Lean Six Sigma Approach to Improve Further Processing Efficiency using Burger Manufacturing as a Model Process.

By

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Abstract

Operations management plays a crucial role in industries, enhancing operations through the application of process improvement philosophies. Among these, Six Sigma reduces variation, and Lean Manufacturing ensures quality along the process. The combination of these philosophies leads to Lean Six Sigma, an approach that incorporates DMAIC (Define, Measure, Analyze, Improve, and Control) and Kaizen (continuous improvement) and has been applied widely. This study focuses on a consulting project in a burger patty manufacturing facility to reduce shrinkage and waste. The consulting project crossed four key stages: (1) receiving room scales (calibration and area cleanliness); (2) combo dumping (purge loss and leak issues); (3) water misting system (effectiveness of the and patty weights after the freezing process); and (4) ensure accurate tare weight of boxes at the scale room. This thesis introduces a convergence that merges food science and operations management, presenting a unique methodology and philosophy with significant potential to impact the food industry.

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List of Abbreviations

5S	Sort, Set in order, Shine, Standardize, Sustain
BRC	British Retail Consortium
CFU	Colony Forming Units
CI	Continuous Improvement
COPQ	Cost of Poor Quality
Cp	Process Capability Index
Cpk	Process Capability Index (adjusting for centering)
CTPs	Continuous Improvement Techniques
CTQ	Critical to Quality
DFSS	Design for Six Sigma
DIMDOV	Define, Identify, Measure, Design, Optimize, Verify
DMADV	Define, Measure, Analyze, Design, Verify
DMAIC	Define, Measure, Analyze, Improve, Control
FMEA	Failure Modes and Effects Analysis
FSIS	Food Safety and Inspection Service
Gage R&R	Gage Repeatability and Reproducibility
ISO 9001	International Organization for Standardization 9001
JIT	Just-In-Time
LSCM	Lean Supply Chain Management
LSL	Lower Specification Limit
LSS	Lean Six Sigma
Mb	Myoglobin
MetHb	Methemoglobin
MetMb	Metmyoglobin
MSA	Measurement System Analysis
NHANES	National Health and Nutrition Examination Survey

PAA	Peracetic Acid
PDCA	Plan, Do, Check, Act
PMSS	Project Management Support System
PTMs	Post-translational Modifications
PUV	Pulsed Ultraviolet
PVC	Polyvinyl Chloride
QMS	Quality Management System
REDIS	Rapid Evaporative Ionization Mass Spectrometry
SCM	Supply Chain Management
SMEs	Small and Medium-sized Enterprises
SOPs	Standard Operating Procedures
SPC	Statistical Process Control
TPS	Toyota Production System
TQM	Total Quality Management
USDA	United States Department of Agriculture
USL	Upper Specification Limit
VM	Visual Management
VOC	Voice of the Customer
VSM	Value Stream Mapping

Chapter I.

Literature review

1.1 Six Sigma in Operations Management

The origins of Six Sigma can be traced back to Motorola in the 1980s. The company, faced with increasing competition and a compelling need for enhanced quality, pursued a revolutionary strategy to tackle defects in its manufacturing processes. Bill Smith, a senior engineer and scientist at Motorola, pioneered Six Sigma as a data-driven methodology designed to minimize defects and optimize quality (Breyfogle, 2003; Peter et al., 2000).

The word "sigma" (σ) in Six Sigma originates from the Greek alphabet and signifies variability. Traditionally, Six Sigma gauges defects per unit. The sigma quality level predicts defect occurrence frequency. A greater sigma quality level suggests a process with a reduced chance of defect production (Montgomery & Woodall, 2008; Peter et al., 2000). "Six Sigma" originates from a statistical measure that assesses process capability, determining how many standard deviations fit within customer-defined limits. Achieving Six Sigma quality means that 99.99966% of products manufactured are statistically free from defects, translating to a mere 3.4 defects per million opportunities (Breyfogle, 2003). This distinct methodology blends the strengths of statistical and non-statistical instruments, all composed within a strategic and organized structure (Peter et al., 2000).

Within the frameworks of Six Sigma methodologies, statistical quality control emerges as a central force steering continuous process improvement. Grigg and Walls (2007) undertook a study in the food manufacturing industry, emphasizing the critical role that statistical thinking plays in determining the success of such quality control implementations.

As Kumar (2017)highlighted, Six Sigma's primary goal is to elevate product quality by refining processes and addressing the root causes of defects. Their research, which employs the DMAIC (Define, Measure, Analyze, Improve, and Control) approach, provides insight into the drivers of capacity waste, particularly within process industries such as thermal power plants. The study demystifies certain perceptions regarding the applicability of Six Sigma in these industries, emphasizing performance enhancement.

A study by Noone et al. (2010) investigates the impact of applying Six Sigma principles to customer-facing processes during service exchanges. Contrary to expectations, the findings suggest that integrating Six Sigma in such processes does not necessarily boost customer satisfaction. This research offers a unique perspective, emphasizing the high degree of customer involvement typically found in service exchanges. Prashar (2014) detailed the application of Six Sigma tools to address and mitigate the cost of poor quality (COPQ). The study pinpointed the underlying causes for the frequent failure of the equipment, excessive tolerances, and inappropriate specifications. This research emphasized the potential of the Six Sigma DMAIC methodology to significantly reduce costs related to product rejections or reworks.

1.1.1 Six Sigma Core

Six Sigma incorporates a structured five-phase problem-solving strategy: Define, Measure, Analyze, Improve, and Control, commonly called DMAIC. This systematic approach employs various foundational statistical tools, such as control charts, designed experiments, process capability analyses, and measurement system capability studies. The DMAIC methodology serves as an exceptionally potent framework for enhancing processes. However, it is crucial to note that DMAIC can stand independently and is not exclusively linked to Six Sigma. It is a versatile method widely adopted for managing change and improvement. Notably, DMAIC originates in Walter Shewhart's Plan-Do-Check-Act (PDCA) cycle, providing a structured pathway that integrates diverse tools into a comprehensive approach to quality improvement (Montgomery & Woodall, 2008).

The DMAIC framework promotes innovative thinking concerning challenges and their solutions, staying within the original parameters of the product, process, or service. Poor process performance and the need for a new process for a product or service are the primary targets for the 'Improve' phase of DMAIC and the “Desing” phase of DMADV (Define, Measure, Analyze, Desing and Verify). In the context of a Six Sigma organization, this implies that a Design for Six Sigma initiative becomes essential (Montgomery & Woodall, 2008).

A study by Abualsauod (2023) utilized the DMAIC methodology, comprising five phases, to address production defects using customer data. The analysis showed that most complaints centered on fitting (42.6%), pricing (30%), and service quality (12.1%). The DMAIC's structured approach and the diverse tools provided by LSS streamlined the problem identification and data analysis processes, facilitating the selection of optimal improvement solutions aligned with specific process activities.

Soundararajan K. (2019) explored the efficacy of the Six Sigma DMAIC framework in enhancing both cost efficiency and quality within small-medium enterprises. Using straightforward tools in the DMAIC process, they witnessed a substantial quality improvement from 2.9 to 4.4 sigma. Their investigation focused on the excessive wear of a guide wheel's outer layer and addressed it by transitioning to a higher-grade rubber. This strategic move led to marked cost reductions and elevated product quality, bolstering the brand's reputation.

1.1.1.1 Define

The initial stage of the DMAIC methodology is centered on outlining the project's objectives and boundaries based on customer needs and crafting a procedure that meets these specifications. Forming a group of individuals familiar with the procedure is a foundational step in the Six Sigma approach to problem-solving (Gijo et al., 2011). This crucial beginning phase of the DMAIC strategy emphasizes problem identification, goal setting, and identifying processes needing refinement. Tools such as Voice of Customer (VOC), Critical to Quality (CTQ), and process mapping are utilized during this period.

1.1.1.1.1 Problem Statement

In the Define phase of the Six Sigma methodology, framing the problem statement is essential. The problem statement sets the stage for the entire project by clearly and concisely describing the business issues. It articulates the problem but not why it exists or how to solve it. It clearly shows the gap between the current and desired states (Ray & Das, 2010).

Crafting an effective problem statement requires specificity before applying the Six Sigma methodology. Unclear or overly broad problem statements can hinder the project's progress, leading to an unclear path forward or a scope too large to manage. A well-defined problem statement will answer questions such as:

- What is the issue?
- Where does the problem occur?
- When does it happen, and how often?
- What is the impact of the problem?

1.1.1.1.2 Customer Requirements

Identifying customer requirements is vital for delivering value in any product or service. This involves segmenting the customer base and understanding their specific needs. Johannsen and Leist (2009) categorize these requirements into three main types based on the Voice of the

Customer (VOC). First are the service requirements that focus on a solution's service aspect. Next are the output requirements related to the results or deliverables of the service component. Finally, requirements are centered around the manufactured part, emphasizing the actual product specifications. This detailed categorization facilitates organizations in delivering a comprehensive and integrated solution that aligns with varying customer expectations.

1.1.1.1.3 Voice of the Customer

A central component of this phase is the Voice of the Customer (VOC), which serves as a mechanism to capture, analyze, and interpret customer-supplier needs, wants, preferences, and expectations (Found & Harrison, 2012). VOC provides a comprehensive understanding of customer requirements, which is essential for prioritizing business objectives and setting clear and measurable project goals.

1.1.1.1.4 Critical to Quality

Central to the Six Sigma methodology is Critical to Quality (CTQ). CTQs are instrumental in identifying and categorizing a product's or process's essential measurable attributes. These attributes are fundamental in that their performance standards or specification limits must meet specific criteria to ensure customer satisfaction (Chakrabarty & Chuan Tan, 2007); (Bañuelas & Antony, 2004)

Chakrabarty and Chuan Tan (2007) emphasized the significance of CTQs in their analysis of Six Sigma applications in services. They search into the transformative impact of crucial research, highlighting the vital factors for success, key performance indicators, CTQ characteristics, and the benefits and limitations of integrating Six Sigma in service-based sectors. Their work underscores that understanding and addressing CTQs are vital for businesses to ensure service quality, which is directly tethered to customer satisfaction.

Bañuelas and Antony (2004) thoroughly explored the growing acceptance and integration of Six Sigma and Design for Six Sigma (DFSS) across manufacturing and service sectors. Although Six Sigma principles were initially implemented to enhance existing processes, their application has now expanded to the design and redesign stages, ensuring the consistent achievement of superior quality. This effort has crystallized into what is known as DFSS. In their study, Bañuelas and Antony (2004) tested the suitability of a multicriteria decision-making technique, the analytic hierarchy process, to differentiate between the application of Six Sigma and DFSS in two multinational companies. Their findings underscore the significance of understanding the specific contexts in which these methodologies are most beneficial.

1.1.1.1.5 Project Selection

Selecting the right project is crucial in any business improvement endeavor. The chosen project should present an opportunity for a substantial enhancement in either the product or service. Assessing the project's potential financial impact on the business is essential. Naturally, projects with the most significant potential for positive financial returns are most desirable. A top-down approach with an effective team design is a characteristic of Six Sigma. It should be incorporated into any DMAIC project, whether or not the organization utilizes Six Sigma (Ray & Das, 2010).

Project selection stands out as the pivotal element of any business enhancement strategy. Projects should be viable within a reasonable duration and exert a tangible influence on critical business indicators. Therefore, significant debate is required to identify the organization's primary business processes, understand their interrelation, and craft suitable performance metrics (Montgomery & Woodall, 2008).

Marques et al. (2013) discuss the benefits of combining Six Sigma with the ISO 9001 quality management system (QMS). They provide guidelines that help in better project selection, aligning objectives, and understanding roles in both systems. The integration also enhances internal audits and management reviews. Their work provides a roadmap for businesses aiming for continuous improvement using both Six Sigma and ISO 9001.

1.1.1.2 Measure

In the measurement phase of Six Sigma, a robust system is established to serve as a reference point for subsequent enhancements. This system discerns the magnitude of the existing problem. For accuracy, it is crucial to identify and accumulate data attributes within this validated measurement framework (Gijo et al., 2011).

The primary objective of the "Measure" phase is to collect relevant data and establish the baseline performance of the current process. This phase ensures that the problem or opportunity for improvement identified in the "Define" phase is clearly understood and quantified to develop potential strategies to reduce the variation levels (Antony, 2006). Central to the "Measure" phase is the development of a data collection plan. To develop an effective data collection plan, it is essential to determine sampling frequency, who will measure it, the data collection form format, and measurement instruments. Attention must be paid to the data type, discrete or continuous, as this impacts the measurement approach. Discrete data are categorized into distinct groups and require more samples for analysis due to statistical inefficiency. Continuous data, measured on a scale, enable direct process capability calculations and sigma level determination based on defect rates (Yang & El-Haik, 2008).

Measurement System Analysis (MSA) is another essential component of this phase. MSA evaluates the data collection system's precision, accuracy, and reliability, ensuring that the measurements are consistent and not affected by any process-related variations (Galli, 2020). Galli (2020) explored the use of MSA through Gage Repeatability and Reproducibility (Gage R&R) to determine the precision of the instrument. The research points out the value of establishing standardized production protocols and ensuring measurement consistency using three inspectors. The study further underlines the significance of maintaining uniformity in tools and procedures to achieve consistent outcomes.

The conclusion of this stage is reflected in the process's sigma level, determined by the type of data under consideration. Cp and Cpk values serve as the standards for continuous data, while DPMO (Defects Per Million Opportunities) serves as the metric for discrete scenarios.

Both Cp and Cpk values should be equivalent and be > 1.00 for optimal process performance. These indices are expressed through the formulas below, as described by (Montgomery, 2020)

$$Cp = \frac{USL - LSL}{6\sigma}$$

$$Cpk = \min\left(\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right)$$

In these equations:

- USL stands for the upper specification limit.
- LSL represents the lower specification limit.
- μ is the process average or mean.
- σ denotes the process standard deviation.

1.1.13 Analyze

During this phase, the primary focus is on identifying root causes leading to process variations. Additionally, it details the necessary corrective actions to address the gap between the current operations and the envisioned optimal state.

In a study conducted by (Hakimi et al., 2018), a rigorous statistical analysis of the fractional factorial design was undertaken. They set a significant threshold (α) at 5 percent to discern critical factors and their interactions. Based on their analysis of variance, factors or interactions with a p-value less than this threshold were considered statistically significant. On the contrary, if the p-value surpassed α, the factor or interaction was determined to be statistically insignificant.

In a comprehensive study by (Miguel et al., 2012), a benchmark analysis was carried out to measure the adoption of tools and techniques within Six Sigma programs in a developing country. The results showed that the companies' "ten most prevalent tools and techniques" were data collection, histogram, Pareto diagram, brainstorming, control charts, capability measures, flow chart, process mapping, measurement system evaluation, and statistical process control charts.

While the above-mentioned tools are commonly employed in Six Sigma practices, additional specialized tools are specifically adapted- for data analysis. Among these tools are:

1. Cause and Effect Diagram (Fishbone or Ishikawa Diagram): Helps in visualizing the potential causes of a problem, categorizing causes under various significant headings such as People, Process, Equipment, and Environment (Koripadu & Subbaiah, 2014).
2. 5 Whys Analysis: A technique to explore the cause-and-effect relationships due to a particular problem. By asking "Why?" multiple times, the root cause of an issue can be identified (Koripadu & Subbaiah, 2014).

3. Pareto Analysis (80/20 Rule): Helps identify the most significant factors in a data set. It distinguishes the few vital causes from the many trivial ones. (Sarkar et al., 2013)
4. Hypothesis Testing: Used to determine if a particular factor significantly affects the process output. Standard tests include t-tests, chi-square tests, and ANOVA (Bower, 1998); (Kalpande & Toke, 2023).
5. Regression Analysis: Helps in modeling and analyzing the relationships between a dependent variable and one or more independent variables (Rahman et al., 2010)
6. Scatter Plots: Provides a visual way to examine the relationship and overlaps between two variables (Keim et al., 2010).
7. FMEA (Failure Modes and Effects Analysis): A step-by-step approach for identifying all possible design, manufacturing, or assembly failures measured by risk factors such as occurrence (O), severity (S), and detection (D) (Zhou & Thai, 2016).
8. Process Stream Maps and Flowcharts: Visual tools that represent the flow of a process, helping to pinpoint areas of inefficiency or sources of problems, which represent the current or future state of the manufacturing system (Chen et al., 2010).

1.1.1.4 Improve/Desing

The "Improve" phase in the Six Sigma DMAIC (Smętkowska & Mrugalska, 2018) model is continuous improvement, and the "Design" phase in the DMADV (Chandan et al., 2022) model as process launch designer both stand out as central foundations for Six Sigma. The improvement phase addresses the causes identified in the analysis phase by selecting and targeting solutions to eliminate them. This phase focuses on developing, testing, and implementing solutions or designs that lead to identified problems or customer needs (Bañuelas et al., 2005).

According to van Iwaarden et al. (2008), the improvement approach is perceived as a structure that links the organization's strategy strongly, elevates the management's involvement, and improves financial results. Within the realm of problem-solving, the analysis of the “Improve” phase can be understood through five distinct themes. These cover the general applicability of new methods contrasted with specialized methods for particular areas, the structured nature of problems, overarching tasks in problem-solving, the diagnostic aspects of problem-solving, and the remedial actions taken in response to issues identified (de Mast & Lokkerbol, 2012).

