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COST OPTIMIZATION WITH INTERNET SUPPORTED FMEA AND FUZZY FMEA ANALYSIS

NESNELERİN İNTERNETİ DESTEKLİ HTEA VE BULANIK HTEA ANALİZİ İLE MALİYET OPTİMİZASYONU

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Abstract

The global competitive environment forces businesses to produce high-quality and low-cost products and they develop strategies in this regard. At the same, production risks should be identified and their effects on quality and cost should be minimized. The FMEA method is a risk analysis method that produces effective results. Traditional FMEA and Fuzzy FMEA analyses were conducted in the machining workshop of an enterprise with a wide range of products and semi-products in this study. Real-time data was obtained with the help of an embedded set of data processing cards, which use IoT technology. These data have been used to identify errors that cause production bottlenecks, and they were obtained without relying on the machine operator. Improvements were made in the riskiest subjects during the three-month analysis, and it was discovered in the cost records that a total reduction of 6% in production costs was achieved. Simultaneously, traditional FMEA and fuzzy FMEA results were compared.

Keywords: Failure Mode and Effect Analysis (FMEA), Fuzzy FMEA, Production, Risk Analyses, Cost Optimization.

Öz

Küresel rekabet ortamı işletmeleri yüksek kaliteli ve düşük maliyetli ürünler üretmeye zorlamaktadır ve bu konuda stratejiler geliştirmektedirler. Aynı zamanda üretimdeki rislerin belirlenerek bunların (bu risklerin) kalite ve maliyete etkilerinin giderilmesi gerekir. FMEA yöntemi risk analizinde etkili sonuçlar veren bir yöntemdir. Bu çalışmada ürün ve yarı mamül çeşitliliği fazla olan bir işletmenin talaşlı imalat atölyesinde geleneksel FMEA ve Fuzzy FMEA analizleri yapılmıştır. Gömülü bir dizi veri işleme kartının desteğiyle çalışan IOT teknolojisi ile gerçek zamanlı veriler elde edilmiştir. Bu verilerde üretimde darboğaz oluşturan hatalar belirlenmiştir ki bu veriler makine operatörüne bağlı olmadan elde edilmiştir. Üç aylık dönem için yapılan analiz ile en riskli konularda iyileştirmeler yapılarak üretim maliyetlerinde toplamda %6 düşüş sağladığı maliyet ile ilgili kayıtlarında gözlemlenmiştir. Aynı zamanda geleneksel FMEA ve fuzzy FMEA sonuçları karşılaştırılmıştır.

Anahtar Kelimeler: Hata Türü ve Etkileri Analizi (HTEA), Bulanık HTEA, Üretim, Risk Analizi, Maliyet Optimizasyonu.

GENİŞLETİLMİŞ ÖZET

Çalışmanın Amacı

Bu çalışmanın amacı, talaşlı imalat biriminde bulunan makinelerden operatörlere bağlı kalmadan makinelerin çalışma durumları, kapasite kullanım süreleri, makinelerin (yatay torna, dikey torna, freze makineleri için) çalışma süreleri, sadece yatay torna makinelerine ait parça sıkılmış durumda bekleme süreleri, boşta bekleme süreleri, çalışma süreleri ve duruş sürelerinin elde edilmesidir. Operatörlere bağlı kalmadan elde edilen veriler doğrultusunda HTEA analizi uygulayarak, en çok hataya sebep olan hata türlerini belirlemek ve en yüksek değere sahip hata türleri için düzeltici & önleyici faaliyetler uygulanarak, maliyetlerin en aza indirilmesi hedeflenmektedir. Geleneksel HTEA verileri elde edildikten sonra Fuzzy-HTEA da uygulanarak RÖS değerlerinin karşılaştırılması hedeflenmektedir.

Araştırma Soruları

Çalışmanın temel sorusu; Hata Türü ve Etkileri Analizi (HTEA) yöntemi uygulayarak Risk Önceliği Sayısı (RÖS) değeri 100'den büyük olan hata türleri için düzeltici ve önleyici faaliyetler uygulandığında, maliyetlerin düşüş gösterdiği oran nedir? Geleneksel HTEA, Fuzzy HTEA RÖS değerlerine göre hata türlerinin büyükten küçüğe doğru sıralanmasında değişiklik var mı? Her iki teknik sonucu ne derece benzer?

Literatür Araştırması

Artan rekabet ortamında çeşitlilik gösteren müşteri isteklerine daha iyi cevap verebilmek için tedarik zinciri yönetiminin gerektirdiklerini etkin ve verimli şekilde yerine getirmek, üretim sürelerini kısaltmak, maliyetleri doğru analiz etmek ve azaltmak, üretim hatalarını en aza indirmek gerekmektedir. Literatürde – Hata Türü Etkileri Analizi (HTEA) – yönteminin üretim sektöründe uygulanması ile ilgili birçok çalışma yapıldığı görülmektedir. Çevik ve Aran (2009), Ghani vd. (2013), Mariajayaprakash ve Senthilvelan (2013), Yee, Ahmed, Quader (2014), Ünğan (2017), Mzougui ve Felsoufi (2019), Hung ve Chen (2019), Lo vd. (2019), Dağcı (2019), Sánchez vd. (2020), Li vd. (2021), Filz vd. (2021).

Yöntem

Bu çalışma kapsamında, endüstriyel mutfak ürünleri imal eden işletmenin talaşlı imalat biriminde ortaya çıkan hatalar, üretim sahasında yer alan kiosklardaki ERP programına girişleri operatörler tarafından yapılmaktadır. Operatörlerin kontrol edilebilmesi için birimde yer alan 12 adet makineye PLC kart yerleştirilmiş olup, anlık makinelerin çalışma süreleri, duruş süreleri elde edilmektedir. Operatörlerin girmiş olduğu veriler ise PLC kartlardan alınan veriler ile karşılaştırılmakta ve kullanıcıya bağlı kalmadan süreç kontrol altına alınmıştır. Operatörler kontrol edildiğini bildiği için yüksek performans ile işlerini yerine getirir hale gelmişlerdir. İmalat atölyesinde 12 adet CNC tezgâh kullanılmaktadır. PLC kartlardan elde edilen veriler ile operatörlerin ERP programına iş emrine bağlı olarak girdiği veriler karşılaştırılır, verilerin doğruluğu kabul edildikten sonra ilgili birimde hem

Geleneksel Hata Türü ve Etkileri Analizi ve Fuzzy HTEA yöntemi uygulanmıştır. Uygulama öncesi ve sonrası toplam üretim maliyeti karşılaştırılmıştır.

