-friendly instructions. Concurrently, it outlines the improvements made in the item organization within the crates, aimed at streamlining the unpacking and assembly processes. This dual approach is aimed at reducing assembly errors and enhancing overall customer satisfaction.

3.3.2.1 Item Organization and Labelling

In response to customer dissatisfaction, the organization of items within the packaging was meticulously refined. This adaptation involved several elements of the existing system, which were adjusted to attain a higher degree of efficiency and user-friendliness, leading to a significant transformation in the customer experience.

A systematic packing order was developed as an integral part of this solution. Rather than employing a weight-based hierarchy, the components were arranged according to the sequence of assembly. This logical structure guided customers through the assembly process, considerably reducing time spent on searching for specific parts.

In the assembly instructions, for each crate is included a packing list specifying the exact location of individual components, enabling customers to effortlessly navigate through the various layers of packed items. The sequential placement of items in the crates, directly reflecting the assembly order, provided a self-explanatory unpacking process.

Figure 34: Cardboards and CDX Panels Dividers

Protective measures were significantly improved to safeguard the components during transportation. Previously, cardboard dividers were used to mitigate friction between parts. This has now been integrated with the use of internal panels covered in grey tweed fabric, providing a higher level of protection. Custom-made protective elements or partitions were introduced to fit around unique or fragile components, preventing excessive movement during transit and significantly reducing the risk of damage.

Finally, the external and internal labelling of crates were improved to facilitate the setup process. The external labelling began to include the unpacking order of the crates, while internal labels clearly indicated the placement of components within each crate. This strategic labelling further streamlined the assembly process.

Figure 35: Internal Labels

Figure 36: Zoom on Internal Labels

3.3.2.2 Packing Instructions

The significant relationship between customer satisfaction, packaging instructions, and item organization within the crates demanded a thorough re-evaluation and improvement of these key areas. The aim was to alleviate the confusion customers experienced during assembly, streamline the process, and ultimately improve satisfaction levels.

A central part of these changes was the overhaul of the packaging instructions. Previously, customers reported difficulties understanding the setup process due to dense text and limited visual guidance. To rectify this, the company shifted towards a more visual and user-friendly format. Detailed diagrams were integrated to depict the assembly process, complemented by succinct, easy-to-understand text. These enhanced visual aids provided clear assembly direction, making the instructions more intuitive and user-friendly.

To further assist customers, an additional section was introduced at the end of the instructions, indicating the specific location of each component within the crate. This inclusion greatly facilitated both the assembly and the repacking processes for customers.

The introduction of a new Enterprise Resource Planning (ERP) system in June 2023 played a crucial role in improving the accuracy and reliability of component listings. Thanks to the ERP system, the company was able to document the precise components contained in a specific crate, thereby improving the accuracy of the instructions and reducing instances of missing parts.

Further enhancing the repacking process, labels were added to each crate. These labels, paired with the improved instructions, allowed customers to quickly identify the designated location for each component during repacking.

3.4 Verify: Evaluation and Continuos Improvement

3.4.1 Crate Test

A series of tests was conducted to validate the resilience and functionality of the crate, mimicking the real-world handling and transportation scenarios. These experiments were crucial to ensuring the structural integrity of the crate and the safekeeping of its contents.

The first test was designed to simulate the conditions of a warehouse or storage facility. In this scenario, an operator lifted the crate using a forklift and deliberately collided it with another crate. This was a practical assessment of the crate's ability to endure unexpected impacts during operations. The second test involved stacking the crate above another crate. This tested the stability of the crate when positioned on top of others and its ability to maintain its structure and protect its contents under such conditions. Subsequently, the test was reversed where other crates were stacked on top of the crate under consideration. This test was crucial to determine the crate's load-bearing capacity, simulating a condition where it might be stacked under other crates in a warehouse or during transit.

Lastly, the crate was moved briskly around the testing area using a forklift. This test mimicked the fast-paced and often hectic handling of crates in transportation or warehousing environments.

The findings from this rigorous testing process were remarkably positive. The items contained within the crate remained undamaged throughout all tests, illustrating the high level of protection provided by the crate's design and construction. Furthermore, the crate proved its robustness by successfully sustaining the weight of two additional fully loaded crates stacked on top of it. These results demonstrate the effectiveness of the crate's design in maintaining the safety and integrity of its contents under varied and challenging conditions.

3.4.2 FMEA analysis

To maintain the efficacy and reliability of the newly developed crate system, conducting an in-depth Failure Modes and Effects Analysis (FMEA) is a significant part of the design and development process. The FMEA is a tool that identifies possible failures within a system, product, or process, ranks them based on their severity, likelihood of occurrence, and detectability, and eventually aids in the development of strategies to tackle these risks.

Here are the potential failure modes identified, pertinent to the design and fabrication of the crate, their potential effects, severity, occurrence, the current design control for prevention and detection, and detection ratings:

1. Design Miscalculations: Structural instability of the crate or an inability to fit the targeted items or the shipping truck might result from errors in the design phase. Ensuring the accuracy of all measurements and calculations during the design phase is a vital step in preventing such failures.

2. Fabrication Errors: Compromising the crate's structural integrity can result from mistakes during the fabrication process. A stringent quality control process during fabrication and thorough inspection of the final product can help mitigate this risk.

3. Material Supply Issues: Delays or quality issues from suppliers can disrupt the production schedule and affect the overall quality of the crate. Regular communication with suppliers and maintaining a buffer stock can help manage this risk.

4. Cost Overruns: If the volume of crate production increases drastically, we might face scale diseconomies leading to increased costs and reduced profit margins. Regular cost analysis and sourcing cost-effective materials can help prevent this.

5. Insufficient Protection of Items: If the crate does not adequately protect the items during transport, it can lead to damaged items. Regular stress tests and feedback from users can help improve the crate's protective capabilities.

6. Inadequate Staff Training: Errors in assembly procedures due to insufficient staff training can affect the crate's performance. Regular training and monitoring during the training process can mitigate this risk.

The highest Risk Priority Numbers (RPNs) determine the most significant risks (Figure 37). They are:

1. Cost Overruns with an RPN of 160: Due to the potential for scale diseconomies if production volume increases, this is the most significant risk. To mitigate this risk, close

monitoring of costs and volume must be conducted, and contingency plans for dealing with scale diseconomies must be put in place.

2. Material Supply Issues and Inadequate Staff Training, both with an RPN of 84: These risks represent operational issues that can be mitigated through proactive management. For material supply issues, fostering strong relationships with suppliers and maintaining a buffer stock can be beneficial. Regular training sessions and monitoring can prevent assembly errors resulting from inadequate staff training.

Potential Failure Mode	Potential Effects of Failure	Severity	Occurrence	Current Design Control (Prevention)	Current Design Control (Detection)	Detection	RPN
Design Miscalculations	Structural instability, inability to fit items/truck	9	3	Quality control in design, use of CAD software	Verification and validation by multiple engineers	3	81
Fabrication Errors	Compromised structural integrity of the crate	9	2	Quality control in fabrication	Regular inspections during and post-fabrication	3	54
Material Supply Issues	Disruption in production schedule, compromised quality	7	4	Good relationship with suppliers, maintaining a buffer stock	Regular supplier communication and updates	3	84
Cost Overruns	Scale diseconomies, reduced profit margins	10	4	Regular cost analysis, sourcing cost-effective materials	Financial auditing and cost reviews	4	160
Insufficient Protection of Items	Damage to items during transport	8	2	Regular stress tests, new design features	User feedback on item condition	3	48
Inadequate Staff Training	Errors in assembly procedures	7	4	Regular training regarding new procedures	Monitoring and evaluations during training	3	84

Figure 37: FMEA table and RPN Computation

These risks should be the primary focus for mitigation strategies in the next stage of the crate's development process.

While these are the most pressing risks, it's essential not to overlook the other identified risks. Even those with lower RPN values could pose significant problems if not addressed. An effective risk management strategy must consider all these factors while focusing on the high RPN risks. It's crucial to remember that the FMEA is an ongoing process. As the crate's design continues to evolve and process improvements are made, the FMEA should be updated to reflect the changing risk landscape.

This FMEA analysis, though comprehensive, is not exhaustive. Risks can evolve over time, and continuous risk assessment is necessary to maintain the robustness of the crate design. This analysis has proved to be instrumental in ensuring a successful redesign of the Orbus crate, focusing on reliability, safety, and performance.

3.4.3 Continuous Improvement and Iterative Refinement of Packaging Designs

The process of continuous improvement and iterative refinement will be a fundamental part of our strategy going forward in the development and enhancement of our packaging designs. These two concepts are crucial in the ever-evolving world of packaging as they allow for the accommodation of new industry trends, regulatory changes, and customer requirements. They also serve as a mechanism to identify and correct potential design and process inefficiencies, thereby improving the quality of our crates over time.

Continuous improvement approach for our crate design, involves systematically reviewing and refining our designs based on the feedback received from various stakeholders, including customers, transporters, and internal assembly staff. The aim is to gradually enhance the efficiency, functionality, and longevity of our crates, making them more competitive in the market. This process will also allow us to regularly reassess our costs and find innovative ways to enhance our profitability while ensuring quality.

Iterative refinement relates more directly to the design development process. It is a cycle of prototype development, testing, analysis, and refinement. The insights we gained during the design and prototyping stages of our crate development will play a vital role here. The aim is to learn from each iteration and integrate those learnings into subsequent design versions. This iterative process will be crucial in resolving any design flaws, enhancing usability, and improving the overall performance of our crates.

The principles of continuous improvement and iterative refinement will underpin our future approach to packaging design. They will ensure that our designs remain up-to-date and continue to meet and exceed the expectations of our customers. This approach also places us in a position to effectively anticipate and navigate any challenges or opportunities that may emerge, thereby securing our place as a leader in packaging solutions.