The design phase in DMADV, primarily used in Six Sigma's DFSS variant, has a distinct objective. While Six Sigma was initially employed to enhance existing processes, it has started to focus on designing and redesigning processes capable of achieving Six Sigma performance levels using a distinct methodology. In this context, the emphasis is not on improving an existing process but on designing a novel method or product that aligns with customer needs and specifications from its inception (Bañuelas & Antony, 2004).

Furthermore, by using simulation tools, teams can predict the impact of changes, ensuring that improvements are both practical and sustainable. Combining simulation techniques with Six Sigma methodology offers a promising avenue for enhanced process improvement. (Ahmed et al., 2020), examined closely into this integration, presenting a thorough literature review that points to both theoretical and applied dimensions of this synergistic approach. Their findings offer a detailed overview of existing knowledge and highlight areas for further exploration and research.

Yang et al. (2022) emphasize the importance of shifting the quality improvement focus to the initial phases of product development. They advocate for a refined DFSS methodology, introducing a new process termed DIMDOV (Define, Identify, Measure, Design, Optimize, and Verify). This approach, backed by their extensive consultancy experience, promises enhanced design quality assurance in both product and manufacturing process design.

In the improvement phase, Al-Aomar and Chaudhry (2018) highlighted the importance of testing proposed alternatives to enhance clinical performance. They utilized simulation to verify these improvement plans. Further, after gathering simulation-based performance data in the "analyze" stage, they employed the entropy method. This technique provided an objective approach to deduce the relative importance weights, ensuring a more systematic and accurate improvement process.

In summary, while both the "Improve" and "Design" phases come at advanced stages of their respective Six Sigma models, they underscore Six Sigma's dual strength: refining existing processes and building new ones from a foundation of quality and customer-addressed direction.

1.1.1.5 Control

The "Control" phase in the Six Sigma DMAIC process sets improvements, ensuring they become part of daily operations. This stage finalizes the remaining project tasks and hands the refined process to its owner, who is equipped with a control plan. The main goal is to formalize the improvements while maintaining consistency and quality. Key elements include standardization and defining clear ownership, fostering accountability, and promoting the possibility of extending across similar business functions (Montgomery & Woodall, 2008).

The Six Sigma Methodology's "Control" phase is primordial in sustaining the improvements initiated in the preceding phases. According to (Sarkar et al., 2014), the essence of the control phase lies in maintaining leveled performance and ensuring swift detection and correction of any deviations in the process. This phase stresses the necessity of ongoing surveillance via a comprehensive control plan. This plan, enriched with a formidable feedback mechanism, is pivotal to guarantee the consistent alignment of the process with its anticipated outcomes.

During the "Control" phase of the DMAIC framework, traditional Shewhart control charts are often utilized. However, Goh and Xie (2003)) introduce alternative methods for managing a well-improved process, particularly beneficial for Six Sigma Black Belts managing high-quality processes. Their approach promotes a uniform shift from managing low sigma to maintaining high sigma performance at the end of a Six Sigma project. In particular, plotting is unnecessary if a process consistently produces non-defective items and remains stable, implying that the process is evidently under control.

1.1.1.5.1 Six Sigma Tools for Control

The "Control" phase of the Six Sigma DMAIC methodology ensures that the improvements made during the improvement phase are sustained over the long term. This phase involves monitoring the processes to ensure consistent performance, preventing defects, and implementing control systems. Here is a list of standard tools used in the "Control" phase:

1. Control Charts (or Process Behavior Charts): These plots monitor the stability of processes over time, suggesting timely improvements in process mean and variation. This approach assumes that an average population is described by the known specification of the process/product characteristics, although this may not be the case in all instances (Joghee, 2017).

2. Standard Operating Procedures (SOPs): Provide a standardized set of instructions designed to ensure uniformity and consistency in performing a task. They ensure that every

individual assigned to the task follows the same guidelines, leading to consistent results regardless of who performs the work (Manghani, 2011).

3. Statistical Process" Control"(SPC): This is a crucial tool in quality management, emphasizing statistical techniques to ensure consistent and optimal process outcomes (Goh & Xie, 2003).

4. Visual Management: Visual management is an approach within lean manufacturing that prioritizes the clear and transparent presentation of information to enhance organizational flow and drive continuous improvement (Eaidgah et al., 2016).

5. Mistake-Proofing (or Poka-Yoke): Poka-yoke, often called mistake-proofing systems, acts as a visual assurance for organizations, classified broadly into control and warning methods (Uhanovita et al., 2023).

6. 5S: The 5S system, derived from traditional Japanese management practices, represents an integrated management approach. 5S stands for Sort, Set in Order, Shine, Standardize, and Sustain. This system emphasizes organizational efficiency and continuous improvement (Gapp et al., 2008; Randhawa & Ahuja, 2017).

7. Training and Development: A systematic approach that combines knowledge, career advancement, and goal setting to enhance the efficacy and relevance of employee growth initiatives. Organizations frequently employ Information Technology systems in contemporary settings to facilitate these learning programs (Bashir, 2013).

8. Internal Audits and Reviews: A process emphasizing the role of internal audit (IA) in bolstering organizational value. This understanding is based on a conceptual model that

underscores the significance of IA in fostering organizational learning and driving positive change throughout the institution (Roussy et al., 2020).

9. Feedback Mechanisms: Feedback mechanisms refer to the insights from experts that guide the development and enhancement of tools like the project management support system (PMSS). Such feedback loops are integral to iterative refinement and ensuring alignment with user needs and objectives (Graafmans et al., 2021).

1.1.2 Total Quality Management

Throughout the years, various management systems have been developed to champion the cause of quality improvement. Total Quality Management (TQM) stands out within this array, as it is designed to anchor and streamline quality enhancement throughout organizations. Tracing its origins to the early 1980s, the core tenets of TQM have been influenced by the visionary teachings of figures like W. Edwards Deming and Joseph Juran.

However, while numerous organizations viewed TQM primarily as a training-centric initiative, its tangible successes have been somewhat limited. Various factors contributing to this muted success include (Montgomery & Woodall, 2008):

i. A discernible absence of robust commitment from upper management.
ii. A limited application of statistical techniques and a diminished focus on curbing variability.
iii. Objectives that leaned more towards generic goals rather than concrete business outcomes.
iv. A disproportionate stress on broad-based training instead of nuanced technical instruction.

1.1.2.1 Poor Quality Cost

Poor quality costs, often termed "Cost of Poor Quality" (COPQ), represent the financial drain associated with producing and rectifying substandard products or services. According to (Prashar, 2014), the significance of COPQ in impacting total costs and the bottom line is profound. Despite its substantial influence, COPQ often remains a hidden cost because conventional accounting practices do not easily trace it. Within Six Sigma, the meticulous examination of COPQ reveals potential savings achievable by eliminating defects and inefficiencies. The costs are typically categorized into overt expenses, like warranty claims, and concealed ones, such as lost customer goodwill. Prashar (2014) elaborates further on the application of the Six Sigma DMAIC methodology, aiming to minimize COPQ in the repair division of a helicopter company.

Gaikwad et al. (2016) explored the application of Six Sigma in reducing supplier quality costs within the manufacturing realm. While Six Sigma is widely accepted in modern organizations, there is a paucity of detailed case studies. Employing a case study approach, the selected company aimed to cut down on quality expenses and optimize specific processes using Six Sigma methodologies. The article thoroughly details the deployment of the Six Sigma DMAIC framework. Moreover, the benefits of a Six Sigma project, like quicker time-to-market, cost savings, morale boost, an improved organizational reputation, and other less tangible gains, can lead to significant savings, albeit they may be hard to quantify precisely.

1.1.2.2 Food Manufacturing Application / Quality Application.

Hakimi et al. (2018) embarked on an analytical study centered on the quality improvement of plain yogurt production. The assessment identified two fundamental factors influencing yogurt pH values: incubation time and fat percentage. Optimal conditions were established: an incubation duration of 12 hours and a fat content of 1.5%. This research underscores the viability of the Six Sigma DMAIC methodology in refining the yogurt manufacturing procedure. Such findings can potentially catalyze organizational leaders to employ the Six Sigma strategy in resolving intricate challenges, especially in scenarios where causative elements are unclear. The central intent of Hakimi's exploration was to optimize factors impacting yogurt's acidity, thus enhancing its overall quality.

Gilligan et al. (2023) utilized the structured DMAIC methodology within an Irish meat processing environment. Through Six Sigma's application, they pinpointed areas of variation, effectively reducing excessive meat trimming. This approach enhanced process capabilities, elevated revenues, and reduced wastage, backed by implementing key performance indicators, control charts, and advanced cutting tools. This pioneering study showcases Six Sigma's efficacy in the meat sector, offering a strategic framework for other food manufacturers.

Shokri et al. (2014) explored the application of Six Sigma as a strategic approach to enhance logistical measures in small-to-medium-sized food distributors. Their findings underscored the suitability and advantages of Six Sigma within these entities. Critical determinants for successful adoption included requisite training, management features, organizational size, employee education, and workplace environment. The study emphasized that food distribution in medium-sized enterprises (SMEs), especially those prioritizing customization, can effectively integrate Six Sigma to bolster their logistics. Furthermore, when contrasted with Lean and ISO9000 methodologies, Six Sigma emerged as a more dependable strategy for uplifting business performance in this sector.

Powell et al. (2017) explored the integration of Lean Six Sigma (LSS) in the continuous process domain, particularly within the food processing industry, aiming to understand its effects on environmental sustainability. Through a case study of a Norwegian dairy producer, they shed light on how LSS can sustain ecological sustainability, an aspect scarcely covered in existing literature. The study underscores key elements for employing LSS to enhance environmental practices in fresh-food supply chains and outlines specific results and success indicators following the Value Stream Mapping (VSM)-DMAIC method. The findings offer both theoretical and practical insights, emphasizing critical success factors for effective LSS implementation in food processing.

Sánchez-Rebull et al. (2020) studied the application of Six Sigma in addressing cash flow deficits in a German food can manufacturing firm. Their qualitative case study, covering the DMAIC phases, focused on enhancing the payment process in administrative and financial domains, areas often untouched by Six Sigma. Findings indicated that the approach optimized the company's cash flow and led to substantial savings, particularly in minimizing bank interest expenses. The results emphasized Six Sigma's versatility in managing financial challenges.

Tsarouhas and Sidiropoulou (2023) explored the significant impact of drained weight variation in olive packaging on customer satisfaction and an organization's finances. Utilizing data analysis throughout the project, they identified root causes for product rejections and optimized the manufacturing process. This optimization resulted in a remarkable 51.02% reduction in the drained weight's standard deviation, diminishing defectives by 99.97%. Consequently, production yield surged by 8.24%, translating to an estimated annual savings of US$ 228,000 from decreased rejections and reworks. Through Six Sigma, the company enhanced its product quality, meeting stringent specification limits and strengthening its reputation. This potentially leads to customer acquisition, increased profitability, and heightened customer satisfaction.

1.1.3 Origins of Lean Manufacturing

Lean manufacturing's origins can be traced back to Japan, specifically to the pioneering work of the Toyota Motor Corporation. This innovative production philosophy, famously known as the Toyota Production System (TPS), was led by Taiichi Ohno, a visionary engineer and executive within Toyota. A singular goal drove the genesis of TPS – eliminating waste throughout the manufacturing process, ultimately leading to improved efficiency and cost-effectiveness (Ohno & Bodek, 1988).

The TPS lies in two foundational pillars that have since become synonymous with lean manufacturing: Just in Time (JIT) (Ramanathan et al.) and Jidoka (Ohno & Bodek, 1988). These principles marked a model shift in how manufacturing was approached in Japan and globally, and they found enthusiastic adoption within the U.S. manufacturing model (White & Prybutok, 2001). JIT, as its name implies, emphasizes the precise delivery of materials and components exactly when they are needed in the production process, thus eliminating unnecessary inventory holding costs and the associated waste (Mackelprang & Nair, 2010). Simultaneously, Pagliosa et al. (2019) introduced the revolutionary concept (Industry 4.0) of infusing quality directly into the production process by using technologies to assist problem detection. This empowered both machines and operators to promptly detect and rectify defects, leading to a reduction in rework and an overall enhancement in product quality (Pagliosa et al., 2019).

The motivation for TPS and the concept of lean manufacturing emerged in post-World War II Japan when Toyota transitioned from textile machinery manufacturing to automotive production. Toyota had to adopt new management practices to remain competitive in the global market. This change was required by resource absence and a pressing need for economic recovery, inducing Toyota to innovate and devise novel methods to optimize its operations management (White & Prybutok, 2001); (Womack & Jones, 1996).

TPS underwent evolution and expansion as time progressed, reinforced by a solid commitment to continuous improvement. Lean manufacturing principles transcended their origins in the automotive industry (Womack & Jones, 1996) and found applications in diverse sectors. These included food manufacturing (Dora et al., 2016), healthcare (Henrique et al., 2016), aerospace (Parry & Turner, 2006), and even services (Staats et al., 2011).

Lean manufacturing is fundamentally oriented towards enhancing the perceived value of products at each production stage. The effectiveness of lean manufacturing practices is contingent upon several critical factors, including active employee involvement, comprehensive training programs, and solid commitment from top-level management (García et al., 2013). Furthermore, various control variables, such as the size of the organization and its country of origin, play a substantial role in influencing the adoption and advantages gained from lean manufacturing practices (Dora et al., 2014). Alternatively, lean is described by some as an intellectual approach system comprised of many measures and methods that, when integrated, result in an organization becoming "lean" and exceptionally competitive (Warnecke & Hüser, 1995).

Womack and Jones (1996) subsequently laid the groundwork for lean thinking by emphasizing the pivotal role of "value." In this context, value is generated by the producer and holds significance when the product perfectly matches customer requirements. Toyota's car production systems consistently overtook their Western complements, motivating them to disseminate this pioneering production approach, which became known as "Lean." Car production typically involves high-volume repetitive manufacturing or mass production, while lean manufacturing distinguishes itself by existing at two levels, strategic and operational, through its customer value objective (Hines et al., 2004). While Lean initially focused on clarifying its benefits within similar manufacturing operations, it has, over the years, demonstrated remarkable adaptability to do more with less across various food industries, administrative domains, and service sectors (Bower, 1998); (Bicheno & Holweg, 2016).

1.1.3.1 Lean Foundation

One of the defining features of lean manufacturing is its strong emphasis on waste elimination. This ideology is fundamental to the lean approach and distinguishes it from other manufacturing methodologies. In lean manufacturing, waste refers to any activity or process that does not add value from the customer’s perspective. The goal is to streamline production by removing these non-value-adding activities, which in turn leads to more efficient processes, cost reductions, and improved product quality (Ohno & Bodek, 2019)

The focus on waste elimination in lean manufacturing is based on the principle that reducing waste directly contributes to business process improvement; by identifying and eliminating wasteful practices, companies can reduce production time and costs, increase quality, and improve overall customer satisfaction (Widodo et al., 2021).

The common types of waste in lean manufacturing are often remembered by the acronym "TIM WOOD":

- Transport: Unnecessary movement of products or materials and usage of logistics (Villarreal et al., 2017).
- Inventory: Excess products and materials not being processed (Hofer et al., 2012).
- Motion: Unnecessary movements by people (e.g., walking, reaching, lifting) (Rawabdeh, 2005).

- Waiting: Waiting for the next production step and delay times (Arunagiri & Gnanavelbabu, 2013).
- Overproduction: Producing more than is needed or before it is needed (Chen et al., 2019).
- Over-processing: More work or higher quality than required (Dold, 2008).
- Defects: Effort involved in inspecting and fixing defects (Sreedharan V et al., 2018).

Eliminating these wastes leads to more efficient production processes, lower costs, and better-quality products. This approach streamlines operations and helps create a more engaging and productive work environment.

1.1.3.2 Just In Time

JIT represents a manufacturing philosophy recognized for its constant pursuit of excellence through the ongoing elimination of waste and consistently enhancing productivity. Over the past two decades, global manufacturing enterprises have actively pursued replicating the innovative JIT (Ramanathan et al., 2022) system. Recent research has indicated a correlation between adopting JIT practices and the specific type of production system in place. Notably, this inaugural study shows the advantages of JIT implementation, considering the status of particular JIT management practices and the nature of the production system (White & Prybutok, 2001).

At its core, JIT is founded on the fundamental principles of producing each item precisely when needed, in the correct quantity, and through the most efficient means possible with all types of performance outcomes. JIT's feature is a commitment to continuous improvement reinforced by a well-defined problem-solving and decision-making system for assessing and implementing changes (Mackelprang & Nair, 2010); (White & Prybutok, 2001). Originating in Japan, this manufacturing philosophy promotes outstanding quality through the ruthless elimination of waste and the relentless pursuit of productivity improvements (Ohno & Bodek, 1988).

