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DMAIC Cycle for the New Product Launch Process: FMEA and DOE Applications for Built-in Oven

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ABSTRACT

Objective: Six Sigma-SS and the DMAIC-Define, Measure, Analyze, Improve, Control cycle are employed to enhance the success of the launch of a new built-in oven with a digital panel.

Method: Following the define and measure phases, to identify and eliminate potential failures, Failure Mode and Effect Analysis-FMEA is conducted and control plans were composed during the analyse phase. In the improvement phase, the Risk Priority Numbers-RPNs obtained through FMEA and recommendations were listed. Using Design of Experiments-DOE, the lifespan of bulbs in ovens was maintained at the target value while reducing procurement costs. In the control phase, the results of validation experiments and the gains were reported.

Findings: After reporting the RPNs related to high-risk failure modes and providing improvement recommendations, DOE and Analysis of Variance were employed to determine which type of oven and brand of bulb could be used. If implemented, the expected annual savings are approximately 20,000 Euros.

Originality: This article focuses on an integrated approach for a product that is set for a new launch. It aims to improve design and production processes using the SS while also targeting cost reduction in procurement processes. To the best of our knowledge, no similar study has been encountered in the literature.

Keywords: Six Sigma, Built-in Oven, Design of Experiment, Failure Mode and Effect Analysis.
JEL Codes: C12, C19, M11, M21.

Yeni Bir Ankastre Fırını Devreye Alma Sürecinde TÖAİK Döngüsü: HTEA ve DT Uygulamaları

ÖZET

Amaç: Altı Sigma Metodolojisi ve TÖAİK-Tanımla, Ölç, Analiz Et, İyileştir, Kontrol Et döngüsü ile ilk kez piyasaya sunulacak olan dijital panelli ankastre bir fırın lansmanının başarısını artırmak hedeflenmiştir.

Yöntem: Tanımlama ve ölçme aşamasını takip eden analiz aşamasında Hata Türü ve Etki Analizi-HTEA ile muhtemel hata kaynakları belirlenip elimine edilmeye çalışılmış, kontrol planları oluşturulmuştur. İyileştirme aşamasında, HTEA ile elde edilen Risk Öncelik Sayıları (RÖS) ve iyileştirme önerileri listelenmiştir. Deney Tasarımı (DT) ile ankastre fırınlarda kullanılan ampül ömrünü hedef değerde tutarak satın alma maliyetlerini düşürmek amaçlanmıştır. Kontrol aşamasında doğrulama deneylerinin sonuçları ile elde edilen kazançlar raporlanmıştır.

Bulgular: Yüksek riskli hata türlerine ilişkin RÖS ve iyileştirme önerileri raporlandıktan sonra DT ve Varyans Analizi ile hangi fırın tipinde hangi marka ampülün kullanılabileceği tespit edilmiştir. Uygulamaya geçilmesi halinde beklenen yıllık kazanç yaklaşık 20.000 Euro civarındadır.

Özgünlük: Bu makale; henüz seri üretime geçmemiş ve yeni devreye alınacak olan bir ürün için, Altı Sigma yaklaşımı ile tasarım ve üretim süreçlerini iyileştirirken, satın alma süreçlerinde de maliyeti azaltmayı hedefleyen bütünleşik bir yaklaşıma odaklanmaktadır. Bilindiği kadarıyla literatürde benzer çalışmaya rastlanmamıştır.

Anahtar Kelimeler: Altı Sigma, Ankastre Fırın, Deney Tasarımı, Hata Türü ve Etki Analizi.
JEL Kodları: C12, C19, M11, M21.

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1. INTRODUCTION

SS is a problem-solving and quality improvement philosophy that can be applied in various industries. The DMAIC cycle is a structured problem-solving approach widely used in SS methodology (Antony and Banuelas, 2002; Girmanová et al., 2017). This methodology aims to identify waste, eliminate defects, and increase customer satisfaction.

The phases of DMAIC are systematically connected and continuously monitor the process according to the Deming PDCA (plan-do-check-act) cycle. Through these phases, the process is defined in detail, data is gathered, causes of defects are analyzed, and solutions are processed, tested, and implemented (Cheng and Kuan, 2012; Matthew, 2011; Singh et al., 2017; Smętkowska and Mrugalska, 2018).

The five steps of DMAIC are summarized below (Ahmad et al., 2018; Monica and Beata, 2018; Karamustafaoğlu and Sontay, 2018: 224):

Define- the problem is defined based on the voice of the customer (VOC) and what is critical to quality (CTQ). The problem statement is developed, and the goals for improvement are established. *Measure*-data is collected to understand the current state of the process. The process is mapped out, and key metrics are identified and measured. *Analyze*-potential root causes of the problem are identified through data analysis. The vital few causes are determined, and possible solutions are generated. *Improve*-solutions are tested to eliminate the root causes of the problem. The best solution is selected and implemented, and the process is improved. *Control*-the improved process is verified and validated to ensure that it is stable and meets the desired quality standards. Standard procedures are established, and continuous monitoring is performed to ensure that the process remains in control.

This paper proposes a step-by-step DMAIC procedure for a new product (digital-display built-in oven) launch process. Various basic and advanced tools and techniques were used to improve performance and product quality. In the *Define phase* of the project, workflow was utilized to visually represent the steps of a process. After analyzing the production process in detail, the problem has been described and the defects have been identified. In the *Measurement phase*, potential failure modes were identified, and decisions were made on what the severity (S), occurrence (O), and detection (D) values would be. RPN is determined by these three risk parameters (Kaoudom et al., 2019). RPNs were utilized to determine the most critical failures in this phase. In the analyze phase, tools such as Pareto, fishbone and why-why analysis were used to detect root causes and identify the necessary actions for preventing those failures. In the *Improve phase*, corrective actions were recommended and the RPNs were recalculated for comparison. DOE was also used to optimize the life span of bulbs and identify the factors that had the greatest impact on lifespan. General Linear Model-GLM and regression models were utilized to analyze and understand the relationship between variables. In the *Control phase*, control plans were created to monitor improvements and ensure standardization. The validation experiments of DOE studies are also examined in this phase.