CHAPTER 4

MARKET AND ENVIRONMENTAL CONSIDERATIONS

4.1 PESTEL Analysis

The PESTEL Analysis is a valuable tool for understanding the broad market or industry environment. This acronym stands for Political, Economical, Social, Technological, Environmental and Legal areas of analysis [53].

These comprehensive sectors provide a panoramic view of the market, offering a macro perspective of the conditions in which a specific service will operate. Each letter of the PESTEL analysis represents a distinct area of interest, all of which are crucial to a complete market assessment. It's important to systematically investigate each of these areas in order to form a comprehensive understanding of the market landscape.

In this chapter, each aspect of the PESTEL analysis is developed. This approach will ensure a detailed and thorough review of each sector, which in turn, will provide valuable insights into the market dynamics where the service is intended to be provided.

4.1.1 Political

As of 2021, the U.S. leadership consists of President Joe Biden and Vice President Kamala Harris from the Democratic Party. The country's political scene in 2022 was largely affected by Russia's invasion of Ukraine, which saw a rare bipartisan support for humanitarian and military aid to Ukraine. U.S. policy leaned towards multilateralism, coordinating sanctions against Russia with NATO and western partners.

In 2022, a new USD 1.58 billion aid package was announced following a meeting between Biden and Ukraine's President Zelenskiy. Despite high inflation and recession fears, the Democrats held the Senate after the mid-term elections, while the Republicans barely won a majority in the House of Representatives. Former President Donald Trump's continued political presence, along with pending investigations, affected Republican performance. Trump announced his intent to run for president again. Tensions with China remained high, specifically on trade and intellectual property issues, while human rights violations in Iran reduced the chances of a nuclear deal.

The two major political parties, the Democratic Party (favoring social progression and market regulation) and the Republican Party (supporting free-market capitalism, social conservatism, and national defense), dominate the U.S. political landscape.

As a federal republic, the U.S. operates on representative democracy, with a bicameral Congress comprising the Senate and the House of Representatives checking the President's powers. Each of the 50 states enjoys significant self-governance [54].

Orbus, operating in this political context, faces challenges and opportunities. With the current government favoring multilateral approaches, Orbus may benefit from potential international collaborations or support for industry innovation. However, international tensions, particularly with China, may impact global supply chains, increasing operational costs. Also, the bipartisan support for aid to Ukraine could signal a political willingness to support sectors providing essential services, such as transportation, in times of crisis. Orbus should closely monitor U.S. political developments, particularly around economic policies, to strategically align its operations and growth plans.

4.1.2 Economical

During the COVID-19 pandemic, the U.S., the world's largest economy, faced severe disruptions [55]. Although GDP growth initially turned negative, resilience and effective monetary and fiscal policies led to a swift recovery, rebounding to 5.7% in 2021. Despite the recovery, economic conditions are expected to tighten, causing GDP growth to decelerate to 1% in 2023. Fiscal measures to contain the COVID-19-induced crisis impacted public finances, with the government's debt-to-GDP ratio increasing. However, the U.S. benefits from substantial financing flexibility as the issuer of the world's main reserve currency.

Inflation spiked to 8.1% in 2022 due to supply-chain disruptions, high energy prices, and labor shortages. Nonetheless, inflation is predicted to stabilize towards the Federal Reserve's 2% target in the coming years.

Despite the initial impact of COVID-19 on unemployment, the labor market has shown strong recovery. However, due to a slowing economy, unemployment is expected to increase. Though the average American enjoys one of the highest GDP (PPP) per capita globally, significant inequalities persist.

Orbus operates in an environment recovering from the COVID-19 pandemic but faces challenges such as economic deceleration, fiscal deficits, inflation, and socio-economic inequality. These factors could affect business strategy and operations. For Orbus, changes in the economic landscape could influence demand for their products, costs of materials and labor, and ultimately their bottom line. The company needs to remain agile, responding to these evolving conditions by innovating their product offering, optimizing costs, and potentially expanding into new markets or segments. Furthermore, the social inequality and higher poverty levels could create a demand for more affordable, yet reliable, shipping solutions. As a result, Orbus may need to consider these factors in their business strategy and product design process.

4.1.3 Social

The USA, with a population of about 335 million, ranks third globally in population size. The country has a significant aging population, impacting labor supply, yet doesn't feature in the top 20 nations with an aging populace [55].

Cultural diversity is a hallmark of the US, demonstrated in its music, literature, art, cuisine, and entertainment, influenced by various ethnic and racial backgrounds. The US stands among the world's most educated countries, hosting esteemed universities like Harvard, Stanford, and MIT.

The country's healthcare system is advanced, but it is not universally free or affordable. Issues such as police violence, crime, and infant mortality remain serious concerns. Despite a health-conscious population, fast food culture contributes to obesity and related health issues. Recent racial tensions indicate social challenges, despite a generally liberal mindset.

American cuisine, a fusion of traditional and international flavors, is globally renowned. The vibrant entertainment scene offers diverse activities and events. Although the US is famous for social mobility, a decline has been noticed over the past decade.

Orbus could leverage the US's cultural diversity and rich education base to diversify and innovate its product offerings. The aging population might bring about unique needs in the exhibits, events, and interior sectors, demanding more accessible and easy-to-use display structures. The high level of healthcare awareness could open up opportunities for specialized exhibits or events related to health and wellness. However, social issues and a decline in social mobility should be taken into consideration while strategizing the marketing and affordability of products. The vibrant entertainment and event scene in the US provides a thriving market for Orbus's product portfolio, and the company can capitalize on this by continuously adapting to the evolving trends and demands of this dynamic market.

4.1.4 Technological

The USA, as a global leader in science and technology, boasts cutting-edge tech companies such as Apple, Microsoft, Google, and Facebook. These corporations cater to technological needs worldwide, dominating their respective fields [55]. The country has an advanced mobile and broadband network infrastructure, along with sophisticated satellite systems used for various purposes like communication, navigation, and weather forecasting.

Technological adaptation and application are paramount in the USA, revolutionizing numerous fields. However, the transfer of jobs and relocation of production facilities to other countries for cost reduction have caused discontent among some Americans.

Despite the high speed of technological innovation, the USA faces competition from countries such as China, South Korea, and India. These nations are rapidly advancing in their technological capacities, thus presenting significant challenges.

For Orbus, the technology-rich environment of the USA presents both opportunities and challenges. On one hand, technological advancements could allow Orbus to innovate and improve its product offering, streamline its manufacturing processes, and enhance its customer interface and services. On the other hand, the rapid rate of technological change means that Orbus needs to continuously invest in research and development to stay competitive. The increasing global competition in technology also suggests that Orbus must stay vigilant about international trends and disruptions that could impact its operations or market position.

4.1.5 Environmental

The USA is characterized by its diverse geography, climate, and wildlife, which draw millions of tourists from countries like Canada, Mexico, the UK, Japan, Brazil, and China. The country's breath-taking natural attractions, quaint towns, vibrant cities, and impressive wilderness areas contribute to its allure [55].

However, the USA often endures severe weather conditions, suffering over 220 weather and climate disasters in the past 40 years. These disasters have resulted in billions of dollars in damages, disrupting daily life and necessitating greater efforts towards damage minimization.

Orbus could experience effects from both positive and negative environmental factors in the USA. The country's thriving tourism industry presents opportunities for Orbus to supply its products to various tourism-related businesses, events, and exhibitions.

On the flip side, the frequency of severe weather events and climate disasters may pose a threat to Orbus's operations, potentially causing disruptions in the supply chain, production, or delivery processes. Given the increasing focus on environmental sustainability worldwide, Orbus should also consider incorporating eco-friendly practices in its operations, such as using sustainable materials and reducing waste. This can not only minimize its environmental footprint but also enhance its brand image and appeal to environmentally conscious consumers and businesses.

4.1.6 Legal

The legal environment in the USA is multifaceted given the federal structure, where each state has its unique regulatory and legal system. Therefore, for Orbus, a thorough understanding of both federal and state-specific regulations, where its operations and customer base are located, is essential.

The country's commitment to equal treatment of nationals and foreigners provides a level playing field for businesses, regardless of their origin. This signifies that Orbus, irrespective of its national or international status, can operate without unjust disadvantages in the marketplace.

Furthermore, the robust legal protection of Intellectual Property Rights (IPR) in the USA is advantageous for Orbus. This would safeguard the company's innovative design solutions and patented technologies, protecting its competitive advantage and encouraging further innovation.

However, the multiplicity of regulations across different states can pose a challenge. Orbus must ensure compliance with various state-specific laws, including those related to business operations, taxation, employment, environment, and health and safety. This legal diversity necessitates a dynamic approach to compliance management and business strategy across different states.

In conclusion, the legal environment in the USA requires businesses to navigate a complex web of federal and state laws. However, it also offers considerable protection to businesses in terms of IPR and ensures a fair competitive environment. Thus, Orbus must develop a robust compliance framework tailored to the different regulatory landscapes it operates within and leverage the strong IPR protection to secure its innovative edge.

4.1.7 Conclusion

Drawing from the PESTEL analysis, Orbus operates within a multifaceted environment in the USA. Given the economic conditions, technological advances, societal shifts, and political realities, Orbus' approach to packaging should be responsive and innovative.

Considering the prevailing rapid technological innovation, it's crucial for Orbus to consider integrating advanced tech in their packaging design. This can include QR codes, interactive labels, or NFC chips, offering customers a value-added and interactive experience. This aligns with the objective of meeting and exceeding customer expectations.

Economic fluctuations necessitate a cost-effective approach to packaging without compromising quality, crucial in satisfying customer requirements. Therefore, adopting efficient packaging techniques that economize resources while ensuring product protection is essential. This could include modular packaging designs that can be adapted for different product sizes, reducing material use and cost. The sociocultural landscape signifies a preference for individuality and diversity. Customizable or personalized packaging options could be an avenue to explore, catering to the desire for unique, tailored experiences, and offering a competitive edge for Orbus.

Considering the political landscape and potential regulatory changes, it's crucial for Orbus to remain compliant with packaging standards and regulations, ensuring customer trust and business continuity.

