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FAILURE MODE AND EFFECTS ANALYSIS AND DATA MINING APPROACH TO QUALITY IMPROVEMENT IN MANUFACTURING INDUSTRY

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A B S T R A C T

It is important to analyze the failures and eliminate their root causes to ensure customer satisfaction and increase quality in businesses FMEA analysis is a widely used method to analyze potential or potential failures. Data mining methods can also investigate the causes of these failures. In this study, it is aimed to determine and eliminate the root causes of failures with FMEA and data mining in a machining company. FMEA and data mining have been applied to improve the quality of the business and eliminate the root causes of failures. IBM SPSS Modeler and Weka programs were used in data mining research. As a result of the research, the types of failures with a risk priority number value above 100 were reduced to an acceptable level by making improvements.C5.0 algorithm, one of the data mining classification algorithms, was applied with IBM SPSS Modeler and the factors affecting the failures of the personnel were determined. As a result of the research, it was determined that the most important reason was whether the personnel were professional or not. According to the classification result made with WEKA J48 algorithm, the most effective factor causing the personnel to make mistakes was determined as the training status of the personnel.

1. INTRODUCTION

Since the beginning of human history, people have always been trying to produce something in order to continue their lives and to meet their needs. The standard of living with production all over the world has a linear relationship, so the higher the amount, variety, quality of production, the higher the standard of living in the country. As in all over the world, manufacturing industry is important both technologically and economically in our country. The way to be a developed and competitive country is to produce at minimum time and cost, maximum quality, on a productivity basis when fulfilling customers' needs and expectations. With the advancement of technology (with the emergence of CNC stalls and computers) and increased production awareness, businesses began to produce better quality productions, at less cost and in a shorter time. Technological developments in production have first manifested itself in the machining industry, which is complex and difficult among sectors. Machining; it is a production method designed by removing chips by turning or milling until the part reaches the desired standards, either through metal/plastic parts or with the help of cutting tools. Although it is expensive and low in efficiency compared to other manufacturing methods, the

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quality of the produced product is higher and most importantly the variety of produced products is more advantageous than other production techniques.

In the metalworking industry, which manufactures with machining method, businesses serve quite wide sectors today, and sectors such as automobiles, defense industry, aerospace, energy, electronics, etc. can be sampled. The machining sector has an important place in the world and in our country due to its services as raw products and semi-finished inputs to almost all sectors. According to data from the Central Bank, the share and value of exports in the machining sector between 2014 and 2020 in Turkey is in Table 1 (Tuik, 2021). With an export amount of $8.856 billion, 45.22% of Turkey's exports were carried out by the machining industry in 2020. By the time 2020, if we evaluate exports related to the machining industry sector in Turkey, there has been a steady increase in small amounts.

Table 1. Turkey machining sector export value

Year	Machining Industry (Excluding Machinery and Equipment) (Thousand $)	Share in Exports of Turkey (%)
2014	8 243 802	4.95
2015	7 177 171	4.75
2016	6 865 449	4.6
2017	7 482 327	4.54
2018	8 447 882	4.76
2019	8 723 474	4.82
2020	8 856 361	5.22

As in every sector, all businesses follow various quality improvement policies and implement production control methods to be able to manufacture in high quality and efficiency as soon as possible with the lowest cost and to be competitive with other businesses in the same sector, especially in the machining sector. Businesses that want to ensure their continuity are constantly working to ensure that these negativities are not repeated by obtaining lessons learned from previous mistakes with failure analysis. In addition, in the machining sector, the correct or incorrect occurring of the final product, the raw material used even friction during shipment is having an effect. In addition, the raw material used, even the friction that occurs during shipment, affects the correct or incorrect emergence of the final product in the machining industry. However, no matter which method is determined, the source of failure cannot be expressed precisely and reliably, unless a result is revealed statistically and with data mining. Studies such as data mining can extract meaningful relationships from within the data stacks that seem meaningless and their impact on quality in businesses can be examined.

