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Six Sigma Application in an Irish Meat Processing Plant to improve process yields

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Abstract

Purpose: This study aims to utilise Six Sigma in an Irish-based red meat processor to reduce process variability and improve yields.

Design/Methodology/Approach: This is a case study within an Irish meat processor where the structured Define, Measure, Analyse, Improve and Control methodology was utilised along with statistical analysis to highlight areas of the meat boning process to improve.

Findings: The project led to using Six Sigma to identify and measure areas of process variation. This resulted in eliminating over-trimming of meat cuts, improving process capabilities, increasing revenue, and reducing meat wastage. In addition, key performance indicators and control charts, meat-cutting templates and smart cutting lasers were implemented.

Research limitations/implications: The study is one of Irish meat processors' first Six Sigma applications. The wider food and meat processing industries can leverage the learnings to understand, measure and minimise variation to enhance revenue.

Practical implications: Organisations can use this study to understand the benefits of adopting Six Sigma, particularly in the food industry and how measuring process variation can affect quality.

Originality/value: This is the first practical case study on Six Sigma deployment in an Irish meat processor, and the study can be used to benchmark how Six Sigma tools can aid in understanding variation, thus benefiting key performance metrics.

Keywords : Agri-Food Industry; Six Sigma; primal yields; Meat processing

1. Introduction

As the global population is in an explosion of growth, there is a heavy focus on food production to achieve zero hunger (Giller et al., 2021). According to the United Nations (2019), the world's population is expected to hit 9.7 billion by 2050. The global challenge is to feed the growing population, prioritising agriculture to be more sustainable and efficient (Pawlak and Kołodziejczak, 2020). Organisations in the food industry trade with powerful retailers that require a wide range of specific products to meet customer requirements. The meat industry, in particular as part of the food industry, is recognised as one of the biggest polluters in the food industry(Djekic *et al.*, 2016).

Through implementing continuous improvement (CI) initiatives, the industry is assisted in managing global and local market challenges. The benefits of Six Sigma or synergy of both (LSS) for continuous improvement have been studied across various industries, for example, the automotive (manufacturing), healthcare and construction industries (Aziz and Hafez, 2013; Gonzalez and Martins, 2016; McDermott, Antony, Bhat, *et al.*, 2022). However, there is a shortfall of literature on implementing Six Sigma in the food industry (Maalouf and Zaduminska, 2019; Azalanzazllay *et al.*, 2020). There is even less literature within the meat processing industry, but Costa et al. (2018) have highlighted an increase in studies in this area. It has been suggested that introducing continuous improvement methodologies in the food processing industry is lower than elsewhere due to the conservative food industry (Lim and Antony, 2019). According to Azalanzazllay *et al.* (2020, the key obstacles are resistance to change and industry-specific characteristics such as compliance with strict food regulations, compulsory cleaning activities and frequent changeover of different products on production lines. Specifically, Six Sigma and its statistical tools have been of advantage to the industry as reducing variation and ensuring process capability for specification has aided the food industry in avoiding being fined for underweight packaging or underfilling of customer items while avoiding overfilling prevents excess stock na inventory and protects revenue (Ahmed, 2021; Dora and Gellynck, 2015; Lim and Antony, 2019). This research takes place within the boning hall of a red meat processing plant. The plant has issues maintaining a controlled and capable process yield and avoiding variability resulting in not meeting customer requirements. The processing plant is growing rapidly due to rapid growth in meat processing. However, this sector is considered one of the largest contributors of pollutants within the food industry, generating much wastewater (via cleaning agents, livestock blood, manure and dirt) as well as solid waste (head, legs, fat, hairs, offal and skin) and consumes excessive energy (cooling treatments and heat)(Djekic *et al.*, 2016). Many different air pollutants (sulfur oxides, nitrogen oxides and carbon dioxides) are produced in meat processing facilities due to excessive utilisation of raw materials and ineffective waste control systems (Roy *et al.*, 2012). Thus there was a need for this study to aid the boning hall in the reduction of both process wastes and aid reduction of environmental wastes. Six Sigma was selected for this study as it can aid in reducing variation and has shown to be successful in reducing variation. The study's research objectives (RO’s) are

RO1: Deploy Six Sigma methods to improve primal yields to meet customer requirements, obtain financial gains, and reduce environmental waste.

RO2: Establish the sources of variation and where variation can be reduced

Section 2 outlines the literature review, Section 3 the methodology deployed, and sections 4 and 5 contain the results and discussion. Finally, the conclusion is outlined in Section 6.

2. **Literature Review**

2.1 Six Sigma in the Food Industry

For years, food product and production variability have challenged food technologists (Lim *et al.*, 2014). To overcome this, the food industry has utilised Six Sigma statistical tools to help understand process variability and capability. However, the uptake of Six Sigma and its associated statistical tools has been low. Costa *et al.* (2018), in a systematic literature review (SLR) on Lean, Six Sigma and Lean Six Sigma in the food industry, found that while 74% of the studies reviews related to Lean implementation in the food industry, only 16% of studies were related to Six Sigma implementation and its associated statistical tools. Lim *et al.* (2014), in their SLR study on Statistical Process Control (SPC) in the food industry, found that reduced process variability and conformance to the food regulations were the biggest motivations for the implementation of statistical tools but resistance to accepting statistical methods were the most cited challenge. The literature consistently advocated that the key benefits of implementing continuous improvement methods in the food industry are improved food safety and reduced process variation. However, other studies on the Six Sigma application in the food industry have discussed cost reduction as the biggest driver, but as variability in the process drives cost, there is a correlation here between cost and variation (Jain and Lyons, 2009).

There are examples of Six Sigma applications in food processing and manufacturing industries to reduce variation in the process. Indian food processing industries have used Six Sigma to reduce the variation in weights of milk powder pouches and reduce line rejections by 50% (Desai et al., 2015). DMAIC was similarly applied in a yoghurt production process to improve the process by optimising the settings(Hakimi et al., 2018). A case study of a Norwegian Dairy producer focused on how Six Sigma improved environmental sustainability in the industry by implementing Statistical Process Control (SPC) to aid in removing wasted raw materials and energy usage (Powell et al., 2017). Dora and Gellynck (2015) proposed a problem-solving framework utilising DMAIC to reduce the overfill of gingerbread in a food processing SME to reduce rework to enhance the revenue.