The primary objective driving JIT is the ongoing reduction of manufacturing costs, achieved by simultaneously elevating product quality, reducing inventory levels, and shortening lead times (Shah & Naghi Ganji, 2017). Incorporating lean production practices, including JIT methodologies, has been recognized as a significant driver for enhancing product quality. Agus and Shukri Hajinoor (2012) found that implementing a lean production shop floor directly influences process quality. Additionally, lean product development improves product quality and decreases customer complaints. Such lean methodologies, when integrated with supply chain management, offer manufacturing companies a robust strategy to boost product quality and overall business performance.

Despite the lean principle of JIT production (Ramanathan et al., 2022), many firms produce beyond customer demand.(Lyonnet & Toscano, 2014) Highlight the challenge of categorizing companies as JIT adopters. A singular pull or push strategy is not always suitable. Instead, companies should evaluate each product individually to determine the best production approach.

Three JIT practices consistently impact both nonrepetitive and repetitive logistic regression models (White & Prybutok, 2001). Specifically, total quality control enhances external quality, multi-function employees boost labor productivity, and Kanban improves throughput time. These practices retain their significance irrespective of the type of production system.

Research has extensively examined the combined implementation of TQM and JIT practices to create a holistic approach that enhances quality performance and minimizes waste in operations (Phan et al., 2019). This study highlights a positive association between JIT and TQM practices and flexibility performance, suggesting that companies can better cater to customer flexibility needs by prioritizing both TQM and JIT. The research underscores the interrelation of TQM and JIT practices, pinpointing their substantial impact on flexibility performance. Specifically, flexibility can be reinforced through the combined efforts of three pairs of TQM and JIT practices: process control with setup time reduction, supplier involvement paired with JIT delivery, and customer involvement combined with JIT customer links (Phan et al., 2019).

1.1.3.3 Jidoka

Jidoka, integral to Toyota's practices, involves pausing operations upon detecting defects or anomalies. This approach allows for an immediate stoppage of specific equipment or an entire production line initiated by machinery or workers. It serves two primary objectives: ensuring production strictly aligns with demand, avoiding overproduction, facilitating focused attention on identified issues, and maximizing the workforce's efficiency (Sugimori et al., 1977).

One of Jidoka's primary features is its ability to halt operations immediately when a problem arises, allowing for swift problem identification and resolution (Ohno & Bodek, 1988). This proactive approach leads to continuous process improvement by addressing the root causes of defects.

Jidoka, called "automation with a human touch" by Toyota, fundamentally transforms production processes. It equips production hardware with the capability to stop operations if it senses the production of a defective part. (Womack & Jones, 1996) this approach revolutionized operations by freeing workers from constantly monitoring machines to prevent defects in the early stages of Toyota's system development. Even though Jidoka technology is widely accessible today, many operations still employ workers to oversee machine displays, waiting to respond to issues. This approach emphasizes integrating technology with human expertise for optimal production.

In recent years, (Deuse et al., 2020) introduced the concept of Jidoka 4.0, which builds upon the traditional principles of Jidoka. Jidoka 4.0 retains the essence of low-cost automation, aligning with lean manufacturing's focus on efficiency. It also emphasizes the active involvement of operators in developing automation solutions, fostering a sense of ownership and expertise among the workforce. This approach can prevent errors and predict failures within manufacturing cells, further enhancing quality and efficiency.

Additionally, Chiarini et al. (2018) highlighted the wealth of theoretical and practical insights that Japanese culture offers to lean manufacturing. Beyond Jidoka, they emphasized principles such as JIT manufacturing, waste identification and elimination, Kaizen (continuous improvement), Genchi Genbutsu (going to the source), respect for people, and teamwork as valuable lessons that can be applied to enhance manufacturing processes and outcomes.

In the scope of quality management, (Pagliosa et al., 2019) acknowledged Jidoka as a technology that aids in problem detection and fosters increased connectivity within manufacturing processes. However, they also noted that specific quality issues Jidoka addresses remain underexplored, presenting opportunities for further research and development.

In conclusion, Jidoka is a foundation of lean manufacturing, enabling the immediate detection and resolution of issues to ensure product quality. Its principles align with the lean philosophy of continuous improvement and waste reduction. The introduction of Jidoka 4.0 and the recognition of Japanese cultural principles further demonstrate the enduring relevance and adaptability of Jidoka in contemporary manufacturing practices (Pagliosa et al., 2019); (Deuse et al., 2020)

1.1.3.4 Standardized Work

As Emiliani (2008) defined, standardized work encompasses clearly defining leadership, articulating business principles, and identifying a specific skill set for executives. A practical framework aligns with executive leadership's strategic and routine responsibilities by offering a refined definition of leadership and outlining core business principles and necessary skills. Emiliani's concept introduces "standardized work" to executive leadership duties, delivering a comprehensive blueprint that can guide the enduring success of organizations across successive leadership eras.

Furthermore, research by El-Khalil et al. (2020) highlights that operations managers in lean environments prioritize implementing technical-oriented practices to enhance process stability and standardization. However, the authors conclude that the comprehensive integration of technical and social lean management practices is vital (Chen et al., 2019). This balanced approach ensures the reduction of operational variability and optimization of the consistency in executing value-added tasks, ultimately facilitating successful lean implementations on the shop floor.

Simons and Zokaei (2005) explored the impact of lean techniques such as “Takt-time” and “work standardization” in a beef processing plant, where in the further processing (cutting) rooms, noting a 25% productivity increase in advanced settings compared to traditional ones. Their study, set in the red meat industry, emphasizes the value of standard work practices in enhancing training, retaining knowledge, and improving efficiency at both the individual and team levels.

1.1.3.5 Continuous Improvement (Kaizen)

The term Kaizen, which signifies "good change" and means “Improvement,” has its roots in Japan. It was introduced by Imai in 1986 and, since its inception, has become a foundation in Japanese management practices, widely recognized for promoting operational excellence and success.

In a study conducted by Farris et al. (2009), insights were gleaned about the influence of organizational practices on kaizen capabilities and attitudes. Internal processes and goal clarity stood out as primary influencers for both areas. Management support was found to be pivotal for attitudes, but it did not translate to kaizen capabilities. On the other hand, attributes such as team autonomy and experience were determinants of kaizen capabilities but did not sway attitudes. Interestingly, some expected factors like tool quality and event planning did not exhibit discernible ties with the outcomes.

In business, Kaizen pertains to the methodical identification and rectification of discrepancies within production and operational systems. It has emerged as a crucial strategy for organizations aiming to achieve operational excellence. By adapting to varied conditions across organizations, Kaizen ensures that objectives are met within a goal-oriented planning framework. (Carnerud et al., 2018).

Kaizen is fundamental to the operational philosophy of the TPS, embracing various methodologies and techniques designed for optimizing work and solving problems (Ohno & Bodek, 1988).

In practical applications, such as the automotive industry, kaizen methodologies play a critical role where precision is vital. They involve systematic data collection, identifying core issues, selecting optimal solutions, implementing corrective actions, and maintaining detailed records of improvements made (Imai, 1986). The benefits of kaizen are multifaceted, including mitigating errors, enhancing cost-efficiency, and simplifying work processes, contributing to overall organizational productivity and quality (Womack & Jones, 1996).

Specifically, kaizen incorporates methods like 5S, Plan-Do-Act-Check (PDCA), the "5 Whys," and Value Stream Mapping (VSM), each serving distinct purposes in the improvement lifecycle

(Emiliani, 2008) (Mor et al., 2019). Chan and Tay (2018) emphasized the benefits of implementing combined lean tools in kaizen events. Their findings revealed that correct kaizen application led to enhanced quality, reduced cycle times, and increased productivity. The study notably extends the lean literature, suggesting that combining specific lean tools can accelerate the kaizen process, especially in industries with operations similar to their case study.

A study by Bhardwaj et al. (2018) emphasized improving productivity in automobile service stations. The research was carried out at a service station, and the PDCA tool of lean manufacturing was utilized to monitor and minimize rejections. The results revealed that analyzing rejections daily added wasteful activities. By transitioning to weekly monitoring, the service station saved approximately seven hours weekly, enhancing employee morale and customer satisfaction. The research underscores the effectiveness of lean principles in streamlining activities, even beyond manufacturing settings.

Engelund et al. (2009) delineate that improvement in lean manufacturing encompasses two distinct elements: daily continuous improvement, referred to as "kaizen," and breakthrough improvements, known as "kaizen blitz." kaizen involves incremental enhancements to daily processes and emphasizes the collective contribution of all employees in refining operational processes. Employees are urged to propose suggestions, no matter how minor they may seem, to optimize the efficiency of production processes, like the rearrangement of raw materials or minor adjustments in the production line.

On the other hand, kaizen blitz is an intensive, focused effort to improve specific aspects of production, such as a particular process, area, or safety issue within the plant. It comprises collaborative efforts from employees and management to examine machinery setups and production protocols to reveal opportunities for efficiency augmentation. During this event, modifications are suddenly implemented, and alterations in equipment are executed to assess the impact of the proposed ideas, potentially giving rise to new enhancement ideas (Engelund et al., 2009).

In a comprehensive evaluation by Otsuka and Ben-Mazwi (2022), the efficacy of intensive kaizen training programs in South Africa was meticulously assessed, focusing on its impact on enterprise performance in developing countries. Their study supports the claim that kaizen, originating as a Japanese management system, has demonstrated significant effectiveness in enhancing enterprise performance in the context of developing nations. Their research findings indicated that implementing the kaizen method substantially improved efficiency within South African entities.

Soundararajan K. (2019) delves into the systematic application of lean-kaizen manufacturing techniques combined with TQM tools, emphasizing their crucial role in boosting manufacturing productivity. Their study underscores the essence of ongoing improvement and the strategic removal of inefficiencies ranging from wasted time and effort to high costs through incremental changes. The paper reveals that incorporating total productive maintenance and structured methodologies like 5S results in substantial improvements in productivity and machine cleanliness. It promotes worker involvement, enhancing the overall working environment and employee satisfaction. The authors effectively quantify and qualify the profound, multifaceted benefits of applying these principles, demonstrating their holistic impact on the system's productivity and organizational environment.

Vo et al. (2019) present a paper with dual objectives, primarily set in the context of the packaging industry in Mexico. The first objective is to illustrate the application and impact of lean production principles through a case study in a packaging facility, emphasizing the repetitive and systematic utilization of kaizen events to enhance quality and delivery performance. Secondly, the paper provides an in-depth exploration and analysis of a kaizen event and its subsequent impacts, conducting a comprehensive examination of how such events influence employee participation and motivation within the packaging sector. Comparative pre- and post-quality measurements are provided to demonstrate the transformative effects of the Kaizen event on production quality and the comprehensive performance of the manufacturing processes within the packaging industry.

1.1.3.6 Visual Management (Poka-Yoke)

Poka-yoke, often called mistake-proofing systems, acts as a visual assurance for organizations, classified broadly into control and warning methods. (Uhanovita et al., 2023) Underscored the potential of poka-yoke, emphasizing its role in enhancing efficiency through the early identification and elimination of factors leading to potential errors. Building upon this, the causes identified were integrated with the poka-yoke principles to formulate a framework.

Patel et al. (2001) examined the use of set-up time reduction and mistake-proofing methods in precision component manufacturing companies. The study revealed that businesses predominantly employed traditional work-study methods rather than adopting Shingo's single-minute exchange of die and poka-yoke techniques. While various mistake-proofing devices such as jigs, sensors, and buzzers were utilized, there was a noticeable lack of familiarity with Shingo's contributions. The findings highlight the potential benefits of embracing the single-minute exchange of die approach, bolstered by tools like Total Productive Maintenance, SPC, and corrective action charts.

Schultz (2017) explored integrating lean principles and visual management in facilities management to enhance organizational alignment and value. Emphasizing the importance of incorporating the organization's core values and strategic goals, the study highlighted the benefits of lean visual workplace systems. Interestingly, the research underscored the centrality of change management, pointing out that challenges arose not just from tangible assets but also from introducing new technologies and performance metrics. Effective change management was crucial to avoid mistrust and resistance within facilities management.

(Tezel et al., 2016) explored the distinctions of visual management (VM), highlighting its role as an effective communication tool in production. The study emphasizes that while VM is often associated with lean production, its significance transcends specific production systems. They present a clear framework and taxonomy for VM, pointing out its diverse functions. However, they also underscore the fragmented nature of existing literature, suggesting a need for a more cohesive understanding.

1.1.3.7 5S

Within the lean methodology, the 5S approach emerges as a foundational tool essential in sculpting an environment that supports efficiency and continual refinement. A systematically organized and clean workspace not only diminishes waste, especially time wasted hunting down items but also enhances the visibility of discrepancies and potential hazards (Gapp et al., 2008).

Expanding on this, the proper depth and uniqueness of the 5S method lie in its dual nature, blending both tangible, technical applications and underlying philosophical tenets. This duality, rooted in traditional Japanese management techniques, showcases 5S not as a broad tool but as an expression of a holistic and integrated management system (Gapp et al., 2008; Randhawa & Ahuja, 2017).

The 5 S's represent critical shop floor practices: "sort, set in order, shine, standardize, and sustain" These practices emphasize orderliness, cleanliness, and efficiency in shop and office environments. The principles not only aid in eliminating the mess and ensuring point-of-use storage but also instill a proactive "do it now" mindset. Consistency is essential, meaning that offices should maintain the same standards as shop areas to enhance service and efficiency

(Emiliani, 1998).

(Randhawa & Ahuja) explored the 5S philosophy, a Japanese approach beneficial for any organization's development. They elucidated its holistic requirements, its synergies with other lean tools, and the ensuing benefits. By reviewing numerous studies, they underscored 5S's significance in sustainable organizational advancement. Critical impact areas include enhanced production, quality, safety, and workspace utilization.

Gupta and Jain (2014) studied the impact of the 5S tool on enhancing productivity in a small-scale manufacturing setup. Through team creation, shop floor analysis, and four data collection methods, they found a significant reduction in tool searching time from 30 minutes to 5 minutes post-5S implementation. The study showcases the versatility of the 5S tool, suggesting its applicability across different industry scales. This research offers valuable insights into the transformative power of 5S for organizational improvement.

1.1.4 Fundamental Principles of Lean Manufacturing

1.1.4.1 The Application of the Five Lean Principles

Integrating the five lean principles is vital for transforming conventional production processes into lean ones. Each principle is crucial in enhancing production lines to become more value-oriented and efficient.

1. Determining Value: Starting with the customer's view of value is essential. It is the bedrock that ensures every step we take adds actual worth to the product (Womack & Jones, 1996). By genuinely understanding customer values, we can shape our production to meet their needs. In short, it is all about pinpointing what the customer wants in a specific product at a particular price.

2. Value Stream Mapping: After defining value, the next step is mapping the value stream in the production process, charting the product's journey from start to finish. The value stream, as outlined by (Womack & Jones), involves every action essential for guiding a product through vital management activities. This includes problem-solving, information management, and physical transformation. During this process, it is imperative to differentiate between actions that add value, those that do not but are currently unavoidable, and those that are both non-value-adding and avoidable. Actions in the last category should be promptly eliminated (Hines & Rich, 1997).
3. Creating Flow: The third principle centers around establishing a continuous flow of value-creating activities at the operational level. This entails eliminating any bottlenecks that might interrupt this flow. (Womack & Jones) and Hodge et al. (2011) underscore the importance of visualizing the 'ideal' production flow. This vision is then actualized through detailed mapping, adjustments to existing procedures, and strategic equipment relocation to ensure that activities seamlessly transition from one phase to the next.
4. Establishing Pull: The fourth principle of lean manufacturing underscores the importance of producing only what is immediately necessary. The research conducted by (Li & Qi, 1995) focuses on how parameter variations can influence production system performance. They use perturbation analysis to examine these effects. Their study compares push and pull production systems through simulation. The findings reveal that the pull system is superior to the push system in several key areas: it leads to shorter lead times, lower inventory levels, and more excellent stability in the production process. This suggests that pull systems might be more efficient and effective in specific production environments. Complementing this, Araújo et al. (2024) introduced a conceptual model for pull

implementation. This model emphasizes the crucial interplay of leadership, organization, operation, and people in ensuring that production is precisely timed to meet demand, further endorsing the benefits of a just-in-time strategy.

5. Pursuing Perfection: The fifth principle of lean manufacturing stresses the continuous pursuit of perfection, focusing on consistent improvement and waste elimination. Engelund et al. (2009) highlight the significance of kaizen in meeting customer demands and reducing defects. In the quest for perfection, Gupta and Jain (2014) underscore the importance of employees in driving continuous improvement. Their deep insights into operations and a comprehensive grasp of lean strategies and underlying principles equip them to provide valuable process enhancement recommendations and discern the appropriate moments to deploy strategies.

1.1.5 Lean in the Food Industry

In the food industry, lean principles are uniquely adapted to address the distinct challenges inherent in food production. A significant focus is on maintaining a continuous flow production system, which is designed to limit disruptions and uphold a consistent production pace, given the industry's critical emphasis on perishability and freshness (Dora et al., 2014).

Naranjo et al. (2023) presented a refined model for lean supply chain management (LSCM) in the Canadian agri-food sector. This model offers valuable guidance to practitioners, helping them select appropriate lean continuous improvement techniques (CTPs) to enhance LSCM productivity and consistency and reduce variability. The study underscores that LSCM strategies should be context-specific, aligning with unique business circumstances and challenges.