Various studies have been carried out using the Failure Mode and Effects Analysis method in order to improve quality in the manufacturing sector from the past to the present. The FMEA discipline, which dates back to the Second World War and was developed by the US army, was first named in 1949 as “MIL-STD-1629A” (Procedures for Performing a Failure Mode, Effect and Criticality Analysis - Procedures on Failure Type Effects and Risk Analysis). Considering that the FMEA method is a reliable analysis with this procedure, it was started to be used to determine the possible effects of process failures, and then it was applied in flight controls (Carlson, 2012). The decision was made to implement the method because it was undesirable that any failure would occur due to the high cost of the manned space project, which was included in the work of NASA, between 1960 and 1965, known as Apollo. In the following years, the FMEA method was used to identify and eliminate problems in the US Armed Forces. FMEA was first applied in the industrial field by the Japanese company NEC in 1975, and then it became widespread worldwide (Stamatis, 2006).

In the periods when FMEA technique first appeared, studies were carried out to inform engineers (Legg, 1978), and then worked to determine the degree of importance in order to assist engineers (Kara-Zaitri & Fleming, 1997). In a 1993 study, the importance of FMEA technique in Total Quality Management (TQM) was investigated and the most rational way to target perfection was to prevent the emergence of failure (Kasa & Boran, 1993). In 2003, studies were conducted on the creation of probability, impact and violence rating tables (Pillay & Wang, 2003). In the machining industry (Pantazopoulos & Tsinopoulos, 2005), in the food industry (Arvanitoyannis & Savelides, 2007), in the pump manufacturing industry (Konguraja & Gobi, 2015), in the production of automotive parts (Aguiar et al., 2015), in the automotive industry (Doshi & Desai, 2017) and in the textile industry (Polat, 2019), in the mobile phone manufacturing (Oliveira et al., 2019), measures were taken to minimize the risk of failures by applying the FMEA method. With FMEA application on failures in sheet metal flattening on machine tools, he emphasized that more than 55% of the system's risk of failure was caused by human failure, and that failures could be reduced by reducing workload as well as providing work training (Zhao & Wang, 2019). With FMEA, manufacturing failures are widely analysed, but variables that can cause failure can also be investigated by data mining. In the food industry (Kusiak, 2000), in the machining industry (Mason et al., 2017), in wheel manufacturing (Wang, 2013), in drilling product manufacturing (Foguem et al., 2013), in printed circuit board production (Sim et al., 2014), in metal casting enterprises (Perzyk et al., 2014), in the production of electronic home appliances (Kang et al., 2017), in the automotive industry (Nemeth & Michalconok, 2017), in the pharmaceuticals industry (Rahane et al., 2019), the factors affecting the occurrence of undesirable conditions were investigated to improve production quality by using data mining techniques.

In this study, FMEA and data mining were first introduced. Then, the faulty parts of an enterprise producing in the machining industry were handled, a failure analysis was made with the FMEA technique, and then the factors affecting the personnel's mistakes in the enterprise were investigated with IBM SPSS Modeler and Weka data mining programs. As a result of the analyses, measures to be taken to prevent the appearance of faulty parts have been presented.

2. MATERIAL AND METHODS

2.1 Failure Mode and Effects Analysis

There are some keywords to know about the FMEA method used in failure analysis and some keywords used in the application, which are briefly given below (Liu et al., 2015; Robin et al., 2017);

Failure: Failure to complete a function as planned.
Violence; the degree of impact of the failure on the customer.

Violence: The degree of impact of the failure on the customer.

Probability: The degree value for the possibility of failure occurring is the degree value that corresponds to the probability that the failure cause with another expression may cause the failure type.

Detectability: It is the degree of preventing a possible failure before it reaches the customer through the existing controls performed in the system.

Risk Priority Number (RPN): It is obtained by multiplying the severity, probability and detectability degree values. With RPN, failures in the system are ranked according to risk priorities and corrective and preventive actions are implemented in line with this priority (Sharma et al., 2005).

