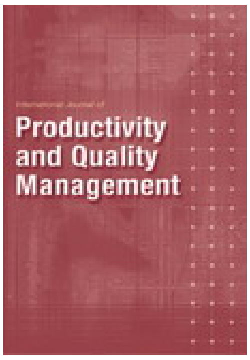

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From scientific research to industrial application: a Lean Six Sigma system for improving the bill of materials of the packaging process

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Abstract: In profit-making organisations like production industries, it is crucial to meet the customer needs while retaining a high profit to cost ratio and continuously improving their operations in order to survive. In this manner, lean philosophy and the Six Sigma approach are considered to be some of the most effective methods in order to achieve continuous improvement and avoid unnecessary expenses. Utilising those practices can lead to an improvement of the process execution and avoidance of errors and defects by determining their root cause, and developing and implementing solutions to correct those problems. Following this philosophy, this paper presents the implementation of the Lean Six Sigma approach via the DMAIC methodology for improving the bill of materials of the packaging process of a copper production company. The results show that the process was greatly improved and a plethora of errors and waste was eliminated.

Keywords: lean; lean production; system; Six Sigma; DMAIC; packing; continuous improvement; process.

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1 Introduction

The concept of continuous improvement (CI) as a strategy and philosophy can be traced back to 2,500 BC when people were building pyramids using division of labour, standardisation, one-piece flow, and many other fundamentals of CI. The history of CI has been long, but the primary growth and development happened during several industrial revolutions over the past 200 years. It started with the first Industrial Revolution, 1780–1880, by harnessing water, steam, and standardisation. Followed by the second Industrial Revolution, 1880–1980, with the birth of scientific management, integrated supply chains, electricity, progressive assembly lines, standard methods, and waste reduction. The third Industrial Revolution, 1980–2010, introduced technological improvements that made electronics and computing available for the masses and led to program-based improvements like Lean and Six Sigma (Liker and Morgan, 2006; Hopp and Spearman, 2011; Ohno and Bodek, 2019; Laureani and Antony, 2021).

Lean philosophy is based on the concept of doing more with less, using optimised processes to use fewer resources, less inventory, fewer workers, less space. The centre of lean thinking stands the idea of defining value from customers' perspective to design or improve services and products, eliminating all activities and features that do not contribute to the customers' value. As a result, organisations improve waste elimination, time reduction, improved quality, safety, and morale. This is achieved by focusing on five Lean Principles explained by Womack and Jones (2003). It is essential to understand that Lean is not only about waste elimination. The five principles should be viewed as consecutive and explain the core of lean thinking and what the companies need to focus on (Womack and Jones, 2003). These five principles are:

1 identifying the value, by determining the products or services that meet the customer needs

2 recognising the value stream, by creating a value stream map lists all activities needed to provide a specific product or offer service

3 creating the flow, by determining how the product, information, or service should move through one value adding-activity to the next one without any delays

4 establishing the pull, trying to reach an ideal state with no buffers of goods in stock as no one from the upstream process should produce or provide anything until there is a request from the customer downstream

5 perfecting the process, by combining the four principles that were previously mentioned, in order to achieve this final and most critical principle.

The lean philosophy also includes the elimination of the waste related to production, processing, transportation, inventory, motion, waiting, defects, and unused talent. This idea of lean philosophy has been studied by numerous authors, and they all agree that lean needs to be viewed as a condition, state of mind, or philosophy rather than a package of improvement tools (Sahoo et al., 2008; Laureani and Antony, 2012; Antosz and Stadnicka, 2017). Six Sigma, one of the main lean philosophy approaches, has become the industry's main strategy to increase profitability and enhance customer satisfaction. Senior company executives averse to other quality management initiatives have embraced Six Sigma as a proven way to decrease costs, grow profit margins, increase market share, and improve customer satisfaction (Antony et al., 2017, 2019). Six Sigma helps organisations to achieve high quality, low cost, and lean in everything they do. The phrase 'Six Sigma' has taken on several different meanings and is considered more of a business strategy than a quality program. Six Sigma essentially supplements an organisation's fundamental business process in a way that ensures the achievement of its long-term vision and objectives (Watson, 2004).

The Six Sigma approach can be related to the Greek letter sigma (Σ, σ) representing the statistical meaning of sum, or a measure of variability, the standard deviation (van Aartsengel and Kurtoglu, 2013; Kubiak and Benbow, 2016; Antony et al., 2017). The relation comes from the Six Sigma movements that started from the need to reduce the variability caused by errors in a production environment. Understanding how variability degrades performance is key to improving manufacturing and service systems. Deviations from the desired value for a product characteristic express the loss of quality which is represented in the relative quality loss function. This function has a parabolic shape and shows the deviation of the product characteristic in relation to a target value expressed in monetary units. Thus, as it becomes clear when examining the form of the quality loss function, the further the measured value of a feature of a product is, the cost of the deduction quadratically increased (Watson, 2004; Kubiak and Benbow, 2016).