Sonuç ve Değerlendirme

Bu çalışma kapsamında, HTEA tekniğin uygulanması sonucunda kaliteli ürünleri düşük maliyet ile tasarlayıp üretmesini, aynı zamanda operasyon maliyetlerini de kontrol altına alarak hatalı ürünlerin müşteriye ulaşmadan en erken önlenmesi hedeflenmiştir. Ayrıca, HTEA tekniği ERP programı ile kolayca entegre edilerek analiz aşamasında doğru ve hızlı sonuçlar elde edilmiştir. HTEA tekniği uygulanması belirlenen riskli yerlerle ilgili yapılan iyileştirmelerle üretim maliyetlerinin düştüğü görülmüştür. Maliyet karşılaştırılmasında üretim miktarı sabit kabul edilmiştir. Ocak ayında 3971 adet parça üretimi yapılmıştır. Ocak ayında hatalı üretilen ürün adedi 129 iken şubat ayında hatalı üretilen ürün adedi 49, mart ayında ise hatalı üretilen ürün adedi 39 ‘dur. Hatalı ürün adet sayısında şubat ayında ocak ayına göre %62 oranında, mart ayında ise %70 oranında azalmıştır. PLC kartlardan ve operatörlerden ayrı ayrı veri akışı elde edilmiş olup, veriler birbirleri ile karşılaştırılmıştır. Mevcut sürecin RÖS değerleri hesaplanmış, değerler büyükten küçüğe doğru sıralanmış ve iyileştirme 16 maddenin öncelikli olarak ele alınması gerektiğine sonucuna varılmıştır. RÖS değerleri Geleneksel HTEA yöntemi ve Fuzzy HTEA yöntemleri ile hesaplanmıştır. Geleneksel HTEA yönteminde RÖS değeri 100’den yüksek olan silindir malzemesinde freze kesim hatası nedeniyle alın kaynağında çatlama, fabrika için uygun kalitede CRNI çubuk tedarik edilememesi, promix karşı yük ürününde ağırlığının düşük olması, mikser mili burcunun alt dış kalınlığının tolerans değerleri dışında olması, O-ring kanalı işlenmemesinden kaynaklı hatalı üretim, üretilen dondurma makinesi haznesinde ezilme olması, delik çapı konumunun hatalı olması, silindir boyunun tolerans dışında olması, CNC tezgaha yanlış CNC programının verilmesi, boyama işleminin teknik dokümanlara uygun yapılmaması, Milkshake check valve şurup bağlantı kafası parçasının eninin tolerans dışında olması, delik çapının tolerans dışında olması, dondurma makinesi ürün ön sacının müşteri isteğine göre uygun boyanmaması, eski revizyonlu programın üretime verilmesi, hammaddenin karıştırılması, üretim hattına yanlış hammaddenin verilmesi hataları için düzeltici ve önleyici faaliyetler uygulanmıştır. Fuzzy FMEA yöntemi ve geleneksel FMEA yöntemi RÖS değerleri karşılaştırılmıştır. İyileştirme öncelikli 16 maddenin üretim maliyetine etkisi de analiz edilmiştir ve üretim maliyetlerinde toplamda %6 düşüş sağladığı maliyet ile ilgili kayıtlarında gözlemlenmiştir.

1. INTRODUCTION

Both the economy and technology rely on production. To better meet changing consumer expectations in an increasingly competitive market, it is critical to meet the needs of the entire supply chain by reducing production times, assessing the process, lowering costs, and avoiding production errors. In an increasingly competitive world, it is no longer enough for businesses to merely produce; they must also be able to satisfy client expectations of efficiency and volume in the quickest period feasible.

In today's machining industry, technical advances connected with computer numerically controlled (CNC) machines, market demand for more complex specific goods, and complex production processes provide a genuine challenge.

Machining is a manufacturing process that involves turning or milling material in layers with cutting tools to produce the required material qualities (surface, size, and form). In a nutshell, the material is cut into the desired shape using computer-controlled cutting tools. Machining is a particularly important manufacturing process since the required material qualities are computed, and the intended products are created digitally with precise dimensions. Unfortunately, it is more expensive than other manufacturing processes, and there is a lot of waste. Companies are constantly trying to meet their customers' needs efficiently and cost-effectively. As a result, they are trying to implement various quality improvement strategies and enhance machining production control systems. They also aim to prevent and eradicate errors to stay competitive by utilizing the knowledge gained from previous mistakes through error analysis methodologies.

Failure Mode Effects Analysis (FMEA) is a risk management strategy that includes error detection and prevention in automated operations, among other things. FMEA predicts possible failures and identifies problems that might have a big impact, such as human errors, equipment difficulties, staff training issues, object misplacement, communication issues, and design faults. For these reasons, FMEA is one of the most widely used error analysis techniques in machining today.

In this study, we examined the types of errors and their consequences in the machining unit of an industrial kitchen goods manufacturing workplace. First, we identified these flaws to reduce induced costs. To achieve this, we used the maps of the computers installed in the manufacturing line equipment. During the research, it was discovered that the machines do not process components when the operators leave them running. The cards were also used as a precaution to check if the devices were operating correctly. On the Programmable Logic Controller (PLC) panel, the data acquired instantaneously via these cards were listed. Then, using the C# programming language, they were translated into a more formal and comprehensive format. The data in this continuous flow format could be captured via communication protocols, and the unit cost data were computed based on the periods used. Utilizing the

ERP interface located near the CNC machines and used by the operators who gather the data provided by the PLC cards, the process of starting the workstation begins as soon as the operators start the operation and stops when the operation is finished. The volume of faulty goods and the cause of the fault are easily detectable in the event of faulty production. At this point, depending on the data supplied during the quality control operation, error analysis would be performed using the FMEA approach. The connected ERP program is also used to assess the types of errors. Following this approach, we conducted a conclusive study on preventing errors before they occur. The factors that cause human errors, as well as total production costs, were examined thoroughly, before and after. As a final step, we performed a comparison between the calculated unit cost database and the data obtained from the PLC cards.

2. LITERATURE REVIEW

To better respond to changing customer demands in an increasingly competitive environment, the supply chain management requirements must be met quickly and successfully; production times must be reduced; costs must be correctly analyzed and reduced and production errors must be minimized. The literature contains numerous studies on the application of the Fault Mode Effects Analysis (FMEA) method in the manufacturing industry. In the study of Çevik and Aran (2009), the FMEA was used in a company that manufactures pistons, The study detected ten different types of errors, three of which had RPN values above 100. It was decided that the first three errors with high ROS values should be dealt with in the first stage, and the remaining seven errors should be dealt with in the second stage. The ROS values were reduced below 100 after corrective and preventive actions for the first three errors were determined. Customer complaints decreased by 47.4 percent as a result of the measures implemented (Çevik & Aran, 2009).