Reflecting on environmental factors, while sustainability may not be the focus, designing packaging that is resilient to various weather conditions can ensure product safety during transit, thus enhancing customer satisfaction. In summary, a customer-focused packaging strategy that is economically viable, technologically savvy, politically compliant, and resilient to environmental conditions will equip Orbus to navigate the dynamic landscape successfully, fulfilling its aim of satisfying customer requirements.

4.2 Market Analysis and Customer Preferences

The landscape of the U.S. business sector is vast and varied, with key segments that significantly contribute to the economy. This chapter provides an analytical overview of two such important areas: the impact of Packaging on Consumer Behavior and Trade Shows, both of which are deeply interlinked with Orbus' business operations.

The way Packaging influences Consumer Behavior in the U.S. has seen a dynamic shift in recent years, driven by evolving consumer preferences and increasing awareness about environmental sustainability. Superior packaging design plays an indispensable role in the consumer buying process, often serving as a critical factor influencing purchasing decisions. As such, an investment in improving packaging can potentially translate into an increase in sales volume for businesses like Orbus.

Simultaneously, the Trade Show market in the U.S. holds substantial relevance for Orbus, given that approximately 95% of its Structure products are purposed for these events. Trade shows are powerful platforms for businesses to showcase their offerings, network with industry professionals, and gain exposure in their respective sectors.

Therefore, a deep understanding of these areas and their interplay with Orbus' business is essential to accurately project the potential increase in revenue resulting from packaging improvements.

4.2.1 Packaging Impact on Consumers

Packaging has transcended its conventional role as a mere product container, evolving into a powerful marketing strategy capable of significantly impacting consumer behavior. In fact, according to a recent study, 72% of Americans attest that product packaging design plays a pivotal role in their purchasing decisions [56]. Thus, the way Orbus redesigns its packaging can deeply influence its customer engagement and overall sales.

Packaging is a vital communication tool between the brand and consumers. It should not only visually convey security but also provide answers to consumer queries. Detailed product labels containing product specifications, relevant dates, and other pertinent details can sway consumers towards a purchase. This transparent communication can foster trust and enhance brand reputation.

In addition, packaging quality directly reflects the perceived quality of the product inside. Superior packaging can engender consumer trust and justify product cost, especially for luxury items. It's been found that 61% of buyers are more likely to repurchase a product if presented in premium packaging. Furthermore, functional elements such as the packaging size, its protective quality, and the ease of opening and storage also influence consumer behavior.

The unboxing experience itself is part of the customer journey, with 55% of consumers who watch unboxing videos claiming it convinced them to buy the product. Finally, packaging can effectively communicate a brand's values and vision. In today's consumer landscape, shoppers are increasingly conscious of ethical and environmental factors. Therefore, displaying labels or certifications signifying eco-friendly practices or ethical sourcing on the packaging can be a decisive factor, as 78% of consumers are willing to buy products with less wasteful, eco-friendly packaging.

In conclusion, packaging is not merely a protective shell but an integral part of the product and the brand. For Orbus, understanding the impact of packaging on consumer behavior is essential. As the company ventures into redesigning its packaging, careful consideration of these factors can potentially lead to an increase in product appeal, customer satisfaction, and ultimately, sales volume.

4.2.2 Trade Shows Industry in the US

The trade show and conference planning industry plays a pivotal role in U.S. business activity, facilitating the organization, promotion, and management of various events. Historically, this industry has demonstrated growth parallel to the broader economy, with clients spanning diverse sectors, government agencies, and nonprofit organizations. Despite experiencing the most significant contraction in its history due to the COVID-19 pandemic, the industry has shown resilience, achieving a Compound Annual Growth Rate (CAGR) of 0.9% over the past five years, with revenue reaching $21.7 billion [2].

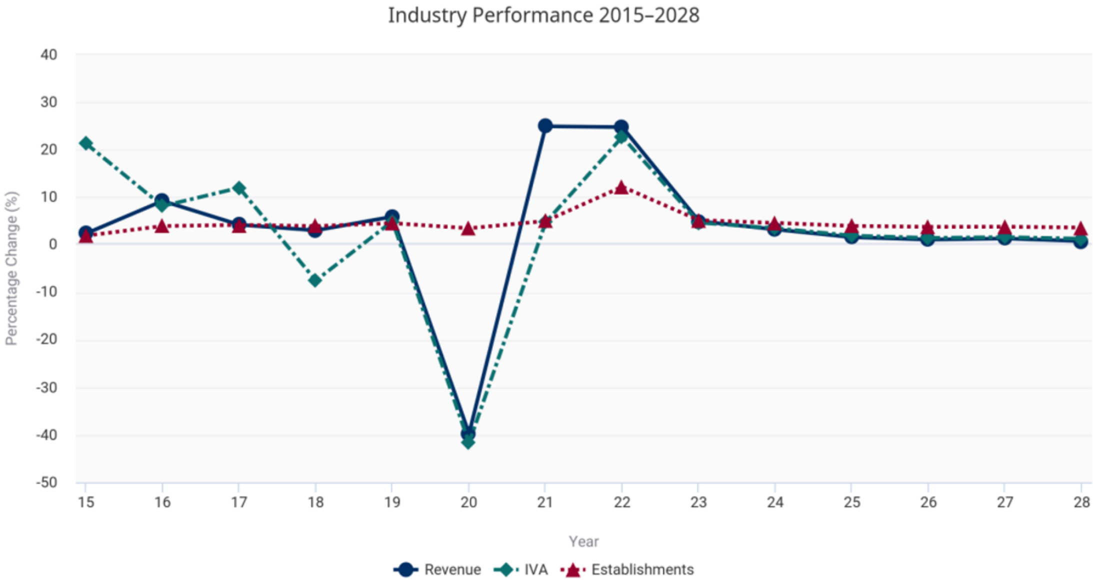


Figure 38: Trade Show and Conference Planning in the US, Industry Performance 2015-2028 [2]

The pandemic disrupted the industry primarily by affecting business expenditure and tourism. During periods of declining corporate profit, businesses curtail discretionary spending on trade shows and exhibitions. Similarly, domestic and inbound travel, which is integral to the industry's functioning, witnessed a severe slump. However, with the advent of vaccines and resurgence in business activities, the industry rebounded, showcasing remarkable growth in 2021 and 2022. Revenue is expected to rise by an estimated 5.0% in 2023.

As the pandemic recedes, several positive trends are expected to benefit the industry. For instance, forecasts suggest an increase in corporate profit and advertising expenditure, indicating that businesses are likely to allocate more funds towards trade shows, conferences, and exhibitions. This recovery could be further bolstered by a revival in air travel. The industry's revenue is expected to increase at a CAGR of 1.6% to $23.5 billion over the next five years. The industry is closely tied to domestic travel trends, corporate profit levels, total advertising expenditure, online business conduction, and inbound trips by non-U.S. residents. An increase in these factors in 2023 presents potential opportunities for the industry, albeit with the caveat of increased online business conduction posing a potential threat.

This analysis has several implications for Orbus. As the industry is expected to grow significantly, there will be more opportunities for Orbus to showcase and sell its products at trade shows and exhibitions. With higher corporate profits, companies may be more willing to invest in higher quality, attractively designed display structures, which could increase demand for Orbus' improved packaging offerings.

CHAPTER 5

EVALUATION AND RESULTS

In this critical chapter, a comprehensive evaluation of the project is delved into by the author, assessing the effectiveness of the redesigned crates and packing process introduced by Orbus. By methodically examining each of the project's objectives in relation to the gathered customer feedback, the degree to which these objectives have been achieved will be discerned. The extent to which these objectives have been accomplished will be determined through a meticulous analysis of each project objective in correlation with the collected customer feedback. Moreover, the ensuing influence on customer satisfaction, as measured by the Customer Satisfaction Score (CSAT), will be assessed. This evaluation aims to shed light on the project's effectiveness, while also identifying potential areas necessitating additional enhancement or fine-tuning. Moreover, it will serve as a guide for similar future initiatives, underlining the importance of customer-centered design and efficient packing processes in the visual communication solutions industry.

5.1 Assessment of Customer Satisfaction and Feedback

After implementing improvements in Orbus' crate design and packing process, another round of Voice of Customer (VOC) collection was conducted, focusing on a different set of customers. The purpose was to assess the impact of the new design and processes on customer satisfaction levels and gather insights from a wider range of customer experiences. These efforts aimed to ensure the objectivity and diversity of customer feedback. The Customer Satisfaction Score (CSAT) derived from this feedback stands at a commendable 88, indicating significant customer satisfaction with the improvements.

Positive Feedback:

"The redesigned crate has been a game-changer for us. With the new lighter design, the crate is much easier to handle, yet it remains robust enough to ensure the protection of our items."

"The packing list for each crate has streamlined our unpacking and setup process. It's effectively a blueprint to our exhibit, saving us significant time during the hectic setup period."

"The comprehensive labelling system is a thoughtful addition. It provides us with a clear indication of the crate contents, making it much easier for us to plan our setup and organization."

"The simplified packing instructions are a hit with our team. The revisions have significantly reduced packing errors and make the entire process more efficient."

"We're very impressed with the new crate dimensions. We can now fit two crates side by side in our standard shipping trucks, optimizing our transport space without compromising the internal volume. This is innovation at its best!" – Internal customer

Negative Feedback:

"While the new instructions are more straightforward, there are still a few points that could use further clarification. More detailed diagrams or illustrations might be beneficial."

"The labelling system is detailed, which we appreciate, but we've noticed that the labels can peel off under certain weather conditions. A more resilient adhesive or label material might solve this issue."

Despite a few areas pinpointed for potential improvement, the overall feedback unambiguously underlines the successful achievement of our project objectives. From enhancing crate durability, to improving item organization with the introduction of per-crate packing lists, each objective has been met to a high degree of customer satisfaction.