This paper follows the lean philosophy and implements the Six Sigma methodology on improving the bill of materials (BOM) of packaging processes of a renowned Greek copper production company. This research is, to the best of our knowledge, one of the very few ones that manage to connect Lean Six Sigma research with practice in the manufacturing sector. Research on this sector has only recently gained popularity and is still mostly at a theoretical level (Khan et al., 2020; Nandakumar et al., 2020; Acosta-Vargas et al., 2021; Kumar et al., 2021). For this study, the defined, measured, analysed, improved, and controlled (DMAIC) methodology of the Six Sigma approach is followed meaning that all processes are DMAIC (Hakimi et al., 2018; Smętkowska and Mrugalska, 2018).

2 Application of Lean Six Sigma

The previous section provided a theoretical background of the lean philosophy and, in particular, the Six Sigma approach. The primary purpose of the practical part of the research is to prove that the BOM of the packaging process of a production company can be significantly improved as it may present a plethora of errors and waste. This can be demonstrated by using the necessary Lean Six Sigma tools and methods and showing their application in each Phase of the improvement project, which contributes to redefining the packaging process's BOM.

The selected company, in order to maintain the position of power, ensures high quality in production through strict controls applied throughout the production process. The company has developed consistently and responsibly based on a customer-centric approach. It aims to maintain long-term partnerships with its customers, closely monitor the market, and develop synergies to meet their specialised and ever-changing needs successfully. Additionally, with a stable and responsible commercial policy, it implements a clear strategy that focuses on extroversion, productive flexibility, and the continuous upgrading of the quality and the solutions provided to its customers, thus building long-term trust relationships.

The company seeks the CI of its employees, adopting a culture of CI, investing in modern technology, always emphasising quality and competitiveness. In recent years the company has invested significantly in its human resources, organising seminars on the Lean Six Sigma approach. The primary purpose of these seminars was to encourage its employees to make decisions based on data and not based on previous experiences and knowledge, as well as the existence of a common communication code when company members need to work on a project.

Although high quality is achieved, the company has a history of experiencing problems with the BOM of the packaging process. The company noticed issues concerning BOM, which leads to incorrect final costing of the products and a burden on the Product Design Department with additional BOM formatting. Although producing superior quality products is a critical factor for businesses to remain competitive, other parameters contribute to a business's success. Besides superior products, organisations must also be capable of competing regarding price and time limitations. A single case study of the company's current BOM was conducted to investigate potential flaws. One of the problems at the company is the preliminary costing of different types of packaging. This issue has been caused due to a lack of specific BOM materials and incorrect quantities of materials. Due to the situation described above, the BOM formatting is performed daily, creating additional workload shared in the Product Design Department.

The main purpose of this practical part of the research, therefore, is to offer an updated BOM with the right materials and exact quantities and implement improvements to reduce potential waste. The project's primary goal is that the improved BOM will lead to the identification of all packaging materials and their quantities in order for the costing process to be accurate and immediate (approximate profit EUR 6.000). The project's secondary goal includes better inventory management and a significant reduction in the time needed for BOM formatting (approximate profit EUR 6.000).

3 Implementation of the DMAIC methodology

3.1 Define phase

During this phase, the project's purpose was determined, the improvements we expect to be achieved, the team called upon to implement it, and its inputs – outputs. They also identified who 'customers' are – internal or external – and their requirements. The Lean Six Sigma tools that we adopted during the implementation of the define phase are:

- Project charter, a document where all the important events of the project are summarised.
- Stakeholder analysis, identifying the major stakeholders, investigating their roles, interests, relative power, and desire to participate.
- Order structure analysis (with ABC analysis), identifying the required materials for each activity and classifying their data outputs into two categories: activities that provide attribute data and activities that provide variable data (through measurements). The activities that their outputs provide variable data are marked 'A', those that provide variable data but are strictly standardised are marked 'B' activities, and those that provide attribute data are marked with 'C'.
- Suppliers, input, process, output, customers (SIPOC) map (as seen in Table 1), presenting who the suppliers and customers are and the requirements formed between them.
- Voice of customers (VOC), asking them what, in their opinion, were the main issues of the problem, and which are the outdated supplements of the BOM.
- Critical to quality (CTQ), turning customer requirements into CTQ objectives.

3.2 Measure phase

During the measure phase of our project the tools that were used, include Makigami process mapping, Pareto charts, XY matrix, and measurement system analysis (MSA). When analysing the process steps, we identified the most crucial activities of the packaging process. We performed a deep-dive analysis to identify which activities in the process steps provide us variable, and which attribute data, in order to further examine them through the MSA.