Abdelhadi (2016) introduced Takt time, a lean manufacturing metric, to assess service quality in fast food restaurants. This study compared the efficiency of three restaurants from different chains, aiming to guide management in enhancing customer service and overall performance. The results demonstrated that takt time effectively gauges service efficiency, revealing relative performance differences and pinpointing bottlenecks across various service providers within the same industry.

Bravo-Paliz and Avilés-Sacoto (2023) explored the integration of lean and the British Retail Consortium (BRC) quality management methodologies in the food sector. They demonstrated their successful cooperation through a case study in an Ecuadorian company. Lean tools, incorporated into the DMAIC methodology, reduced costs and improved overall equipment effectiveness (Sarwar et al.), aligning with BRC standards. Their study shows the potential for lean and BRC to collaboratively enhance quality and compliance while reducing waste in food packaging companies.

Shah and Naghi Ganji (2017) investigated the application of lean production methods in service industries, focusing on a local baked foods supplier plagued by overproduction and waste. The study revealed significant challenges in adopting lean practices, primarily due to a lack of commitment from top management. It underscored the importance of continuous training and enhanced employee engagement measures as prerequisites for improving organizational performance through lean methods.

Morales-Contreras et al. (2020) explore the application of lean service principles in the fast-food industry in Spain, focusing on the identification and elimination of muda—activities that add cost but not value from the customers' perspective. Their study connects a gap in research concerning lean implementation in fast-food services, where the main objective is to separate types of muda observable by customers within fast-food service production processes. This paper is pivotal as it extends the limited literature on lean service in the fast-food sector, offering insights and guidance to enhance productivity, service efficiency, consistency, and quality.

Despite the potential benefits of lean, its deployment in small to medium-sized food enterprises is still in its nascent stages. Practices like total productive maintenance and employee involvement are more commonly adopted, while others, such as flow and statistical process control, see limited application due to barriers like unpredictable demand, variable raw materials, and a general lack of resources and knowledge (Dora et al., 2014).

1.1.6 Lean Six Sigma

Lean Six Sigma (LSS) is a systematic initiative widely adopted by diverse organizations. It employs the DMAIC approach and lean tools to address the challenge of high process variation and defect rates (Idrissi et al., 2016).

LSS is a methodology that prioritizes maximizing shareholder value by boosting quality, speed, customer satisfaction, and cost efficiency. Merging lean and Six Sigma elements offers a robust approach to business enhancement. However, its integration into the service sector is not always straightforward. Factors like the distinct characteristics of services, combined with LSS's manufacturing origins, have led service managers to view processes through a product-centric lens (Alessandro, 2012).

LSS is a recognized approach to enhancing operational excellence and competitive advantage by merging value creation and variation reduction objectives. Although its benefits have been demonstrated in many premier organizations, its uptake in the food sector lags compared to other industries. Implementing LSS is a substantial investment, and numerous businesses falter due to inadequate preparation and an unsupportive company culture. This underscores the importance of pinpointing LSS readiness factors tailored to the food sector to diminish potential implementation setbacks (Halim-Lim et al., 2021).

The food industry, crucial to the global economy, faces challenges in swiftly delivering varied products cost-effectively, especially amidst global economic and political upheavals. Continuous improvement (CI) strategies, such as the combined LSS, could be pivotal in navigating these challenges. These methodologies have proven beneficial in the food sector, enhancing productivity and cutting costs (Costa et al., 2021). Nonetheless, Costa et al. (2018) mentioned that their adoption is still progressing, and there are obstacles, notably the industry's unique characteristics and human factors. The sector has harnessed numerous lean and Six Sigma tools to enhance efficiency, aiming for reduced process variation and bolstered productivity. However, successful implementation faces hurdles, especially human dynamics and industry-specific challenges.

Lean manufacturing and Six Sigma are celebrated as the foundation methodologies for continuous improvement (CI), both integral in advancing operational and service acumen across organizations. In the study by Salah et al. (2010), the synergies between lean and Six Sigma are examined, underscoring the inherent value of merging the two methodologies. The authors present a refined LSS approach, detailing its implementation phases. At the heart of their discussion is the shared objective of both methods, which is to heighten customer satisfaction. Their analysis suggests that blending lean and Six Sigma is practicable and yields substantial benefits.

Lean Six Sigma 4.0 (LSS 4.0) represents a transformative approach to customization, automation, and digitalization, targeting improvements in human-centric operations and sustainable growth. As LSS 4.0 is still evolving, there is a promising need to identify its defining elements, especially as they align with the imperatives of Industry 4.0 (Citybabu & Yamini, 2023). This study, grounded in extensive literature analysis, offers a holistic framework that captures the essence of LSS within the digital transformation landscape. The findings delineate the primary motivators, foundational pillars, relevant tools, and potential challenges tied to LSS 4.0, thereby presenting a blueprint that aids organizations in amplifying their LSS competencies.

Dora and Gellynck (2015) conducted a study to explore the application of LSS in a medium-sized bakery company. The focus was on addressing the problem of overfilling in gingerbread production. The study demonstrated the company's effective utilization of the LSS methodology, which resulted in substantial cost savings by minimizing the overfilling of the final product. The researchers formulated a specific LSS framework to reduce overfill and rework associated with the product. The study underscored the pivotal role of overfill as a primary cause of machine downtime; discrepancies in package sizes often disrupted machine functions. After LSS implementation, key performance metrics showcased substantial enhancements.

A study by Idrissi et al. (2016) investigated a fish canning company in Morocco working towards achieving LSS quality. Their research highlighted the significance of having a well-organized LSS infrastructure. This is evident from the company's approach involving comprehensive training programs for executives and general staff.

Halim-Lim et al. (2021) found that management support is the dominant LSS readiness factor. The study emphasized the critical importance of leadership and management in LSS deployment. For success, top management should convey their LSS vision and establish benchmarks. While regulations and standards often guide the food sector's quality, the urgency for LSS adoption is primarily driven by top management.

In another recent study by Costa et al. (2021), the researchers dig deeper into LSS by developing and validating multi-item measurement scales that epitomize LSS competence and enhance food industry firms' performance. This study focuses on the food industry, pinpointing LSS practices successfully integrated within this sector. By forging valid and reliable LSS scales, they hope to discern the LSS practices suited to the food industry.

Additionally, the researchers note the integral role of food quality and safety, emphasizing that this might highlight the significance of employee participation and the Six Sigma metric-driven approach. They also underline the compatibility of the continuous flow concept with the food sector, given the sector's need to classify a myriad of products based on flavors or packaging sizes.

Lean is recognized as a technique that enhances the provision of products and services. Womack and Jones (1996) articulated that it is a method to pinpoint value, organize value-driven activities in the best order, perform them clearly when needed, and continually refine their efficiency. The essence of 'lean' thinking lies in its ability to consistently achieve more significant outcomes with diminishing resources—using fewer human resources, equipment, time, and space—while closely meeting customer expectations.

Laureani and Antony (2012) underscored the imperative of identifying critical success factors (CSFs) for the efficacy of continuous improvement initiatives. This process provides a roadmap for organizations to allocate resources and efforts strategically. Intriguingly, their research revealed that 46% of firms adopted LSS, primarily driven by the prospects of cost reduction or evasion. Furthermore, their findings resonated with the prevailing sentiment among LSS experts: the pivotal role of management commitment. This commitment is often echoed in literature as a cornerstone for successfully infusing Lean Six Sigma into an organizational fabric.

Azalanzazllay et al. (2022) explored readiness factors for LSS pre-implementation in the food industry. Through semi-structured interviews with twelve experts and an analysis of three food companies, the study identified vital LSS readiness determinants. The research aids managers in assessing their LSS preparation before investment. It introduces a framework highlighting readiness dimensions, facilitating businesses in self-assessing their LSS readiness. Critical factors include management support, organizational culture, process and project management, employee involvement, and external relations.

1.1.7 Beef Meat Production and Consumption

As the global population continues to grow, a population of nine billion by 2050 is estimated, and the demand for protein sources, particularly beef, is meant to increase dramatically, presenting significant challenges and opportunities for the beef industry. Hubbart et al. (2023) reached these challenges, pinpointing the urgent need to meet the global protein demand and ensure sustainability.

Lau et al. (2023) utilized data from the National Health and Nutrition Examination Survey (NHANES) to analyze beef consumption per capita trends in the United States. Their results showed that people aged two years and older consumed an average of 42.2 g (1.5 ounces) of total beef daily. For other lean types of meat, the per capita consumption was 33.4 g (1.2 ounces) per day.

Keayla M. Harr et al. (2022) examined how factors such as fat content, primary lean source, and price information influence consumer perceptions of ground beef palatability. Their results indicated that labeling significantly influences taste experience. Beef labeled as higher in fat was judged as juicier, and labels indicating the primary lean source added a perceived quality level.

On the other hand, meat color is significantly influencing consumer perceptions of quality and freshness, which is crucial in purchasing decisions. Even if it is not a direct indicator of meat quality or safety, it often dictates consumer expectations and preferences (Bekhit & Faustman, 2005); (Ramanathan et al., 2022). Understanding its impact on consumer behavior is essential, given its importance as a quality attribute in the meat industry. Meat discoloration stands as an economic and environmental cost to the market. Ramanathan et al. (2022) analyzed data from over 5,000 stores in 44 U.S. states, assessing the amount of beef meat waste due to color disapprobation. They estimated annual losses of up to $3.73 billion. Efforts by Lybarger et al. (2023) investigated the point at which ground beef appearance becomes unacceptable to consumers due to color discoloration changes. The study aimed to identify the best objective measure for predicting purchase intentions. Consumers indicated that the lean/fat ratio, price, and color are critical factors in their purchasing decisions. D. Andy King (2023) explored how meat color affects customer purchasing decisions. They noted that this depends on light interaction with myoglobin in the muscle, among other factors, which ultimately influence what the human eye sees.

1.1.7.1 Meat Chemistry

Storage conditions and display settings also impact ground beef color. Mancini et al. (2022) observed that increasing metmyoglobin content darkens the meat and significantly reduces its redness (a*) as storage temperatures rise. Cooper et al. (2018) studied how different light types affect beef steak's color and freshness in stores, finding that light type does not accelerate color changes, but steaks lose freshness over time when displayed. Nikki E. Neethling (2017) discussed external (storage conditions) and internal (meat characteristics) factors affecting meat color and longevity. These factors vary by species, breed, and muscle type. Abubakar et al. (2021) studied transport distance and stocking density effects on meat color, observing significant impacts in the first seven days post-slaughter. Lower stocking densities and shorter transport distances did not affect lightness (L*), while medium-density cattle showed higher redness (a*) values in long-distance transport.

To reduce meat discoloration, the beef industry employs strategies like controlling meat age post-slaughter, specialized packaging, and cold chain maintenance. The addition of vitamin E to cattle feed also helps maintain the meat's bright red color (Ramanathan et al., 2022). A study by Wang et al. (2022) demonstrated that dietary vitamin E slows down changes in fats and myoglobin, potentially stabilizing the meat's red color. Fresh meat losing its bright red color can lead to reduced sales or lower prices. Discoloration is a significant issue, and the industry is looking for methods to make red appearance longer on shelves (Ramanathan et al., 2022). Cucci et al. (2020) identified microbiological contamination and color as major causes of meat defects. They used redox potential in meat purge for color measurements, finding faster results at 20°C. Carcass size influences meat cooling rate and quality, with larger carcasses cooling slower and potentially affecting tenderness and color. Electrical stimulation postmortem alters meat chemistry, influencing quality. In this way, carcass weight management is crucial for optimal beef quality (Blanchefort A. Djimsa, 2022). Wang et al. (2021) examined how cold plasma affects beef patty quality, finding that higher plasma voltages reduce redness, increase fat spoilage and browning, and affect meat's ability to retain its red color.

S. Ardicli (2019) reported that year season, age at slaughter, and pH affect meat color parameters influences significant color variations in cattle slaughtered, with winter-slaughtered cattle having more light colors, as meat pH increases during hotter seasons. Similarly, meat from cattle aged 16/17 weeks showed brighter colors. Postmortem muscle chemistry is complex and impacts fresh meat color and its shelf life. Following bleeding, muscles start acidifying, influencing the structure and enzymatic activity (Nikki E. Neethling, 2017; Ramanathan et al., 2022).

Post-translational modifications (PTMs) in muscle proteins, including myoglobin (Mb), affect meat quality. Wang et al. (2021) noted that the impact of PTMs on fresh beef meat color stability remains not investigated. Morgan L. Denzer (2020) studied the nonenzymatic reduction of metmyoglobin (MetMb) and methemoglobin (MetHb) in meat, focusing on cofactors' important roles in enzyme catalysts. They found that different cofactors significantly affect MetMb and MetHb reduction, even more than pH and temperature. Ranjith Ramanathan (2020) explored how postmortem muscle mitochondria influence beef color. They concluded that mitochondrial activities, such as oxygen consumption and metmyoglobin reduction, are crucial for color development and stability, maintaining myoglobin in its ferrous form.

R. M. Mitacek (2018) researched the effects of modified atmosphere packaging (MAP) on the surface color of dark beef aged for 21 days. They found that high-oxygen and carbon monoxide MAP improved surface color. However, dark beef's elevated pH could contribute to bacterial growth and affect the flavor, underscoring the quality of the meat. Bao et al. (2016) investigated how oxygen levels in beef patty packaging and cooking temperatures affect meat quality. Higher oxygen levels accelerated spoilage and made the meat harder when cooked. Different as low oxygen levels that causes early browning. High cooking temperatures in rich environments with oxygen also alter the meat's internal color. Rogers et al. (2014) researched into how different packaging and temperatures affect ground beef, determining that anaerobic packaging maintains meat freshness longer than aerobic types, particularly in color and smell preservation. This study also noted that high temperatures increased spoilage regardless of packaging type.

Furthermore, Hassan (2015) evaluated the effects of ultraviolet (Halim-Lim et al.) radiation on fresh beef in cold storage, focusing on parameters like bacterial growth, color, and chemical and physical properties, with the aim of extending shelf life and improving microbial quality. In order to enhance the effort for meat quality, Mancini et al. (2010) studied the impact of lactate and various packaging types on the color and freshness of ground beef patties. The addition of lactate helped maintain the color of raw patties in most packaging types and reduced spoilage. However, lactate did not prevent the cooked patties from browning prematurely.

Recent studies have highlighted various factors influencing meat quality and color. To understand the meat preservation and presentation, Abubakar et al. (2021) explored the effects of transport distance and stocking density on meat color, particularly noting changes within the first seven days after slaughter. Their findings indicated that while low stocking density and short transport distances did not significantly alter the meat's lightness, medium-density cattle showed higher redness when transported over longer distances. In similar research, María et al. (2003) investigated the quality of beef from cattle transported for different durations, measuring aspects such as pH, water-holding capacity, myoglobin concentration, and texture after seven and 14 days of aging. Their results suggested that transportation for up to 6 hours did not impact these meat quality factors. Christina E. Bakker et al. (2023) explored how transport distance and temperature affect various aspects of meat quality, like purge loss and tenderness in different beef cuts. They observed that higher transport temperatures increased purge loss in some cuts. Additionally, they examined the effects of freezing temperatures over long distances, finding that while freezing affects purge loss at thawing, it did not significantly influence tenderness. Derico Setyabrata (2019) investigated the impact of aging/freezing sequences and rates on beef loin quality. They concluded that the sequence of aging and freezing is even more critical for meat quality than the rate of freezing itself. While fast freezing can improve certain quality aspects, it increases purge loss, mainly when applied before aging.

Recent studies in meat science have significantly improved the understanding of the factors that influence meat quality. Maxwell et al. (2014) compared conventional and natural beef production systems, mainly focusing on pasture methods and the use of growth promoter technologies. Their findings indicated an improvement in the performance and quality of beef through these technologies, with natural cattle requiring a lesser amount of low-quality grass. Innovations in beef quality prediction were explored by Michael J. Hernandez-Sintharakao (2023), who utilized Rapid Evaporative Ionization Mass Spectrometry (REDIS) for real-time data analysis. Their predictive models, based on physical and chemical parameters, demonstrated high accuracy in sample classification, showing the use for carcass sorting applications. Blackmon et al. (2015) conducted a study to determine if special ground beef could be produced from different cuts, like brisket, flank, and plate, with different fat levels. Each type of meat exhibited unique taste and quality characteristics, while brisket patties stand out for their fat composition and flavor profile. Additionally, Nikki E. Neethling (2017) highlighted the importance of considering various factors, such as species, breed, and specific muscle, in understanding meat quality, fat composition, and flavor.

The quality of quick-frozen pork patties, regarding the impact of fat content and freeze/thaw cycles, demonstrated that patties with higher fat content experienced significant quality degradation after multiple freeze-thaw cycles (Pan et al., 2021). El-Magoli et al. (1996) provided other perspectives on the cooking performance of low-fat beef patties with added water and whey protein. Patties retained more moisture and experienced less shrinkage compared to the patties with high-fat content. Berry et al. (1999) explored how hot and cold processing and grind size influence the qualities of cooked beef patties. They observed that hot processed patties were more tender and had more flavor, with a longer cooking time required compared to cold processed patties. The grind size, however, showed minimal impact on these properties.