Although SS methodologies have been commonly applied in the household appliances industry, this paper involved specific design considerations, manufacturing processes, and quality control measures that were tailored to a new built-in oven with a digital display. The goal is to eliminate or reduce failure modes causing poor product quality, reduce procurement costs, meet customer expectations, and improve product quality. All of these objectives are closely associated with the concept of productivity. Therefore, the SS methodology has been chosen for improvement efforts in this firm. The study proposes an integrated approach aimed at improving design and production processes, concurrently focusing on reducing costs in procurement processes through supplier evaluations.

The sections in the study were organized as follows: Introduction provides an overview of the study's purpose and objectives. The second part of the study provides information about the DMAIC cycle and reviews existing literature and research relevant to the topic. Section three (a case for digital-display built-in oven) describes the research design, data collection methods, and analysis techniques employed in the study. It presents the findings of the study, including data analysis and interpretation. Conclusion summarizes the key findings and their implications of the study.

2. THEORETICAL BACKGROUND AND LITERATURE REVIEW

As mentioned before, SS methodology focuses on reducing waste and variability in manufacturing processes, which can lead to improved quality, increased productivity, and reduced costs. The DMAIC cycle is a key aspect of SS, which is used to identify and solve problems. Each stage of the SS methodology is supported by a range of corresponding tools and techniques, including statistical process control and DOE. By leveraging these techniques, practitioners have a diverse set of tools at their disposal to improve critical processes and drive improvements in quality and efficiency (Pepper and Spedding, 2010). SS techniques include basic tools-histograms, Pareto, fishbone and control charts, and advanced tools- DOE, Taguchi, Response Surface Methodology (RSM) and multiple regression analysis (Uluskan, 2016).

DMAIC is a widely used process improvement methodology in the manufacturing sector, and has been applied in various industries to address a range of problems including household appliances (Atmaca and Grines, 2013; Uluskan, 2019; Uluskan and Oda, 2020; Yetimler, 2018), food (Banuelas et al., 2005), textile (Ajmera et. al, 2017; Demirtas et al., 2022; Lingam et al., 2015; Mukhopadhyay and Ray, 2006; Prasad et al., 2020;), automotive (Gijo et al., 2014; Kaoudom et al., 2019; Kaushik et al., 2012; Kumar et al, 2007; Pugna et al., 2016), and the others (Antony et al., 2008; Cheng and Kuan, 2012; Costa et al., 2019; Ehie and Sheu, 2005; Natarajan et al., 2013; Sokovic et al., 2005; Sontay and Karamustafaoğlu, 2017; Prabu et al., 2013; Putri et al., 2018).

Experimental design strategies such as RSM, Taguchi or DOE play an important role for the improve phase of the SS projects. DOE is a highly effective technique for identifying the most important variables (factors) that impact process output, and determining their corresponding levels for optimal performance (Antony, 2002; Goh, 2002; Uluskan, 2019). In essence, DOE is a systematic approach to understanding the relationships between the various factors that can influence a process output (Ryan, 2005).

In the following studies, SS projects were carried out with RSM, Taguchi or DOE:

Kumaravadivel and Natarajan (2013) proposed DMAIC with RSM to minimize defects in sand-casting processes, resulting in optimized casting parameters and reduced rejection rates. The DMAIC methodology has been applied in a study focused on eliminating defects in the spray-painting process (Srinivasan et al., 2014). They used Taguchi robust design, ANOVA and multivariate regression to identify optimal conditions in the pretreatment process (Uluskan, 2019). used statistical process control techniques (Gage R&R, pareto, fishbone, SIPOC diagrams, control charts and process capability analysis) and DOE in improve phase for the electrostatic powder coating process.

FMEA is used for identifying and eliminating potential failures of a product or process. FMEA is typically used during the design phase of a product or process, but it can also be used in the measurement and improvement stages of the DMAIC cycle. Kaoudom et al. (2019), Lingam et. al. (2015), Pugna et al. (2016), Putri et al. (2018) have used FMEA in DMAIC cycle.

Additionally, the effectiveness of several Lean SS methodologies and quality tools such as value stream map (VSM) and systematic layout planning, flow mapping (Lingam et al., 2015; Nagi and Altarazi, 2017; Prasad et al., 2020), SIPOC diagram, Measurement System Analysis-Gage R&R, Process Capability Analysis, Cause-Effect diagrams, Hypothesis tests, Control Charts (Kaushik et al., 2012; Kumar et al, 2007), 5S, Kanban, Kaizen, Poka-Yoke (Demirtas et al., 2022; Prasad et al., 2020; Saleeshya et al., 2012) SMED (Utkun and Güner, 2012) and TPM (Ahmad et al., 2018) within the DMAIC methodology framework, were explored for improving the quality.

As different from other researchers, our paper focuses on an integrated approach, aiming to enhance design and production processes through the SS methodology, with a concurrent focus on reducing costs in procurement processes. To our knowledge, there is no equivalent study found in the existing literature.

3. A CASE FOR DIGITAL-DISPLAY BUILT-IN OVEN

This section provides a comprehensive overview of the research design, data collection methods, and analysis techniques used throughout the investigation. The section also presents the study's findings, encompassing the data analysis process and its corresponding interpretation.

3.1. Define Phase

This article describes improvement efforts using the DMAIC cycle for a new built-in oven that is currently in the commissioning process. To address potential failures and risks in the touchscreen display on the oven door and other critical components before transitioning to mass production, a study has been initiated. The improvement studies were conducted by a team of five engineers, including machine, industrial, and materials engineers, working in the R&D laboratory, quality, and production departments. After analyzing the workflow in detail, FMEA and DOE studies have been started at measure and improve phases. The goal of FMEA is to reduce design changes before mass production and to prevent high scrap rates. DOE studies have also been carried out to ensure that the bulbs used in built-in ovens are low-cost and long-lasting.