Figure 1 High level process map of the packaging process

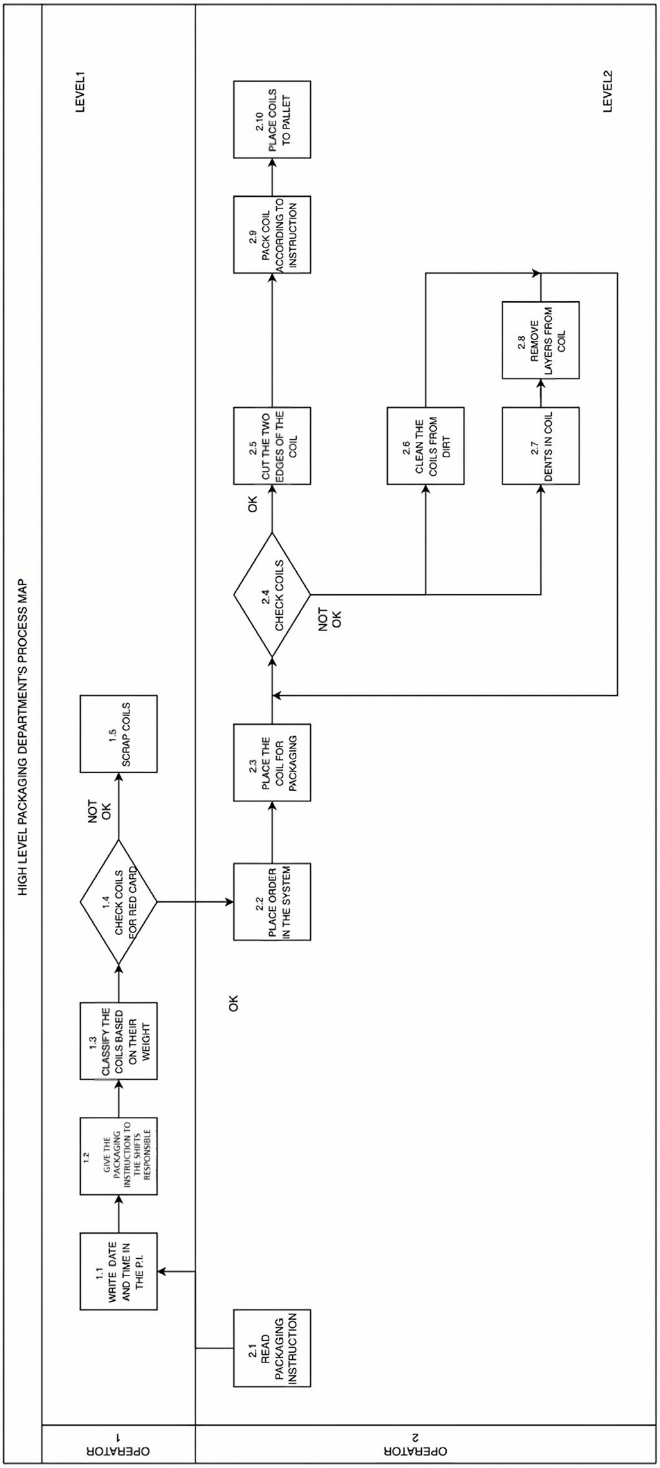


Figure 2 Detailed process: packaging TYPE 1

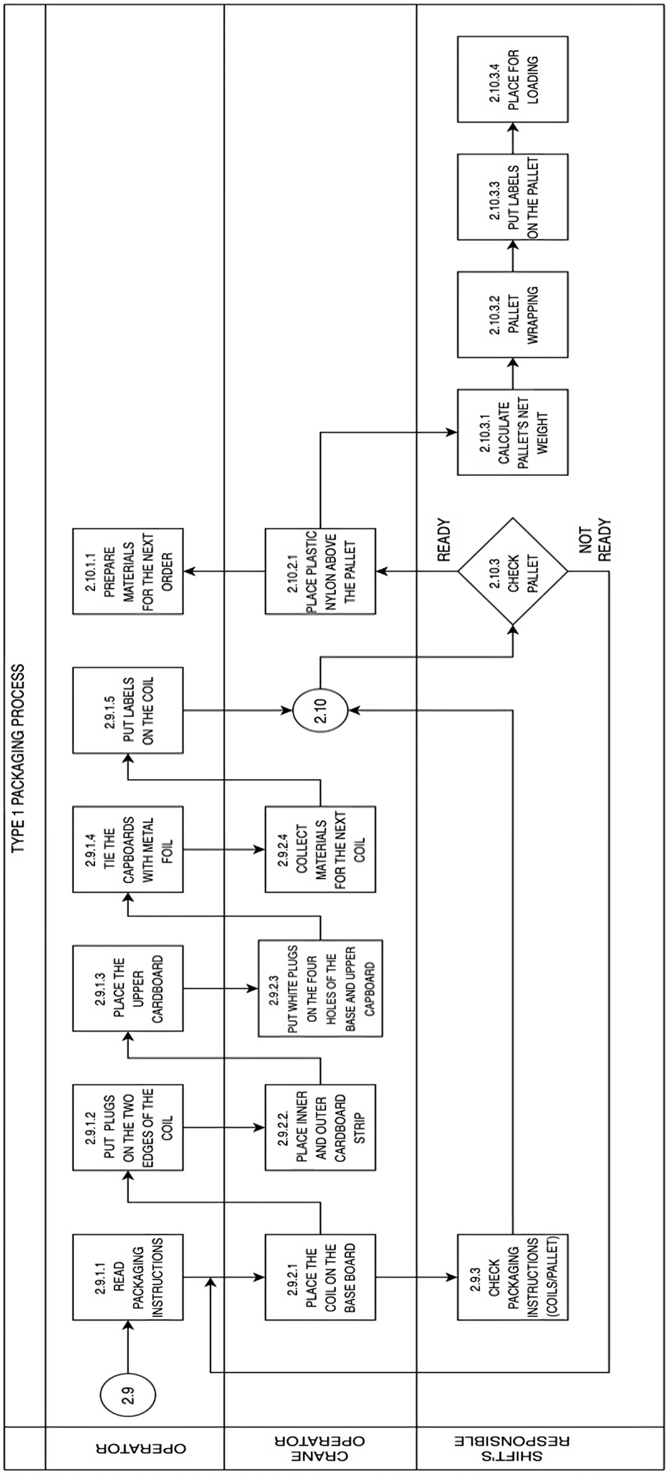


Figure 3 Detailed process: packaging TYPE 2

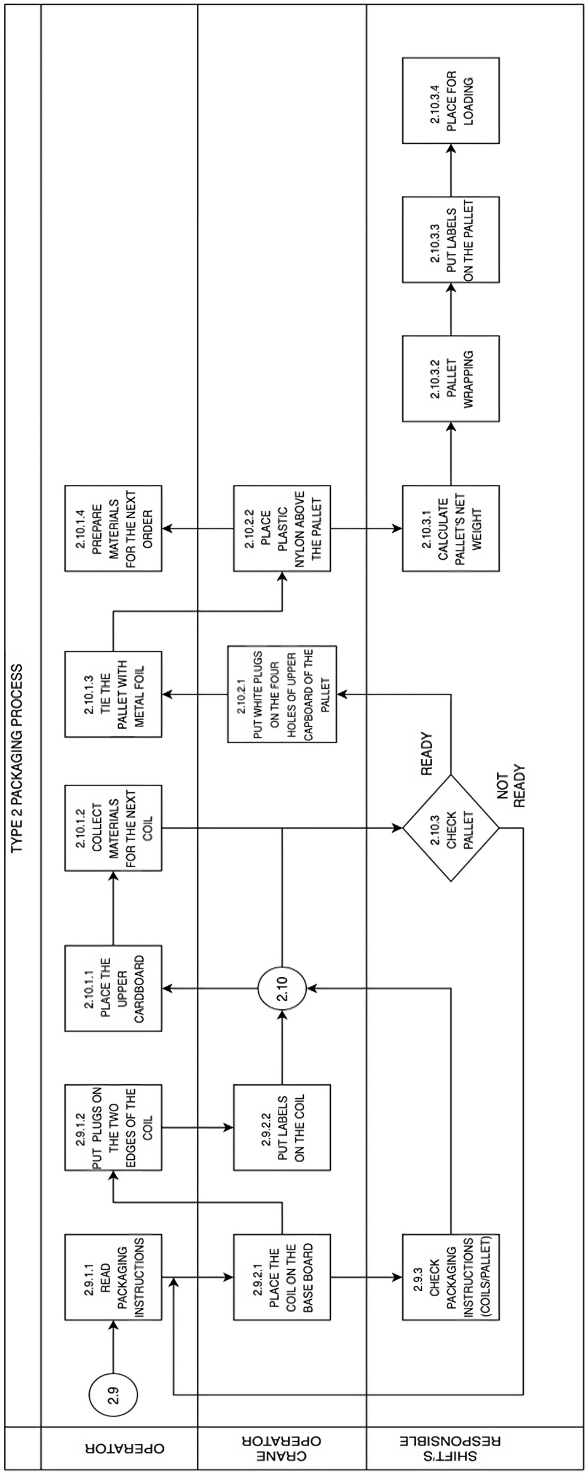


Figure 4 Detailed process: packaging TYPE 3

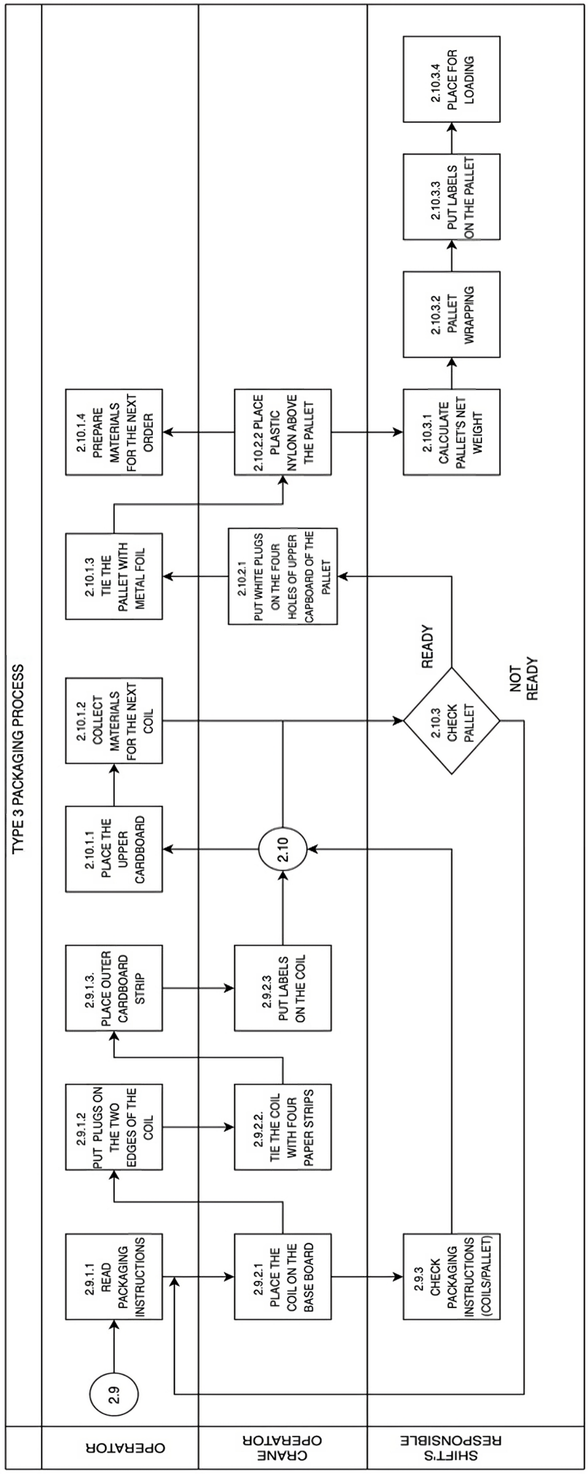


Table 1 SIPOC map

Suppliers	*Input*	*Process*	*Output*	*Customers*	*Customer requirements*
Packaging dep.	Database information Packaging process map	Observation of the packaging process	Activities identified	Materials department	Right identification of the activities of the process.
Materials dep. Financial dep.	Database information Database information	Collect detailed lists with materials' information	Detailed data collected	Packaging dep.	Check information's validity.
Packaging dep.	Database information Packaging process map	Define the materials required for each packaging type	Detailed data collected	Materials dep.	Right identification of material's id and description
Materials dep.	Database information	Define the quantities of the materials.	Detailed data collected	Packaging dep.	Accurate measurements