2.2 Benefits and Barriers to Six Sigma in the food industry

The barriers to Six Sigma deployment in the food industry are not dissimilar from other industries. Challenges can vary from employees' lack of statistical knowledge, lack of management support, lack of an improvement culture, and training in improvement tools(Lim *et al.*, 2014). The main barriers found by Costa et al. (2018) to Six Sigma in the food industry seem to be human-related, with the food industry characteristics as the second most faced barrier. The food industry is unique because of the short shelf-life of food, diverse raw materials, food seasonality, varied harvesting conditions, and a complicated supply chain (Luning and Marcelis, 2007). These factors can strongly affect storage, conditioning, processing, packaging, and quality control, making implementing continuous improvement methodologies more challenging (Dora *et al.*, 2013). Costa et al. (2018) highlighted specific characteristics of the food industry, including demand uncertainty, high cleaning times, high set-up times, traditional layouts, food perishability and seasonality, processing sequencing dependence and variation in raw materials quality and supply that can be barriers for continuous improvement programs.

However, the benefits of Six Sigma deployment have aided the food industry in particular by reducing scrap, rework and machine downtime (Knowles *et al.*, 2004), preventing product overfill and unnecessary in-process weighing scale or machines rejections (Grigg *et al.*, 1998), enhance quality in HACCP system(Dalgiç *et al.*, 2011). In addition, from an organisational point of view, benefits have been improved teamwork, a sense of responsibility, and increased training through involvement in problem-solving (Costa *et al.*, 2020).

2.3 Six Sigma tool application in the food industry

Using quality and improvement tools is a critical success factor for any improvement program (McDermott, Antony and Sony, 2022). However, within the food industry, the use of process improvement, Lean, Six Sigma and quality tools are not widespread, according to Costa et al. (2018). They found that the most commonly used tools and methods highlighted had a % usage of less than 10% each and were value stream mapping (8%), cause and effect diagram (7%), 5S (6%), brainstorming (6%), DMAIC (6%), Pareto chart (5%), process mapping (5%), control charts (4%), visual management (4%). Similarly, Abdulrahman Alsaleh (2007) found more simple quality tools, including Pareto charts, flow diagrams and cause-and-effect diagrams, as moderately utilised in their study on the Saudi food industry. Three of the aforementioned tools are considered part of Ishikawa's seven basic quality tools (cause and effect, Pareto chart, and control charts) and deemed sufficient to solve 95% of any manufacturer's quality problems(Antony, McDermott and Sony, 2021). Many of these tools would be considered "basic" process improvement tools, i.e. they are simple to use and do not require any advanced training (Antony, McDermott, Sony, *et al.*, 2021). These tools would be widely utilised in other industries and not just the food industry, so the food industry is not alone in its usage of these more basic tools (Albliwi *et al.*, 2015), but their usage would not be as high as demonstrated in other industries ((McDermott, Antony, Sony and Daly, 2022; McDermott, Antony, Sony and Healy, 2022; McDermott, Antony, Sony, Rosa, *et al.*, 2022). The low tool usage is correlated with the findings of several studies across the global food industry demonstrating low take-up of continuous improvement methods (Costa *et al.*, 2018, 2020; Manzouri *et al.*, 2013).

Some examples of Six Sigma applications in the food industry are in Table 1.

Table 1: Six Sigma Application in the Food Industry (Source: Authors own)

Articles	Food industry area	Six Sigma tools used	Benefits
(Grigg *et al.*, 1998)	Fish	X bar chart R chart	Reduced variation/product giveaway
(Rai, 2008)	Tea	CUMSUM X bar chart	Reduced variation in overfilling and underfilling

(Özdemir and Özilgen, 1997)	Nuts	P charts DOE	Fixed damaged nuts in the process
(Maheshwar, 2012)	Food production	DMAIC Cpk	Improve equipment effectiveness
(Knowles *et al.*, 2004)	Sweet/confectioner	Cpk SPC	Reduced rework and defects

2.4 Industry 4.0 & Six Sigma in the Food industry

The food industry has not embraced automation and has been slow to adapt to robots despite their possibilities in the food chain (Grobbelaar et al., 2021). However, many traditional dairy systems are transitioning to robots and automation and are expected to embrace smart technology and Industry 4.0 digitisation (Grobbelaar *et al.*, 2021; Noor Hasnan and Yusoff, 2018). Industry 4.0 technologies enable data linkages and analysis across the food supply chain, enhancing business models, providing new production processes, and promoting innovations(Wan *et al.*, 2008). Furthermore, the food industry workforce, particularly meat processing, is dominated by hands-on skills and physical tasks on the production floor, thus lending itself to automation and smart processes (Erol *et al.*, 2016). In addition, industrial processing systems, lasers, and robots are becoming smart, able to "see" and react to different situations based on clearly defined parameters (Noor Hasnan and Yusoff, 2018).

Red meat manufacturing is an area where digitalisation and automation have not been thoroughly explored. However, processes such as cutting, deboning, and shredding meats such as beef, lamb, pork, and poultry, which were completely dependent on the manual skills of the workforce, can now be carried out using robots and automation (Echegaray *et al.*, 2022). While there are limited studies on Six Sigma and Industry 4.0, the literature discusses the benefits of combining Industry 4.0 technologies with Six Sigma problem-solving (Dogan and Gurcan, 2018; Sodhi, 2020). In addition, industry 4.0 data analytics and data mining tools can aid statistical analysis and DMAIC problem-solving to aid improvements (Antony, Douglas, McDermott, *et al.*, 2021). Thus Industry 4.0 has both a synergistic and symbiotic effect for continuous improvement programs as Industry 4.0 technologies enhance improvements while having an in-control capable process eases technology implementation (Antony *et al.*, 2022).

2.5 Conclusion

The literature research has demonstrated that while Six Sigma methodology applications are proven within the food industry that there is still a dearth of Six Sigma application therein. The studies where Six Sigma tools have been deployed within the food industry have shown benefits in reduction of in process variation and in improving process capability. Thus the literature demonstrates proven application of Six Sigma methods to aid in meeting the research objectives to improve yields in line with customer requirements and establish sources of variation in the case study organisation.

3. Research Methodology

The case study organisation where this research was undertaken was within the boning hall of a red meat processing plant based in Ireland. This project utilised a Six Sigma framework, with its DMAIC approach to problem-solving with statistical Six Sigma tools and techniques.

Six Sigma and the structured DMAIC process was the chosen approach as the issues needed structured problem solving and analysis of variation to enhance the primal yields within this boning facility to meet customer specifications better. In addition, six Sigma aids in finding and eliminating causes of defects and variability in processes by focusing on outputs critical to customers (Snee and Hoerl, 2002).