Hoyle Parks et al. (2012) examined the influence of lactic acid bacteria and rosemary oils in high-oxygen packaging on ground beef to determine shelf life. Their results indicated that these treatments did not alter the meat color or smell and were effective in reducing pathogenic bacteria, highlighting their potential in meat preservation. Also, Roberts et al. (2017) investigated the use of sodium nitrite in vacuum-sealed packaging for bison steaks and burgers. They found that this method can help maintain the color of the meat longer compared to traditional PVC overwrap packaging. This approach appears particularly effective in reducing the rapid color loss that often happens in bison meat. Scheeder et al. (2001) examine the role of fatty acid composition in beef patties made from bulls fed with special oils, which had healthier fatty acid profiles with no significant impact on shrinkage or texture during cooking. The taste of the patties varied depending on the type of fat used, suggesting that diet manipulation is a viable method to modify beef patty flavors without affecting texture.

W. Nathan Tapp (2017) investigated the effects of injecting buffered vinegar into high-pH beef strip loins, finding minimal impact on quality attributes (color, texture, spoilage), but there was a change in raw color and pH. R. Ramanathan (2019) studied the impact of extended aging, MAP, and display time on high-pH beef. They discovered that meat with a high pH retained more moisture and had similar protein and fat content compared to meat with an average pH. This research emphasized the necessity of appropriate packaging systems to mitigate oxidative discoloration, especially in aged beef. Chauhan et al. (2019) did research comparing muscle glycolysis and pH drop in various muscles in beef, lamb, chicken, and turkey. Findings indicated that oxidative muscles in these species maintain a higher postmortem pH, even with an excess of glycogen. This implies that oxidative muscles naturally cease glycolysis at a higher pH, resulting in a higher ultimate pH level.

Britton et al. (2018) conducted research to evaluate the effectiveness of pH-modified peroxyacetic acid (PAA) solutions against *Escherichia coli* strains and *Salmonella* on beef. Their studies revealed that pH-adjusted and PAA solutions effectively reduced bacterial counts. Immediate post-application results showed no significant difference between the effectiveness of acidified and nonacidified PAA treatments.

Research from McMinn et al. (2018) examined if USDA and FSIS thermal guidelines, mainly used for *Salmonella* in cooked meats, also work for other bacteria in different meat products. The research focused on *Salmonella*, *Listeria monocytogenes*, and *E. coli* In roast beef, turkey breast, and ham. Results showed these guidelines are good for killing *Salmonella* and *E. coli* at 60°C or higher in these meats. However, for L. monocytogenes, longer cooking times might be needed.

Roth (2020) study highlights a new meat pasteurization technology that injects steam into ground meat and then cools it quickly under a vacuum. This method ensures that raw beef is safer. It removes harmful bacteria from raw ground meat while preserving its protein structure. Research on ground beef indicates that this technology keeps the protein quality and color of the meat unchanged, a significant benefit compared to current chemical treatments that can alter meat quality.

Cassar et al. (2019) explored the use of pulsed ultraviolet (PUV) light to reduce bacteria in chicken thigh meat. The technique effectively decreases *Salmonella*, *E. coli*, and *Campylobacter* levels, with more significant reductions achieved by closer proximity to the PUV light and longer exposure times. In trials, a 45-second exposure decreased *E. coli* by 1.96 log10, *Campylobacter* by 1.85 log10, and *Salmonella* by 1.82 log10. This method shows promise as a decontamination strategy for raw chicken meat surfaces. Furthermore, Butler et al. (2018) tested how buffered vinegar prevents *L. monocytogenes* growth on cooked chicken breasts. The chicken was marinated with varying vinegar concentrations and stored for up to 60 days. Results showed that from 35 to 60 days, vinegar-treated chicken had significantly less *L. monocytogenes* compared to untreated chicken, especially with 0.8% dry and 1.5% liquid vinegar. All vinegar levels (0.4 to 1.5%) effectively reduced *L. monocytgenes* when stored at two °C for 35 to 60 days.

Campbell et al. (2021) focused on the safety of producing dry-cured beef bresaola without using heat to kill bacteria. The research aimed to see how well the curing and drying process reduces harmful bacteria like *E. coli* O157:H7, *Salmonella*, and *L. monocytogenes*. In the experiment, beef semitendinosus muscle was first contaminated with these bacteria, treated with a Beefxide (lactic acid antimicrobial) solution, and stored overnight in a cooler. Findings revealed that controlling humidity during the drying process is critical to achieving the desired texture and safety in bresaola beef.

Wang et al. (2022) investigated the recurrence of *Salmonella enterica* in a beef processing plant. Three *Salmonella* strains (Cerro, Montevideo, Typhimurium) were isolated, and environmental microbes were sampled from plant drains. The research evaluated biofilm formation on stainless steel by these microbes and the surface colonization by *Salmonella* strains. Pathogen survival and microbial community composition post-sanitization with a quaternary ammonium compound were also examined. Key findings include the *Salmonella* strains intense surface colonization, competitive advantage over other microbes, specific sanitizer tolerance, and interaction with environmental microbes. These interactions enhanced stress tolerance through mixed biofilm formation, explaining the presence of *Salmonella* in the plant.

Singh et al. (2020) discuss the growing consumer demand for convenient, minimally processed meat products over the past two decades, which has presented challenges for meat processors. This demand requires ensuring the safety of meat and meat products without sacrificing quality while also meeting consumer expectations. As a result, there is a push to develop and implement new processing technologies. However, the adoption of these technologies can impact consumer perceptions and choices regarding meat products. Singh et al. (2020) emphasize that these emerging technologies should be integrated into a multi-obstacle approach to food safety. This is due to the limited information about the effectiveness of any single technology in fully controlling or eliminating hazards on its own.

Pietrasik et al. (2016) examined the effects of hot water treatment on beef trimmings, aiming to reduce bacterial counts down to 2 log CFU/g without compromising meat quality. The study found that this treatment darkened the meat and reduced redness, but these color changes were not significant enough to affect consumer preferences. Notably, the fat level of the meat did not play an essential role in bacterial reduction; instead, storage time was a crucial factor. There have been efforts to find new antimicrobials to delay spoilage in meat products. Johnston et al. (2005) investigated the use of clover and wildflower honey in preserving ground beef patties. Their research found that both types of honey were effective in delaying spoilage in refrigerated and frozen environments. Not as strong as traditional antimicrobials like sodium tripolyphosphate, honey demonstrated its potential as a reliable alternative. This study positions honey as a promising natural substitute for chemical preservatives in meat preservation.

Eastwood et al. (2015) researched the effects of antimicrobial applications and thermal treatment (hot water) on beef carcasses and trimmings used for ground beef patty quality. The study found no significant impact on surface pH, as it returned to normal when the antimicrobial action decreased. This research supports the use of antimicrobial treatments to ensure food safety without compromising beef quality, confirming that the combination of antimicrobial interventions does not impact the quality of the patties. Yoon et al. (2013) focused on testing various methods to enhance the safety of ground beef, specifically targeting the elimination of *E. coli* bacteria. The study experimented with different tenderizers and cooking methods. It was found that refrigeration or freezing did not eliminate the bacteria. Broiling was more effective at killing *E. coli* compared to grilling or frying, with acid-based tenderizers enhancing this effect, particularly during broiling. Higher cooking temperatures were more effective in reducing bacterial presence in broiled and grilled beef. Manios and Skandamis (2015) explored how freezing, thawing, and cooking influence the survival of foodborne pathogens like *Salmonella* and *E. coli* in beef patties. Cooking in an oven proved more effective in eradicating bacteria compared to grilling. The method of thawing did not significantly affect the elimination of bacteria. Results showed that prolonged freezing enhanced the survival rate of *E. coli*.

In the current industrial circumstances, there is a significant opportunity for meat processing companies to integrate key operational management tools such as lean manufacturing and Six Sigma. These methodologies offer substantial potential to streamline processes, reduce variability, and optimize overall efficiency. The adoption of these approaches could lead to significant improvements in the revenue flows of these companies. By minimizing resource usage, decreasing waste, and aligning processes more effectively, companies can expect a notable impact on their final production.

Lean manufacturing, with its focus on waste reduction and value maximization, is particularly relevant in the context of the meat industry. It aids in identifying non-value-adding activities and streamlining operations to enhance productivity. Similarly, Six Sigma, with its data-driven approach that helps in identifying and eliminating defects in the manufacturing process, leads to higher quality products. The combined implementation of these tools can significantly enhance operational efficiency, resulting in cost savings and improved profitability.

However, the benefits of implementing lean manufacturing and Six Sigma extend beyond financial gains. These tools play a critical role in improving the quality of the products. By fostering better manufacturing practices, they contribute to increased customer satisfaction. This aspect is crucial in the meat industry, where product quality directly influences consumer trust and loyalty. Furthermore, the rigorous application of these methodologies can lead to a reduction in food safety incidents. By systematically identifying and mitigating risks at every stage of the production process, these tools help in preventing outbreaks, recalls, and other food safety issues. This not only protects consumers but also safeguards the reputation and credibility of the companies in a highly competitive market.

In conclusion, the strategic application of lean manufacturing and Six Sigma in the meat processing industry offers a holistic solution that not only enhances operational efficiency and profitability but also ensures product quality and safety. While the implementation of these methodologies requires investment in terms of time and resources, the long-term benefits they offer in improving processes, reducing waste, and ensuring customer satisfaction and safety make them invaluable for companies looking to thrive in today's dynamic market environment.

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Chapter 2

Lean Six Sigma Approach to Improve Further Processing Efficiency using Burger Manufacturing as a Model Process.

2.1 Abstract

Our aim was to enhance the production efficiency of a further processing plant dependent on meat quality, equipment, and operation procedures. This study combined the Lean Six Sigma approach and Meat Science to improve the efficiency of a further processing plant (burger manufacturing as a model) by reducing waste and shrinkage (yield loss). The research was initiated with an assessment of current processes, a systematic in-plant study was conducted, and the outcomes were discussed with the operations team to ensure process improvement. After evaluating the process, three critical production stages were identified for data collection: (1) receiving room scales, focusing on calibration, organization, cleanliness, and training; (2) combo dumping, examining purge and leak issues; (3) water misting, assessing mister function and patty weights pre-and post-misting and freezing; (4) box weight, determining an accurate weight average of the carboard boxes. The research employed Lean tools such as Define, Measure, Analyze, Improve, and Control (DMAIC), Kaizen, Poka-Yoke, 5S, Statistical Process Controls (SPC), and polynomial regression models using Python Script. The receiving room scales had significant variance (n=345), with 79% of meat combos heavier than vendor weights. This section used 5S methodology for organization and Poka-Yoke for visual management. The combo dumping (n=145) found a 0.42 correlation between lean percentage and purge volume. Kaizen methodology combined with a combo pull system was suggested to improve the machinery design. The water misting process (n=372) showed that 38% of patty weight was lost post-freezing. The box weight (n=1,100) showed to have an average of 0.923 lb., a difference of 0.057 lb., compared to a settled weight of 0.98 lb. DMAIC engaged with SPC, polynomial regression models were used to measure the process, and the Kaizen methodology was recommended for continuous improvement. A Convergence Science approach will improve production efficiencies of further processing operations.

2.2 Introduction.

With the global population projected to reach nine billion by 2050, the demand for protein sources, including beef, is expected to increase to over 100 million kg of global protein consumption per day (Hubbart et al., 2023). Beef consumption for the population over two years of age in the US is 42.2 grams/day, which includes 33.4 grams of lean beef (Lau et al. (2023), indicating a demand for high-quality and nutritious protein sources.

Producing high-quality foods has evolved from traditional methods of manufacturing to highly evolved modern processing technologies and integrating digitization to meet the diverse consumer demands while minimizing food losses along the manufacturing process (Djekić et al., 2023). Poor quality and safety of products, either due to manufacturing practices or globalization of the supply chain, can be economically detrimental to a company (Prashar, 2014).

Gizaw (2019) discusses food safety concerns such as microbial contamination, misuse of additives, false labeling, genetically modified goods, and expired products. With the global expansion of food markets, these safety issues become more critical as they have international implications, given the extensive reach of food supply chains.

To manage these challenges, Critical to Quality (CTQ) characteristics are crucial in identifying and categorizing the essential measurable attributes of a product or process (Bañuelas & Antony, 2004). Total Quality Management (TQM) is a strategic approach designed to enhance quality across organizations. TQM and CTQs guide the establishment of performance standards or specification limits that are vital to ensuring customer satisfaction and keeping the integrity of the beef industry (Bañuelas and Antony (2004); Chakrabarty and Chuan Tan (2007); Montgomery and Woodall (2008)). The integration of Total Quality Management (TQM), Supply Chain Management (SCM), and Six Sigma (SS) into operations management has significantly enhanced manufacturing efficiency and product quality, playing a vital role in the group's innovative expansion. This approach begins by pinpointing critical challenges using feedback from customers and business insights, as well as by examining SCM processes (Mo Yang et al., 2007).

To assure quality and maintain a streamlined process, Lean Six Sigma (LSS) emerged as a systematic initiative that various organizations have widely adopted. It integrates the DMAIC (Define, Measure, Analyze, Improve, Control) approach with Lean tools to address the issues of high process variation and defect rates (Idrissi et al. (2016). However, the implementation of LSS represents a significant investment, so it highlights how important it is to identify specific LSS readiness and critical success factors for the food industry to avoid potential problems when implementing (Halim-Lim et al. (2021).

The term "sigma" (σ) comes from the Greek alphabet and is used in Six Sigma to represent variability or quantifying a change. Six Sigma is a method that measures how many defects there are in a process. The idea of a "sigma quality level" is to show how often defects might happen; the higher the sigma quality level, the fewer defects are likely to be produced (Montgomery & Woodall, 2008; Peter et al., 2000). The main aim of Six Sigma is to improve the quality of products by finding and solving the main reasons for defects and making the processes better (Kumar, 2017).

On the other hand, Lean manufacturing utilizes the term Kaizen, meaning "good change" or "improvement," which originated in Japan and was introduced by (Imai) in 1986. Since then, it has become integral to Japanese management practices and has been widely acknowledged for fostering operational excellence and success. Kaizen involves systematically identifying and addressing discrepancies and opportunities for improvement within production and operational systems. It has become essential for organizations motivated for operational excellence. By adjusting to diverse organizational contexts, Kaizen ensures that goals are achieved within a framework of goal-oriented planning (Paul Brunet & New, 2003).

The fusion of Lean Manufacturing and Six Sigma elements provides a robust method for improving business operations to seek perfection and standardization. Nonetheless, integrating these approaches into the service sector presents challenges. Service managers often encounter difficulty due to the unique attributes of services and Lean Six Sigma's origins in manufacturing, which can lead to a product-centric perspective on processes (Laureani & Antony, 2012).

While Lean Manufacturing and Six Sigma have individually shown significant effectiveness in various manufacturing sectors, this study proposes that their combined application within a burger patty manufacturing company will lead to reduced waste and shrinkage in the production process. By promoting continuous improvement and addressing root issues, it is anticipated that operations will be significantly efficient. The aim of this study is to evaluate the efficacy of Lean Six Sigma methodologies with the goal of minimizing all forms of waste while maximizing resource utilization.

2.3 Materials and Methods

2.3.1 DMAIC Cycle

Six Sigma utilizes a structured problem-solving strategy known as DMAIC, which stands for Define, Measure, Analyze, Improve, and Control. This systematic approach incorporates various foundational statistical tools, including control charts, designed experiments, process capability analyses, and measurement system capability studies. It is essential to recognize that while DMAIC is closely associated with Six Sigma, it can be applied independently and is highly adaptable for managing change and driving improvement initiatives. Derived from Walter Shewhart's Plan-Do-Check-Act cycle, DMAIC offers a structured five-stage framework that integrates various tools, providing a comprehensive approach to enhancing quality. It serves as a process improvement methodology applicable to numerous areas within the enterprise. The DMAIC cycle consists of five interconnected stages (Montgomery & Woodall, 2008):

Define the Path and Objectives for the Beef Burger Patties Project:

- Develop an A3 Problem-Solving Framework to outline beef patties production's current situation and issues briefly.
- Document the entire beef burger patties manufacturing process, identifying key steps and potential areas for improvement.
- Establish a baseline for current performance and define entitlements to set clear improvement targets.
- Calculate estimated financial benefits from project implementation to justify the investment.
- Create a comprehensive project charter that outlines the project scope, objectives, stakeholders, and timeline.
- Prepare detailed data collection plans, identifying critical hotspots where measurements will be focused in the manufacturing process.

The Define step in DMAIC aims to identify project opportunities and validate their potential breakthroughs, ensuring alignment with both customer needs and business objectives. Crafting a clear problem statement is essential, as well as outlining business issues without delving into causes or solutions. Clarity is essential for successfully implementing Six Sigma. Unclear statements can slow down progress by making it difficult to understand the direction of the. (Ray & Das, 2010).