Packaging dep.	Operators training	Ensure measurements validity, by setting specifications.	Data validity secured	Product design dep.	Meet certain BOM specifications.
Product design dep.	Database information BOM specifications	Update BOM	Updated BOM	Company	Financial results

3.2.1 Makigami process map

A Makigami process map is used to define the sequence of process steps in the packaging process. The main focus was to distinguish each activity into particular data categories. For each process step, we added information about who is executing each particular process step and classify them in one of the categories mentioned above. Further, we added information about which of these activities lack material instructions to examine how they influence our measurements' validity. By doing so, we gathered process steps. The process map of the packaging process, as well as the detailed process maps of each packaging type are presented in Figures 1, 2, 3 and 4.

3.2.2 Pareto charts

The Pareto chart's functionality is that it groups the various factors that mostly affect a measured performance of an activity that is displayed at the y-axis of the chart. The factors that mostly affect the activity's performance are displayed in bars in decreasing size order. Therefore, the most critical factor is displayed firstly, at the left side of the chart, and the least critical one is placed at the right side of the chart. This type of chart was based on the Pareto principle, a.k.a. the 80–20 rule, meaning that for any given activity approximately, 20% of all inputs or factors that affect it, are responsible for 80% of the outcomes of the activity. Therefore, this type of chart is utilised when we are willing to distinguish the critical few factors in contrast to the trivial many ones. As it becomes clear, these critical few factors are the ones that mostly affect the performance and therefore all improved measures should be focused on them in order to achieve a performance improvement. In this paper, Pareto charts are used to identify major factors that influence our measurements. In Figure 5, the packaging type preferences are presented. This figure provides us with useful information related to the packaging type that helped us prioritise our measures.

Figure 5 Packaging type preferences (see online version for colours)

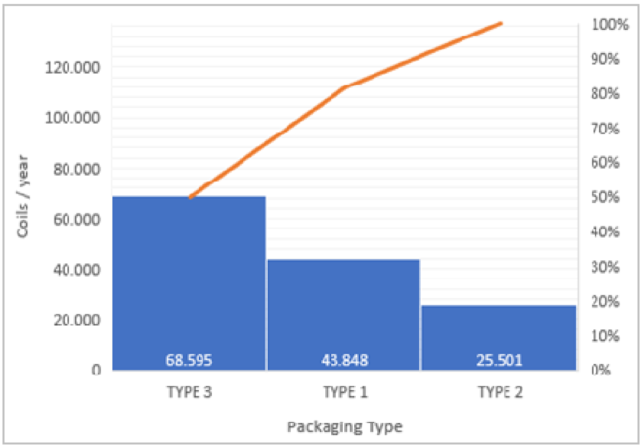
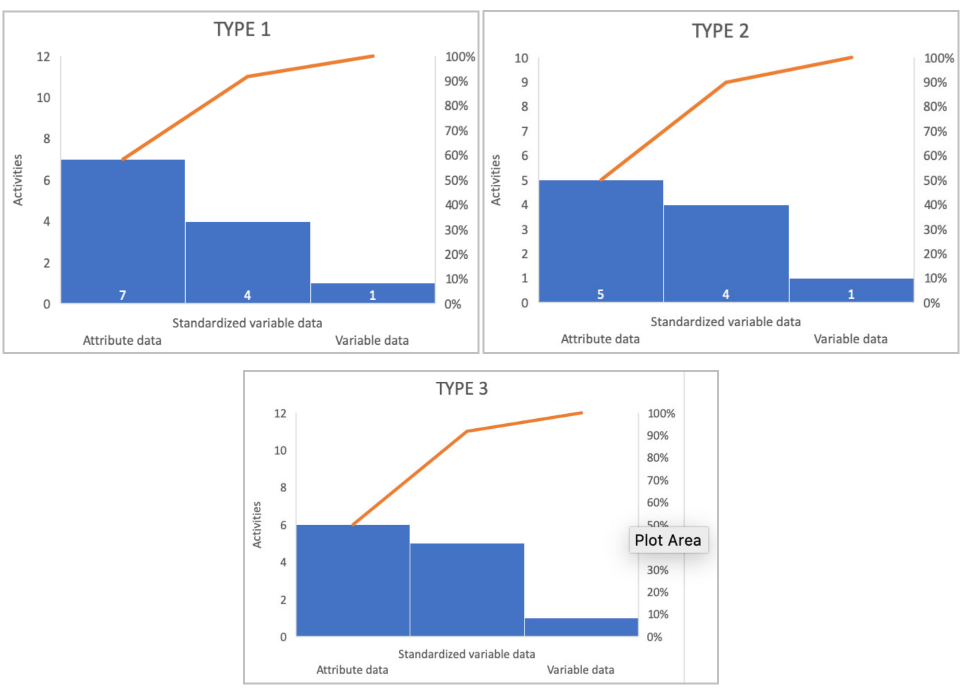