3.1 Define

Step one in the problem-solving approach is to scope the problem statement and gather the voice of the organisation and customer. The team captured the problem statement as a project charter in this case. The problem statement was defined as *variability in the cutting and boning process was leading to loss of revenue and product not meeting customer expectations.*

Identifying the critical-to-quality (CTQ) processes through the voice of the customer (VOC) was pivotal for capturing customer expectations. The process's lower spec limits (LSL) and upper spec limits (USL) needed to be clear to establish if the boning hall could meet the customer's requirements. A stakeholder analysis was conducted where the goals and objectives of the project were supported by the stakeholders, those who were either impacted by the project or who may have influenced the project (Taghizadegan, 2013). To assist the wider team in the define phase and understanding the process flow, an operational assessment was performed using a high-level process map, Suppliers Inputs Process Output Customers Diagram (SIPOC)(Figure 1). The process map helped the team Visualising the measures that would improve the customer's need and viewpoint.

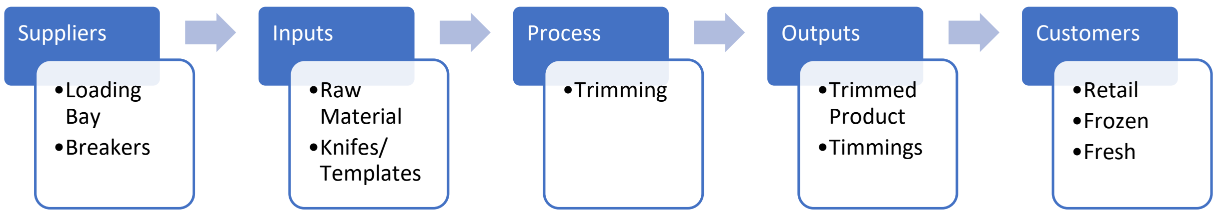


Figure 1: SIPOC Diagram (Source: Authors own)

3.2 Measure

An important step within the measure phase and following from the SIPOC was a process map to help the team visualise the process and identify where data could be collected; this was an important first stage of the data collection plan. The process map is demonstrated in Figure 2.

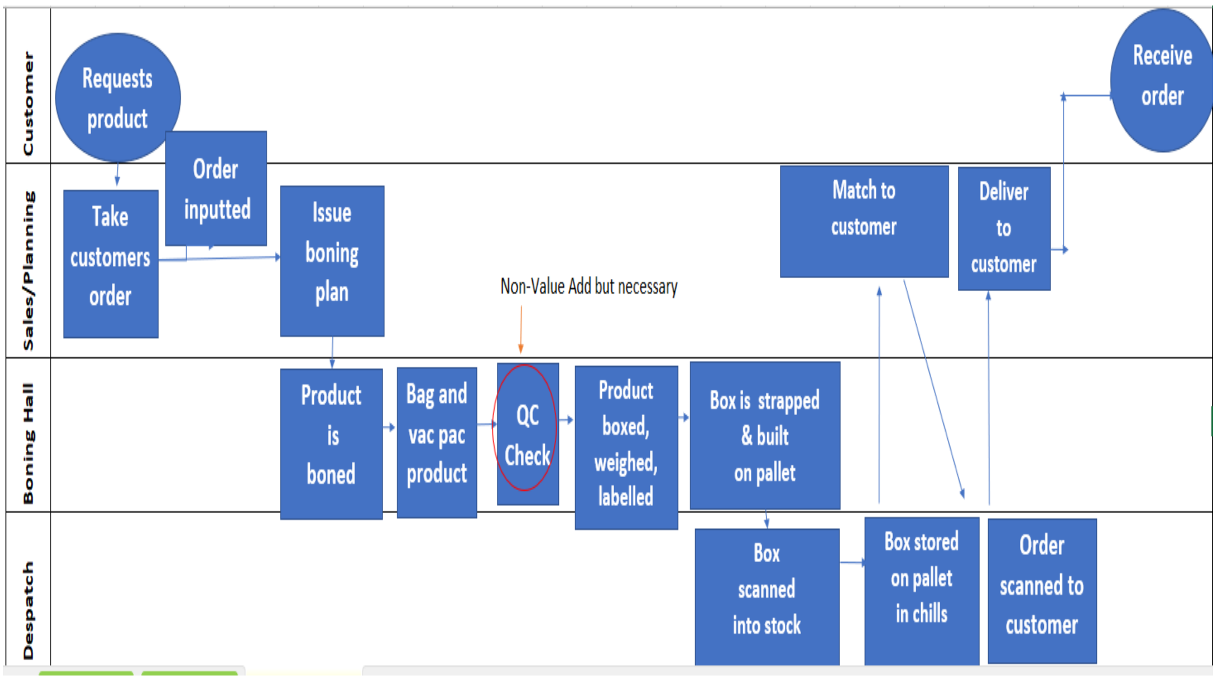


Figure 2: Process Map of Meat Processing Line(Source: Authors own)

Next, the team measured the current state upon identifying the data types and forms to collect. This involved the team taking physical measurements of the different red meat cuts for the different customer specifications of different meats.

The measurement tool used was a detectable metal ruler. A breakdown of the measurements taken is shown in Table 2.

Table 2: Breakdown of Primal Measurements Collected (Source: Authors own)

Primal	No. of Customer Specs Measured	No. Primal Measured per Spec	No. of Measurements taken per Primal	Total Measurements Collected
gluteus medius Tail	4	25	4	400
longissimus dorsi Tail	4	25	5	500
longissimus dorsi Backstrap	4	25	4	400

Following the measurement analysis a Cause and Effect diagram was utilised as part of the transition from Measure into Analysis to ascertain why over trimming or measurements were out of specification. This analysis highlighted variation in the cutting process in in relation to the methods used, the personnel employed, and the equipment utilised.

3.3 Analyse

The analysis phase consisted of Six Sigma tools, including basic statistical analysis. Next, the researcher applied statistical tools in worksheets and the statistical software JMP Version 15.2.0 to analyse baseline data. The data was stored/collected in worksheet format; therefore, the researcher ran a basic analysis in the early stages, which included determining the average, max and min results for the different products under each customer specification. The researcher then extended the analysis of baseline data to JMP, where tools applied included basic distribution analysis, process capability and histogram charts. The process capability index Cpk has been widely used in manufacturing industry to provide numerical measures of process potential and performance (Pearn, 1998). Practitioners use Cpk to determine whether a process is meeting its specifications in terms of its upper and lower limits and if a process is in control. From analysis of Cpk decision can be made about altering the process or its parameters.