The loading and unloading effects of the coated carbide cutting edge during milling were researched by Ghani et al. (2013). Feed rate, depth of cut, coolant application, and cutting speed are the milling factors that impact coated carbide tool failure. The most significant factors in coated carbide tool failure and fatigue for milling titanium alloy are cutting speed and depth of cut. Because of their brittleness, carbide tools were found to be shattered in the study. Since carbide is a brittle material by nature, the cutting speed should be reduced to 120m/min if this sort of carbide cutting tool is to be used. It was also suggested that employing ultra-fine carbide cutting tools with sintering methods like nitriding, as well as novel coatings like HT-Ti(C, N)/k-Al2O3, TiSiCN, and CrSiCN, might improve carbide cutting tool qualities (Ghani et al., 2013).

Mariajayaprakash and Senthilvelan's (2013) research focused on a power outage in an Indian sugar refinery. The most serious issue in the sugar factory was boiler failure, resulting in a loss of output. Faults were commonly seen in the screw conveyor of the boiler fuel delivery system, and rarely in the boiler grille. To discover and eliminate boiler problems that occurred consistently was the main goal of their study. The Failure Mode and Effect Analysis was used to find the most relevant factors that caused boiler failures. The following were the outcomes: Firstly, Taguchi's Method was demonstrated to increase the quality of the drum feeder during the process at the lowest feasible cost. Second, the Ishikawa (Cause and Effect) Diagram was shown to be quite helpful in outlining all the probable factors impacting the drum feeder's quality during operation. Third, during the procedure, the fuel parameter was demonstrated to have a considerable impact on the quality of the drum feeder. Fourth, it was possible to predict the best fuel type, moisture content, engine load, and silo level. Fifth, the expected error range for drum failure during operation was 1.37 <1.86 <2.35. The optimum level of boiler component failure was determined with a 95% confidence range (Mariajayaprakash & Senthilvelan, 2013).

Various statistical tools and techniques, such as histograms, control charts, Pareto charts, flow charts, and cause-effect charts, were used in the study by Yee, Ahmed, and Quader (2014) to enhance process performance and product quality at a car-door glass manufacturing firm. The findings revealed that process behavior and capability have a significant relationship, because the characteristics of the process are important in establishing its capability. While the tempering procedure was the most challenging, the back glass was chosen as the product to be studied. The tempering procedure was found to have a rejection rate of 9.49 percent, compared to 5.91 percent for cutting and 3.38 percent for thermal printing. Separate solutions such as vocational training, repair, pre-process control, and adjustment were offered for difficulties such as inappropriate bending speed, low-quality work preparations, inexperienced workers, and uneven heating (Yee et al., 2014).

Ünğan (2017) identified error types in the delivery of raw materials and supplementary materials, incoming quality management, storage, and interim shipping and packaging processes, all of which are sub-processes of a company that manufactures stamps, springs, and derivative products in the automotive and metal processing industries. The study's goal was to advise management in taking steps to avoid making such mistakes. Measures to prevent various mistake types and their impacts were determined in the study. According to the findings of the study, raw and auxiliary material acceptance, inbound quality control, stocking, and intermediate shipments were enhanced by 52.6 percent, while the packing process improved by 54.3 percent (Ünğan, 2017).

A solution that combines the Advantages of Expected Fault Detection (AFD) and FMEA approaches was offered by Mzougui and Felsoufi (2019). The defect detection process was improved with this technique, and FMEA analysis was used despite the lack of cost information. The suggested method incorporated focal points, failure hypotheses, and scenarios. Additional elements such as cost and sustainability were employed to enhance error priority and categorization. The addition of weighting variables was recommended in this study since the Traditional Risk Priority Score (RPN) has been highly criticized in many studies, and weighing variables increased the accuracy and sensitivity of the analyses. Anticipated failure detection (AFD) identified possible problems and assisted engineers in assessing risks. Failure detection was enhanced, and the efficacy of the demolition analysis and action plans was boosted because of these two additional factors: cost and sustainability. However, the findings were lower when weighting was applied to the Risk Priority Number (RPN) computation, and the threshold values had to be adjusted to make critical analysis more acceptable. The severity, probability, and detection values were multiplied in the traditional Risk Priority Score (RPN) calculation, but this article added weighted values in the calculation as well. There was no consideration of the weighted form of severity, probability, or determination (Mzougui & Felsoufi, 2019).

Hung and Chen (2019) suggested a new AIN (Aluminum nitride) ceramic substrate metallization process in their study, based on the laser-coated copper (LPC) technique rather than the current ceramic substrate manufacturing method. In the LPC research and development phase, the root causes of process failure were considered beforehand to avoid possible process failure. A defect analysis model was created to lower the cost and time required to solve product process problems by addressing the root causes. The traditional AlN metallization was compared with the laser radiation-coated copper method. Additionally, three different methods, selective chemical copper, selective electroless nickel, and electroless gold, were discussed. These applications include process simplification, precision design, easy production of three-dimensional extrusions, and green manufacturing. Several flaws were detected throughout the AIN metallization process of electroless copper plating. Scrap losses were traced back to factors such as top coating and contamination. Better results were obtained by increasing the time spent rinsing with water and an alcohol solution to remove the particulate contaminant because FMEA analysis prevented these errors (Hung & Chen, 2019).

FMEA was used in a study by Lo et al. (2019) to improve machine tool reliability, identify error types, and prevent risk. Results of the hybrid model and the traditional FMEA method were compared. Furthermore, FMEA-MCGDM approaches were contained in the hybrid model. MCGDM multi-criteria group was utilized in the FMEA error mode and effects analysis. First, the R-BWM (weighted best-worst method) was used to calculate the criteria. This was a straightforward and efficient method of calculating ROS values. Second, the R-TOPSIS method was used to categorize the different types of errors. As a result of the method's application, the noise and vibration problem was highlighted as the most important aspect that required adjustment. The findings are expected to be valuable in the creation and refinement of product design plans along with defect prevention measures. Although it addresses some of the flaws in the original FMEA research, researchers claim that more of its obstacles need to be addressed (Lo et al., 2019).