Measurement of the Current Process and Identification of Hotspots:

- Overview of the Voice of the Process to understand current performance and variability.
- Determine an appropriate data collection method that aligns with project objectives and process specifics.
- Create a detailed data collection plan, specifying:
    - Process Steps to be Measured: (e.g., combo weight, purge loss, water added)
    - Methodology for Data Collection: (e.g., observational, quantitative measurements, categorical analysis)
    - Frequency of data collection (e.g., every unit, every batch, daily, weekly)
    - Tools and equipment needed for data collection (e.g., thermometers, scales, special equipment)
- Validate the collected data for accuracy and reliability.
- Identify primary opportunities for improvement based on data analysis, focusing on areas with the most significant impact on quality waste elimination.

The Measure phase is crucial because accurate and relevant data collection is essential for guiding decision-making in the following stages. In this process, Measurement System Analysis (MSA is another integral part of this stage. MSA checks how well the data collection system works, making sure that the measurements are accurate and consistent and not affected by changes (Galli, 2020).

Analyzing measurement results and identifying the reasons behind process imperfections:

- Employing appropriate statistical methodologies for data analysis.
- Pull out Six Sigma Statistical parameters (e.g., process capability).
- Determining the root causes of problems.

- Evaluating gaps between current and desired performance levels.
- Model/Simulate potential future outcomes or solutions.
- Estimating necessary resources for target achievement.
- Identifying potential barriers to progress.

In the Analyze phase, the goal is to pull the data gathered during the Measure phase to identify cause-and-effect dynamics within the process and pinpoint the various factors contributing to variability. Essentially, this stage aims to identify possible reasons for defects, quality issues, customer complaints, challenges with cycle time and throughput, or any inefficiencies and waste that prompted the initiation of the project (Montgomery & Woodall, 2008).

Improve the process, implement changes to align it, and reduce variations:

- Organize the work breakdown structure and assign responsibilities.
- Develop and assess potential solutions, conducting pilot tests.
- Develop a detailed implementation plan and model the proposed solutions.
- If improvement opportunities are limited, explore redesign options.

The objectives within the improvement phase are viewed as a framework that strongly connects to the organization's strategic goals, enhances management engagement, and boosts financial outcomes. In problem-solving, the analysis during the Improve phase is segmented into five key themes, as outlined by de Mast and Lokkerbol (2012). These themes encompass the broad applicability of novel approaches versus specialized techniques for specific issues, the structured nature of problem identification, essential tasks in problem-solving, the diagnostic process in identifying issues, and the corrective measures implemented to address these problems. This perspective is supported by van Iwaarden et al. (2008), who emphasize the integration of these elements in the improvement process.

The final step is control, monitoring the improvements to ensure success:

- Develop performance metrics and control charts.
- Establish a routine monitoring schedule.
- Implement a feedback mechanism for continuous improvement.
- Train staff on new standards and procedures.
- Use statistical process control (SPC) tools (e.g., X-bar and R charts, histograms, scatter diagrams).
- Regularly review process performance of improved targets.
- Adjust control limits as necessary for process changes.
- Document all changes and updates in procedures.
- Perform periodic inspections to ensure compliance.
- Adopt a culture of quality and continuous improvement.

The Control phase aims to maintain the process's future state by minimizing deviations from set objectives and implementing corrective actions before any negative impact arises. In the Six Sigma DMAIC framework, this phase cements the improvements, integrating them into everyday operations. It wraps up the project by transitioning the enhanced process to the designated owner, complete with a control plan to ensure sustained performance. The main goal is to embed these improvements within the organization, ensuring stable and high-quality outcomes. Essential to this phase are standardization, establishing clear ownership, and promoting responsibility, which supports consistency, quality, and the possibility of applying these improvements to similar processes across the organization (Montgomery & Woodall, 2008)

2.4 Case Study

2.4.1 Defining the Issues

The study began with a board meeting at the company to discuss operational challenges. The company serves only B2B customers, focusing on supplying burger patties to the southeastern United States and trying to achieve a daily production target of 4.2 million (1/10 lb) beef burger patties. This compares to approximately 11,000 boxes, each weighing 38 lbs. The daily average meat usage is between 375,000 and 425,000 pounds of beef. Each week, the company receives up to 1,200 combos of meat, with a lean percentage varying between 50% and 95% and fat content from 5% to 50%. Daily, between 180 and 220 combos are pulled from inventory for production. Historical data on monthly shrinkage and waste percentage changes across a period of three years shows significant variability. The shrinkage percentage oscillates above 0.10%, extending to 0.40%. The waste percentage shows a more controlled and lower pattern of variation when compared to shrinkage, which ranges from 0.10% to just above 0.60%. Following a thorough analysis and streamlining of the process, various segments were determined for potential improvement opportunities, with waste, shrinkage, and bottlenecks identified as primary concerns.

The initial issue focused on the scales in the receiving room, which exhibited measurement variations and inaccuracies, affecting inventory control. The second concern emerged after meat combos were dumped into the production line, leading to operator negligence, such as leaving meat trims in combos, hopper overfilling (resulting in meat falling off), and equipment design, leading to purge loss. Progressing further, the company encountered anisotropic shrinkage post-freezing. To counteract this, a water compensation system was implemented, spraying 0.5 mL of water on each patty before freezing to lessen weight loss. Nonetheless, this solution faced challenges with uniform water application. In the last step of production, where boxes are arranged on pallets, incorrect tare weights of the packing boxes were found, leading to potential losses and affecting the accuracy of production metrics. Once the project was initiated, key stakeholders were integrated to prioritize and concentrate on the continuous improvement of quality across the company. This team primarily included the Project Manager, Supply Chain Director, Director of Operations, Senior Director of Operations, and Plant Engineer.

In order to address and assess the primary causes of inefficiencies, An A3 problem-solving approach was implemented to address four distinct hot spots: the 'Receiving Room,' 'Combo Dumper,' 'Water Misting Process,' and 'Finished Product Scale Room,' each at different stages of the process. This systematic method facilitated a thorough examination and sequential development of solutions made to the specific needs of each area.

2.4.2 Process Measurement

After identifying the problems, the subsequent steps included data collection to follow the existing process and accumulate historical data for future comparison with an improved process. This data collection specifically involved tracking shrinkage and waste percentages over time (Figure 1.). The four steps pinpointed for enhancement were explicitly measured. The methodology for this study includes systematic data collection: defining the objectives, selecting the data to be collected, determining the data source and collection plan, collecting and verifying the data, and organizing it for analysis to interpret the current process accurately. Observational procedures were then implemented to gain a precise understanding of the actual process.

2.4.2.1 Receiving room scales.

A total of 17 trailers containing 344 combos of beef meat (lean and fat) underwent weight checks. These combos were obtained from national packers in Texas and Oklahoma and transported in refrigerated trailers set to 40°F, arriving at the facility within 2-3 business days. Upon arrival, the combos' temperatures were checked with a probe, and their weights were measured using a floor scale (Metler Toledo IND 570, Cap: 5,000 lb). These details were recorded in the inventory system along with the vendor's weight, the receiving scale weight, the date, and the type of meat. Each combo served as an experimental unit. After receiving, the combos were stored at 32°F for later use. The collected data were analyzed through comparisons and visual interpretation using Python.

During the Measure phase, this issue was further measured. The collected data shows a wide range of variation, pointing out that the current process is incapable of providing accurate measurements. Statistical evidence revealed that the maximum weight deviation recorded was 47.0 pounds (lb.), with a minimum deviation of -36.0 pounds, resulting in a significant range of 83.0 pounds. The mean weight inconsistency was found to be 7.09 pounds, with both the mode and median at 8.00 pounds, further pointing out the consistency of this issue across measurements. The variation in weight inconsistencies was calculated to be 146.83 pounds, and the standard deviation was 12.117 pounds. The Process Mean (μ) of 7.09 pounds indicates an average deviation from the vendor's reported weight.

2.4.2.2 Combo Dumper

A total of 145 combos were checked at the time they were dumped into the Heavy Duty Stainless Steel Self-Dumping Forklift Hopper to be incorporated into the process. Before dumping, details such as the vendor information, receipt date, use date, expiration date, and percentage of lean were recorded. At the time of placement in the hopper, leaks were detected and collected. The purge was collected using plastic trays placed underneath the leaks. After collection, the purge was weighed on a floor scale (Metler Toledo IND 570) and recorded. The data was utilized to perform a correlation analysis using age, received temperature, and percentage of lean to quantify the purge according to the percentage of lean as well as the supplier.

The data shows a distinct correlation between the lean percentage of the beef and the average amount of purge (drip loss) measured in pounds. For meat with a lean percentage of 65%, the average purge is approximately 6.71 pounds, indicating a higher purge loss compared to beef with an 80% lean percentage, where the average purge drastically reduces to about 1.30 pounds. Interestingly, as the lean percentage increases to 85% and 90%, the average purge amounts rise again to approximately 5.27 and 5.13 pounds, respectively. This pattern suggests that the lean percentage along the age of meat and transportation practices significantly influences the amount of purge dripped during combo dumping.

2.4.2.3 Water Misting and Water Coverage

A total of 372 patties were evaluated at three distinct stages: pre-water misting, post-water misting, and post-freezing, with measurements taken using a gram scale (Uline Balance Scale - 220 g x 0.01 g, model H-9884). To assess the efficacy of the water nozzles and the performance of the misting process, water-sensitive paper (Innoquest Inc. SpotOn Paper 1" x 3") was utilized. This allowed for the visualization of droplet dispersion patterns and the identification of issues such as clogged, worn, or incorrectly set up of sprayer nozzles. This was followed by an analysis of the collected pattern data using image analysis software (Java-based image processing program – ImageJ, version 1.54), which facilitated the calculation of the percentage of surface area coverage. Critical features considered in the analysis included the weight of the patties at the three stages mentioned above, the rate of water coverage, the volume of water added to each patty measured in milliliters, the speed of the conveyor belt recorded in feet per second, the airflow rate in Standard Cubic Feet per Hour (SCFH), and the water flow rate in Gallons Per Hour (GPH). These parameters were meticulously recorded for future reference and to inform subsequent stages of the research.

The statistical analysis of the initial parameters for the patty former indicates a standard deviation of approximately 0.992, suggesting a consistent distribution around the mean weight of 45.265 grams. With Six Sigma metrics, the process capability index (Cp) is slightly above 1.49, and the process performance index (Cpk) is around 1.38, both of which exceed the benchmark of 1.33, indicating a capable and well-controlled process. These values demonstrate that the process is not only able to meet the specified standards consistently but also operates with a centered distribution, minimizing the production of non-conforming products.

For the post-water misting phase, analysis reveals the average patty weight to be around 45.66 grams, with both the median and mode closely matching at 45.5 grams, pointing to a symmetrical distribution. The processing capability has seen enhancement, with a Cp value of about 1.51, indicating a closer adherence to specification limits. Nonetheless, the process performance index (Cpk) has risen to approximately 1.27. While this marks an improvement, it signals that the process, despite enhancements, may not yet be fully optimized to meet the desired specifications consistently.

Following the freezing conveyor stage, the weight of the burger patties stabilizes at an average of 45.10 grams compared to the initial patty weight, with the mode and median values confirming these measurements. The observed standard deviation of 0.973 points to a moderate degree of variation among the patties. Six Sigma analysis shows a process capability (Cp) of 1.52, demonstrating a reasonable degree of conformity to the specified weight standards and a process performance index (Cpk) of 1.47, which implies that the process is well-centered. Despite these positive indicators, there remains room for improvement to enhance the uniformity of patty weights further within the set specifications.

2.4.2.4 Finished Product Scale Room

In the last stage of the measurement phase of this Lean Six Sigma project, a total group of 1,100 boxes was weighed in a Mettler Toledo ICS429 Scale, focused on detecting weight variations. The analysis of the collected data revealed a maximum weight of 1.058 pounds and a minimum of 0.804 pounds, with the mean weight across all samples being 0.923 pounds. Notably, the mode, or most frequently occurring weight, was 0.932 pounds, and the median weight, indicating the midpoint of the data set, was 0.916 pounds. The range of weights was shown to be 0.254 pounds. Comparatively, the previously established tare weight for the boxes was 0.98 pounds, indicating a minor gap of 0.057 pounds compared with the observed mean weight of 0.923 pounds. This variance highlights an area for potential process adjustment or standardization in the project.

2.4.3 Analyzing the Issues

To analyze the measurements obtained in the previous phase, we examine each process individually to identify opportunities for improvement and pinpoint where problems are occurring.

A comprehensive problem source matrix was conducted to assess and identify the root causes of current process issues. Table 1. categorizes these issues according to their origin: people-related, process-related, equipment/machine-related, and design-related, providing a clear overview of the areas affecting the process.

2.4.3.1 Receiving room scales

According to the DMAIC Six Sigma methodology outlined by Montgomery & Woodall (2008), the results section of this study begins with a clear definition of the problem at hand. We have identified a substantial variation between the weights reported by vendors and those measured on scales. Figure 2. presents a Value Stream Map detailing the stages of the combo-receiving process. The process initiates with the supplier, progresses through production planning and the purchasing department, and then bifurcates into quality control checks: temperature checks and combo weighing, recording, and labeling. Following these parallel processes, the materials are taken into acclimated storage (30°F to 34°F) inventory and available for the grinding phase.

The data indicates that most of the combos had differences in weight (Figure 3), 79% of them (344 items) were overweight, 19% (65 items) were underweight, and only 2% (7 items) matched the expected weight exactly.

2.4.3.2 Combo Dumping

We examined factors contributing to purge loss from five suppliers for this study event. The correlation analysis focuses on the age of the product, transport temperature, percentage of lean, and average purge loss in weight. Regardless of varying conditions, all suppliers demonstrated a consistent pattern in average purge loss, measured in pounds per combo. This consistency across different sources indicates that the factors contributing to purge loss are familiar and potentially predictable.

A moderate positive correlation coefficient ($r = 0.339$) was identified between product age and average purge loss, suggesting that purge loss increases as the product ages. In contrast, a weak inverse correlation ($r = -0.29$) was observed between transportation temperature and average purge loss. Furthermore, the lean percentage of the product showed a moderate positive correlation with both the average purge loss (r = 0.420) and the rate of purge per combo (r = 0.512), indicating that products with a higher lean percentage tend to lose more weight and contribute to an increased purge loss.

2.4.3.3 Water misting

A study was conducted using the principles of Kaizen and the DMAIC Six Sigma methodology (Montgomery & Woodall, 2008) to enhance the efficiency of the water misting process across eight production lines. Initial assessments revealed that the final weight of the patties varied, with a 9.9% increase, 37.4% decrease, and 52.7% showing no change (Figure 4). The process was set with an initial mean of 0.45 g of added water, equivalent to 0.45 mL for misted water, targeting 85% water coverage. Although results suggested that the desired amount of water was being added, analysis indicated that half of the production lines were not meeting the target mean.

The correlation matrix (Figure 7) shows how various process features affect the final product. Notably, speed and contact time show a perfect negative correlation (-1.0), consistent with previous findings. A robust positive correlation (0.87) was observed in the case of water flow and misted water, indicating that higher water flow rates lead to more water being misted in the patty. The relationship between contact time and misted water was also strong and positive (0.7), suggesting that longer contact times result in increased water misting and that adjustments in conveyor belt speed could affect water misting effectiveness. Furthermore, water flow and disposed water showed a positive correlation (0.72), indicating that increases in water flow are associated with higher volumes of disposed water. Additionally, mistreated water and disposed of water demonstrated a strong positive correlation (0.7), where more mistreated water led to more disposed of water, pointing towards the efficiency of water usage or application. Lastly, speed and misted water had a moderate negative correlation (-0.65), suggesting that as conveyor speed increases, the amount of misted water tends to decrease, likely due to the reduced contact time available for misting.

2.4.3.4 Water Coverage.

Six water-sensitive papers were placed on top of a burger patty on the conveyor belt to check the water spray. The results (Table 2) showed significant differences in how much water each patty got, from as little as 7% to as much as 88% coverage. Also, the amount of water per patty changed between 0.30 mL and 0.51 mL.

2.4.3.4.1 Predictive model.

Using the Python Jupyter Notebook, we utilize several modules and algorithms from scikit-learn, a machine learning library for Python, to construct and evaluate a polynomial regression model. Initially, PolynomialFeatures is employed to expand our set of independent variables, "Water flow" and "Speed" from the data frame to include their interactions and quadratic terms, which helps capture non-linear relationships. A linear regression model is then constructed and fitted to the training data (70% for training, 30% for testing) with a random state of 42. The model's performance is evaluated on test data, with the R^2 score and RMSE (Root Mean Squared Error) calculated to assess its accuracy and predictive power. This rigorous training and verification process validates the model's ability to estimate 'Disposed Water' based on the inputs. Furthermore, by fixing the 'Water flow' and setting a target for 'Disposed Water', we can use this model to compute the necessary 'Speed'. This capability is particularly useful for optimizing operational parameters to meet specific performance criteria.

The coefficients, intercept, and specific evaluation metrics are described below:

$$Coefficients: 2.58713399, 0.20288336, -0.05198065, -0.10841979, \quad 0.04233455$$

$$Intercept: -16.138954553047714$$

The coefficients represent the weights assigned to each feature and their interactions in the polynomial equation.

- The coefficient 2.58713399 corresponds tohe linear term of water flow.
- The coefficient 0.20288336 corresponds to the linear term of speed.
- The coefficient -0.05198065 corresponds to the interaction between water flow and speed.
- The coefficient -0.10841979 corresponds to the square of water flow.
- The coefficient 0.04233455 corresponds to the square of speed.
- The intercept -16.13, represents the value of the target variable (disposed water) when all the input features are set to zero.