After statistical analysis and brainstorming through the fishbone exercise, the team evaluated each primal under the following conditions: Was waste generated? Is the process adding value/non-value adding?

3.4 Improve

The team considered the root cause analysis and drew countermeasures to improve the process. Each countermeasure went under appraisal for cost, percentage impact, the effort to implement and overall rating. During the improvement phase, the team ran further analysis after implementing countermeasures to determine if improvements were achieved before proceeding to the control phase. This involved re-measuring the primal cuts under the same specifications. Variability analysis in the form of a Gauge R&R was performed in JMP to compare the baseline and post-improvement measurements for improvements implemented.

3.5 Control

The primary objective of the control phase was to ensure that the improvements obtained from the improvement phase were maintained after the project was completed (Singh and Khanduja, 2014). As part of the control phase and understanding its importance in preventing the problem from recurring, the team established a daily check sheet, key performance indicator scorecards (KPI) and control charts (Figure 4). The check sheets and control charts allowed the production team to record/track a specified number of measurements daily at different time intervals. This assisted the production teams at daily meetings in identifying if the process was stable and in control and if the improvements were being sustained.

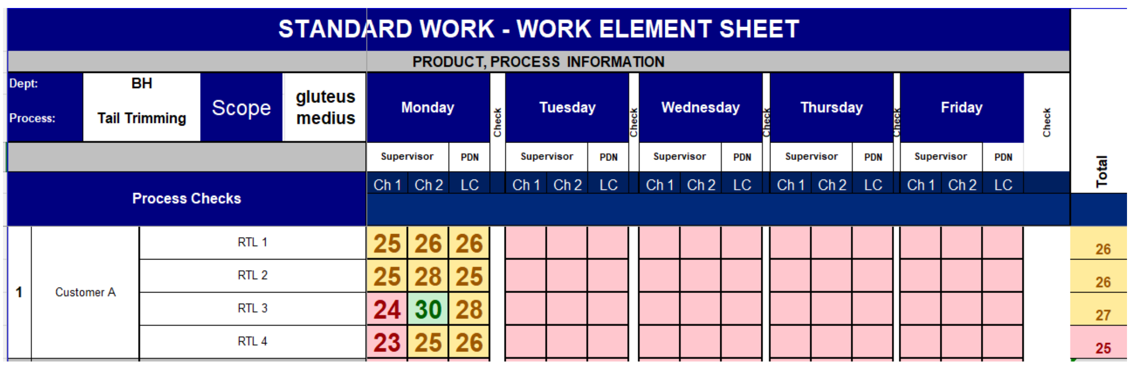


Figure 4: Daily KPI scorecards (Source: Authors own)

4. Results

The results focused on comparing baseline analysis with measurements taken post-countermeasure implementation. Therefore, results for a selection of customers (A-E) are used in the findings (baseline and post-process improvement measurements). However, the customer selection may vary between primal cut (longissimus dorsi and gluteus medius).

4.1 Baseline Analysis

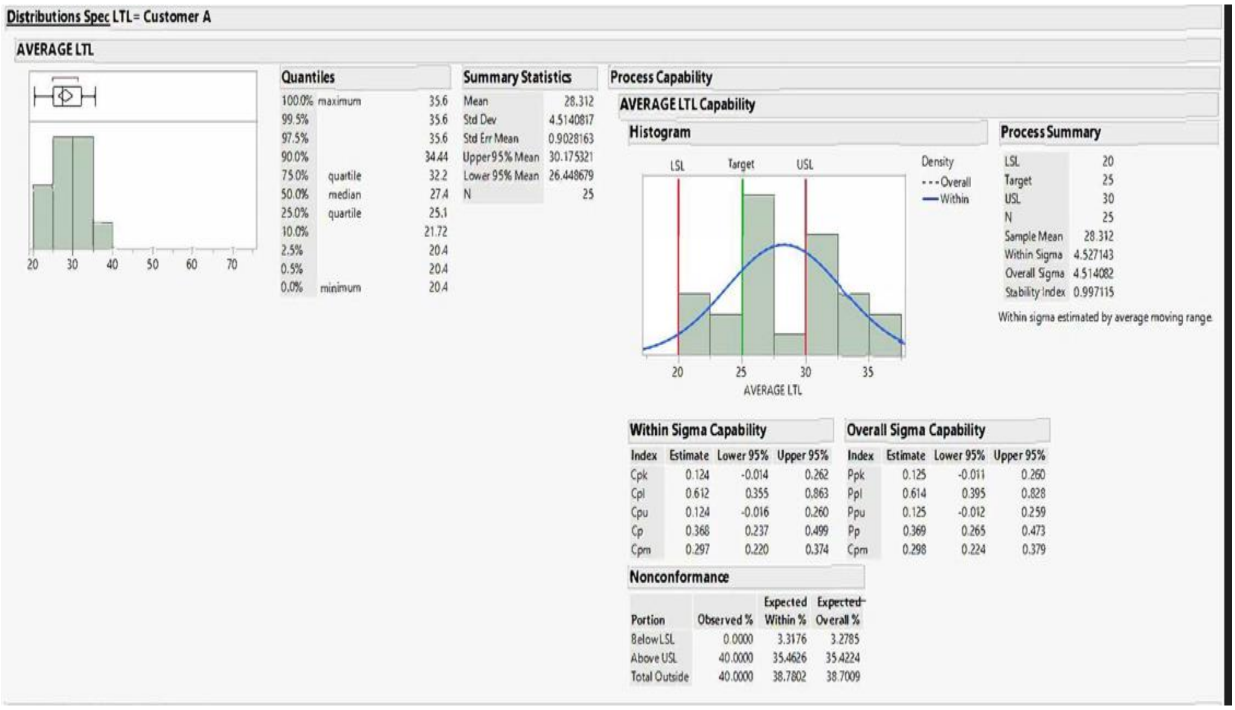
Customer baseline primal measurements were taken for all meat cuts. For example, as per table 2 in gluteus medius tail, 4 different customer specifications were measured, with 25 primal samples measured more spec and 4 measurements taken per primal, giving a total of 400 measurements collected. A subsequent 500 and 400 measures were collected for the longissimus tail and Backstrap, respectively.