The company operates in the durable consumer goods industry. It manufactures, sells, markets, exports, and provides after-sales services for washing machines, dishwashers, dryers, refrigerators, freezers, cookers, full-size and built-in ovens. 90% of the products are exported, and 10% are used in the domestic market.

The manufacturing process of the built-in oven begins with the storage of sheet metal in the warehouse (Figure 1). The raw materials are then transferred to the production line, where computer numerical control

(CNC) metal-forming presses are used to shape the cavity frame. These presses allow for easy bending of the sheet metal or plate with the help of simple fixtures. After spot welding, the metal surface points are joined together. Subsequently, the oven cavities are loaded onto hangers to undergo the enameling process. During enameling, one or more layers of enamel are applied to the pre-prepared cavity. Following that, the cavities are subjected to firing at a temperature ranging from 780°C to 850°C, allowing the enamel to securely adhere to the surface through the application of heat (as shown in Figure 2). Subsequently, the cavities, now coated with enamel, are transported to the assembly area using hangers. Simultaneously, the spalla pieces are affixed and secured to the door glass using an adhesive. Once the adhesive has dried, the door glasses are transported to the assembly area. Additionally, panels obtained from external suppliers are also transferred to the assembly area.

The assembly line is initiated with the control of cavity enamel. Subsequently, nuts are installed for interior rack assembly, and door glass hinges are placed. These steps are followed by resistor assembly, motor fan insulation and assembly, and fan blade assembly. Next, the rear resistor and rear resistor protection sheet are assembled. Afterwards, the cavity is covered with an insulation sheet. Once the oven chassis base is assembled, the right and left chassis parts are joined together. Finally, the fan cover and thermostat bulb holder are assembled. Before the panel assembly, a quality check is conducted on the digital screen and cables. Once verified, the cables are installed, and the digital screen is securely fixed in place using silicone sealant. Following that, the light bulbs and panel are assembled, and labels are attached for identification and information purposes. After the assembly of the inner racks, the oven tray is checked and placed in position. Then, the thermostat switch is inspected and installed. Once the ventilation plate, temperature limiter, and cooling fan are assembled, the top chassis is secured to the sides by screwing, thus closing the body. Then, the oven door is assembled, and the inner glass is installed, if necessary, followed by the installation of the gasket. The gap between the glass and panel is checked and adjusted as needed. After the barcoding process, electrical and panel tests are conducted. The oven is wrapped with protective foam and packaged before being transferred to the warehouse for storage and shipment.

Figure 1. Workflow of built-in oven (adopted from Yetimler, 2018)

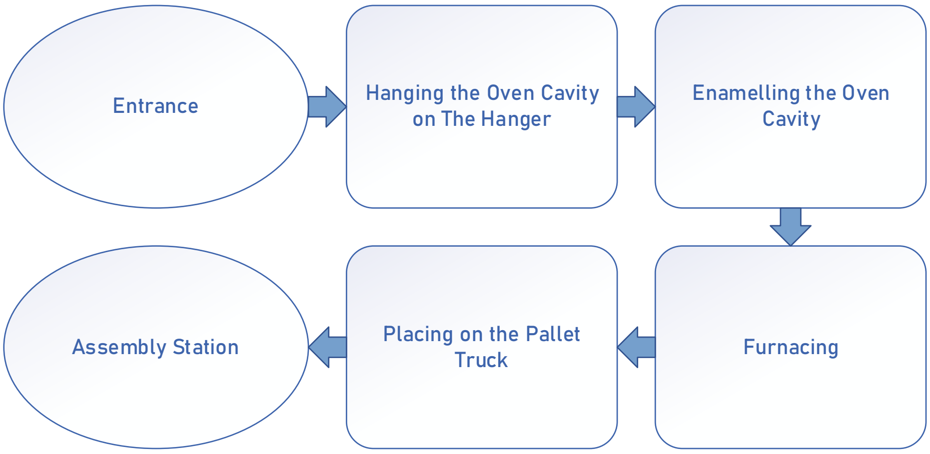

Figure 2. Workflow of cavity (adopted from Yetimler, 2018)

3.2. Measure Phase

Since the digital display built-in oven is still in the commissioning phase, FMEA studies were carried out during pilot production. Possible failure modes, effects and causes of failures are determined. Severity, probability, and detection scores for the failures were calculated. High risk failure modes and RPNs of the failure modes have been listen in Table 1.

Table 1. Failure Modes and Risk Priority Numbers

Code	*Failure Modes*	*RPN*
F1	Long cable harness	315
F2	Failure to data cable enclosure	315
F3	Improper fixing of the door handle	245
F5	Failure to install the door front frame properly	245
F6	Improper assembly of sheet metal	225
F7	Failure to install the filter properly	189
F8	Visual defects on the touchscreen	175
F9	Failure to mainboard	175
F10	Damage to the inner glass	147
F11	Damage to the monitor during the spalla fixing process	147
F12	Damage to the monitor and its parts mounted on the door group	147
F13	Failure to hinges	135
F14	Enamel problems in cavity	105
F15	Failure to mount the monitor protector to the door group properly	105
F16	Failure to data cable	105

After determining RPNs, measurement and analyses were conducted using basic quality tools for the identified high-risk failures. These efforts were sampled for the cavity enameling process in this paper. Defective cavities received from the enameling cannot be used in the assembly line and are scrapped. This leads to loss of time, labor, and increased costs. In order to reduce the number of defective cavities, the process has been thoroughly examined. Data has been collected for one month on the cavities that are scrapped after enameling, and a Pareto analysis has been conducted (Figure 3).

As seen from the Pareto diagram, the most significant cause leading to scrap is impact, accounting for 78.1% of the total. Out of the 919 scrapped cavity, 718 are due to impact-related issues. Following that, enamel buildup accounts for 7.7%, high enamel thickness for 7.3%, enamel burn for 2.4%, and other reasons for 4.5% of the total scraps.