FMEA was used for the entire process, from raw material procurement to product shipment in the study of Dağcı (2019), to prevent errors in a machining business. It was observed that raw material acceptance and distribution, machine processing and manufacturing, purchasing, leveling, measurement monitoring, shipping, and external processes were all very influential in productivity. When comparing the number of scrap products in 2018 to the number of scrap products by type of defect in the first four months of 2019, it was discovered that an incorrect NC program gave the machine 47.05 percent of the error type, while incorrect information gave the operator 25% of the error type. In addition, 87.01 percent of the thickness was out of tolerance (thinner), 87.09 percent of the large hole diameter was erroneous, and the hole position was incorrect. After the analysis, the burring error type on the part was reduced by 42.85%, the part error type was reduced by 71.42 percent, and the size decrease error type was reduced by 62.5 percent. Overall, the old revision program's running error type was reduced by 100% (Dağcı, 2019).

Sanchez et al. (2020) set out to investigate the use of the Activity-Based Costing (ABC) system to offer relevant cost information to enterprises that produce and sell IoT-based goods. As a result of this research, the cost of a smart wind generator was determined to be US$ 6,091.76. If indirect costs were not applied to each product, the cost would be 7.9% lower (Sanchez et al., 2020).

Li et al. (2021) used an AHP-FMEA technique to investigate the failure of floating offshore wind turbines. Fifteen fault situations were uncovered throughout the research. Corrective and preventative strategies were found to cut fault propagation pathways and limit fault effects. The most important system of the floating offshore wind turbine is the wind turbine itself (with an RPN of 0.44), then the mooring system (0.18), the floating foundation (0.17), the tower, and the transition components (0.16). In addition, broken mooring lines and 14 other failure modes were identified as failure risks. The study revealed that experts' RPNs differ, demonstrating that FMEAs are subjective methods influenced by personal judgments. Experts are selected from diverse backgrounds, and the accuracy of the AHP-FMEA results needed to be confirmed by conventional methods (Li et al., 2021).

In the Study of Filz et al. (2021), a data-driven FMEA technique using industrial investment products that apply deep learning models to historical and operational data was carried out. A case study from the aviation sector was used to examine this method. Because the possibility of failure estimation was not the only aspect related to the expected risk, FMEA was performed on the employees to study the many types of mistakes in greater depth. Because data-driven error estimation is so accurate, components are only changed when necessary, allowing them to last longer. Failures of parts or components can be foreseen by utilizing the linked approach and immediate RPN values (Filz et al., 2021).

3. METHODOLOGY

The failure type and its consequences in the machining unit of an industrial kitchen goods manufacturing facility were investigated in this study. The research was conducted in a real-time production scenario at a machining workshop, where computer-connected cards were installed on 12 machines. The operators entered the mistakes that occurred in the machining unit of the company that manufactures industrial-type kitchen goods into the ERP application in the kiosks positioned in the production area. PLC cards were installed in 12 machines in the unit to monitor the operators, and the working hours and downtimes of the machines were collected. The operators' data was compared to the data received from the PLC cards, and the process was brought under control without the need for user intervention. Because the operators were aware that they were being watched, they would perform at a high level. In the production workshop, there are 12 CNC machines. The data from the PLC cards were compared to the data entered by the operators in the ERP program based on the work order. Before and after the application, the entire manufacturing cost was examined.

3.1. Conventional Failure Mode Effects Analysis (FMEA) Method

FMEA is an analytical approach that evaluates and prevents known or probable mistakes in a product or process based on prior experiences and technology (Besterfield et al., 1999; Söylemez, 2006). It assesses the consequences of current or potential failures, defines measures to decrease or avoid the development of these errors, reevaluates the possibility of errors after the actions are implemented, and documents the whole process of analysis (Gönen, 2004).

3.1.1. Procedure of Failure Mode Effects Analysis (FMEA) Method

FMEA implementation can be divided into the following steps. These steps are briefly explained as follows:

Step 1: Organize the system's functions into a hierarchical structure. Divide the system into subsystems, each with its own set of components.

Step 2: Determine the types of errors and their consequences for each component. Assign the severity - degree of importance (S) of each error type based on its effects on the system.

Step 3: Determine the causes of the various error types and the likelihood of each error occurring. Assign the probability of occurrence of each error type the degree of occurrence - probability (O).

Step 4: Make a list of methods for detecting errors and assess the system's ability to detect them before they happen. For each error type, assign a detectability rate (D).

Step 5: Determine the risk priority number (RPN) and set priorities for attention.

$$RPN=S*O*D \tag{1}$$

Table 3.1 shows the scales used to calculate the three risk factor values (Stamatis,1995).

Step 6: Take the suggested actions to improve the system's performance.

Step 7: Develop a tabular version of the FMEA report.

Table 1. Types of Potential Defects and Their Main Causes in The Machining Unit

Severity (S)	**Rating**	**Detectability (D)**	**Rating**	**Probability of occurrence (O)**	**Rating**
No	1	Almost impossible	10	Almost never	1
Very slight	2	Remote	9	Remote	2
Slight	3	Very slight	8	Very slight	3
Minor	4	Slight	7	Slight	4
Moderate	5	Low	6	Low	5
Significant	6	Medium	5	Medium	6
Major	7	Moderately high	4	Moderately high	7
Extreme	8	High	3	High	8
Serious	9	Very high	2	Very high	9
Hazardous	10	Almost certain	1	Almost certain	10

Source: Stamatis (1995)

3.1.2 Failure Modes in Machining Processes

The machining process shapes pieces with a specific volume, dimensions, and surface quality by cutting (chipping) them with specific equipment. The cutting equipment rotates at a specific speed and feed rate to process the workpiece in machining. Shaping occurs when the machining of a workpiece creates tension in a specific part of the workpiece. Specifically, the chip removal process is a mixed one that is established using tools appropriate to the workpiece's mechanical characteristics (chip shrinkage, breakage, deformation, hardening of the workpiece's surface, cutting tool wear, deformation, friction, and heat generation). In most cases, mechanical energy is employed in the machining process. Chemical, electrical, and water energy are also employed in several innovative production processes (plunge erosion, laser cutter, water jet, and so on) (Güngör & Paçal, 2004).

Machining methods and the cutting tools used in these techniques are varied. Some machining methods involve shaping and planing, turning, drilling, milling, crochet and broaching, reaming, grinding, sawing and leveling, and boronizing (Çiğdem, 2006).