These coefficients indicate how much each term contributes to the prediction of the target variable (Disposed Water). Positive coefficients suggest a positive relationship with the target, while negative coefficients suggest a negative relationship.

The equation for a polynomial regression with a degree of 2 can be written as: $y = b_0 + (b_1 \times x_1) + (b_2 \times x_2) + (b_3 \times x_1^2) + (b_4 \times x_1 \times x_2) + (b_5 \times x_2^2)$

Where:

- y is the predicted target variable (disposed water).
- x_1 represents water flow.
- x_2 represents speed.
- b_0 is the intercept (intercept value you obtained, approximately -15.44).

- b_1, b_2, b_3, b_4 and b_5 are the obtained coefficients.

Equation with the coefficients:

$$Disposed\ Water = -16.13 + (2.59 \times Water\ flow) + (0.20 \times Speed) + (-0.05 \times Water\ flow^2) + (-0.11 \times Water\ flow \times Speed) + (0.04 \times Speed^2)$$

After generating these polynomial features, the dataset is divided using *train_test_split*, allocating 70% to training and 30% to testing, ensuring reproducibility with a random state of 42 we obtained the following results:

$$R\hat{}2\ Score: 0.67011017421749$$

$$RMSE: 0.06069947049962922$$

2.4.3.5 Box Weight

The analysis of 1,100 data-driven and observational samples revealed that the average weight of the boxes varies, with a range from 0.804 to 1.058 pound, due to factors such as the length of the inner bag, the quantity of glue applied, and the cardboard lot. These findings indicate that by addressing variations in these areas, it could lead to more consistent box weights, ranging from lighter to heavier, and overall improved packaging quality.

2.4.3.6 Statistical Analysis

In this study, we used Python and its Jupyter Notebook program language for various statistical analyses. Initially, a criteria was established to categorize weight changes in burger patties. If the weight after freezing minus the weight before freezing is less than 0, it's labeled as 'loss'; if equal to 0, as 'none'; and if greater than 0, as 'gain'. Exploratory data analysis was conducted using a pie plot design to illustrate the distribution of patties across these three categories. Additionally, X-bar and R charts were implemented to monitor the production line's performance concerning specific process limits (Upper and Lower). Bar graphs were employed to examine the line behavior using the mean amount of misted water per patty (mL) and the mean of added water (mL), as well as the coverage area (%). A Correlation Matrix facilitated the correlation analysis between variables. The seaborn library's sns.histplot along with a grid.map provided a detailed visual of the distribution of specific variables. In the exploratory data analysis, a polynomial regression was performed using the *scikit-learn* library, to predict a target value, enhancing our understanding of the patties' weight change dynamics.

2.4.4 Improvement Suggestions

To ensure success and enhance process reliability and efficiency, it is crucial to implement targeted improvements. A comprehensive analysis across all four cases highlights a significant need for operator and personnel training. Achieving this goal involves several key steps:

- Lean Manufacturing Training: Educate personnel on Lean Manufacturing principles to foster a deep understanding of efficient and waste-reducing processes.
- Emphasize the Importance of Lean Principles: Clearly communicate to all employees the critical role that Lean principles play in improving operational efficiency and overall success.
- Motivate Commitment to Change: Encourage employees to embrace these changes by offering incentives that align with adopting Lean practices and principles.
- Foster a Culture of Continuous Improvement: Cultivate an organizational environment that values ongoing learning and continuous process improvement, ensuring sustainable progress and innovation.

To address the challenge of inconsistent weight variations on the receiving scales and ensure measurement accuracy, we propose a comprehensive strategy encompassing several vital actions:

- Implement the 5S Methodology: Adopt the 5S framework (Sort, Set in order, Shine, Standardize, Sustain) to enhance consistency, efficiency, and standardization across operations. This includes establishing a precise protocol for setting tare weights at the start of each shift to ensure uniformity.
- Regular Calibration of Scales: Schedule routine calibrations of the receiving scales to maintain their accuracy and reliability. This step is crucial for verifying the scales' performance and ensuring consistent measurements.
- Mistake-Proofing Measures: Introduce mistake-proofing methods, such as a double-check system, to promptly detect and correct any deviations in weight measurements. This approach helps minimize errors and enhance process reliability.
- Encourage Employee Engagement: Motivate employees to actively participate in the process by reporting observed issues or irregularities and offering suggestions for improvement. This cultivates a culture of continuous improvement and leverages collective insights for better process management.
- Data Analysis and Trend Monitoring: Conduct regular reviews and analyses of weight variation data to identify trends, patterns, and potential areas for improvement. The organization can take proactive steps to reduce inconsistencies and optimize accuracy by understanding these dynamics.

To address the issues of waste at the combo dumping stations and enhance operational efficiency, the following improvement strategies are suggested:

- Implement a Pull System: Introduce a pull system to ensure that a new combo is only brought from inventory when the hopper is empty. This approach prevents meat trims from falling off the hopper, thus reducing waste. Successful implementation of this system requires a strong commitment from the operators to follow to this new procedure thoroughly.
- Machinery Design Intervention: To address the issue of shrinkage loss due to purge leakage in the hopper, a redesign or modification of the machinery is necessary. Incorporating a gasket or similar sealing solution at known leak points can significantly reduce leakage. This intervention aims to enhance the machinery's efficiency and minimize product loss.

To optimize the water misting processes and ensure uniform application on each patty, the following improvement actions are proposed:

- Effective Water Misting System: Develop and implement an efficient water misting system that includes a robust water filtration process. This ensures that only clean, filtered water is used in the misting process, maintaining product quality.
- Regular Calibration of Air and Water Flow: Establish a routine calibration program for both air and water flow rates. This ensures that the misting system operates at optimal levels, providing consistent and precise water application.
- Optimization of Misting Process: Focus on optimizing the entire misting process by ensuring regular maintenance and proper functioning of the misting equipment. This includes timely repairs and adjustments to prevent any disruptions in operations.
- Calibration Procedure for Water Dispensation: Develop a calibration procedure that accurately measures the amount of water (in milliliters) dispensed per square inch on each

patty. This step is crucial for achieving uniform water coverage and maintaining product consistency.

- Visual Inspection and Monitoring: Implement a system for visual inspection and ongoing monitoring of the water misting process. This allows for immediate verification that each patty receives the correct amount of misting, ensuring quality control.
- Establish a Monitoring System: Set up a comprehensive monitoring system to track the performance of the misting process. This system should be capable of recording data on misting efficiency and identifying any deviations or issues in real time, allowing for prompt corrective actions.

To address issues related to box weight and ensure accuracy and consistency in the packaging process, the following solutions, inspired by the Kaizen continuous improvement philosophy, are proposed:

- Establish Standard Box Weight: Initiate the process by defining a standard weight for the empty boxes. Ensuring that this standard weight is consistently maintained is crucial for enhancing the accuracy and uniformity of the overall packaging process. A standardized weight helps in streamlining operations and reducing variability in the packaging process.
- Accurate Tare Weight Setting: Focus on regularly verifying and setting an accurate tare weight for the boxes. By accurately determining the tare weight, the net weight of the product can be precisely calculated by subtracting the tare weight from the gross weight. This practice ensures that the final product weight is accurate, reliable, and consistent across all packages.
- Box Forming Calibration: A calibration process for the box forming machinery at the beginning of each shift will ensure the correct length of the plastic bag and the precise

amount of glue used are consistently applied. Such regular calibration is crucial for maintaining accurate operations, significantly reducing the probability of measurement errors and inconsistencies.

By implementing these strategies, we aim to foster a culture of continuous improvement that enhances accuracy, reliability, and efficiency across all processes. This streamlined approach focuses on precision in packaging, minimizing waste in combo dumping, and ensuring effective water misting, directly contributing to product quality and operational effectiveness. We strive to improve process frameworks through committed planning and adjustments, achieving operational resilience and customer satisfaction with fewer resources and higher quality outcomes.

2.4.5 Controlling the Improvements and Process

Upon the implementation of the suggested operational improvements, establishing a robust control mechanism is essential to evaluate their effectiveness and contribution towards enhancing the production process and the company's profitability. To facilitate this, a comprehensive control plan must be developed. This plan will detail the types of data to be collected, methodologies for data collection, the frequency at which these collections should occur, and the designation of responsible individuals or teams. Moreover, the plan must include a protocol for identifying non-conformities, with explicit instructions for the subsequent actions required to address these issues, ensuring swift and effective resolution.

As the process goes on and initial evaluations are conducted, it is necessary that the control plan undergoes periodic reviews and updates. This adaptive approach allows the plan to remain relevant and effective considering new findings and operational insights, fostering an environment of continuous improvement. By systematically monitoring, analyzing, and refining the control processes, the organization can sustainably advance its operational efficiency, product quality, and customer satisfaction, securing a competitive edge in the market.

2.5 Discussion.

This study has revealed significant inconsistencies in the weights of beef meat combos, with most combos deviating from the expected weight. There is an evident need for process improvement to ensure quality control and accurate inventory management. The significant variation, with a range of 83.0 pounds and an average deviation of 7.09 pounds from the vendor-reported weight, highlights a critical issue within the receiving and inventory process. The finding that 79% of combos were overweight could imply potential inefficiencies in vendor packing processes or inconsistencies in scale calibration and measurement at the vendor or receiver scale. The underweight 19% also raises concerns about possible losses along the supply chain.

Curtis and Weier (2009) pointed out that variability in measurement error can be partly attributed to several factors: a) the range of actual weights being measured, b) the placement of the abnormal standard on the left, right, or center stack, and c) the action of adding or removing the last standard before weighing. By controlling these variables and keeping them consistent, the calculated estimates of random uncertainty could potentially be decreased by approximately 66%.

Considering the Six Sigma DMAIC framework and Lean tools, the following steps should involve thoroughly analyzing the weighing equipment calibration process and the vendor's packing accuracy. Solutions might include more rigorous scale calibration protocols, enhanced training for personnel in handling and weighing procedures, and the application of 5S methodology to ensure a better work area.

Swarnkar and Verma (2017) discussed the beneficial effects of 5S on various aspects of organizational efficiency, including labor productivity, floor space savings, fostering a positive shift in work culture, and enhancing workers' safety and health. The 5S approach, as a fundamental aspect of Lean manufacturing techniques, is recognized as an effective strategy for minimizing and eradicating waste and promoting a positive shift in organizational work culture.

Rizkya et al. (2019) highlighted the application of the 5S methodology as a transformative tool for elevating the efficiency and effectiveness of employees in their work activities. Through its structured approach, 5S aids in creating a more functional and orderly work environment, enabling employees to perform their duties with greater competence and precision.

Rahman (2010) explained that using a 5S audit helps companies understand how much they can improve quality. It also lets them see what each part of the company is good at and what needs work. To see how well 5S works, the study looked at two manufacturing companies. This helped show how 5S can make a difference in how a company performs and identify specific areas that might need more attention.

The purge loss in beef meat combos has yielded critical perceptions of the factors influencing this loss. The consistent pattern of average purge loss across varying conditions and suppliers indicates that the underlying causes of purge loss are not isolated but rather systemic and potentially predictable within the supply chain. The moderate positive correlation ($r = 0.339$) between product age and average purge loss is a significant finding. This indicates that the probability and extent of purge loss increases as the beef ages. This relationship is crucial for supply chain management and inventory turnover strategies, suggesting that minimizing storage time could reduce purge loss, thereby maintaining product quality and reducing waste.

Conversely, the weak inverse correlation (r = -0.164) between transportation temperature and average purge loss suggests that increments in transport temperatures may reduce purge loss. This finding could inform transportation practices, although the weak nature of this correlation indicates that temperature control might not be the most critical factor in managing purge loss.

The investigation also reveals a moderate positive correlation between the product's lean percentage and both the average purge loss (r = 0.420) and the percentage of purge per combo (r = 0.512). This finding is significant, as it suggests that products with a higher lean percentage are more susceptible to weight loss and higher purge levels. This could have implications for product selection and supplier criteria, especially in terms of lean percentage specifications.

Given these correlations, it is evident that product age and lean percentage are more influential in determining purge loss than transportation temperature. These findings can guide operational adjustments, such as prioritizing the use of fresher combos and reconsidering the lean percentage requirements from suppliers to optimize product quality and minimize waste.

In a study performed by Diss et al. (2019), short loin cuts of beef were vacuum-packed and stored at 4°C for 10 days. To measure purge loss, they weighed each sample before the vacuum packing and then again after the 10-day aging period, calculating the percentage weight change. The results showed that there was a notable difference in purge loss based on the storage type and the specific section of the loin.

The presence of purge in beef meat combos could be attributed to the practices employed by packers. This consideration is particularly relevant given that bacterial levels can significantly influence purge. Factors such as stringent sanitation protocols, adherence to Good Manufacturing Practices (GMP), and the treatment processes applied to the final product play pivotal roles.

In a study, Dorsa et al. (1996) analyzed the microbial content in the purge from beef combos. Their findings showed a high correlation (r = 0.94) between the total bacteria count in the purge and on the meat surface. They discovered that bacteria, including those from bovine feces, could move into the purge within 24 hours. This study suggests that testing the purge for bacteria is a more effective way to understand the overall bacterial presence, including coliforms and E. coli, than taking random meat samples. They concluded that purge sampling is a valuable method for monitoring raw beef in grinding operations, especially for Hazard Analysis and Critical Control Points (HACCP) plans.

These practices are critical concerns and may be key indicators in understanding the variations in purge levels observed. Greater attention to these aspects at the packing stage could provide valuable insights into reducing purge and ensuring product quality. Furthermore, the consistent average purge loss pattern across different suppliers implies that industry-wide standards or practices could be contributing to this issue. Collaborative efforts with suppliers to address these practices may be beneficial. Additionally, further research could explore the biological or chemical processes contributing to purge in relation to product age and composition. Shrinkage is an inevitable aspect of specific processes and is primarily influenced by the practices and procedures along the process. The level of shrinkage can vary based on how these processes are managed and executed. This implies that by optimizing and improving operational practices and procedures, it may be possible to control and reduce the amount of shrinkage, thus enhancing overall process efficiency and product quality.

The study of the water misting process is a shrinkage analysis with the objective of reducing it in the burger patties process. The study showed critical findings about the effectiveness and consistency of the water misting process in patty production. This was done using accurate scale measurements at different stages (before and after water misting and after freezing) and water-sensitive papers. The observed variation in final patty weight, with a significant portion showing no change post-misting, raises questions about the uniformity and effectiveness of the current misting setup. Despite the target of achieving 85% water coverage with an initial mean of 0.45 g (equivalent to 0.45 mL) of added water, the results indicated discrepancies across production lines. This variation in water application, evidenced by the wide range in water coverage (min of 7% to a max of 88%) and the volume of water added (from 0.30 mL to 0.51 mL), points to inconsistencies in the misting process that could impact product quality and uniformity.

Water misting plays a crucial role in the processing sequence, as it serves a dual purpose. Firstly, it compensates for the weight loss that typically occurs during the freezing stage. By adding moisture at this point, it effectively balances the reduction in weight, ensuring that the final product meets its specified weight requirements. Secondly, water misting helps in reducing shrinkage, which is a common issue in processing. The reduction in weight or quantity of the final product can lead to inefficiencies and economic losses. By introducing the misting step, the process helps maintain the quality of the product, ensuring that it retains its desired physical properties and weight throughout the processing cycle. Thus, water misting is not just an additional step but a vital one that enhances the overall effectiveness and efficiency of the production process.

The correlation matrix presents intriguing findings, particularly the perfect negative correlation (-1.0) between conveyor speed and contact time. This suggests that faster conveyor speeds reduce the time patties are exposed to misting, thus potentially diminishing the effectiveness of water application. Moreover, the strong positive correlations observed, such as between water flow and misted water (0.87) and contact time and misted water (0.7), reinforce the idea that both the rate of water flow and duration of exposure are critical factors in achieving optimal misting.

The strong positive correlation between misted and disposed water (0.7) raises concerns about the efficiency of water usage. It implies that a considerable amount of the water used in misting is not adhering to the patties, leading to wastage. This inefficiency could be attributed to factors such as nozzle design, water pressure, or even the physical properties of the patties themselves.

Furthermore, the moderate negative correlation (-0.65) between conveyor speed and the amount of misted water underscores the need for a balanced approach to production speed and misting effectiveness. An increase in conveyor speed might lead to a decrease in the amount of water each patty receives, thereby affecting the uniformity and possibly the quality of the final product.

2.6 Conclusion

In summary, the application of Lean Six Sigma and its data-driven insights provided by this study serves as a foundation for targeted process improvements. By addressing the root causes behind weight inconsistencies, product waste, and significant sources of shrinkage, the facility can move toward minimizing waste, enhancing operational efficiency improving inventory accuracy, and ensuring compliance with quality standards, all of which are central to Lean Manufacturing principles and Six Sigma quality control methodologies.