On average, there was 6 mm over trimming on gluteus medius (per gluteus medius). Therefore, the trim would be left on the gluteus medius by preventing over-trimming, and a greater value would be obtained for the product. For example, where over-trimming does not occur i.e. in customer A for example, the organisation make €7.75/kg, whereas when trimmed, the trimming goes for visual lean (VL), which is of lesser value at €5.50/kg.

From baseline analysis of the longissimus dorsi tails (Figure 5), it was clear that Customer E was the most significant spec in over-trimming, where this product was over-trimmed by almost half the spec requirements.

Figure 5: Basic Distribution and Process Capability Analysis Spec E of the longissimus dorsi tails (Source: Authors own)

Instead, for all other specs/customers (Figure 6), the organisation was "under-processing", i.e. leaving more Backstrap on the product than the spec stated. As the organisation has, on average, left 5mm more Backstrap on the product than the specs required, no value was lost on the product (i.e. the Backstrap left on the meat cut was worth more than if removed). There were also no customer complaints regarding the volume of backstraps left on the products, so the organisation decided not to pursue this aspect of the project.



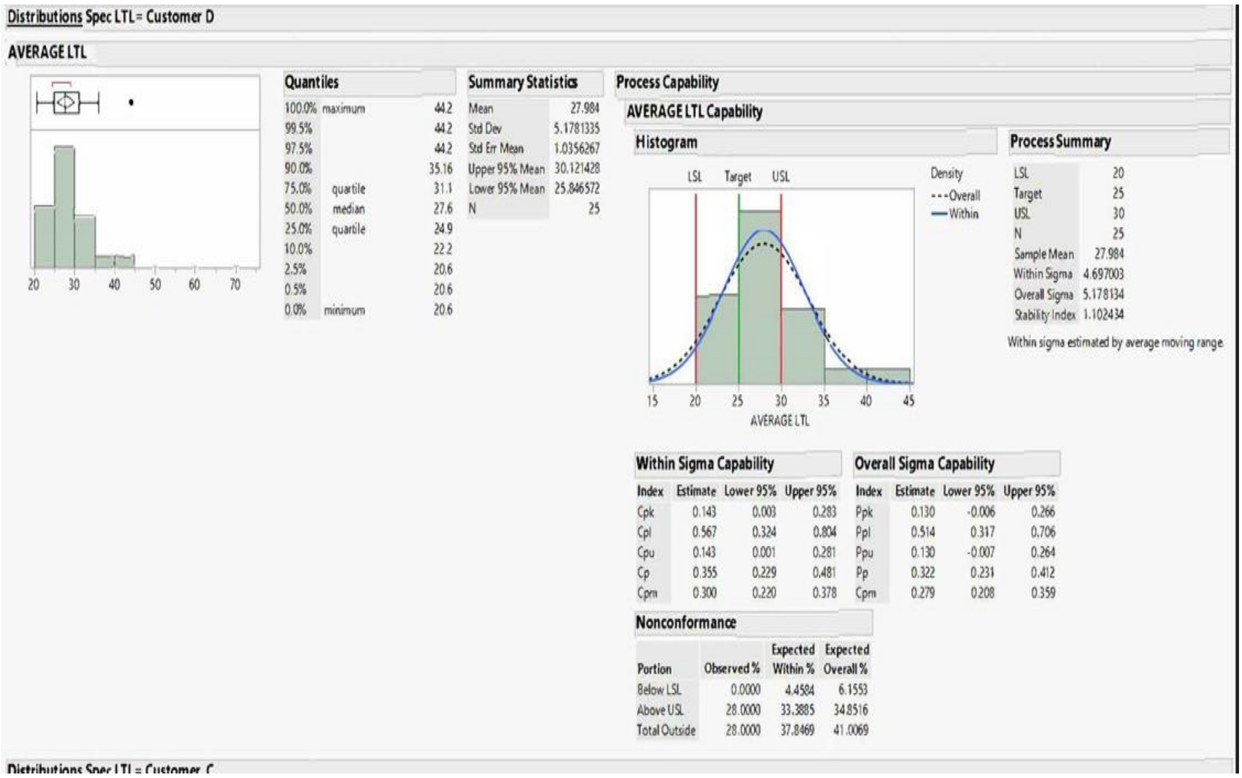


Figure 6: Basic Distribution and Process Capability Analysis of Customer A and D specs of the longissimus dorsi tails (Source: Authors own)

Customer A & D were not over-trimmed; instead, for these specs, on average, 3mm more than the spec stated was left on each longissimus dorsi. As mentioned previously the organisation makes more profit per kg when over trimming does not take place. Depending on the spec and cut of the meat some cuts were more prone to over trimming.

On average, across all specs, it was calculated that over-trimming was occurring at 11mm. Therefore, if over-trimming were resolved, the organisation would get €15.00/kg for the product left on the longissimus dorsi compared to the trimmed product being downgraded to the flank where the organisation was only getting €3.10/kg.

In summary, the results from the measure phase showed that in the baseline measurements, over-trimming was occurring in both gluteus medius and longissimus dorsi backstraps, while under-processing was occurring in longissimus tails. Thus as mentioned previously, the team decided not to pursue the under-processing or under-trimming aspect of the project and instead focus on the instances of over-trimming. The Six Sigma value for the longissimus dorsi backstraps process was 6.9, significantly greater than the other results observed for the other cuts justifying the focus on the other cuts. The JMP results suggest that the processes for gluteus medius tails and longissimus dorsi tails must be more capable and stable.

Table 3 outlines the results of the process capability analysis carried out on the 3 cuts of meat, thus aiding the decision to focus on the aforementioned two meat cuts.

Table 3: Results of Process Capability Analysis of Meat cutting processes (Source: Authors own)

Meat cut/customer type	**Process Capability analysis results**
gluteus medius tails	The process is not capable (Cpk <1.3)
A	Outlier observed A customer specification – however, it was the most conforming specification, with only 16% non-conforming in the USL
B	non-conforming at both the upper and lower specification limits
C	non-conforming at the lower specification limit at 84 and 88%, respectively
D	non-conforming at the lower specification limit at 84 and 88%, respectively
E	20% outside specifications

Longissimus dorsi backstrap	Process Capability Analysis
A	Outliers - 100% non-conforming with the specification requirements
B	Non-conforming
C	20% were non-conforming within the specifications left skewed of the target (i.e. the non-conforming longissimus dorsi were found towards the lower limit (LSL)
D	Outliers -present Non-conforming
E	20% were non-conforming within the specifications -Right skewed of the target (i.e. that non-conforming were found towards the upper specification limit (USL))
Longissimus dorsi tails	**Process Capability Analysis**
A	Customers A & D were most capable with greater Cpk and Ppk values
B	Capable: limited over trimming
C	100% non-conforming, where the results fell largely below the lower specification limit. No over-trimming
D	Customers A & D were most capable with greater Cpk and Ppk values
E	over-trimmed by almost half the spec requirements

4.2 Actions taken

A fishbone diagram was used to generate countermeasures and perform root cause analysis (RCA) on overprocessing and over-trimming.