Cutting speeds and feed rates for the tool and workpiece should be determined after the machining method is chosen in planning. Tool breakage, employee injury, machine failure, faulty operation, part deterioration, rework, and delivery delays are the risks associated with incorrect selection, use, and adjustment of these factors (Güngör & Paçal, 2006)

Operators are in high demand because it is desirable to access data via work order tracking. However, if the operators do not correctly enter the work start and end times into the system, it will be impossible to obtain the required information. Alternatively, machine operation data can be obtained without relying on the operators due to the PLC cards installed on the CNC benches in the production units. In this case, the operator can be monitored, and the machine's working times can be precisely determined.

3.2. Fuzzy Failure Mode and Effect Analysis (F-FMEA)

Fuzzy logic is a useful technique for estimating the output response from given input data. Business commentators use a fuzzy logic system for a variety of reasons, including the following (Kusumadewi, 2002):

1- The concept of fuzzy logic is simple to understand. In the Fuzzy Interface System, the fundamentals of mathematics are also simple.

2- This system is adaptable and can tolerate data inaccuracies in the datasets.

3- This methodology can model complex non-linear functions in a short time.

4- This method can also help specialists gain experience without the extra training needed.

5- This method will work using simple natural language.

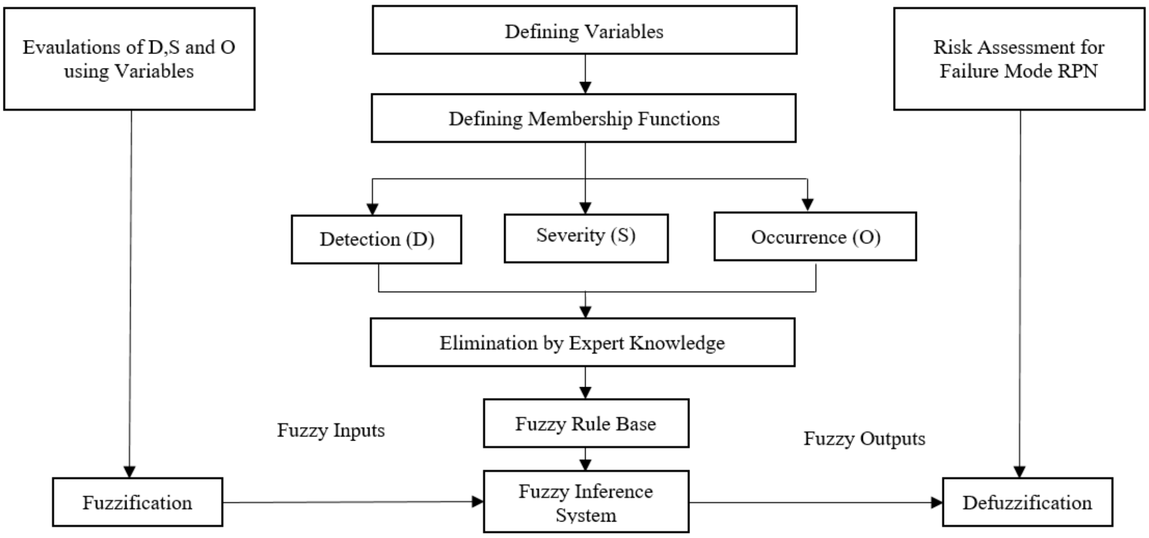
The fuzzy methodology is an important theory that manages information breakdown (Wang, 2008). Fuzzy-FMEA fuzzifies the risk-indexed parameters Occurrence (O), Detection (D), and Severity (S) with appropriate membership functions. This is a knowledge-based approach, and Fuzzy if-then statements can be developed with proficiency and knowledge (Tay & Lim, 2006). The RPN value is obtained by de-fuzzing the fuzzy conclusion. In Figure 1, the fuzzy concepts of fuzzification, defuzzification, and fuzzy rule base are depicted.

Fuzzification: It's the process of converting a precise quantity into a fuzzy number. This is accomplished by declaring various known crisp and deterministic quantities to be completely nondeterministic and highly uncertain. This uncertainty may have arisen because of ambiguity and imprecision, leading to the variables being represented by a membership function because they are fuzzy ("Difference Between Fuzzification and Defuzzication", ty., par. 1).

Defuzzification: It is the inversion of fuzzification, in which the mapping is done to turn crisp results into fuzzy results, however, in this case, the mapping is done to turn the hazy results into crisp ones. This procedure can generate a nonfuzzy control action that depicts the distribution of an inferred fuzzy control action ("Difference Between Fuzzification and Defuzzication", ty., par. 3).

Fuzzy Rule Base: The fuzzy rule base explains the amount of the system criticality for any combination of input variables. In general, a linguistic form of the combination of input variables may be generated, for example, by employing rule-based logic like "if-then," "or-else," and so on. This can be achieved in two ways: first, through a specialist's familiarity and proficiency, and second, through the Fuzzy based model's process (Yang, 2007).

Fig. 1. Flow Chart of Fuzzy Technique



Source: Tay & Lim (2006)

3.3. Programmable Logic Controller (PLC)

PLCs receive data from sensors in the field and process it according to the program on the PLC. As a result, they have complete control over all devices in the field. PLCs are industrial computers with INPUT (input) and OUTPUT (output) units for receiving and writing information from field devices, as well as communication units for communicating with field devices that can work in tandem with SCADA (remote control and monitoring system) (Mirzaoglu & Saritaş, 2008).

PLCs, auxiliary relays, time relays, and counters are all examples of command control elements that can be replaced with this system. The software in these systems performs all operations such as counting, timing, and sorting. As a result, using PLC for all types of sophisticated automation challenges produces rapid and highly trustworthy outcomes.

In a sense, the Internet of Things approach is being used. The data received from the machines through PLC cards is presented promptly on the management screen via the interface, and it is retrieved in real-time. The information is used in the appropriate decision-making processes. One of the key components of Industry 4.0, the Internet of Things (through communication protocols of PLC cards), has been integrated into the system.

3.4. Kitchen Equipments Manufacturing Company

Cookers, open buffets, refrigerators, ice cream machines, dishwashers, cold rooms, furniture, laundry, and other kitchen products are among the company's product range, which is the subject of this study (workbench, washing bench, hood, wall shelf, service shelf, tray transport trolleys, floor grid, material cabinet, premix counters, temperature cabinet, etc.). Within the company, it can produce all of the products that should be in a hotel's kitchen. It employs 330 people and covers an area of 76000 m2 to provide services to leading companies.