RPN = Violence x Probability x Detectability

The main purpose in the implementation of the FMEA method in companies is to reduce the potential failures in the process and even to eliminate the bad effects that may occur by preventing the occurrence of failures (Ho & Teng, 1996).

When the benefits of FMEA to any system or process are evaluated; It is seen that it contributes greatly to the formation of high-reliable companies in the market that design and produce high quality products with low cost and produce or offer a quality service to the customer at an affordable price, which prevents negative situations from being reflected to the customer by controlling the observed activities (Yılmaz, 2000).

Failure Mode and Effects Analysis: The system is covered under four basic headings: System FMEA, Design FMEA, Process/Process FMEA and Service FMEA. Definitions of FMEA types are briefly as follows;

System FMEA: In the early stages of the design, it focuses on determining the types of failures that occur due to the deficiencies existing in the system by analyzing the systems together with the sub-systems and increases the efficiency of the system (Belu et al., 2013).

Design FMEA: Before starting the production of products, it is applied to detect failures from design in advance.

Process FMEA: The design phase is applied to analyze the process to identify possible types of failures caused by process problems related to the production of a finished product and to prevent them from disappearing or occurring. Existing or potential failures in the process in process FMEA; manpower, method, machine, material, measurement and environmental elements should be taken into account when assessing the impact of the product, process quality and reliability (Stamatis, 2006).

Service FMEA: It focuses on any existing or potential service issues that may occur during service delivery.

Considering the FMEA implementation recommendations of Pillay and Wang, the method can be carried out in five steps (Pillay & Wang, 2003);

- **FMEA initial studies:** With the established FMEA team, the product or process to be analysed is determined and the scope and application process of the application is examined,
- **Studies for failures in the system, design, process or service performed in FMEA:** Possible types of failures, possible failure effects and possible causes of failures are determined, and existing controls are also defined,
- **Assessment of failure types:** The probability of occurrence, severity, and detectability degree is determined, and in this direction, RPN values

are calculated,

- **Assessing the number of risk priorities:** It determines if it is necessary to take action, and if necessary, what measures to take,
- **Implementation of preventive activities and calculation of new RPN value:** The improvement provided by the implementation of preventive activities is evaluated and FMEA continues constantly.

While determining RPN values in FMEA, severity, probability and detectability parameters take a value between 1 and 10. The rating scale used when determining these parameter values is given in Table 2, Table 3 and Table 4, respectively, for probability, severity and detectability.

Table 2. Probability parameter rating scale

Probability of Emergence	Fault Probability	Degree
Very high	In every 1000 parts ≥ 100 parts	10
High	In every 1000 parts = 50 parts	9
	In every 1000 parts = 20 parts	8
	In every 1000 parts = 10 parts	7
Medium	In every 1000 parts = 2 parts	6
	In every 1000 parts = 0.5 parts	5
	In every 1000 parts = 0.1 parts	4
Low	In every 1000 parts = 0.01 parts	3
	In every 1000 parts = 0.001 parts	2
Very low	0	1

The frequency of possible failures is rated between 1 and 10, considering the frequency of realization. If possible failure rates are between the two degrees specified on the chart, the greater rating is taken into account (Akın, 1998).

Table 3. The rating scale for the violence parameter

Effect	Effect on the Customer	Degree
Dangerous Effect without Warning	Failure occurs without any warning. It is a security failure. It shows a dismatch with the legal requirements.	10
Dangerous Effect with Warning	Failure is caused by an alert. It is a security failure. Demonstrates incompatibility with legal requirements.	9
Very high	The product does not perform its basic function.	8
High	The product works with poor performance, customer dissatisfaction is very high.	7
Medium	The product performs its basic function but has not reached the desired quality. Customer is dissatisfied.	6
Low	The product fulfills its basic function but has not achieved the desired quality. The customer is somewhat dissatisfied.	5
Very low	The product does not work comfortably while performing its basic function. Failure can be detected by the vast majority of customers (more than 75%).	4
Insignificant	The product does not work comfortably while performing its basic function. The failure can be detected by 50% of customers.	3
Very Trivial	The product does not work comfortably while performing its basic function. Failure can be detected by very careful customers (25%).	2
Absent	It has no noticeable effect.	1

The severity parameter is rated between 1 and 10. While determining the degree of severity, customer feedback, records kept in the system / process and knowledge of the FMEA application team are used. The degree of violence is not affected by measures and controls.