The introduction of a comprehensive labelling system, which was another objective, has notably facilitated crate content identification, leading to more efficient setup planning for our customers. Further, the revision of packing instructions, making them more accessible and easier to understand, has substantially reduced packing errors and improved the overall process from our customers' perspective. Notably, the resizing of the crate dimensions, a critical project objective, has received an overwhelmingly positive response. The reduced crate width allowing for a side-by-side arrangement in standard shipping trucks, has optimized transport space utilization.

The Voice of Customer (VOC) feedback has clearly validated these objectives, with customer responses highlighting the effectiveness of the implemented changes. The strong CSAT score of 88 further corroborates the customer satisfaction with the improvements, showcasing the success of the project. The minor concerns identified in the feedback offer a roadmap for further enhancements, allowing us to keep refining our processes in line with our customer-centric ethos. As we continue on this journey, we remain committed to pushing the boundaries of excellence and ensuring a premium customer experience at Orbus.

5.2 Packaging Efficiency and Cost Optimization

5.2.1 Measurement of Packaging Redesign Efficiency: KPIs Assessment

To evaluate the effectiveness of the packaging redesign, several Key Performance Indicators (KPIs) were closely monitored. These measurements played a crucial role in understanding the extent to which the improvements met the stated objectives:

1. Customer Satisfaction Score (CSAT): The CSAT score provides a direct indication of overall customer satisfaction related to the packaging. The objective was to improve upon the previous score of 76, and this has been achieved with a significantly raised CSAT score of 88. This impressive result clearly indicates a high level of customer satisfaction with the new crate design and packing process.

2. Average Time to Assemble (ATA): The goal of the redesigned crates and improved packing instructions was to streamline the unpacking and setup process for customers. The ATA KPI measures the average time taken by customers to assemble products from the crates. The previous average assembly time of 27 hours has been drastically reduced to a much shorter 18 hours. This improvement confirms that the changes have indeed made the assembly process quicker and more efficient for customers.

3. Transport Efficiency Ratio (TER): The crate redesign aimed to optimize transport space without compromising internal volume. The TER calculates the proportion of a transport vehicle's load capacity used effectively. The initial TER was 16.3%, but with the

redesigned crates, it has been boosted to 31.69%. This substantial increase in transport efficiency indicates the successful achievement of optimization efforts.

4. Rate of Returns due to Packaging Errors (RRPE): The RRPE serves as a critical KPI for Orbus, measuring the effectiveness of packing instructions, overall item organization strategy, and the crate's ability to keep items safe. The goal was to decrease the rate from 1.2% to an improved rate of 0.5%. In the first month after implementation, the RRPE showed a significant decrease, reaching a score of 0.3%. This decrease demonstrates the success of the new packaging strategies and improvements in item organization.

The assessment of these KPIs clearly demonstrates the achievement of the project's set objectives. The substantial improvements across all measures confirm the success of the redesign in enhancing customer satisfaction, increasing efficiency, and improving the environmental footprint.

5.2.2 Financial Evaluation

5.2.2.1 Case Scenario

In conducting the financial analysis to ascertain the impact of the newly proposed packaging solution, four distinct scenarios are incorporated, each reflecting a range of potential outcomes. These scenarios are used to calculate the Net Present Value (NPV), a measure of profitability that accounts for the time value of money. In each case, the NPV calculated is differential, contrasting it against a base case where the packaging design remains unmodified, and the demand and revenue stay consistent with the levels of the year 2022 (261 orders, $10,451,673 revenues).

- Worst Case - Constant Sales Scenario (5% probability): This represents the worst-case scenario. Here, it is presumed that the volume of sales remains unchanged over the ensuing six years, signifying no growth in sales volume despite the packaging redesign.
- Realistic Case 1 - Market Growth Scenario (35% probability): This scenario mirrors a realistic yet somewhat pessimistic perspective. It is proposed that the volume of sales increases annually, following the same growth pattern as the Trade Shows market in the United States. This annual growth rate varies between 0.8% and 4.8% over the next six years.
- Realistic Case 2 - Enhanced Growth Scenario (45% probability): This scenario portrays a realistic yet optimistic standpoint. It is assumed that the sales volume increases annually at the same rate as the growth of the Trade Shows market in the United States. Moreover, an extra annual growth of 2% is factored in, attributed to enhanced packaging quality.
- Best Case - Optimistic Scenario (15% probability): This constitutes the best-case scenario, where sales volume rises annually at the same rate as the growth of the Trade Shows market in the United States, with an additional annual growth of 5% factored in. This supplementary growth is credited to the impressive improvements in packaging quality and exceptional customer service. As with the other scenarios, the amplified revenue from increased sales is balanced against the supplementary cost of the redesigned packaging.

In each scenario, the differential NPV is calculated by discounting the differential revenues over the next six years at a risk-free rate of 5.25% (3 months US treasury bill) [57][58]. This offers a nuanced perspective on the potential profitability of the new packaging design, considering a variety of potential future circumstances.

5.2.2.2 NPV

The key measure of interest is the Net Present Value (NPV), which encapsulates the present value of future cash flows, discounted back to today's terms using a risk-free rate. The NPV allows us to incorporate the time value of money into our analysis and provides a comprehensive measure of the expected financial benefits accruing from our packaging redesign.

The NPV is computed using the formula:

$$\mathrm{NPV} = \sum \left[\frac{\mathrm{CF}_t}{(1+r)^t} \right] - I_0 \tag{5.1}$$

Where:

- CF_t is the cash flow in year t,
- r is the risk-free rate (5.25%),
- t is the year, from 2023 to 2028; where 2023 is equal to 1, 2024 is equal to 2 and so on,
- I_0 initial investment.

The CFs employed are calculated differentially by subtracting the profit of each scenario from the profit of the baseline scenario where the packaging remains unaltered.

5.2.2.3 Assumptions

Our analysis will rely on the following assumptions:

1. Baseline sales and revenue will remain constant over the next 6 years (261 orders, $10,451,673 revenue) if we do not redesign the packaging.
2. I_0 is equal to $20000.
3. The new packaging incurs an additional cost of $9 per package.
4. The risk-free rate is 5.25%.
5. Growth rates for the trade show market in the US for the next 6 years are [2]: 2023: 4.8%, 2024: 3.1%, 2025: 1.5%, 2026: 0.9%, 2027: 1.3%, 2028: 0.8%.
6. The rate of returned items (in the baseline scenario and in the other scenario) will remain constant during the period.
7. The risk-free rate will remain constant during the period.
8. The gross profit margin is 35% [59] and is constant during the period.
9. The average cost of shipping is $2023/shipping [60] and is constant during the period

5.2.2.4 Cost Structure

In the endeavor to refine and enhance Orbus' product packaging, a comprehensive understanding of the associated cost structures is of utmost importance. It is pertinent to note that the costs computed herein are differential and related specifically to the base case scenario, meaning they are over and above the standard operational costs.

Fixed Costs:

The initial investment required for the packaging improvements involved certain fixed costs. These fixed costs, totalling $20,000, were primarily directed towards the creation and testing of new packaging prototypes. The crux of the affordability advantage was that Orbus managed to circumvent the need for new machinery acquisition, leveraging its existing wood shop facilities for all crafting and testing procedures. Thus, this initial investment comprised the cost of labor devoted to crafting the prototypes, in addition to the cost of the materials employed for their construction.


Figure 39: Wood Shop Station


Figure 40: Work In Progress Crate


Figure 41: 2 by 4s


Figure 42: Panels

Variable Costs:

Following the initial implementation phase, certain variable costs distinct from the original operational configuration were incurred. This resulted primarily from the incorporation of metal connector plates in the packaging design and increased usage of CDX panels equipped with grey tweed fabric. Each crate equipped with these connector plates led to an incremental cost of \$9 per unit. This represents a significant variable cost in the revised cost structure and will fluctuate with the number of units produced. A substantial factor contributing to the variable costs is the cost associated with returned items, which averages at \$20,000 per crate returned. These return-related costs can dramatically impact the profitability and need to be thoroughly accounted for in any financial analysis. Lastly, shipping costs, another key component of the variable costs, are directly tied to the number of crates shipped. The more crates shipped, the more trucks are required, escalating the shipping expenses. The variation in the number of crates and the related shipping costs emphasizes the fluctuating nature of these costs and the need for efficient logistics planning.

5.2.2.5 Financial Impact

This chapter conducts a thorough financial impact analysis on the adoption of the optimized packaging solution across four scenarios: Baseline (Worst case), Realistic/Pessimistic, Realistic/Optimistic, and Best case scenario.

Each scenario follows a comprehensive set of calculations, with all computations made differential to the Baseline scenario. The baseline scenario assumes no changes to the existing packaging and maintains the sales volume and revenue of the year 2022.

The computation process begins with revenue, which is multiplied by the gross profit margin to yield the gross profit (expressed in \$):

$$GrossProfit = Revenues \times GrossProfitMargin \tag{5.2}$$

Subsequently, various cost components are deducted from the gross profit to derive the net profit.