Figure 6 Distribution of activities in data categories for every packaging type (see online version for colours)



In Figure 6, the activities associated with the packaging process are presented. This figure provides us with information about the total number of activities of each packaging type, gives us an insight into the distribution of activities for each data category, and helped us organise the next steps of the project.

3.2.3 XY matrix

The XY matrix is a table, which presents the critical outputs (outputs-Ys) of the project and the various inputs (inputs-Xs) that affect them. Creating an XY chart allows the project team to determine the most critical outputs and rate them on a scale of 1–10 based on their impact on the customer. Finally, the team is asked to evaluate each input's influence on these outputs to identify the inputs that should be of interest. Figures 7 and 8 show the results of the XY matrix. As presented in both figures, the most crucial sub-process is the pallet wrapping with stretch film.

Figure 7 XY matrix (full packing) (see online version for colours)

XY Matrix

Project: Update BOM

Date: 11/10/20

		1	2	3	4	5		
	Output Variables (Y's)	Accurate Measurements	Waste during Measurements					
	Output Rating	10	8					
	Input Variables (X's)	Association Table					Rank	% Rank
1	Place the coil on the base board	0	0					
2	Put plugs on the two edges of the coil	0	0					
3	Place inner and outer cardboard strip	3	2				46	14,20%
4	Place the upper cardboard	0	0					
5	base cardboard	0	0					
6	Tie the cardboards with metal foil	4	0				40	12,35%
7	Put labels on each coil	0	0					
8	Place plastic nylon above the pallet	6	2				76	23,46%
9	Pallet wrapping with stretch film	9	9				162	50,00%
10	Put labels on the pallet	0	0					

3.2.4 Measurement system analysis

Conducting an MSA helps us distinguish inconsistencies in measurements. Despite the fact that for every packaging type, most activities include attribute data outputs, as presented in Figure 6, our main focus lies on the activity with non-standardised variable data outputs. While the case study department follows all the necessary standardisations (operator's training and certification, visual aids, etc.) the pallet wrapping should be tested in order to ensure the same results. The same measurements are conducted multiple times to ensure that the same findings are produced every time. To increase the validity of the collected data, we examined data from two different operator groups, and we took 15 measurements from each group. We confirmed there is no variation in the measurement system by completing the MSA, as presented in Figure 9.

Figure 8 XY matrix results (full packing) (see online version for colours)

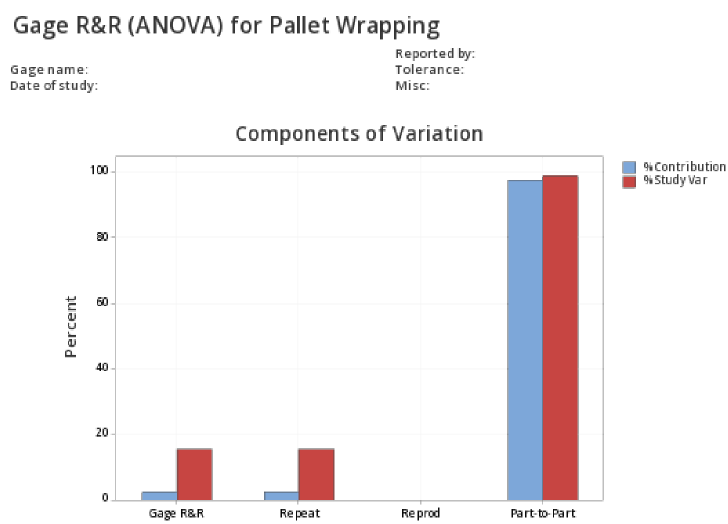
XY Matrix

Project: Update BOM

Date: 11/10/20

	Output Variables (Y's)	1 Accurate Measurements	2 Waste during Measurements	3	4	5		
	Output Rating	10	8					
	Input Variables (X's)	Association Table					Rank	% Rank
1	Place the coil on the base board	0	0					
2	Put plugs on the two edges of the coil	0	0					
3	Place inner and outer cardboard strip	3	2				46	14,20%
4	Place the upper cardboard	0	0					
5	base cardboard	0	0					
6	Tie the cardboards with metal foil	4	0				40	12,35%
7	Put labels on each coil	0	0					
8	Place plastic nylon above the pallet	6	2				76	23,46%
9	Pallet wrapping with stretch film	9	9				162	50,00%
10	Put labels on the pallet	0	0					

Figure 9 Measurement system analysis (see online version for colours)



3.3 *Analyse phase*

At the end of the measure phase, all necessary information and data have been collected. In the analyse phase, the main goal is to use these data to understand the defects in the current process in order to execute improvement tasks during the improve phase. We examine whether there are possible sources of delays, material losses, and insufficient quality during the procedure's execution stages. The tools we used during the implementation of the analyse phase were the Muda hunt checklist, the Pareto chart, and the cause-effect diagram (a.k.a. Ishikawa diagram).