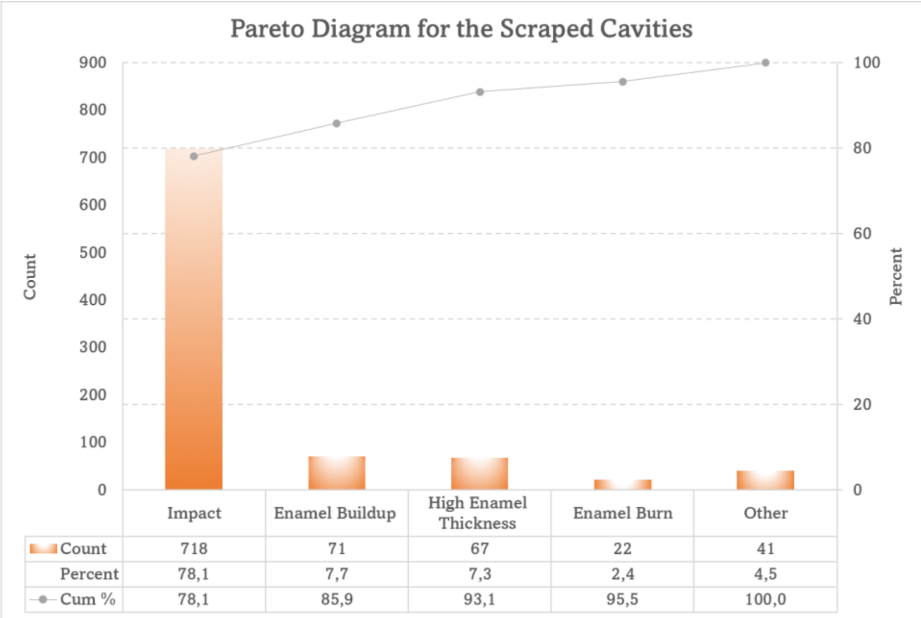

Figure 3. Pareto Diagram for the scraped cavities

The impact and buildup issues have been further examined in detail using a Cause-and-Effect diagram (Figure 4). This diagram, also known as a Fishbone or Ishikawa diagram, helps identify the root causes contributing to the observed problems. By understanding the underlying factors causing impacts and buildup, proper actions can be taken to mitigate these issues and reduce the number of scraps. Suggestions for the impact and buildup problem are given in the following section.

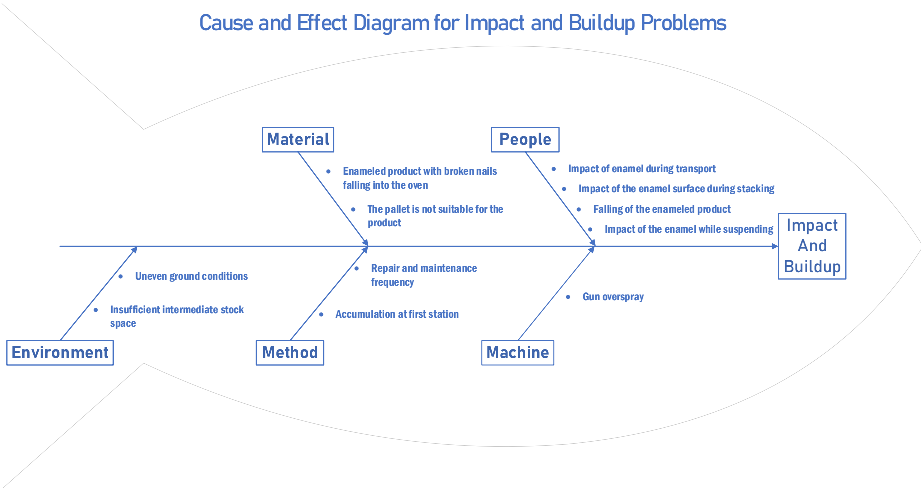

Figure 4. Cause-Effect Diagram for impact and buildup problems

3.3. Improve Phase

This phase contains FMEA and DOE studies. Actions have been taken for high-risk failures, which are identified based on their RPN scores. The corrective actions and the revised RPNs thereafter are listed in the improve phase (Table 2).

Furthermore, based on the revised FMEA forms for processes with high RPN values and planned improvement studies, control plans have been developed (please see Yetimler, 2018). For one of the processes with a high RPN value, which is the enameling of the oven cavity, quality tools have been utilized to target the reduction of scrap rates. The analysis of cause-effect diagram has revealed the following actions contributing to the improvement efforts:

- To prevent the cavities from falling into the furnace during enameling, operators have been informed and warning signs have been added to the panels, emphasizing the need for careful handling while hanging the cavities on the furnace hooks.

- Uneven floor conditions have been identified as a cause of cavities receiving impacts during transportation. It has been determined that floor improvement work is necessary to address this issue.
- Insufficient storage space leads to storing the cavities in proximity, increasing the chance of collision during transportation. It has been recognized that a new storage area is required to avoid collision.
- It is recommended to use a suitable rack for storing the cavities while they are waiting to be transferred from the enameling to the assembly line.
- Excessive enamel spraying from the gun results in buildup defects. To address this issue, operators have been trained for application. They also informed to perform more frequent and meticulous maintenance and repair of the enamel gun.
- The cavities can also receive impacts during the transportation and stacking after the enameling process, due to factors such as falling or collisions. Therefore, improvement suggestions have been provided for the transportation method. Prior to the improvements, stacking was done on wooden pallets, and transportation was carried out using these pallets. However, the wooden pallet can cause impacts during stacking and transportation. To prevent impacts resulting from contact between the cavities or external sources, a more protective transportation vehicle has been recommended.
- In the recommended cart, the cavities will be surrounded by vertical profile material to protect them from external impacts. For ease of use, the top part of the profile will have detachable slats. Additionally, the bottom part of the cart will be designed to protect the front frame of the cavities from external impacts while also providing a convenient placement for the cavities. Furthermore, considering the possibility of impacts during stacking, it has been observed that the inner surfaces of the transportation vehicle should be covered with a soft material.
- The use of heat-resistant material, such as polyamide, is recommended for the transportation carts considering that the cavities are placed on the carts at an average temperature of 80°C after coming out of the 800°C furnace. Polyamide is known for its excellent heat resistance and durability, making it suitable for this application.
- By considering the cost of 125 transportation carts required by the operation and comparing it with the monthly scrap cost, it has been determined that the business will recoup the investment in 5 months.