The first cost component considered is the total shipping cost. Orbus currently operates under an order system where each order, on average, requires four crates. With the existing crate dimensions, a truck is only capable of accommodating three crates. This limitation necessitates the use of two trucks for each order's transportation, resulting in increased operational costs. However, with the implementation of the packaging improvement initiative, the capacity of each truck is optimized. Each truck, under the new system, can transport six crates, which is sufficient for the delivery of a complete order. This means that just one truck is required per order, thus effectively halving the truck requirements for Orbus and leading to significant cost savings. The cost is computed by multiplying the total number of shipments for the year by the cost per shipment (expressed in \$/shipment):

$$TotalShippingCost = NumberofShipments \times CostperShipment \tag{5.3}$$

The second cost component is the returned items cost. The amount of orders returned accounts for the 1.2% of total orders returned due to damage in the baseline scenario and the 0.3% in the case of improved packaging. The total returned items cost is obtained by multiplying the total number of orders returned by \$20,000, covering the costs of reproduction of the item, reshipping, penalty fees, and in some cases, order cancellation:

$$ReturnedItemsCost = TotalNumberofReturnedOrders \times CostperReturnedOrder \tag{5.4}$$

The third cost component is the differential crate cost. This is calculated by multiplying the number of crates required under the optimized packaging design (expressed in number of crates) by \$9. This cost is an additional expense as the new crate design is more expensive to produce:

$$DifferentialCrateCost = NumberofCrates \times AdditionalCostperCrate \tag{5.5}$$

The net profit is then computed by subtracting the total cost from the gross profit, representing the company's earnings after considering all the costs:

$$\begin{split}\text{Net Profit} = \text{Gross Profit -}\\ (\text{Total Shipping Cost} + \text{Returned Item Cost} + \text{Differential Crate Cost})\end{split} \tag{5.6}$$

The final step involves calculating the Net Present Value (NPV) for each scenario. The NPV is an important financial indicator that discounts future cash flows to their present value using a risk-free rate:

$$NPV = \sum \left(\frac{NetProfit}{(1 + Risk - freeRate)^n} \right) - InitialInvestment \tag{5.7}$$

,where n is the year (from 1 to 6).

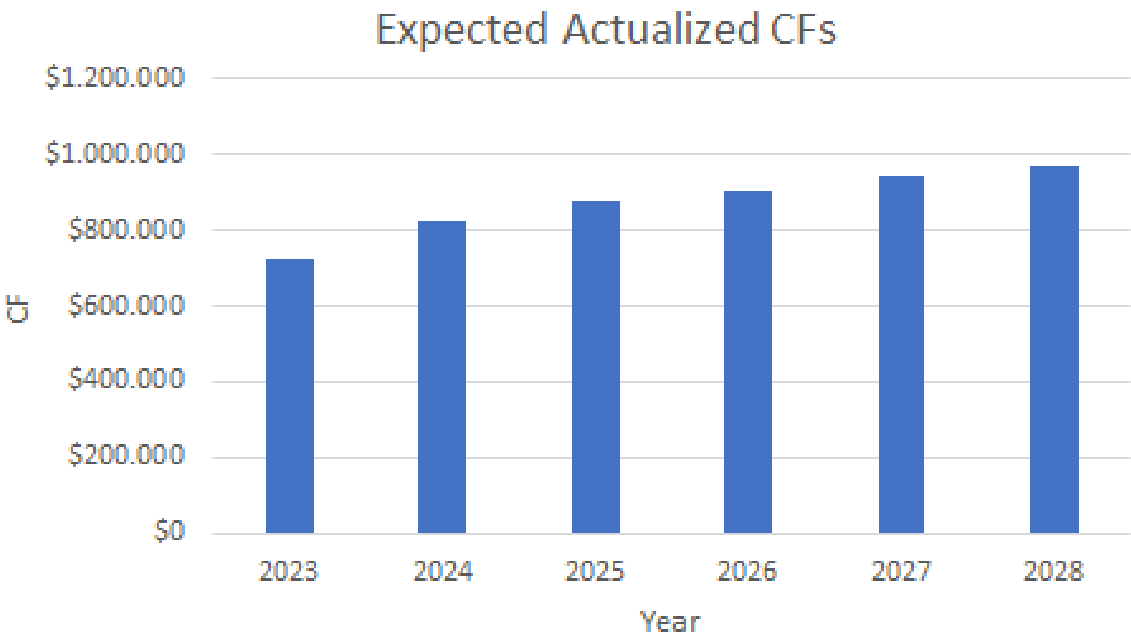


Figure 43: Expected Actualized Cash Flow

The computed NPVs for the scenarios are as follows:

- Worst case scenario: \$2,827,936
- Realistic case 1 scenario: \$4,309,850
- Realistic case 2 scenario: \$5,477,382
- Best case scenario: \$7,373,003

To arrive at the overall expected NPV, the NPVs of each scenario are multiplied by their respective probability of occurrence and then summed:

$$ExpectedNPV = \sum(NPV \times Probability\,of\,Scenario) = \$5,220,617 \tag{5.8}$$

More detailed computation tables and further insights can be found in the appendix. These calculations highlight the potential financial benefits of adopting the optimized packaging design across all considered scenarios.

5.2.3 Environmental Impact

The environmental savings can be computed by assessing the decrease in carbon emissions due to fewer trucks on the road.

Given that the average pollution of a truck shipping is 161.8 grams of CO2 per ton-mile [61], and the average travel length is 206 miles [62], the CO2 emissions per truck can be calculated. However, needs to take into account the fact that the weight of the truck changes with the number of packages, therefore, the calculation will be performed for both scenarios: The total weight of a loaded truck in the initial scenario is 30,000 pounds (26,000 pounds empty trucks [63] + 2,000 pounds per crate), which converts to approximately 13.6 metric tons. Hence, the emissions per truck amount to:

$$13.6\,\text{tons} \times 161.8\,\text{g CO2/ton-mile} \times 206\,\text{miles} = 450,733\,\text{grams of CO2/truck} \tag{5.9}$$

This means that the total emissions for an order amount to:

$$2\,\text{trucks/order} \times 450,733\,\text{g CO2/truck} = 901,466\,\text{g of CO2/order} \tag{5.10}$$

In the new scenario, the total weight of a loaded truck is 34,000 pounds (26,000 pounds empty trucks + 2,000 pounds per crate), which converts to approximately 15.4 metric tons. Hence, the emissions per truck in this scenario are:

$$15.4\,\text{tons} \times 161.8\,\text{g CO2/ton-mile} \times 206\,\text{miles} = 512,606\,\text{grams of CO2/truck} \tag{5.11}$$

The total emissions for an order in the new scenario are:

$$1\,\text{truck/order} \times 512,606\,\text{g CO2/truck} = 512,606\,\text{g of CO2/order} \tag{5.12}$$

This results in a unitary reduction in CO2 emissions of the 43%/order.

This signifies a substantial environmental benefit, corroborating Orbus' commitment to sustainability and responsible business practices.

The redesigned packaging solution has yielded significant benefits, both in terms of cost savings and reduced environmental impact. It represents a tangible manifestation of how operational efficiencies can harmoniously intertwine with ecological responsibility.

CHAPTER 6

CONCLUSIONS AND FUTURE RECOMMENDATIONS

6.1 Summary of Findings and Achievements

6.1.1 Recap of the Research Objectives and Outcomes

The purpose of this research was to optimize Orbus's existing packaging solution for Customized Exhibit Structures, evaluate the financial impact of introducing this solution, and ascertain its effect on a set of Key Performance Indicators (KPIs). The results have not only met but exceeded the initial expectations, underscoring the value of thoughtful design and planning in all aspects of business operations.

Between the design objectives, the enhanced durability, improved item organization, comprehensive labelling, user-friendly packing instructions, and crate design optimization emerged as the focal points. Each element played a significant role in creating a packaging solution that safeguards fragile items, organizes contents efficiently, provides clear labelling, and offers simple packing instructions.

Additionally, the redesigned crates were made from lightweight yet durable materials that protect critical elements and prevent crate damage when stacked. One fundamental design change was the reduction of the crate's external width from 53 inches to 50 inches, without reducing the internal volume. This allowed two crates to be transported side by side within a standard shipping truck, significantly enhancing transport space optimization and reducing transport-related CO_2 emissions by a remarkable 43% per order. This constitutes a substantial contribution towards Orbus's sustainability initiatives, demonstrating that operational efficiency and ecological responsibility can go hand in hand.

On the financial front, four scenarios — worst case, realistic case 1, realistic case 2, and best case — were considered to measure the potential outcomes. The resulting Net Present Values (NPVs) for the differential cash flows over a six-year period were encouraging across all scenarios. With a calculated expected NPV of $5,220,617, the proposed packaging solution demonstrates substantial economic potential.

Moreover, the performance evaluation of the new packaging design revealed a positive effect on several KPIs. Notably, the Customer Satisfaction Score (CSAT) increased from 76 to 88, and the Average Time to Assemble (ATA) reduced from 27 hours to 18 hours. This attests to a heightened customer satisfaction and a more efficient assembly process. The Rate of Returns due to Packaging Errors (RRPE) also declined from 1.2% to 0.3%, emphasizing the efficacy of the new packaging design. This significant reduction in the costs associated with returns, coupled with a 50% decrease in shipping costs, highlights the economic value of the new packaging solution.

The redesigned packaging solution has yielded significant gains in financial savings, customer satisfaction, assembly efficiency, and environmental responsibility. The outcomes of this research validate the project objectives and confirm the profound influence of thoughtful design and planning on multiple dimensions of business operations. The packaging solution, in its new form, represents a milestone in Orbus's commitment to delivering excellence to its customers, while concurrently advocating sustainable and responsible business practices.

6.1.2 Key Insights derived from the Study

This research has led to several notable insights, contributing to a more profound understanding of the role packaging design plays in various facets of business operations, customer satisfaction, and environmental responsibility. The key insights derived from the study are as follows:

1. Importance of User-Centric Design: The drastic improvements in the Customer Satisfaction Score (CSAT) and Average Time to Assemble (ATA) underscore the criticality of a user-centric approach in packaging design. Detailed instructions, efficient item organization, and a comprehensive labelling system not only make the assembly process easier and more intuitive for customers but also enhance their overall product experience, thereby increasing customer satisfaction.

2. Financial Impact of Design Decisions: The study has highlighted the substantial financial impact that design decisions can make. The reduction in shipping and return costs by optimizing the packaging design translates into substantial cost savings, as evidenced by the positive Net Present Value (NPV) across all evaluated scenarios. This illustrates that investment in thoughtful and efficient design can yield significant financial returns.

3. Environmental Responsibility and Operational Efficiency: A key insight derived from the study is the intersection of operational efficiency and environmental responsibility.

The reduction in transport-related CO_2 emissions per order by 43% exemplifies that business operations can be streamlined without compromising environmental stewardship. Businesses can, and indeed must, find innovative ways to harmonize operational and ecological goals.