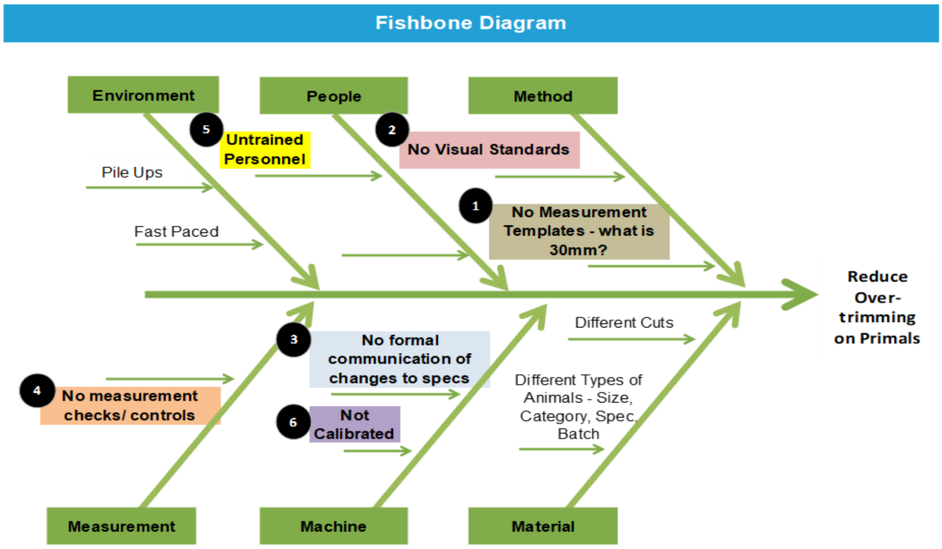


Figure 3: Cause & Effect (Fishbone) Diagram (Source: Authors own)

Countermeasures established through the RCA were initially appraised and then assigned responsibility with due dates for implementation (**Error! Reference source not found.**).

As per the literature on decision making and criteria decision making, the criteria or countermeasures selected were measured on measurable attributes (ASQ, 2023). In this case, these criteria were the cost in euros of the solution, the % impact the solution would have on the issues, and the amount of time/effort required to deliver the solution and resources for the solution implementation. Thus Cost, Impact and Effort criteria were the countermeasure factors used to assess the proposed actions best. All options were costed with the Finance and Engineering team, and the length of time proposed to achieve the action estimated and the difficulty with impacting the proposed solution were voted on based on input from stakeholders.

Table 1 Countermeasure Appraisals(Source: Authors own)

Actions for Reducing Over-trimming of Primals		**Countermeasure Appraisals**			
		Low (√); Medium (-); High (X)	Low (√); Medium (-); High (X)	Low (√); Medium (-); High (X)	Good = √ Bad = X
No.	**Countermeasure**	**Cost (€)**	**% Impact**	**Effort**	**Overall Rating**
1	Implement Templates - e.g. 30 mm block	-	X	√	√

2	Implement Visual Standards - (Customer C longissimus dorsi = 40mm tail)	√	X	√	√
3	Communicate Changes in Spec -	√	X	√	√
4	Implement Measurement Checks / Control	√	X	√	√
5	Train Untrained Personnel on Specs	√	-	√	X
6	Calibrate Machine	√	√	√	X

Poke Yoke and brainstorming were utilised to identify and implement templates and plastic cutting blocks to prevent over-cutting meat cuts (Figure 7).

Figure 7: Examples of Poke Yoke measures (Source: Authors own image)

While the templates were adequate, they took up space on the work surface. As a result, the templates were modified and identified by the size and chained to the workstations in a more ergonomic location so that they could not go missing or become a foreign body concern. In designing the blocks and templates, specific material was used to withstand the washdown at the end of the day. The templates successfully defined the normal state for operators, making it easy for them to identify if anything was deviating from normal visually.

A key learning from this study was the importance of Key performance indicators (KPI) and scorecards. Unfortunately, KPIs for primal yields were not recorded before commencing this project. However, the use of KPIs aided in the monitoring of performance and highlighting potential improvement opportunities.

The control charts successfully ensured the operatives were using the templates and meeting the specification requirements; however, the check sheets and control charts only reflected a percentage of the day's production.

As part of the DMAIC process, more automated, smart and technological solutions were also investigated to aid the operators. Lasers were subsequently implemented to identify and record the tail measurements, allowing the organisation to populate a "live" control chart. In the case of this study, the customer specification limits are the “target”, and the tail measurements are the KPI metric being measured/displayed on a live control chart for the operator to observe. In addition, the organisation operated a smart boning system linked with the lasers to identify what specification each product should be. The same lasers will demonstrate to the operative where the recommended trimming line will be and will replace the templates. As shown by the operators, the lasers are shown in Figure 8.

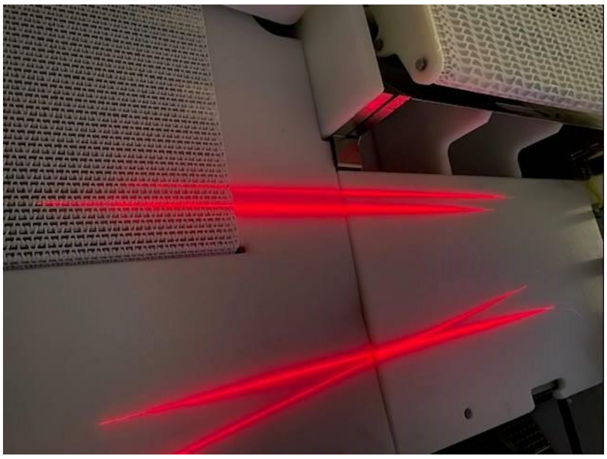


Figure 8: Laser Cutting Blocks (Source: Authors own image)