To evaluate the bulbs from the new supplier and the existing bulbs used in the company, a DOE strategy has been decided upon. The objective is to conduct lifespan tests on the bulbs and evaluate the results. The goal is to find suppliers who can provide the required quality and performance at a lower cost.

During the improvement studies, it was determined that if the new bulb brand can be used in all voltage ranges and in all brand ovens, an estimated annual savings of approximately 80,000 Euros can be achieved. To achieve this goal, a supplier evaluation was conducted by operating the bulbs from the new supplier in different models of ovens and at different voltage levels, while observing the results of lifespan tests. This evaluation aimed to assess the compatibility and performance of the bulbs in various operating conditions and ensure that they meet the required standards for reliability and longevity.

The new bulbs from the alternative supplier and the existing bulbs used by the company were tested in 3 different types of ovens and at 3 different voltage levels in a 2 replicated (36 samples) experiment. The factors and their levels are encoded as shown in Table 3. During the experiments, lifespan tests were conducted by setting the voltage values to 230, 250, and 270 volts. These different voltage values represent the company's customers in different countries. 230 volts is the designated voltage for products offered in the Turkish market, while 250 and 270 volts are designated for the French and British markets, respectively. The bulbs are expected to complete 1000 hours of operation to pass the lifespan test successfully.

Table 2. RPNs after improvement

Failure Mode	*Definition*	*Improvement Efforts*	*RPNs after improvement*
F1	Long cable harness	The R&D department has recommended implementing cable fixation in specific regions. This involves securely fastening the cables to prevent movement or dislodging, reducing the risk of damage or malfunction.	105
F2	Failure to data cable enclosure	The short length of the conduit used to protect the data cable is causing damage to the cable. To address this issue, it has been requested that the R&D department update the technical specifications and communicate with the supplier to extend the length of the conduit.	105
F3	Improper fixing of the door handle	To improve the ease of proper adhesive application for the oven door handle, it has been determined that the existing convenience needs improvement. After consultation with method engineers, a more functional convenience has been designed.	49
F5	Failure to install the door front frame properly	Consultation with method engineers has taken place to improve the frame bonding method. In addition, the production engineers have created a maintenance plan for the apparatus used in frame bonding.	63
F6	Improper assembly of sheet metal	The problem of assembly issues arises from the necessary mounting holes either not being drilled or being drilled incorrectly. This issue has been discussed with the R&D department, and after technical drawing updates RPN has been reduced.	75
F7	Failure to install the filter properly	During the assembly of the parasitic filter onto the sheet metal, it has been observed that the operator faces difficulty in performing this task. The challenge stems from the instability of the sheet metal onto which the filter is being attached. The failure is attributed to a lack of convenience in the process. To address this issue, method engineers have developed a new convenience that improves the ease of assembly. By implementing this improvement, the RPN associated with the assembly operation has been reduced.	63
F8	Visual defects on the touchscreen	A visual inspection instruction has been added to the control plan to examine visual defects on the touch screen.	75
F9	Failure to mainboard	The mainboard can sometimes arrive at the assembly line from the supplier faulty or may not be properly installed by the operator, resulting in potential damage and non-functionality of the board. To address these issues, it has been requested to ensure control over the storage and transportation conditions from the supplier. Additionally, training has been provided to the operators regarding this matter.	21
F10	Damage to the inner glass	To prevent damage to the glass during the inner glass assembly process, a visual form has been created.	63
F11	Damage to the monitor during the spalla fixing process	During the fixing process, it has been anticipated that the cables on the monitor may be at risk of damage, which can potentially lead to malfunctions. To address this issue, the R&D department has introduced a tape in the technical drawing, and the cables are now secured with the tape. Additionally, an improvement project has been initiated for the spalla fixing robot.	49
F12	Damage to the monitor and its parts mounted on the door group	To prevent any damage to the components during the assembly of the door assembly group, maintenance plans have been created by the production engineers for the fixtures used.	49
F13	Failure to hinges	The inability of the hinge legs to lock properly results in the door not closing correctly. This issue stems from design flaws in the Soft Close mechanism. The R&D department has made improvements to the Soft Close mechanism, resulting in a reduction in the RPN.	45
F14	Enamel problems in cavity	Detailed studies have been conducted regarding this matter, and the findings can be summarized in the measure and improve phase.	35

Table 2. (*Continued*)

Failure Mode	*Definition*	*Improvement Efforts*	*RPNs after improvement*
F15	Failure to mount the monitor protector to the door group properly	To prevent any damage to the monitor, a visual guide should be created. This guide will provide instructions on how to handle the monitor properly to ensure its safety and integrity.	35
F16	Failure to data cable	After the improvement efforts in the process, the data cable is now securely fixed onto the oven without any bending. This ensures that the cable remains straight and properly connected, reducing the risk of damage or disconnection.	35

Table 3. Factors and coded levels

Factors	*Coded Levels*		
Oven type (A)	X {1 0}	Y {0 1}	Z {-1 -1}
Bulb brand (B)	Current {-1}	New {1}	
Volts (C)	230 {-1 1}	250 {0 -2}	270 {1 1}

In the conducted 36 experiments, the lifespan of each bulb was measured in hours, and the results were recorded. The lifespan test results of the existing and new brand bulbs were analyzed using ANOVA. Considering that the oven model, bulb brand, and voltage variables are categorical, GLM was employed for the analysis. The analysis results are summarized in Table 4 and Table 5.