4. Reduction in Product Returns: The significant decrease in the Rate of Returns due to Packaging Errors (RRPE) reflects the effectiveness of the improved packaging design and instructions. This reduction translates into considerable cost savings and emphasizes the importance of meticulous design and planning in minimizing packaging errors and product damage.

5. Strategic Utilization of Space: The research highlights the value of space optimization in transport logistics. By simply reducing the external width of the crates without affecting their internal volume, two crates could be fit side by side within a standard shipping truck. This led to a significant increase in the Transport Efficiency Ratio (TER), reinforcing the importance of strategic space utilization in enhancing transport efficiency and reducing costs.

The key insights from this study attest to the multifaceted value of effective packaging design, extending beyond pure aesthetics to encompass elements of cost-efficiency, customer experience, environmental stewardship, and logistical optimization. The findings underscore the need for businesses to approach packaging design as a strategic function with the potential to deliver substantial benefits across the value chain.

6.2 Implications for the Visual Communications Solutions Industry

The research outcomes and insights derived from Orbus's case present several implications for the broader visual communications solutions industry. From an increased emphasis on user-centric design and lean management principles to an elevated focus on sustainability, there are crucial takeaways for industry participants.

6.2.1 Lean Management Principles and DFSS in Packaging Optimization

The study illuminates the efficacy of lean management principles and Design for Six Sigma (DFSS) methodologies in the optimization of packaging design. DFSS, coupled with lean management, enables companies to design processes with minimum waste and maximum efficiency. This case study offers a tangible demonstration of these principles in action, with clear, measurable outcomes.

Firstly, the application of lean principles and DFSS allowed for a considerable reduction in waste, both in terms of material usage and costs associated with returns and transport. The optimized crate design, using less material and space, showcases lean management's emphasis on reducing waste and increasing process efficiency. Secondly, the reduction in the Rate of Returns due to Packaging Errors (RRPE) demonstrates the effectiveness of the DFSS methodology in achieving near-perfect product quality and process efficiency. By focusing on customer needs and incorporating extensive planning in the design stage, Orbus was able to significantly decrease packaging errors, highlighting the value of these methodologies for the visual communications industry.

6.2.2 Lessons Learned and Potential Industry-Wide Implications

Several lessons can be gleaned from this study, with the potential to influence the broader industry. Among the key takeaways are the importance of considering user experience in packaging design, the financial benefits of efficient design, and the potential for operational efficiencies to contribute to environmental sustainability. The substantial improvement in customer satisfaction and assembly times underscores the necessity of user-centric packaging design. Industry players should consider investing more resources in understanding their customers' needs and preferences to inform their packaging design processes.

The financial benefits of efficient design are another vital lesson for the industry. This study demonstrates that careful design planning and execution can lead to significant cost savings and positive financial outcomes, making a compelling case for companies to invest in thoughtful packaging design.

Lastly, the harmonization of operational efficiency and environmental responsibility presents a potential model for the industry. As the pressure to operate sustainably continues to mount, businesses need to find innovative ways to balance their operational goals with their ecological responsibilities. The study suggests that it is indeed possible to achieve this balance, providing a blueprint for the industry.

Overall, the implications of this study suggest that there are numerous potential benefits to be derived from applying lean principles, DFSS, and a user-centric approach to packaging design within the visual communications industry.

6.3 Limitations and Future Directions

While this study has yielded meaningful insights and demonstrated significant potential benefits from packaging optimization, it's important to acknowledge its limitations and explore potential avenues for future research and continuous improvement.

6.3.1 Research Limitations and Potential Areas for further Exploration

A key limitation of this research pertains to the Verify phase's duration in the DMADV process, confined to a span of one month post-implementation. This limited timeframe might not wholly reflect the long-term effects or account for potential seasonal variations in orders, returns, or customer feedback.

Another considerable limitation lies within the accuracy of the financial data used. Until June 2023, Orbus operated with a monitoring system that, while reliable, lacked precision. This limitation might have led to a certain degree of imprecision in the calculated financial impact of the new packaging solution.

Furthermore, the study focused on Orbus, a single entity within the expansive visual communications industry. While the outcomes are indeed promising, their application across the industry, marked by a diverse range of products, operational scenarios, and customer needs, is constrained.

Future exploration could concentrate on applying these principles and methodologies across other operational areas within the visual communications industry. This could involve evaluating lean management and DFSS principles' effectiveness in refining manufacturing processes, customer service protocols, or logistics operations.

6.3.2 Recommendations for Future Research and Continuous Improvement

With the Kaizen philosophy of continuous improvement as a guiding principle, future research should focus on further refining the packaging solution. This could involve a more detailed analysis of specific elements of the packaging process, such as material sourcing, labor practices, and transportation logistics.

Continuous collection of customer feedback is another critical avenue for future research. Understanding customer needs and preferences should be an ongoing endeavor, with packaging designs evolving in response to these insights.

A broader perspective would involve future research delving deeper into the intersection of packaging design and sustainability. While this study acknowledged the environmental benefits of a more efficient packaging solution, a more exhaustive investigation into sustainable materials, lifecycle analysis, and end-of-life disposal practices for packaging could significantly influence industry practices and standards.

In conclusion, this study, despite its limitations, represents a significant stride towards optimizing packaging design within the visual communications industry. There is substantial room for further research and continuous improvement. Future endeavors should leverage the insights and methodologies from this study, fostering a consistent commitment to customer satisfaction, operational efficiency, and environmental sustainability.

6.4 Conclusion

The research conducted throughout this thesis has examined the potential benefits of packaging optimization in the visual communications industry, specifically through the lens of the case study company, Orbus. A series of clear research objectives were outlined, each targeting a distinct aspect of the existing crate design for improvement. These objectives guided the successful redesign of the crate, focusing on enhancements to its durability, item organization, labeling, packing instructions, and overall structure, including a critical reduction in external width to boost transport efficiency. The redesign had a profound impact on several crucial Key Performance Indicators (KPIs), including the Customer Satisfaction Score (CSAT) risen to the score of 88, Average Time to Assemble (ATA), Transport Efficiency Ratio (TER), and the Rate of Returns due to Packaging Errors (RRPE). As evidenced by the improvements in these KPIs, the project achieved its primary goals.

Moreover, the new design demonstrated significant financial benefits. Depending on different scenarios (worst-case, two realistic cases, and best-case), the redesign resulted in a range of Net Present Values (NPVs), with an expected NPV of \$5,220,617. Besides financial gains, the project also made a substantial contribution to reducing the environmental footprint by decreasing CO_2 emissions by 43% per order.

This case study illustrates how Lean Management principles and Design for Six Sigma (DFSS) methodologies can be effectively applied to achieve a win-win situation – both financially and ecologically – in the visual communications industry. It serves as a reminder that focusing on the customer, improving quality, and striving for efficiency can lead to better operational outcomes and higher customer satisfaction.

However, the research recognizes its limitations, particularly in terms of the short duration of post-implementation monitoring and the level of precision in the financial data. The recommendation for future research is to embrace the concept of Kaizen, or continuous improvement, for further refinement of packaging solutions and exploring other areas of operations.

The learnings from this study are not a definitive endpoint, but rather a starting point for further development. Future endeavors could focus on integrating more sustainable packaging materials, utilizing more precise financial data, and continuing the quest for operational efficiencies.

This thesis showcases the value of customer-centric design thinking in business processes and the importance of continuous improvement for operational excellence. It highlights the fact that businesses can operate sustainably without sacrificing profitability. This research has demonstrated that the journey to profitability and sustainability is interconnected, thereby providing a roadmap for the visual communications industry and beyond. Through careful design, responsible operations, and a continuous commitment to improvement, businesses can reach a future that is not only financially successful but also environmentally sustainable.

APPENDICES

Appendix A

WORST CASE NPV COMPUTATION

YEAR 1 (2023)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (1)
SCENARIO 1	$10.451.673	$3.658.086	261	1044	261	$528.003	$15.660	$9.396	$3.105.027	$565.587
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 2 (2024)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (2)
SCENARIO 1	$10.451.673	$3.658.086	261	1044	261	$528.003	$15.660	$9.396	$3.105.027	$565.587
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 3 (2025)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (3)
SCENARIO 1	$10.451.673	$3.658.086	261	1044	261	$528.003	$15.660	$9.396	$3.105.027	$565.587
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 4 (2026)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (4)
SCENARIO 1	$10.451.673	$3.658.086	261	1044	261	$528.003	$15.660	$9.396	$3.105.027	$565.587
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 5 (2027)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (5)
SCENARIO 1	$10.451.673	$3.658.086	261	1044	261	$528.003	$15.660	$9.396	$3.105.027	$565.587
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 6 (2028)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (6)
SCENARIO 1	$10.451.673	$3.658.086	261	1044	261	$528.003	$15.660	$9.396	$3.105.027	$565.587
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

Figure 44: Differential CF Computation

NPV (1)	NPV (2)	NPV (3)	NPV (4)	NPV (5)	NPV (6)	NPV - TOTAL
CF (1) / (1+5.25%)^1	CF (2) / (1+5.25%)^2	CF (3) / (1+5.25%)^3	CF (4) / (1+5.25%)^4	CF (5) / (1+5.25%)^5	CF (6) / (1+5.25%)^6	∑ NPV (t) - Investment
$537.375	$510.570	$485.102	$460.905	$437.914	$416.070	$2.827.936