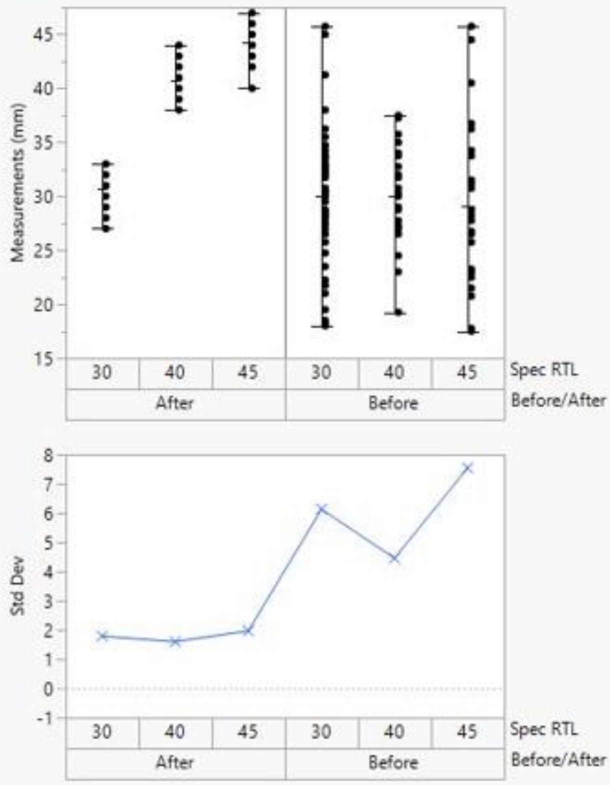
4.3 Countermeasure Analysis

After implementing countermeasures, the team assessed the collected data to reflect the "after" phase. This variability and Gage R&R analysis were solely conducted in JMP. **Error! Reference source not found.** and **Error! Reference source not found.** are the before vs after data comparisons in JMP. Observing the gluteus medius tails variability chart (**Error! Reference source not found.**), it was clear that there is less variance after implementation across all specifications, making the results much more compact.

The longissimus dorsi tails variability chart (**Error! Reference source not found.**) indicates that the 25mm spec is less variable after implementation. The 40mm spec is more variable – it was closer to the target after implementation, whereas the before results were closer to the LSL. The 100mm spec was similar in variance but more off-target than the before measurements. It was likely that the 100mm spec was more off-target due to the batch of animals selected for the after-measurements. In addition, a 100mm tail was difficult to achieve, as it would often be <100mm without any trimming, making it a difficult target.

Variability Gauge

Variability Chart for Measurements (mm)



Gauge R&R

Measurement Source		Variation (6*StdDev)		which is 6*sqrt of
Repeatability	(EV)	27.093162	Equipment Variation	V(Within)
Reproducibility	(AV)	27.923031	Appraiser Variation	V(Before/After) + V(Before/After*Spec RTL)
Before/After		19.843627		V(Before/After)
Before/After*Spec RTL		19.645002		V(Before/After*Spec RTL)
Gauge R&R	(RR)	38.906749	Measurement Variation	V(Within) + V(Before/After) + V(Before/After*Spec RTL)
Part Variation	(PV)	13.589063	Part Variation	V(Spec RTL)
Total Variation	(TV)	41.211621	Total Variation	V(Within) + V(Before/After) + V(Before/After*Spec RTL) + V(Spec RTL)

6 k

94.4072 % Gauge R&R = 100*(RR/TV)

2.86309 Precision to Part Variation = RR/PV

0 Number of Distinct Categories = 1.41*(PV/RR)

Using last column 'Spec RTL' for Part.

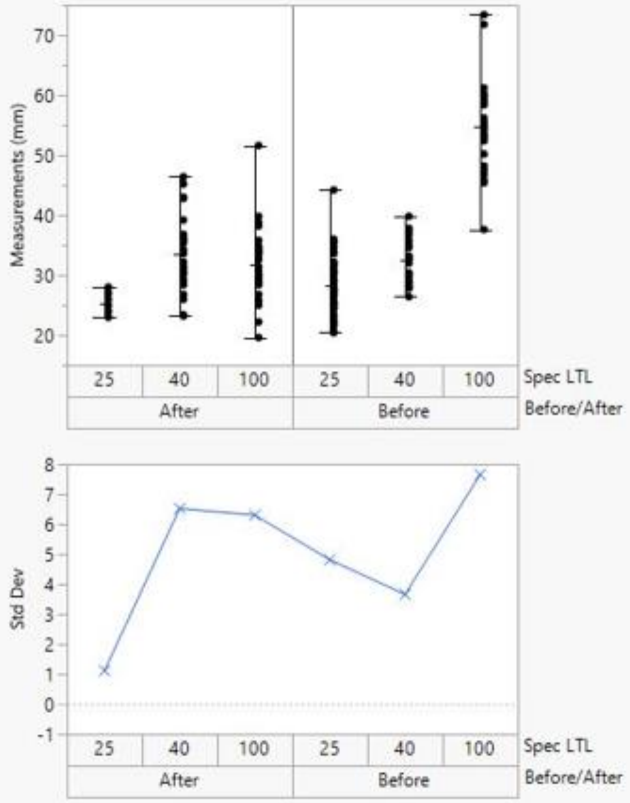
Variance Components for Gauge R&R

Component	Var Component	% of Total	20 40 60 80
Gauge R&R	42.048197	89.13	
Repeatability	20.389984	43.22	
Reproducibility	21.658213	45.91	
Part-to-Part	5.129517	10.87	

Figure 9 Gage R&R on Baseline vs Post Process Improvement – gluteus medius tails (Source: Authors own)

Variability Gauge

Variability Chart for Measurements (mm)



Gauge R&R

Measurement Source		Variation (6*StdDev)		which is 6*sqrt of
Repeatability	(EV)	30.263046	Equipment Variation	V(Within)
Reproducibility	(AV)	56.304068	Appraiser Variation	V(Before/After) + V(Before/After*Spec LTL)
Before/After		14.977328		V(Before/After)
Before/After*Spec LTL		54.275480		V(Before/After*Spec LTL)
Gauge R&R	(RR)	63.921828	Measurement Variation	V(Within) + V(Before/After) + V(Before/After*Spec LTL)
Part Variation	(PV)	32.274571	Part Variation	V(Spec LTL)
Total Variation	(TV)	71.607597	Total Variation	V(Within) + V(Before/After) + V(Before/After*Spec LTL) + V(Spec LTL)

6 k

89.2668 % Gauge R&R = 100*(RR/TV)

1.98056 Precision to Part Variation = RR/PV

0 Number of Distinct Categories = 1.41*(PV/RR)

Using last column 'Spec LTL' for Part.