Furthermore, the study's correlation analysis provides a foundation for targeted strategies to reduce purge loss in beef meat combos as well as to align the water misting process. By understanding and addressing the factors contributing to this loss, the company can enhance product quality, improve operational efficiency, and potentially reduce costs associated with waste, all along with the principles of Lean Manufacturing and effective operations management. The findings, guided by the principles of Kaizen and the DMAIC Six Sigma methodology, highlight the need for a more controlled and consistent process and the adoption of a continuous improvement culture.

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Figures.

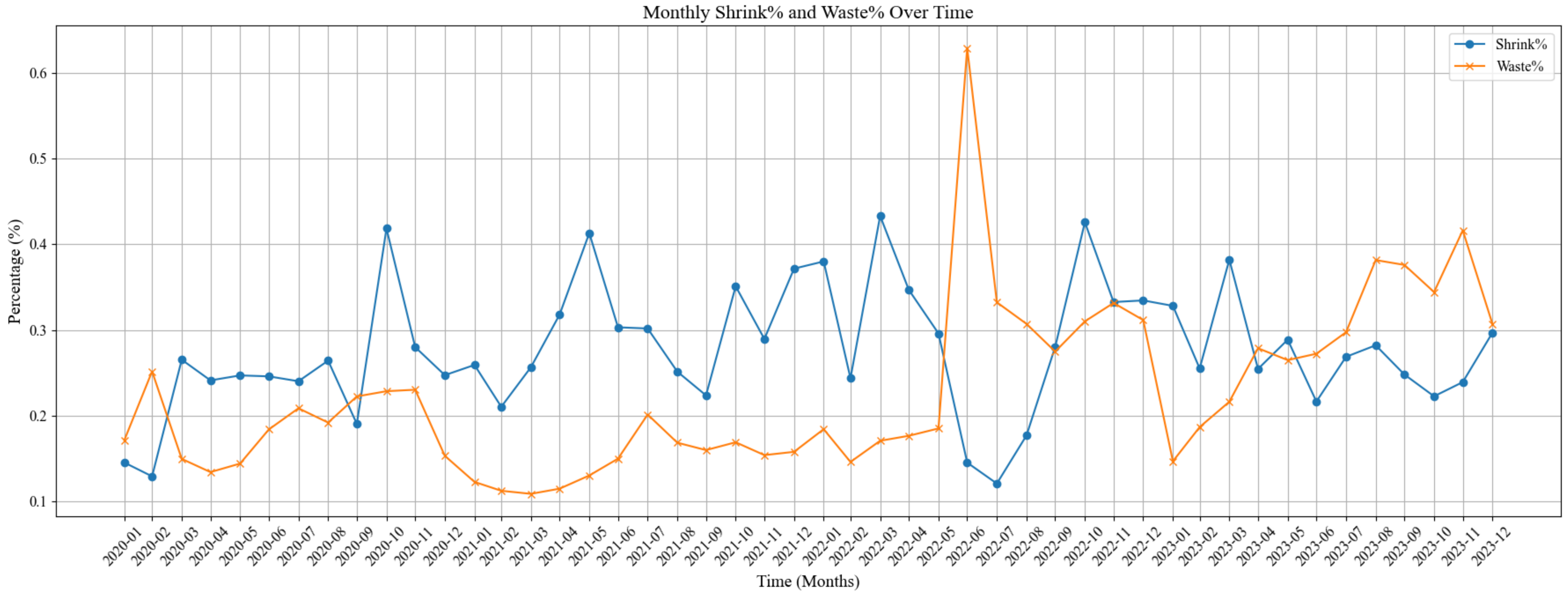

Figure 1. January 2020 to December 2023 Production Metrics, Production vs Shrinkage.

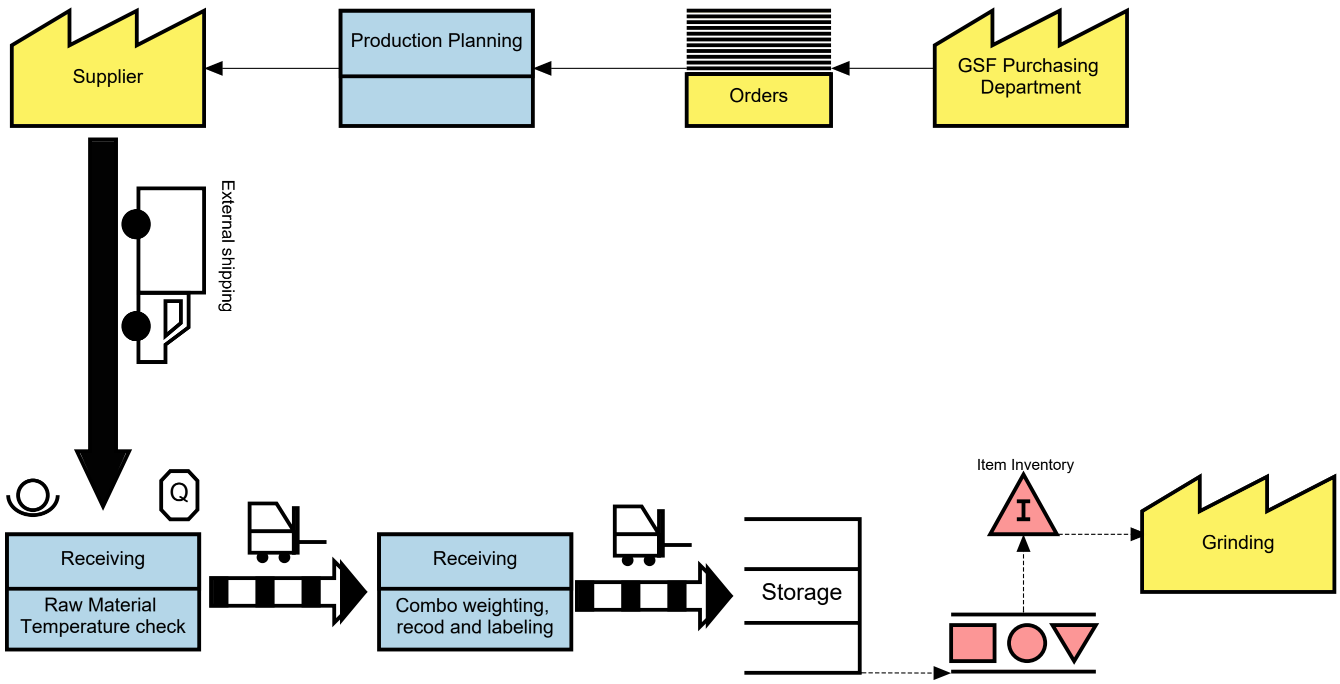

Figure 2. Value Stream Mapping (VSM): Streamlining Combo Receiving Process.

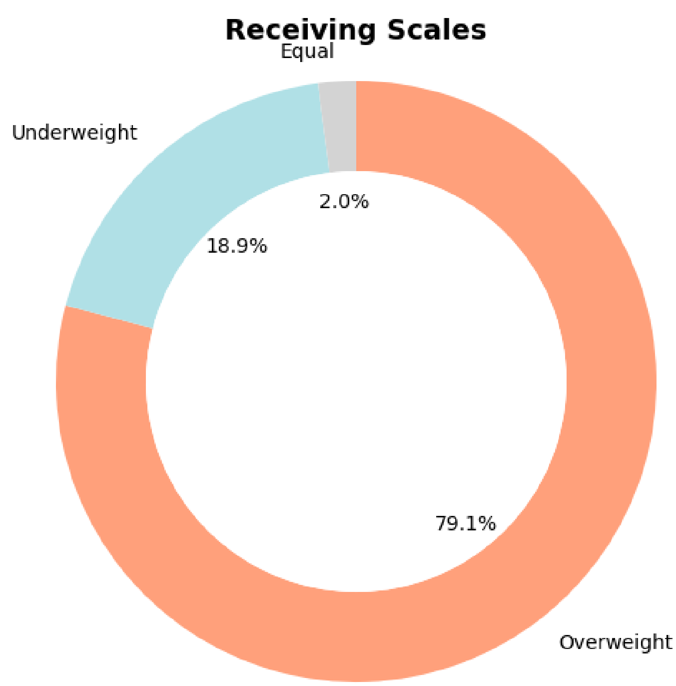

Figure 3. Donut chart illustrating the distribution of items according to weight classification.

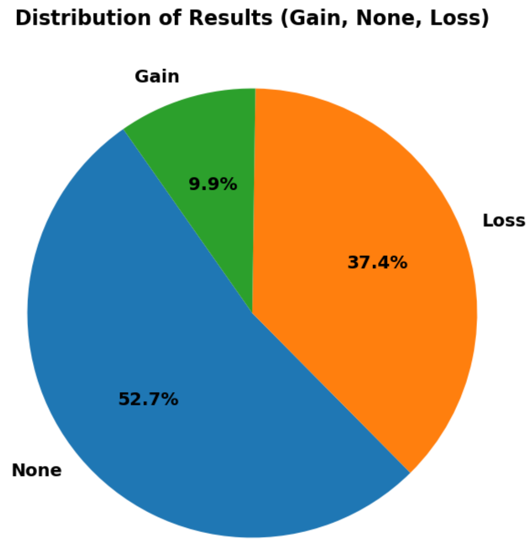

Figure 4. Pie chart visualizing the proportional distribution of the results for water misting process.

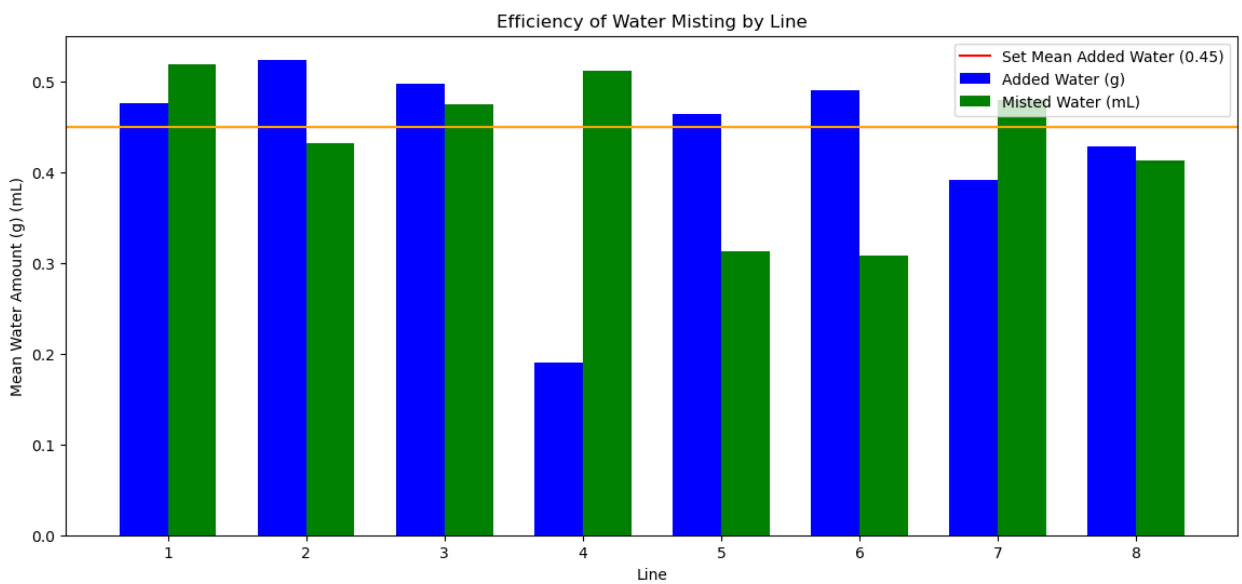

Figure 5. Bar graph showing the efficiency of the water misting process by line, comparing theoretical weight added and water added.

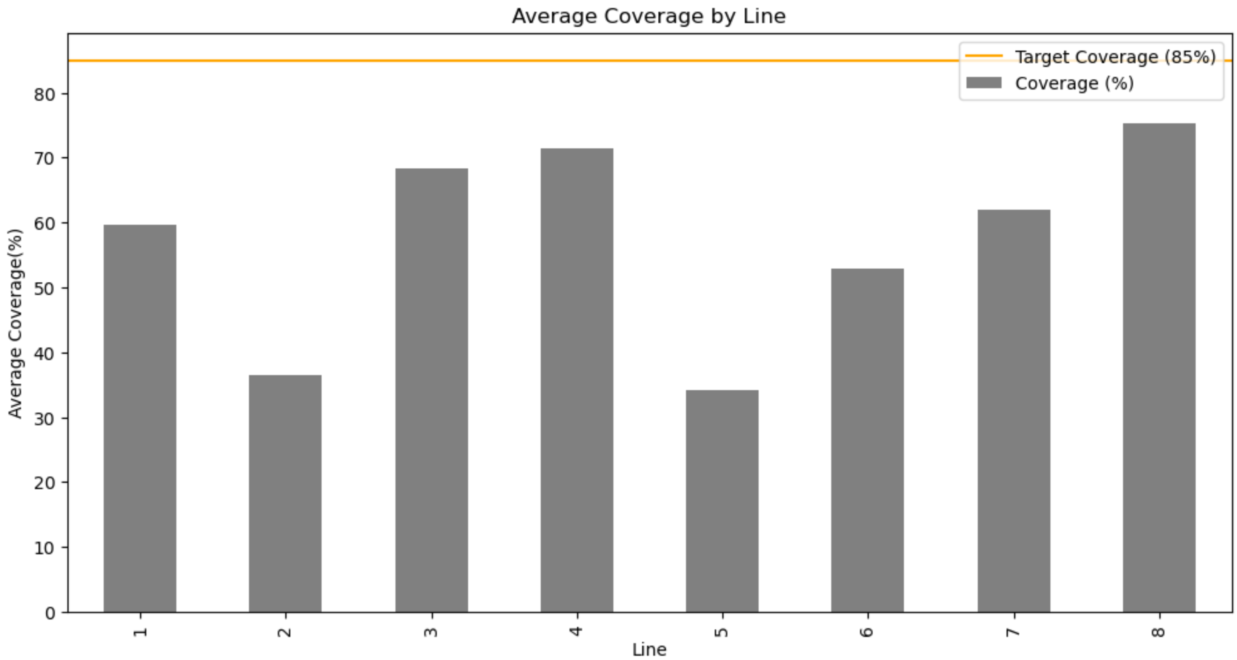

Figure 6. Bar graph showing the average percentage coverage of water misting nozzles across different lines.

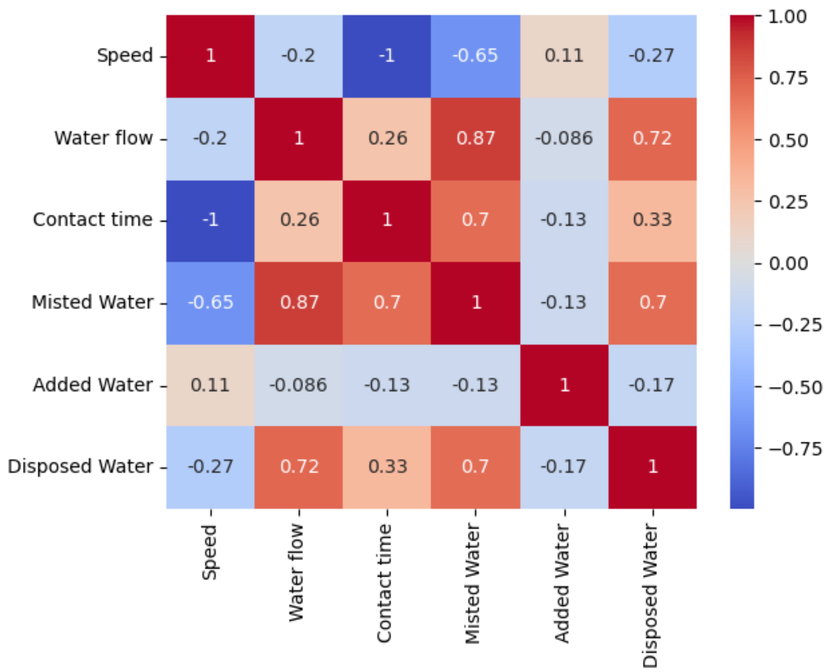

Figure 7. Correlation matrix showing the process features that affect the final product and their interaction/correlation.

Tables:

Table 1. Problem Source Identification Matrix in Production Process.

	People-related	Process-related	Equipment/Machine-related	Desing-related
Receiving	×		×	
Combo Dumper	×		×	
Transfer Points	×	×	×	
Water Misting	×	×	×	
Scale Room	×		×	
End of Production				×

Table 2. Water Coverage Percentage measurement along the lines and the patty formers.

		Former					
		1	2	3	4	5	6
Line	1	51.42%	47.10%	57.53%	68.03%	64.89%	68.00%
	2	33.79%	37.32%	49.96%	27.29%	38.20%	32.16%
	3	53.06%	71.86%	74.44%	79.22%	66.59%	64.49%
	4	54.13%	66.79%	81.81%	83.73%	81.71%	59.98%
	5	7.25%	32.82%	37.59%	21.66%	38.04%	66.67%
	6	53.02%	47.07%	60.73%	77.01%	64.60%	14.52%
	7	30.96%	77.63%	72.97%	77.51%	75.44%	36.54%
	8	87.91%	83.50%	84.16%	40.95%	33.86%	74.81%