Figure 45: NPV of the Scenario

Appendix B

REALISTIC CASE 1 NPV COMPUTATION

YEAR 1 (2023)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (1)
SCENARIO 2	$10.953.353	$3.833.674	274	1094	274	$553.347	$16.412	$9.847	$3.254.068	$714.628
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 2 (2024)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (2)
SCENARIO 2	$11.292.907	$3.952.518	282	1128	282	$570.501	$16.920	$10.152	$3.354.944	$815.504
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 3 (2025)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (3)
SCENARIO 2	$11.462.301	$4.011.805	286	1145	286	$579.058	$17.174	$10.305	$3.405.268	$865.829
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 4 (2026)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (4)
SCENARIO 2	$11.565.462	$4.047.912	289	1155	289	$584.270	$17.329	$10.397	$3.435.915	$896.476
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 5 (2027)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (5)
SCENARIO 2	$11.715.813	$4.100.534	293	1170	293	$591.865	$17.554	$10.532	$3.480.582	$941.143
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 6 (2028)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (6)
SCENARIO 2	$11.809.539	$4.133.339	295	1180	295	$596.600	$17.695	$10.617	$3.508.427	$968.988
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

Figure 46: Differential CF Computation

NPV (1)	NPV (2)	NPV (3)	NPV (4)	NPV (5)	NPV (6)	NPV - TOTAL
CF (1) / (1+5.25%)^1	CF (2) / (1+5.25%)^2	CF (3) / (1+5.25%)^3	CF (4) / (1+5.25%)^4	CF (5) / (1+5.25%)^5	CF (6) / (1+5.25%)^6	∑ NPV (t) - Investment
$678.982	$736.177	$742.618	$730.550	$728.694	$712.829	$4.309.850

Figure 47: NPV of the Scenario

Appendix C

REALISTIC CASE 2 NPV COMPUTATION

YEAR 1 (2023)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (1)
SCENARIO 3	$11.162.387	$3.906.835	279	1115	279	$563.907	$16.725	$10.035	$3.316.168	$776.729
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 2 (2024)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (2)
SCENARIO 3	$11.731.668	$4.106.084	293	1172	293	$592.666	$17.578	$10.547	$3.485.293	$945.853
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 3 (2025)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (3)
SCENARIO 3	$12.142.277	$4.249.797	303	1213	303	$613.410	$18.193	$10.916	$3.607.278	$1.067.839
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 4 (2026)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (4)
SCENARIO 3	$12.494.403	$4.373.041	312	1248	312	$631.199	$18.721	$11.232	$3.711.889	$1.172.450
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 5 (2027)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (5)
SCENARIO 3	$12.906.718	$4.517.351	322	1289	322	$652.028	$19.338	$11.603	$3.834.382	$1.294.942
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 6 (2028)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (6)
SCENARIO 3	$13.268.106	$4.643.837	331	1325	331	$670.285	$19.880	$11.928	$3.941.744	$1.402.305
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

Figure 48: Differential CF Computation

NPV (1)	NPV (2)	NPV (3)	NPV (4)	NPV (5)	NPV (6)	NPV - TOTAL
CF (1) / (1+5.25%)^1	CF (2) / (1+5.25%)^2	CF (3) / (1+5.25%)^3	CF (4) / (1+5.25%)^4	CF (5) / (1+5.25%)^5	CF (6) / (1+5.25%)^6	∑ NPV (t) - Investment
$737.985	$853.846	$915.882	$955.445	$1.002.628	$1.031.596	$5.477.382

Figure 49: NPV of the Scenario

Appendix D

BEST CASE NPV COMPUTATION

YEAR 1 (2023)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (1)
SCENARIO 4	$11.475.937	$4.016.578	287	1146	287	$579.747	$17.195	$10.317	$3.409.319	$869.880
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 2 (2024)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (2)
SCENARIO 4	$12.405.488	$4.341.921	310	1239	310	$626.707	$18.587	$11.152	$3.685.474	$1.146.034
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 3 (2025)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (3)
SCENARIO 4	$13.211.845	$4.624.146	330	1320	330	$667.443	$19.796	$11.877	$3.925.030	$1.385.590
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 4 (2026)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (4)
SCENARIO 4	$13.991.343	$4.896.970	349	1398	349	$706.822	$20.964	$12.578	$4.156.607	$1.617.167
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 5 (2027)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (5)
SCENARIO 4	$14.872.798	$5.205.479	371	1486	371	$751.352	$22.284	$13.371	$4.418.473	$1.879.033
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

YEAR 6 (2028)	REVENUES	GROSS PROFIT	# OF ORDER	# OF CRATES	TRUCK NEEDED	TOTAL SHIPPING COST	RETURNED ITEMS COST	DIFFERENTIAL CRATE COST	NET PROFIT	CF (6)
SCENARIO 4	$15.735.420	$5.507.397	393	1572	393	$794.930	$23.577	$14.146	$4.674.744	$2.135.305
BASE LINE	$10.451.673	$3.658.086	261	1044	522	$1.056.006	$62.640	$0	$2.539.440	

Figure 50: Differential CF Computation

NPV (1)	NPV (2)	NPV (3)	NPV (4)	NPV (5)	NPV (6)	NPV - TOTAL
CF (1) / (1+5.25%)^1	CF (2) / (1+5.25%)^2	CF (3) / (1+5.25%)^3	CF (4) / (1+5.25%)^4	CF (5) / (1+5.25%)^5	CF (6) / (1+5.25%)^6	∑ NPV (t) - Investment
$826.489	$1.034.555	$1.188.416	$1.317.851	$1.454.869	$1.570.823	$7.373.003

Figure 51: NPV of the Scenario

Appendix E

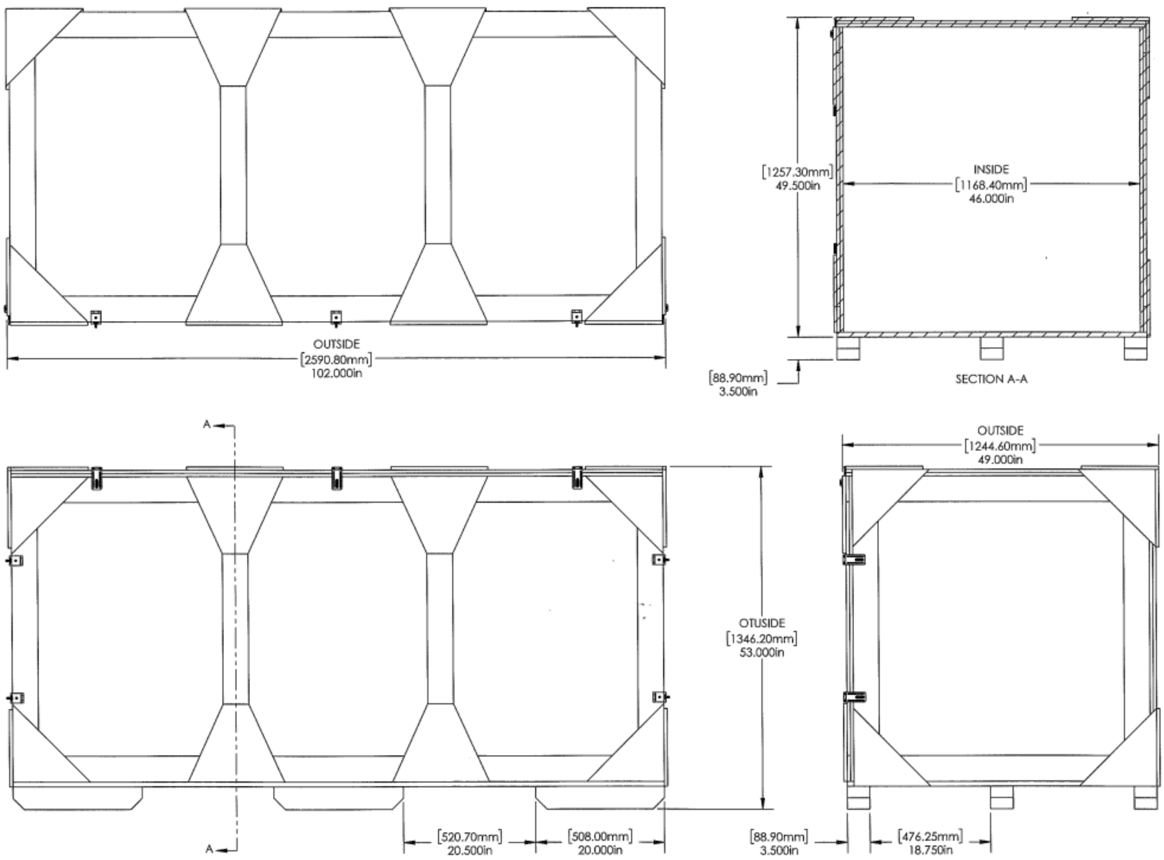
EXPECTED TOTAL NPV COMPUTATION

		NPV (1)	NPV (2)	NPV (3)	NPV (4)	NPV (5)	NPV (6)	NPV - TOTAL
SCENARIO	PROBABILITY	CF (1) / (1+5.25%)^1	CF (2) / (1+5.25%)^2	CF (3) / (1+5.25%)^3	CF (4) / (1+5.25%)^4	CF (5) / (1+5.25%)^5	CF (6) / (1+5.25%)^6	∑ NPV (t) - Investment
4	0,15	$826.489	$1.034.555	$1.188.416	$1.317.851	$1.454.869	$1.570.823	$7.373.003
3	0,45	$737.985	$853.846	$915.882	$955.445	$1.002.628	$1.031.596	$5.477.382
2	0,35	$678.982	$736.177	$742.618	$730.550	$728.694	$712.829	$4.309.850
1	0,05	$537.375	$510.570	$485.102	$460.905	$437.914	$416.070	$2.827.936
	EXPECTED NPV	$720.579	$822.604	$874.581	$906.366	$946.351	$970.136	$5.220.617