According to the variance analysis results shown in Table 4, the F-value is 81.70 and the p-value (Prob > F) is less than 0.05, indicating that the model is significant at a 95% confidence level. It is observed that the main factors A, B, C, AB, AC, BC, and ABC, as well as their interactions, are also significant (p-value < 0.05).

Table 4. ANOVA results

Source	*Sum of Squares*	*df*	*Mean Square*	*F Value*	*p-value*	
Model	1.124E+006	17	66141.65	81.70	< 0.0001	significant
A-model	44364.67	2	22182.33	27.40	< 0.0001	
B-bulb	4.303E+005	1	4.303E+005	531.57	< 0.0001	
C-voltage	4.128E+005	2	2.064E+005	254.96	< 0.0001	
AB	18432.67	2	9216.33	11.38	0.0006	
AC	13253.33	4	3313.33	4.09	0.0157	
BC	1.292E+005	2	64614.33	79.81	< 0.0001	
ABC	75978.67	4	18994.67	23.46	< 0.0001	
Pure Error	14572.00	18	809.56			
Cor Total	1.139E+006	35				

In Table 5, the "R-Squared" value is calculated as 0.9872, and the adjusted R-squared value is 0.9751. Both values are close to 1, indicating a high percentage of variance explained by the main factors and interactions in the model. The predicted R-Squared value is also close to the others.

The regression equation obtained for the lifespan test is provided in Equation 1.

$$Y = 1097 + 47.17A_1 - 37A_2 - 109.33B - 130.75C_1 + 5.92C_2 - 30.83A_1B + 8A_2B - 12A_1C_1 + 0{,}5A_2C_1 - 9.33A_1C_2 - 8.17A_2C_2 + 71.92BC_1 - 8.42BC_2 + 35.83A_1BC_1 - 29.67A_2BC_1 + 14.83A_1BC_2 + 25A_2BC_2 \quad (1)$$

The calculations in the regression equation have utilized the dummy variables from Table 3.

To express it more clearly, in Equation 1, it is written as follows:

$A_1 = 1$ and $A_{2=}0$ (for the X model oven), $A_1 = 0$ and $A_{2=}1$ (for the Y model oven), $A_1 = -1$ and $A_{2=} - 1$ (for the Z model oven), $B = -1$ (for the current bulb), $B = 1$ (for the new bulb), $C_1 = -1$ and $C_{2=}1$ (for 230 volts), $C_1 = 0$ and $C_{2=} - 2$ (for 250 volts), $C_1 = 1$ and $C_{2=}1$ (for 270 volts)

For example, for the existing bulb in X model oven at 230 volts, the lifespan is calculated as Equation 2.

Lifespan = 1097 + 47.17(1) – 37(0) – 109.33(-1) – 130.75(-1) + 5.92(1) – 30.83(1)(-1) + 8(0)(-1) – 12(1)(-1) + 0.5(0)(-1) – 9.33(1)(1) - 8.17(0)(1) + 71.92(-1)(-1) – 8.42(-1)(1) + 35.83(1)(-1)(-1) – 29.67(0)(-1)(-1) + 14.83(1)(-1)(1) + 25(0)(-1)(1)= 1525,01 hours (2)

Table 5. R^2 values

Statistics	*Values*
Std. Dev.	28.45
Mean	1097.00
C. V. %	2.59
PRESS	58288.00
R-Squared	0.9872
Adj R-Squared	0.9751
Pred R-Squared	0.9488
Adeq Precision	31.811

Upon examining the residual plots in Figure 5, it can be observed that the assumptions of normality and constant variance are met. The independence of residuals has been verified by conducting the Durbin-Watson Test statistic, confirming that there is no correlation among the residuals.

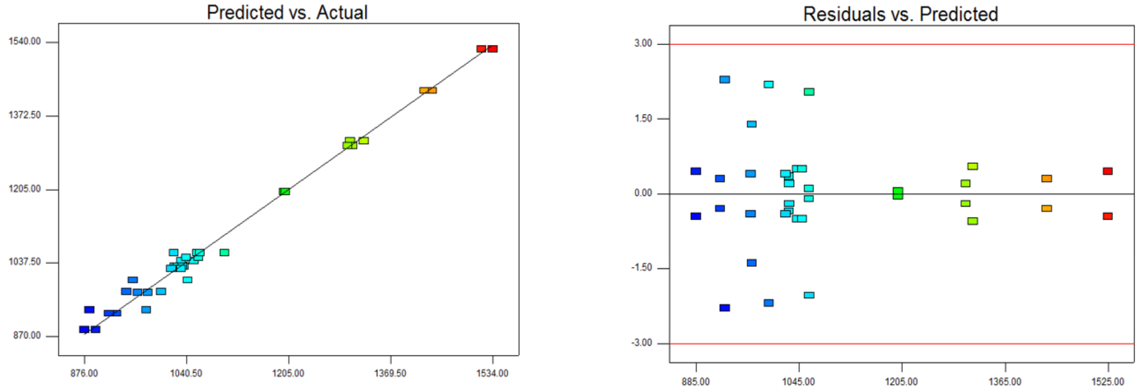

Figure 5. Residual analyses

When the voltage value is 230, in all oven models, both the new and existing bulb brands have exceeded the target value of 1000 hours. It is observed that the lifespan of the existing bulb brand is longer compared to the new one (Figure 6).