The machining unit has 12 CNC machines. These machines are, in order:

Horizontal lathes: DMG MORI CLX450, DMG MORI ECOTURN310, DMG MORI NLX2500/700, TAKISAWA EX710

Vertical lathes: VLGH950, HONOR VL86H, HONOR VL66M

3-axes mills: FRONTIER MCV1166, 2 pcs WELE AQ1265

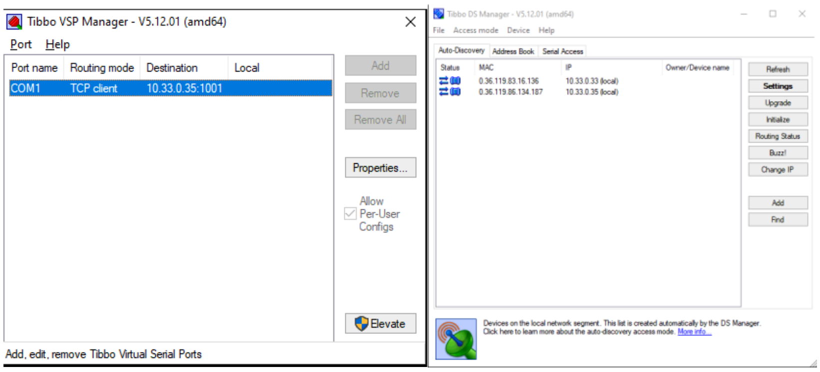
5-axes mills: DMG MORI ECOMILL50, DMG MORI CMX50Ues.

3.5. System Integration: PLC, ERP, C# with WinProLadder

PLC cards were installed on each machine in the unit, and the Tibbo Ethernet Converter was used to make the machines' working periods instantaneously available. A CNC machine with a Tibbo converter is installed in the machining unit. The company's IT staff provided information on unused IP numbers for the commissioning of the Tibbo Ethernet converter, and the communication interfaces are given below. The machine is matched with the IP information given to the VSP Manager in the DS Manager interface, and the IP definition is made with the VSP Manager interface. After the establishment of communication with the machines, the necessary diagrams in the WinPro-Ladder PLC program were created to receive the determined data from the machines.

The C # program was used to write the necessary codes for communication protocols. The data was transferred to the ERP program after it became understandable as a result of communication protocols. Instead of keeping the data executable (.exe) form in the C# program, it was moved to the ERP software so that it could be accessible.

Fig. 2. Tibbo VSP Manager and DS Manager



Port name	Routing mode	Destination	Local
COM1	TCP client	10.33.0.35:1001	

Add, edit, remove Tibbo Virtual Serial Ports

Status	MAC	IP	Owner/Device name
	0.36.119.83.16.136	10.33.0.33 (local)	
	0.36.119.86.134.187	10.33.0.35 (local)	

Devices on the local network segment. This list is created automatically by the DS Manager.
Click here to learn more about the auto-discovery access mode. More info...

Fig. 3. PLC Port Opening Codes

```
/*BIT DEĞERLERİ*/
    <add key="PORTU" value="COM1"/>
    <add key="DATABIT" value="7"/>
    <add key="STOPBIT" value="1"/>
    <add key="HIZI" value="9600"/>
    <add key="PARITY" value="Even"/>
    <add key="ISTASYON" value="01"/>


            if (veri_oku.Enabled == true)
            {
                if (!ComPort.IsOpen)
                {
                    ComPort.PortName = Convert.ToString(ConfigurationManager.AppSettings["PORTU"].ToString());
                    ComPort.BaudRate = Convert.ToInt32(ConfigurationManager.AppSettings["HIZI"].ToString());
                    ComPort.DataBits = Convert.ToInt16(ConfigurationManager.AppSettings["DATABIT"].ToString());
                    ComPort.StopBits = (StopBits)Enum.Parse(typeof(StopBits), ConfigurationManager.AppSettings["STOPBIT"].ToString());
                    ComPort.Parity = (Parity)Enum.Parse(typeof(Parity), ConfigurationManager.AppSettings["PARITY"].ToString());
                    ComPort.ReadTimeout = 500;
                    ComPort.WriteTimeout = 500;
                    try
                    {
                        if (Register.portAc)
                        {
                            ComPort.Open();
                            Register.ComPort = ComPort;
                        }
                    }
                    catch (UnauthorizedAccessException ex)
                    {
                        MessageBox.Show(ex.Message);
                    }
                }
            }
```

The BIT values can be defined as the connection data bits of the port parts. These data bits serve as a means of communication. REGISTERS must be defined to identify from which machines the data comes.

4. FINDINGS AND RESULTS

4.1. Calculation of RPN Values of the Current Process

Raw material acceptance, raw material delivery, machinery, production, and processes conducted outside the unit are the five processes that directly affect production. The acceptance of raw materials, the process of delivering raw materials to production, machine malfunction issues, and other processes and operations are all covered in depth. Because errors arising from transactions made by supplier companies are common, they were deeply analyzed as part of this process.

Evaluating only operational and machine failures within the scope of production problems leads to errors. As a result, FMEA was used to examine the raw material acceptance process as well as the process of delivering the raw material to production. Table 4.1 lists the errors that occur in the processes, which are classified based on the process.

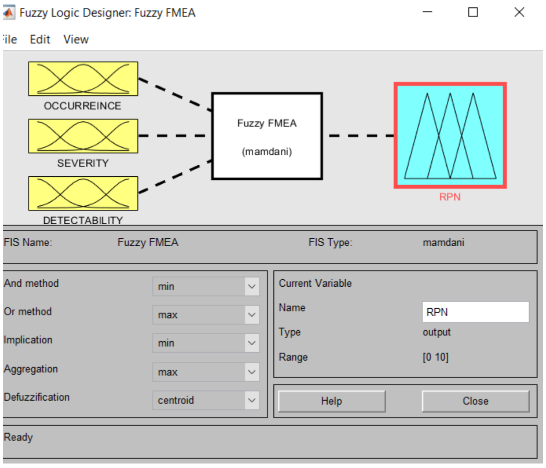
Fuzzy FMEA model has 3 inputs and 1 output. Triangular membership function, which is the most preferred membership function in practice (Sen 2004), was used (Figure 4). In the article, risk priorities were determined with the FFMEA method and the MATLAB fuzzy tool. Fuzzy logic rule base was determined by the opinion of experts (Figure 5). The surface viewer for the severity, probability and detectability values of the FFMEA analysis in the model is shown in figure 6-7-8.