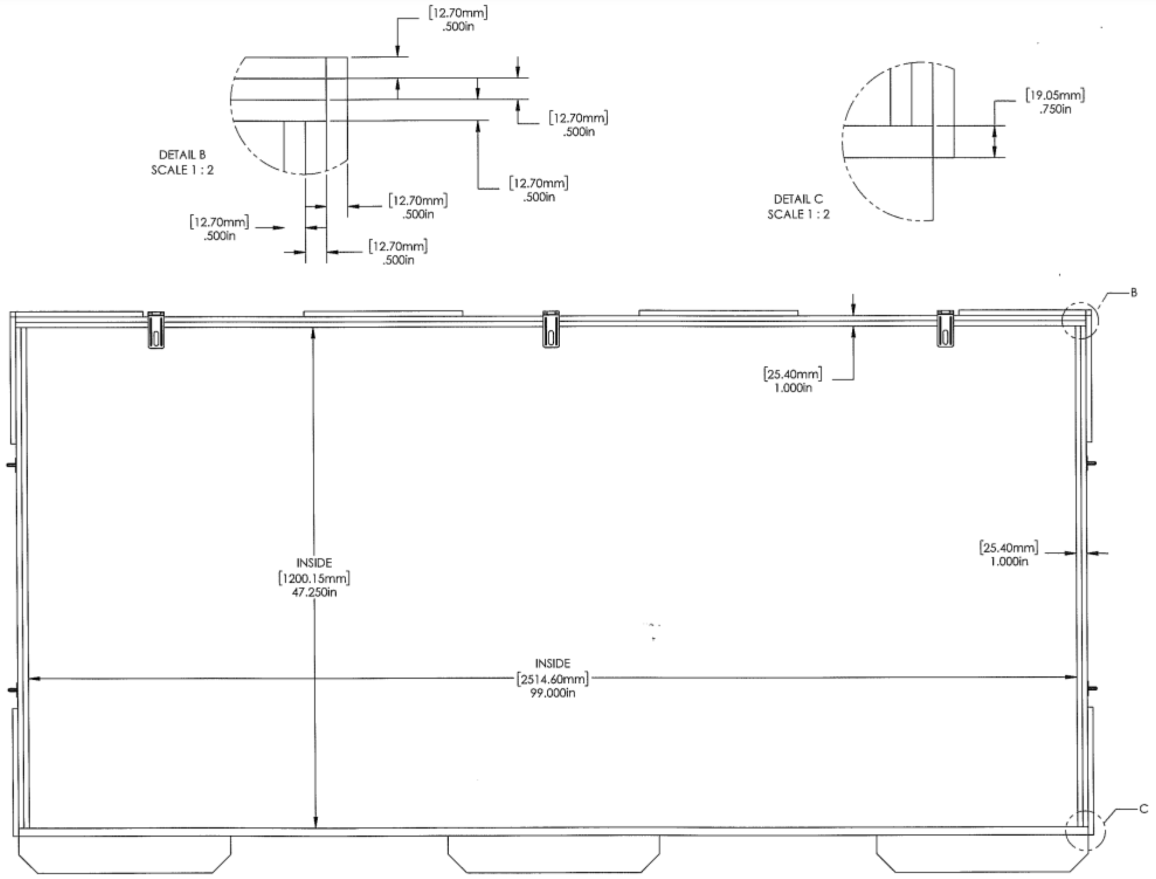
Figure 52: Expected NPV

Appendix F

DETAILED DRAFTING OF THE SECOND PROTOTYPE

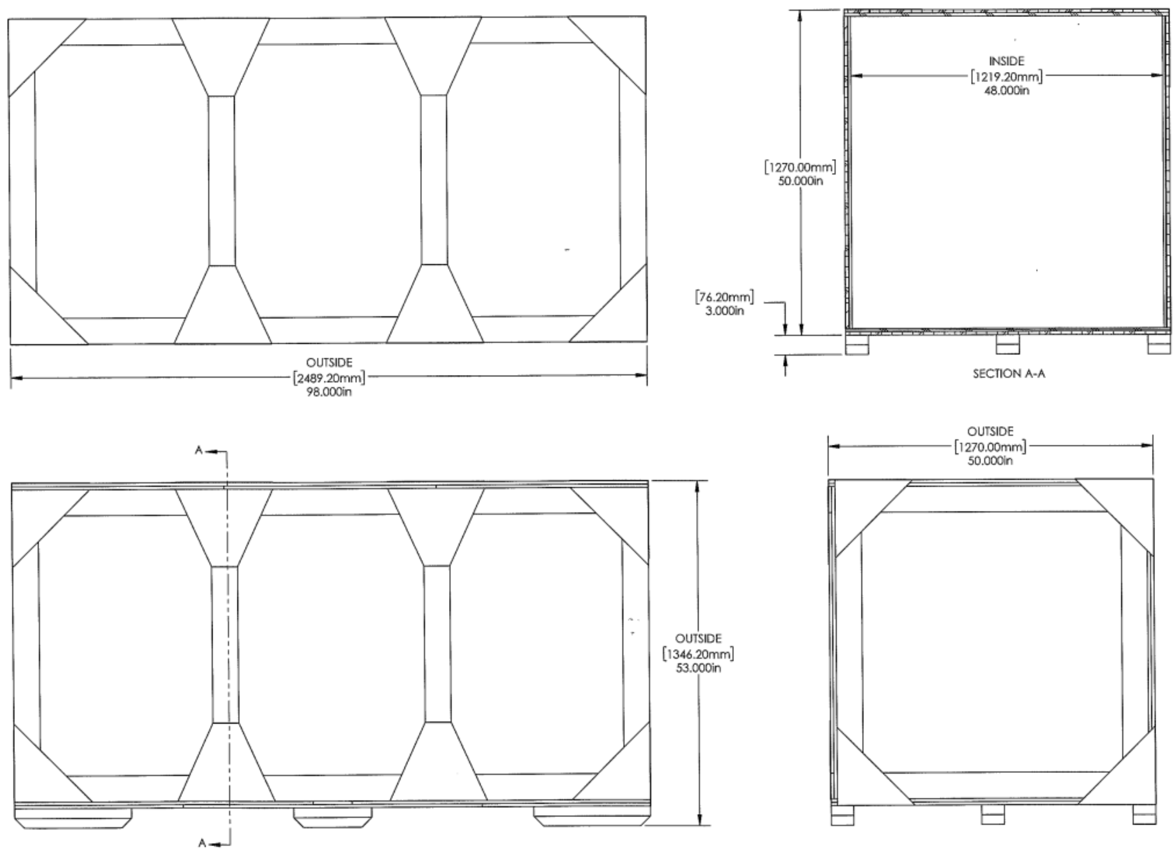


Appendix F (continued)

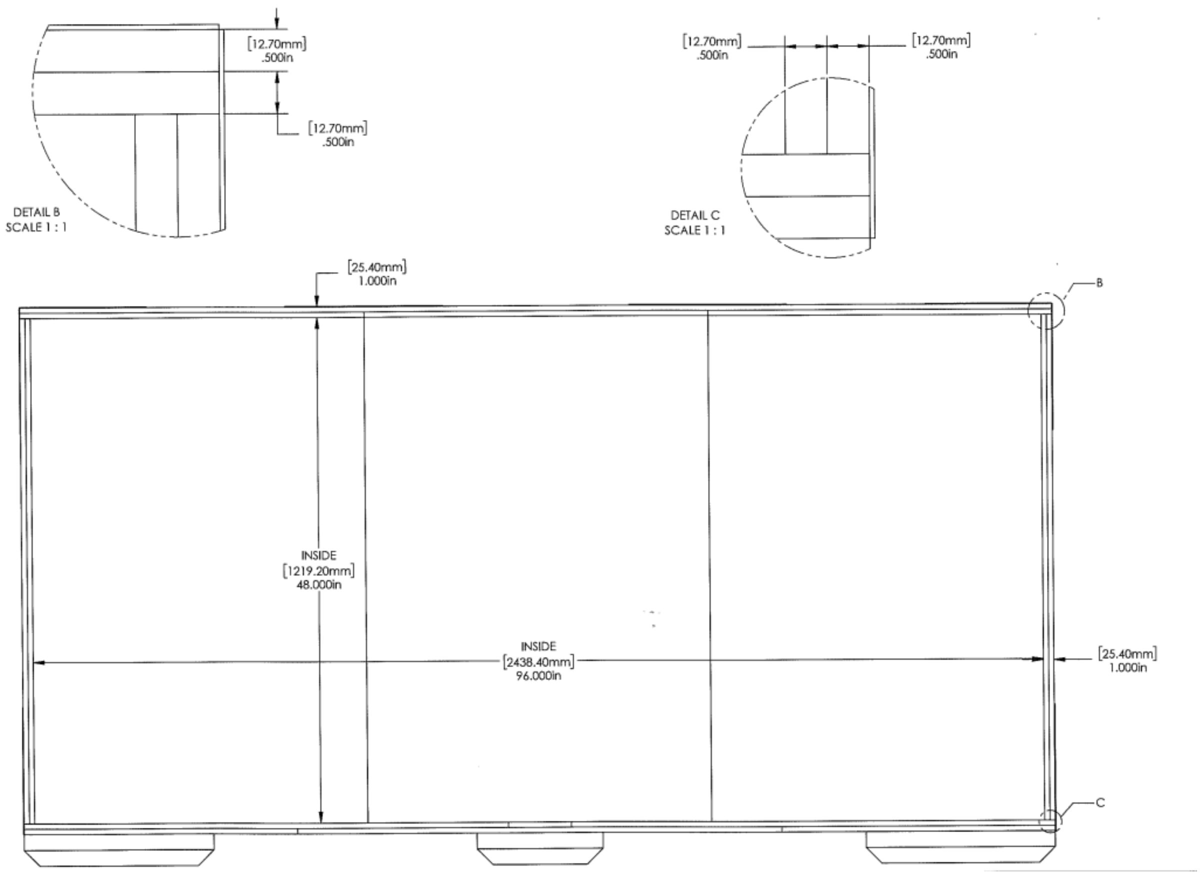


Appendix G

DETAILED DRAFTING OF THE THIRD AND FOURTH PROTOTYPE



Appendix G (continued)



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March 2023 – present	Continuous Improvement Engineer at Orbus Exhibit and Display Group
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PROJECTS	
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August 2022 – December 2022	Predicting the Satisfaction of an Airline Company's Passengers with University of Illinois at Chicago