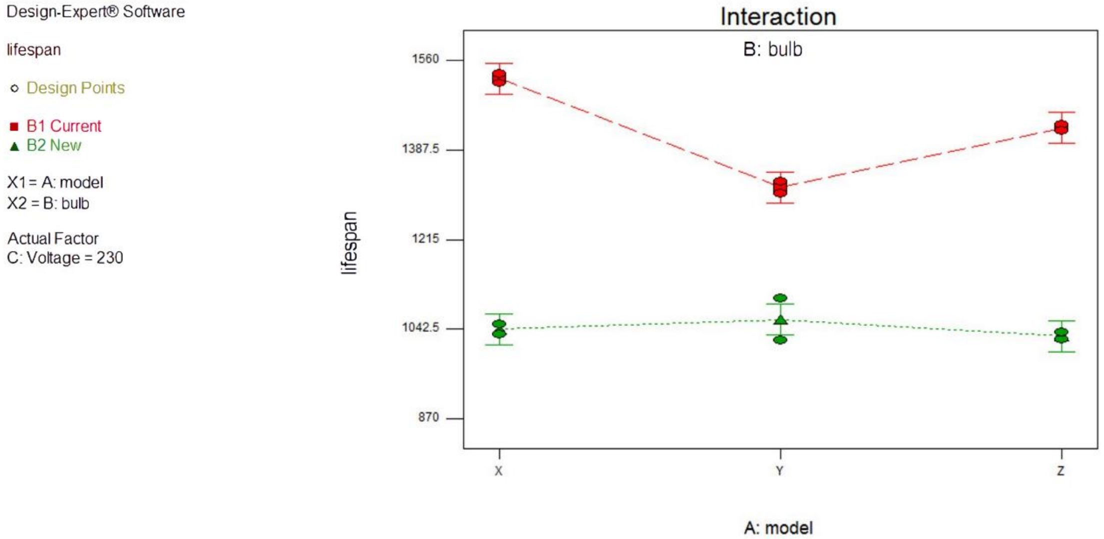

Figure 6. Interaction plots (230 Volts)

When the voltage value is 250, the existing bulb has successfully passed the lifespan test in all oven models, while the new bulb has exceeded the target value in the Z model. The lifespan of the bulbs is longer for the existing bulb in X and Y model ovens, while the new bulb brand has a longer lifespan in the Z model oven. (Figure 7).

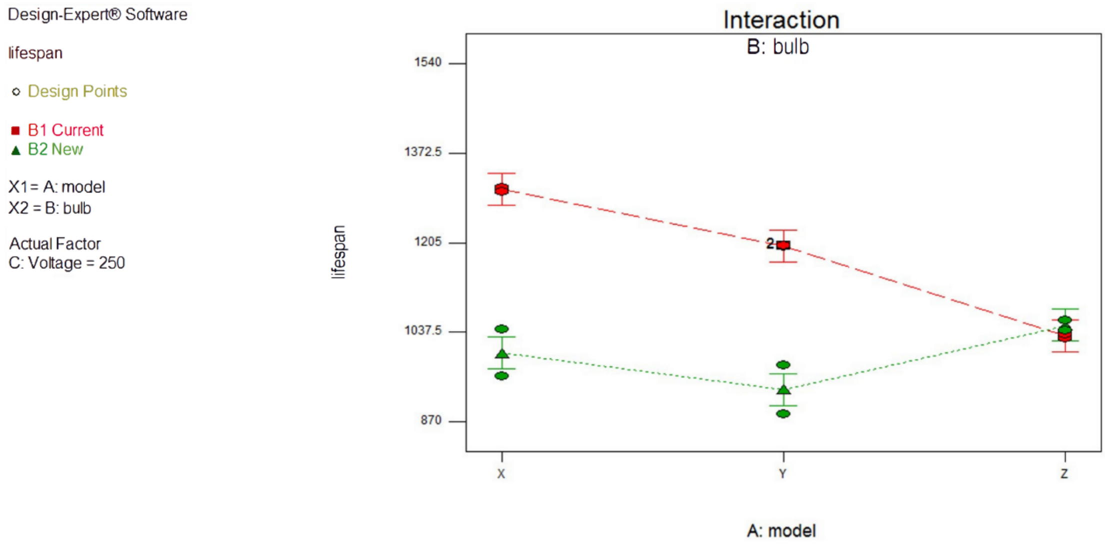

Figure 7. Interaction plots (250 Volts)

When the voltage value is 270, it is clearly observed from Figure 8 that the products tested using the existing bulb brand have a longer lifespan.

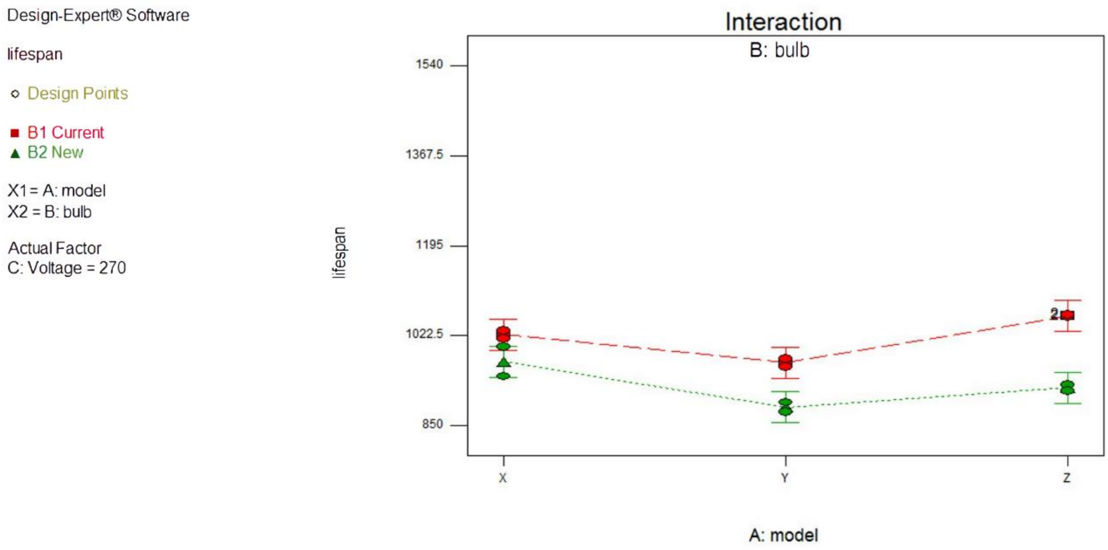

Figure 8. Interaction plots (270 Volts)

After examining the interaction between factors, optimization studies were conducted, and local best solutions were obtained. When the predicted lifespan values of the proposed solutions were examined, the following results were obtained:

- At 230 volts, the lifespan of the new bulb exceeds the target value of 1000 in X, Y, and Z model ovens.
- At 250 volts, only in the Z model oven, the lifespan exceeds the target value.
- At 270 volts, the new bulbs do not reach the target value.
- These findings indicate the optimal conditions for each voltage and oven model combination in terms of the lifespan of the bulbs.