3.3.1 Muda hunt checklist

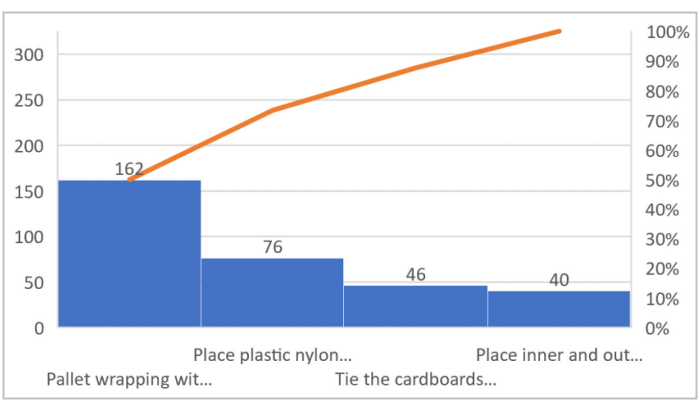
The main purpose of the Lean Six Sigma method is to minimise waste. One tool used to detect waste processes is the Muda hunt checklist. Once the defects are detected during the execution of the process, it falls into one of the seven MUDA categories (overproduction, waiting, motion, over-processing, inventory, transportation, defects) and improvements are set to be implemented. In particular, during the implementation of the project, at the measure phase, two processes were identified, which led to material wastes:

- For the most preferred type of packaging (type 3), where four ties are made with paper tape, it was cut in larger quantities than needed, leading to additional consumption.
- Before the stage of wrapping the pallet, a plastic sheet is placed on top of the pallet in order to protect the product from water, moisture, etc. This process is not automated, and the user, based on experience, chooses to cut the plastic sheet in a longer length.

3.3.2 Pareto chart

Based on the XY matrix, which was implemented during the measure phase, the Pareto diagram of the department's processes was created. Figure 10 presents the criticality of the sub-processes as defined in the XY matrix, based on the measurements made.

Figure 10 Pareto chart (crucial sub-processes)



Based on what we have mentioned, it is understood that the most critical process for the project is the 'wrapping' of the pallet with plastic stretch film. In order to accurately calculate this procedure, different measurements were taken, depending on the different parameters affecting the consumption of stretch film, which are divided into the following categories:

1 measurements (same pallet size – same type of packaging – same coil diameter – different pallet height)

2 measurements (same pallet size – same type of packaging – different coil diameter – same pallet height)

3 measurements (same pallet size – different type of packaging – same coil diameter – same pallet height)

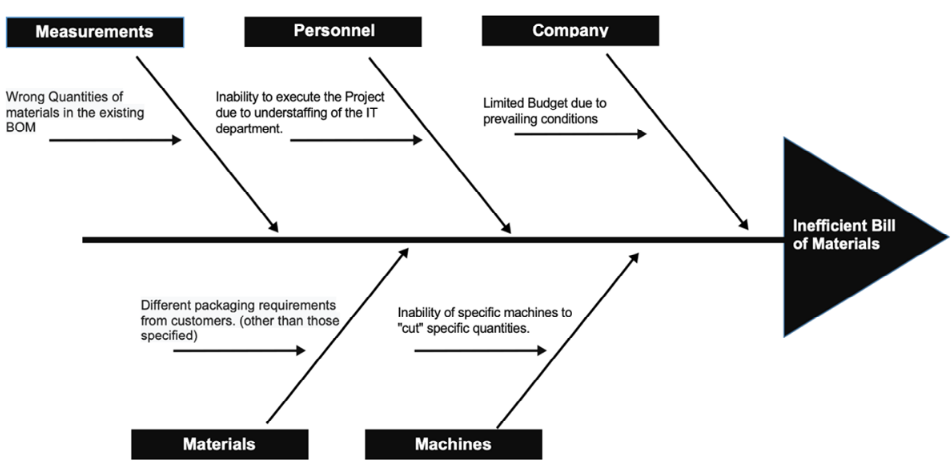
4 measurements (different pallet size – same type of packaging – different coil diameter – same pallet height).

In this way, it was calculated how much each parameter affects the final measurements, and a model for calculating the consumption of the plastic stretch film was determined, as the case may be. Finally, implementing these Lean Six Sigma tools and methods, we came up with innovative ideas to improve the current situation, as will be presented in the following phase.