Table 2. The Possible Failure Modes and Root Causes in The Machining Process

Process	**Failure Mode**	**Root Cause of Failure**	**Conventional FMEA RPN**	**Rating**	**Fuzzy FMEA RPN**	**Rating**
Raw Material Acceptance Process	Quality	Defective product, received from the supplier company	60	31	4,24	31
		Incorrect material order to supplier company	12	40	2,95	40
		Failure of the raw material input quality control officer to fulfill his duty	9	41	2,95	41
	Warehouse	Mixing of raw materials	108	14	5,42	15
		Damage of the incoming material while placing it on the shelf in the warehouse	80	20	5	22
		Incorrect raw material barcode labeling by the warehouse manager	72	26	5,76	11
Process of Giving Raw Material to Production	Production	Giving the wrong raw material to the production line	108	15	5,42	16
		Giving the missing amount of raw material to the production line	28	33	4,17	35
		Giving too much raw material to the production line	14	39	3,99	36
Machines	Failure of horizontal lathe machines line	Machine failure due to pneumatic pressure drop	80	21	5	23
		Machine failure due to lack of cooling water	28	34	4,2	32
		Smartkey device failure	28	35	4,2	33
		Machine failure due to leakage in hydraulic oil pump	84	17	4,93	27
		Motor (servo) failure	96	16	5,23	21
	Failure of vertical lathe machines line	Machine failure due to pneumatic pressure drop	80	22	5	24
		Machine failure due to lack of cooling water	72	27	5,33	18
		Malfunction due to low slideway oil	84	18	4,93	28
		C axis failure	16	37	3,48	38
	Failure of 5-axes milling machines line	Machine failure due to lack of cooling water	72	28	5,33	19
		Machine failure due to pneumatic pressure drop	80	23	5	25
		Machine failure due to low press oil	28	36	4,2	34
		Machine probe read error	16	38	3,24	39
		Malfunction due to clogged filters	64	29	4,93	29
	Failure of 3-axes milling machines line	Machine failure due to pneumatic pressure drop	80	24	5	26
		Malfunction due to low slide way oil	84	19	4,93	30
Production Process	Failure CNC program	Inputting the wrong CNC program to the CNC machine	200	8	6,45	8
	Production	First piece trial error	30	32	3,55	37
		Inability to supply appropriate quality CRNI rods for the factory	350	2	7,71	2
		Giving the old revised program to production	128	13	5,67	13

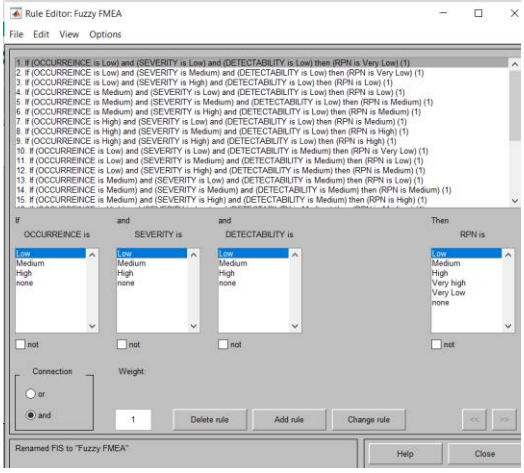
		Faulty production due to not machining the O-ring Groove	280	5	7,05	5
		The mixer shaft bushing's lower outer thickness is out of the tolerance values	320	4	7,2	4
		Crushing in the produced ice cream machine chamber	252	6	7,05	6
		Butt-weld cracking due to milling cut error in cylinder material	400	1	7,97	1
		Lack of weight in the Premix counter load product	350	3	7,71	3
	Quality	The width of the milkshake check valve syrup connection head part is out of tolerance	160	10	6,45	9
		Incorrect hole diameter position	252	7	7,05	7
		Hole diameter out of tolerance	150	11	5,6	14
		Burr in the produced part	24	12	6,45	10
		Cylinder length out of tolerance	252	9	5,76	12
		Inappropriate roller surface cleaning	80	25	5,42	17
		Twisting error on front sheet of ice cream machine	60	30	5,31	20
Processes Performed Outside the Unit	Painting	Inadequate painting of the front sheet of the ice cream machine according to the customer's request	150	8	6,45	8
		Incorrectly conducted dyeing process	162	32	3,55	37
	Marking	Incorrect branding of the company name of the ice cream machine	80	2	7,71	2
		Incorrect marking process	64	13	5,67	13

Fig. 4. Fuzzy system design for FFMEA.



FIS Name: Fuzzy FMEA
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: RPN
Type: output
Range: [0 10]
Ready

Fig. 5. Fuzzy FFMEA Rule Base

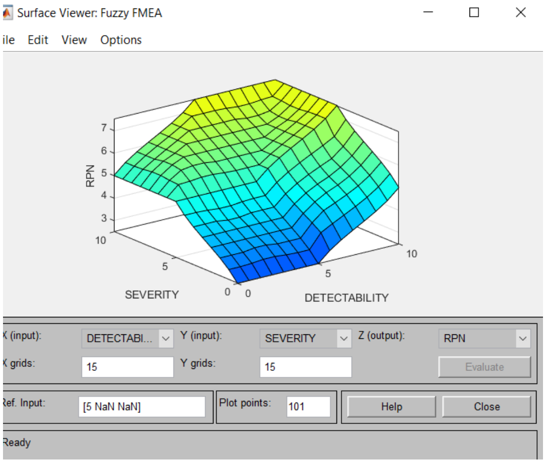


1. If (OCCURREINCE is Low) and (SEVERITY is Low) and (DETECTABILITY is Low) then (RPN is Very Low) (1)
2. If (OCCURREINCE is Low) and (SEVERITY is Medium) and (DETECTABILITY is Low) then (RPN is Very Low) (1)
3. If (OCCURREINCE is Low) and (SEVERITY is High) and (DETECTABILITY is Low) then (RPN is Low) (1)
4. If (OCCURREINCE is Medium) and (SEVERITY is Low) and (DETECTABILITY is Low) then (RPN is Low) (1)
5. If (OCCURREINCE is Medium) and (SEVERITY is Medium) and (DETECTABILITY is Low) then (RPN is Medium) (1)
6. If (OCCURREINCE is Medium) and (SEVERITY is High) and (DETECTABILITY is Low) then (RPN is Medium) (1)
7. If (OCCURREINCE is High) and (SEVERITY is Low) and (DETECTABILITY is Low) then (RPN is Medium) (1)
8. If (OCCURREINCE is High) and (SEVERITY is Medium) and (DETECTABILITY is Low) then (RPN is High) (1)
9. If (OCCURREINCE is High) and (SEVERITY is High) and (DETECTABILITY is Low) then (RPN is High) (1)
10. If (OCCURREINCE is Low) and (SEVERITY is Low) and (DETECTABILITY is Medium) then (RPN is Very Low) (1)
11. If (OCCURREINCE is Low) and (SEVERITY is Medium) and (DETECTABILITY is Medium) then (RPN is Low) (1)
12. If (OCCURREINCE is Low) and (SEVERITY is High) and (DETECTABILITY is Medium) then (RPN is Medium) (1)
13. If (OCCURREINCE is Medium) and (SEVERITY is Low) and (DETECTABILITY is Medium) then (RPN is Low) (1)
14. If (OCCURREINCE is Medium) and (SEVERITY is Medium) and (DETECTABILITY is Medium) then (RPN is Medium) (1)
15. If (OCCURREINCE is Medium) and (SEVERITY is High) and (DETECTABILITY is Medium) then (RPN is High) (1)