Variance Components for Gauge R&R

Component	Var Component	% of Total	20 40 60 80
Gauge R&R	113.50000	79.69	
Repeatability	25.44033	17.86	
Reproducibility	88.05967	61.82	
Part-to-Part	28.93466	20.31	

Figure 10 Gage R&R on Baseline vs Post Process Improvement - longissimus dorsi tails(Source: Authors own)

4.4 Cost Savings Analysis

Cost savings on the improvements sustained were calculated, and the breakdown of the calculations may be seen in Table 5 to Table 7. The team first identified the calculated savings as the value lost by over-trimming; this was calculated by taking the value of the trim when left on the product/primal and comparing it with the value got for the trim; this was done for both the gluteus medius and longissimus dorsi (table 5 and 6).

Table 5 Value of Product vs Trim *(Source: Authors own)*

	gluteus medius tails	**longissimus dorsi tails**
Value on Product (€)	7.75	15.00
Value of Trim (€)	5.50	3.10
Value Lost (per kg)	2.25	11.90

Table 6: Value lost per cut on overprocessing (“Over-trimming”)*(Source: Authors own)*

	Average Over trimming (mm)	**Weight of Over trimming (kgs)**	**Average Value Lost (per cut) €**
gluteus medius tails	7	0.35	0.79
longissimus dorsi tails	12	0.38	4.52

The overall savings are calculated via the average yearly kill figure (89,490 animals) to determine the projected production volume savings for the project (table 7). The average over-trim measurement for longissimus dorsi in Table 7 did not include the Customer E results, where the specification was 100mm. This product was seasonal and was discontinued following collection of the after measurements. Therefore the boning hall manager felt it was not considered an accurate representation of the savings projected for the year ahead. As well as a total savings per year of over € 350,000, there was a meat waste reduction of approximately 130,655kgs of trimmings /per year.

Table 7 Yearly Savings from the elimination of over-trimming*(Source: Authors own)*

	Volume Produced	**Trimmings Saved (kgs) - by eliminating over trimming**	**Savings per Year €**
gluteus medius	178980	62643	€ 49,331.36
longissimus dorsi	178980	68012	€ 307,552.07
			€ 356,883.44

5. Discussion

The statistical analysis and data collection aided the team in identifying where over-processing was occurring. By implementing the various countermeasures, specifically the standard templates, the team reduced the incidences of over-trimming and saved the organisation €356,883.44 per annum. Therefore, the project successfully addressed the research objective of the study to improve primal yields to meet customer requirements and obtain financial gains. Costa et al. (2018) state that the main drivers of applying Six Sigma in the food industry are cost reduction and variation reduction, and this study demonstrates this.

The study's hypothesis was to apply DMAIC as the methodology of choice. However, the statistical analysis was invaluable in establishing what particular meat cuts and processes were incapable and had a high variation and established where over-trimming was taking place and in what meat cuts and customer orders where this was occurring.

KPIs aided performance, helped define targets and goals and aided the operators in highlighting issues and potential improvement opportunities. Similar studies in the food industry -for example, in the Norwegian dairy industry have discussed the necessity of relevant KPIs in aiding improvements(Powell *et al.*, 2017). Without KPIs and control charts, there was no understanding of how each process performed and whether the organisation met customer requirements.

Sustainability and the challenges of feeding a growing population are hot topics for the red meat and agri-food industry (Toldrá *et al.*, 2021). In this case study, the project effectively eliminated 130,655kgs of trimmings which would have otherwise been classified as food waste. Although, as seen in this case study, the application of Six Sigma statistical techniques was necessary to reduce variation and reduce variation and waste, this would have been more difficult to achieve had just a Lean approach been taken.

The application of Industry 4.0 smart lasers and data recording to populate a live control chart demonstrates the benefits of the fourth revolution to continuous improvements. In addition, this study demonstrates a synergistic relationship between Six Sigma and Industry 4.0(Antony *et al.*, 2022). Thus the smart lasers ensure the accuracy of cutting and process capability and reduce variation, while the live control charts aid process monitoring and identifying areas for further improvement.

A limitation of this study is that it is a single case study in one meat processing plant, and thus the results may not be generalisable (Yin, 2016). However, it does demonstrate the application of Six Sigma to reduce costs, improve yield and reduce process wastage. Also, the organisation had one team working on the Six Sigma project and did not utilise Lean then; thus, opportunities for non-value add waste were not identified. It is now planned to complete a plant-wide Lean Six Sigma program to optimise the benefits of Lean with waste reduction and Six Sigma in variation reduction (George, 2002).

6. Conclusion

This study demonstrated how Six Sigma could reduce process variation and enhance revenue while reducing food waste. In addition, this study is one of the first case studies using Six Sigma within Irish meat processors, thus offering opportunities for others to benchmark the learnings and influence the application of Six Sigma within the industry. The structured Define, Measure, Analysis, Improve and Control phases as outlined in this study provided a template for other food manufacturers to follow and employ the methods and tools utilised therein.

Food industry managers will know how variation can be reduced through this study. The findings suggest that the food industry, specifically meat processors industry managers, can adopt DMAIC to understand how organisational problems can be defined, the extent of the problems and specific variations. This will give a full understanding of the root causes of such problems and variations and provide improvement actions that would be used to eliminate or at least reduce the problems. Therefore, research in other sectors and the wider meat processing sector could adopt DMAIC processes and tools to solve organisational problems. Furthermore, training and awareness programs can assist meat processing facilities in enhancing the competencies of their workforce to achieve operational productivity and environmental performance. From a theoretical implication viewpoint, this study furthers the application of the Six Sigma methods in the food industry, thus aiding the understanding of how it can benefit the food sector.

Future steps for this organisation are to implement a Lean Six Sigma program. Applying Lean Six Sigma and green methods will aid the meat processor in becoming more Lean and sustainable. The organisation under study can look at other lines and areas, and products to involve personnel in training and application of Six Sigma and problem-solving, as well as looking at opportunities for further environmental and food waste reduction and costs reduction. Future research will investigate the possibility of incorporating robots with intelligent vision and the ability to multitask to complete red meat butchery tasks. Also, further case study research across the food industry on LSS application is an opportunity. This study can be leveraged across the wider food and meat processing industries to benchmark best practices and demonstrate the benefits of continuous improvement methods.

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