3.4. Control Phase

To validate the local best solutions, verification experiments were conducted. X, Y, and Z model ovens were operated at 230 volts, while the Z model oven was operated at 250 volts, and the lifespan values were recorded. When examining Table 6, the predicted results are presented in column 4, the prediction intervals at a 95% confidence level are presented in columns 5 and 6, and the results of the verification experiments are presented in column 7.

Table 6. Validation results

A	B	C	Predicted Lifespan	Lower PI (%95 CI)	Upper PI (%95 CI)	Validation Results
{1 0}	{1}	{-1 1}	1042	968,79	1115,21	1053
{0 1}	{1}	{-1 1}	1061	987,79	1134,21	1026
{-1 -1}	{1}	{-1 1}	1029	955,79	1102,21	1011
{-1 -1}	{1}	{0 -2}	1050	976,79	1123,21	1032

Based on the results of the validation experiments, when using the new bulb in X, Y, and Z model ovens at 230 volts, and in the Z model oven at 250 volts, the lifespan exceeds 1000 hours. The results obtained from the experiments fall within the lower and upper limits of the prediction intervals. Based on these findings, it is evident that the predictions are reliable.

In these scenarios, the new bulb brand can be used successfully in X, Y, and Z model ovens at 230 volts, as well as in the Z model oven at 250 volts. However, it is not recommended for use in X, Y, or Z model ovens at 270 volts (Table 7). The situations where the new bulb brand can be used are indicated by the (+) symbol, while the situations where it cannot be used are indicated by the (-) symbol.

Table 7. The usability of the new bulb brand

	Volts		
Oven Type	*230*	*250*	*270*
X	+	-	-
Y	+	-	-
Z	+	+	-

As shown in Table 7, the new bulb brand can only be used in X, Y, and Z model ovens in the Turkish market. It can also be used in the Z model oven for the French market. For X and Y model ovens in the French market and X, Y, and Z model ovens in the UK market, it is recommended to use the existing bulb brand. In this case, the estimated annual savings would be around 20,000 Euros instead of 80,000 Euros.

4. CONCLUSION

In today's business landscape, SS has gained significant popularity among organizations across different industries. It primarily emphasizes enhancing production processes to drive improved profitability for the company. Attaining the SS level necessitates a deep understanding of the factors contributing to process variability, conducting thorough cause-and-effect analysis, and assessing associated costs. By employing DMAIC, one of the quality improvement methodologies utilized within the SS framework, organizations can enhance their ability to effectively respond to emerging issues and improve overall process efficiency.

This study demonstrates that organizations can achieve greater success by adopting SS for products that are in the process of being launched, along with the associated improvement efforts. By implementing SS methodologies and DMAIC cycle, organizations can effectively enhance the quality and performance of new products, leading to improved customer satisfaction and business outcomes. The systematic approach provided by SS enables organizations to identify and address potential issues early on, resulting in smoother product launches and increased chances of success in the market.

The implementation of the proposed solutions can result in various benefits not only for the company itself but also for other stakeholders involved in its operations:

- *For the company:* By adopting these solutions, the company can avoid penalties for non-compliance with agreements, reduce production costs, increase productivity, and consequently decrease the amount of work in progress.
- *For customers:* The implementation of these solutions can lead to increased customer satisfaction by improving timeliness and ensuring timely delivery of products or services.
- *For employees:* The solutions can enhance employee comfort and improve organizational efficiency, potentially eliminating the need for overtime work and creating a more balanced work environment.
- *For other entities:* The implementation of these solutions can enable the company to handle a higher volume of orders during peak periods, maximizing business opportunities and benefiting other entities involved in the industry.

In summary, the proposed solutions offer a range of benefits that extend beyond the company itself, positively impacting customers, employees, and other stakeholders in terms of compliance, cost reduction, productivity improvement, customer satisfaction, employee well-being, and increased business opportunities. Introducing employees to SS techniques and establishing a SS culture in small and medium-sized manufacturing businesses can lead to an increase in similar initiatives and the elimination of wastes. By implementing SS, these organizations can improve their operational efficiency, enhance product quality, reduce waste and defects, and ultimately achieve higher customer satisfaction. Additionally, the adoption of SS methodologies promotes a data-driven and problem-solving mindset among employees, fostering a culture of continuous improvement and innovation. This, in turn, can contribute to the overall success and competitiveness of the organization in the market.

Improvements have been made specifically for a new built-in oven with a digital panel, and efforts related to the production processes of other products are not within the scope. However, by extending similar initiatives throughout the organization and establishing a corporate culture, it is possible to enhance the efficiency of processes. The inability to establish a corporate culture and awareness is one of the major barriers for organizations.

In sectors outside the household appliance industry, where inefficiencies and high defect rates are prevalent, similar initiatives can be undertaken by employing statistical tools aligned with quality objectives in future.

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Author Contributions

Ezgi Aktar Demirtaş: Conceptualization, Methodology, Writing-original draft, Modelling *Gamze Yetimler Kostur*: Literature Review, Methodology, Data Curation, Analysis *Mehmet Erol Kara*: Data Curation, Analysis, Writing-review and editing.

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Compliance with Ethical Standards

It was declared by the authors that the tools and methods used in the study do not require the permission of the Ethics Committee.

Ethical Statement

It was declared by the authors that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.

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