OCCURREINCE is: Low, Medium, High, none
SEVERITY is: Low, Medium, High, none
DETECTABILITY is: Low, Medium, High, none
RPN is: Low, Medium, High, Very high, Very Low, none
☐ not ☐ not ☐ not ☐ not
○ or
● and
Weight: 1

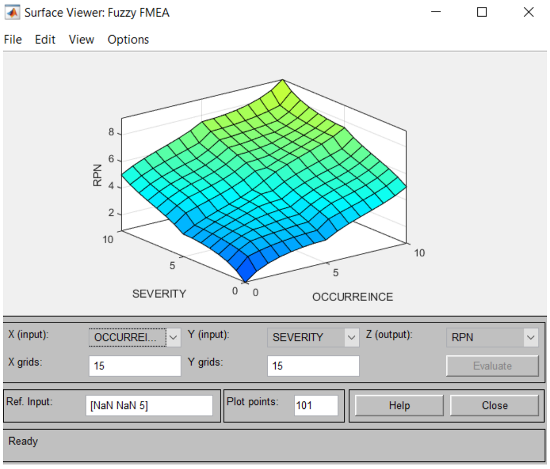
Renamed FIS to "Fuzzy FMEA"

Fig. 6. Suface Viewer for Severity and Detectability



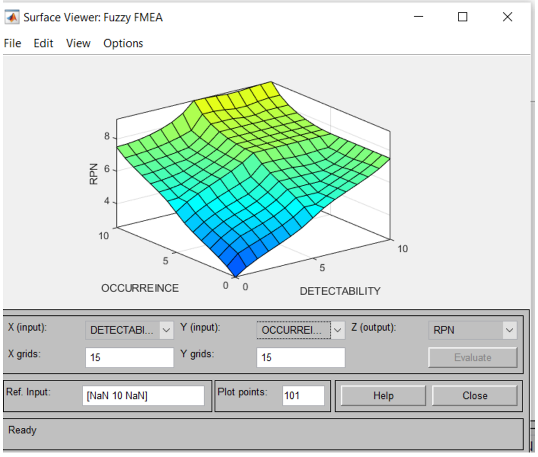
X (input): DETECTABI...
Y (input): SEVERITY
Z (output): RPN
X grids: 15
Y grids: 15
Ref. Input: [5 NaN NaN]
Plot points: 101
Ready

Fig. 7. Surface Viewer for Severity and Occurrence



X (input): OCCURREI...
Y (input): SEVERITY
Z (output): RPN
X grids: 15
Y grids: 15
Ref. Input: [NaN NaN 5]
Plot points: 101
Ready

Fig. 8. Surface Viewer for Occurrence and Detectability



X (input): DETECTABI...
Y (input): OCCURREI...
Z (output): RPN
X grids: 15
Y grids: 15
Ref. Input: [NaN 10 NaN]
Plot points: 101
Ready

According to the findings, the following are the most important possible error types (RPN≥100):

- Butt weld cracking due to milling cutting error in cylinder material
- Inability to supply appropriate quality CRNI rods for the factory
- Lack of weight in the premix counter load product
- The mixer shaft bushing's lower outer thickness is out of the tolerance values
- Faulty production due to not machining the O-ring Groove
- Crushing in the produced ice cream machine chamber
- Incorrect hole diameter position
- Inputting the wrong CNC program to the CNC machine
- Cylinder length is out of tolerance (12)
- The dyeing process is not done according to the technical document.
- The width of the syrup connection head of the milkshake check valve is out of tolerance.
- Hole diameter is out of tolerance
- The product front sheet of the ice cream machine is not painted according to the customer's request.
- Putting the old, revised program into production
- Mixing of raw material
- Giving the wrong raw material to the production line

Fuzzy FMEA and traditional FMEA results were found to be similar. Unlike FMEA, FFMEA draws attention to the " Incorrect raw material barcode labeling by the warehouse manager " issue.

5. CONCLUSIONS

FMEA helps manufacturing companies design and produce high-quality, low-cost products while also preventing defective products from reaching the customer. FMEA technique analysis can be easily integrated with the ERP program and provides accurate and quick results during the analysis phase. It has been observed that production costs have decreased as a result of the use of the FMEA technique. The production amount information is a constant parameter in the cost comparison. A total of 3971 pieces were produced in January. In January, there were 129 defective products; in February, there were 49, and in March, there were 39. There were 62% fewer defective products in February than in January, and 70% fewer in March.

Data flow was obtained separately from PLC cards and operators, and the results were compared. The current process' RPN values were calculated, and the values were ranked from largest to smallest, and it was decided that 16 items should be improved first.

Traditional FMEA and Fuzzy FMEA methods were used to calculate ROS values. In the traditional FMEA method, corrective & preventive actions have been implemented for the following errors: Cracking in butt weld due to milling cutting error in cylinder material with RÖS value higher than 100, inability to supply appropriate quality CRNI rods for the factory, lack of weight in the premix counter load product, the lower outer thickness of the mixer shaft bushing to be out the tolerance values, faulty production due to o-ring malfunction, produced ice cream machine bins to be smashed, incorrect hole diameter position, cylinder length to be out of tolerance, CNC machine to be received wrong CNC program, the dyeing process to be done without considering the technical document, the width of the milkshake's head check syrup connection valve to be out of tolerance, the hole diameter to be out of tolerance, the front sheet of the ice cream machine product to be painted without considering the customer's request, giving the old revised program to production, mixing the raw material, giving the wrong raw material to the production line. Overall, using the fuzzy FMEA method, the impact of 16 high-priority items on production costs was also investigated, and it was discovered in the cost records that they resulted in a 6% reduction in costs.

As part of the Internet of Things, PLC cards are extremely useful in the manufacturing sector, where real-time data can be obtained using protocols written on them.

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