3.3.3 Cause-effect (Ishikawa) diagram

As brainstorming tools to detect all possible root causes of the problems within our process, we used a cause-effect diagram (Ishikawa). During the analyse phase, we also identified waste during the processes. These material wastes include the amount of paper tape used in packaging number 2 as well as the amount of plastic nylon used to cover the pallet. These wastes were eliminated by setting new standards in the processes and are presented as the quick wins of the project. A 'quick win' is simply a process improvement that has low risk, can be implemented shortly after the project begins, and is agreed upon by project team members. With the Ishikawa diagram, we performed team brainstorming to find possible reasons for 'Why is it hard to update the current bill of materials?'. The cause and effect diagram is presented in Figure 11 and reveals the cause that lead to a faulty BOM.

Figure 11 Ishikawa diagram (see online version for colours)



3.4 *Improve phase*

With the completion of the measure and analyse phases, the improve phase follows. In this phase, the main goal was to improve the process by eliminating all possible sources of waste. During the analyse phase, we identified two sub-processes in which there is material waste:

1. For packaging type 3, where four ties are made with paper tape, it was cut in larger quantities than needed, leading to additional consumption. A specific way of performing this sub-process was determined in order to greatly reduce the waste, taking into account the productivity of the operator (estimated benefit EUR 2,000/year).
2. The cutting of the plastic sheet according to specifications registered in SAP was at 2 metres, in contrast to the measurements taken (30 measurements), whose average value is 2.67 metres. For this reason, specific cutting lengths were determined, depending on the packaging needs, by optical means (estimated benefit EUR 4,000/year).

Table 2 BOM comparison (see online version for colours)

Material name	*Improved BOM*	*Existing BOM*	*Unit*
	Quantity		
Cap black ext. 5/16	12	12	piece
Ext. rev. Paper 1,070 × 1,070 hole Φ130 mm	36	36	piece
Int. rev. paper 587 × 587	36	36	piece
Thermoplastic glue fuller	1,207,719	x	gr
Int. line rev. 20 × 2,000	6	6	piece
Ext. line rev. 20 200 × 3,380	6	6	piece
Fiber reinforced adhesive tape 50 × 50	1,368	x	m
Adhesive signs 105 × 148 mm (1,000pcs)	6	x	piece
Cap white rev. F25	48	64	piece
Metal galvanised hoop clip	12	12	piece
Metal hoop black 16 × 0, 40	17,452	18	m
Square cardboard (over pallet)	2	x	piece
Str film transp. 500 × 2, 3 MHX17MY PRES 300%	518	690	gr
Adhesive signs 149 × 210 mm (palet 700pcs)	3	x	piece
VPCI-126 CWS HL2000mm × 250mm × 80µm	2,336	2	m
Inked ribbon 154 × 450 TWR200 OW	0,675	x	m
Inked ribbon ZEBRA Z6M 108 × 450 mm	0,978	x	m
Pine Pallet 1,100 × 1,070 YS-119	1	1	piece

In order to create the BOM some parameters need to be defined as they influence the final outcome. Firstly, the customer needs to be chosen, because the BOM depends on the customer's requirements for a specific packaging type. Next, the packaging type and product category are chosen and also the height of the coil is specified, the total amount of the order is defined, and the desired pallet of the customer is chosen. The coils per order are calculated based on the dimensions of the product chosen by each customer as well as the size of the order. The number of pallets is calculated using the Microsoft Excel Solver aiming to find the fewest possible needed pallets or through loading specifications set by the customer. The type of coil (CD-coil or not) pack is chosen and it is specified whether plugs are needed. Through this procedure, the exact BOM of the packaging process, based on the customer's requirements, is created.

Finally, as seen in Table 2, the comparison of the new BOM versus the previously existing one is performed. The results show that the newly created BOM is vastly improved the existing BOM presented several errors as some materials are not included while the quantities of those that exist in some cases are wrong. The comparison concerned the same product, same requirements of packaging as well as the same order quantity. In particular, a packaging type (full packing) was selected for a pallet with six coils where the height of each coil is 200 mm.

3.5 Control phase

The end of the improve phase follows the control phase, where the process is evaluated and whether it is within the requirements set by the customer. In the improve phase, we enhanced the system to become capable and in line with the customer's requirements. In the control phase, the improved process is monitored in order to maintain its smooth operation. In this phase, the company will take necessary measurements in order to control the process flow. An effort is made so that the control of the process is as automated as possible with minimal need for human intervention.

During this phase, all necessary improvements to the process have been made, and the process control is transferred from the research team to the company so that they can learn to solve any problems that occur, being aided by the already conducted research. The process transfer is done after the improved process has been thoroughly documented and the process owners are well trained on how to control it. Project results are empirically verified, and the control system is adjusted. Some tools used to perform this step are control charts, bar charts, and statistical process control. This stage is expected to be followed for about an eight-month period by the project managers and is the final stage of implementing the DMAIC methodology.

4 Conclusions

In order for a company to be globally competitive, it is particularly important to listen to the trends prevailing in the sector in which it operates, to examine technologies, and apply those that best meet its needs. In this paper, one of the leading methods of CI, Lean Six Sigma was analysed and applied. Initially, the theoretical background of the Lean and Six Sigma methods was presented. The research was followed by the application of the DMAIC methodology. In the define phase, the requirements of the internal customers were determined, which became goals during the measure and analyse phases. In the improve phase, the elimination of waste was sought in two sub-processes from which a significant economic benefit was extracted. The next step of this project concerns the implementation of the control phase where the improved process will be monitored by the company and all necessary modifications will be applied, when needed so that the process retains its significant improvements.

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