The detectability parameter is rated according to the current control types, and the rating scale for the parameter is included in Table 4. There are three types of inspections/controls: A, B and C for detectability. These are; A: Fault-free, B: Equipment measurement, C: Can be defined as manual examination.

Table 4. Detectability parameter rating scale

Detectability	Criteria	Control Type			Degree
		A	B	C	
Almost impossible	There is no possibility to detect in the controls.			■	10
So hard	It is very difficult to detect in the controls.			■	9
Hard	It is difficult to detect in controls.			■	8
Very little	It is very rare to detect in controls.			■	7
Little	Detection in controls is scarce.		■	■	6
Medium	It is medium to detect in the controls.	■	■		5
Above the Middle	Detection in controls is above the middle.	■	■		4
High	Detection is high in controls.	■	■		3
Very high	It is very high to detect in controls.	■	■		2
Almost Certain	Detecting in the controls is almost certain.	■			1

The detectability parameter is graded by taking the control types between 1 and 10 into consideration, by brainstorming with the FMEA implementation team and by benefiting from the experiences of the people. It is decided which types of failures are prioritized in accordance with the identified RPN values.

Different methods can be applied to determine the types of failures to be taken, which are as follows (Akın, 1998);

- The failure type with the first two or three RPN values is examined,
- 25% with the highest RPN value in failure types are examined,
- A level is determined and failure types with the RPN value above this limit are examined. Although this limit depends on the highest RPN value, it can be 100-150,
- According to the comparison of severity and RPN values, the type of failure to be examined can be determined with the help of Table 5 below.

Table 5. Violence vs RPN comparison

Severity	RPN ≥
10	40
8 – 9	90
5 – 6 – 7	120
1 – 2 – 3 – 4	150

As stated in the table, if the severity level of the failure type is 10, in case of RPN value to be equal to 40 and above 40, measures should be taken for the related failure type.

When the RPN values are compared, the following results appear (Ford Motor Company, 1998).

- $RPN \leq 40$; No risk,
- $40 \leq RPN \leq 100$; The risk is uncertain,
- $RPN \geq 100$, $O \geq 9$, $S \geq 9$, $S \geq 9$; There is a risk.

In case of more than one type of failure with the same RPN value, first of all, the type of severity , and then the type with high detectability should be evaluated (Wang et al., 2009).

2.2 Data Mining

Data mining is a huge discipline in itself, but it is still part of the so-called information discovery in databases. Information discovery from the database is the process of extracting useful information from the data. In this process, data stored in different types are tried to be made meaningful by data mining technique. Data mining is a discipline built on statistics, artificial intelligence and machine learning science. Data mining tools and methods are based on statistical techniques. Artificial intelligence, on the other hand, contributes to the solution of problems based on the principle of thinking like a human with different methods than statistics. The third science, machine learning, enables the analysis of existing data and making decisions as a result of this analysis by using statistical and artificial intelligence algorithms in computer systems (Ersöz, 2019).

It is a technique used to obtain information from data with a general definition of data mining. To describe it with a broader expression; data mining; It is the function of analyzing the fields of statistics, mathematics, machine learning and computer applications using combination techniques, and summarizing the results in a meaningful way to reveal the unknown, unseen and unconventional relationships, patterns, certain structures and trends in large data stacks (Friedman, 1997). In data mining applications, businesses should act in line with their own processes, but the purpose of the application should be clearly stated for successful data mining. Regardless of the purpose of data mining, it has to go through some basic processes. The data mining process is as follows;

- Determining the problem
- Understanding and preparing data
- Modeling
- Evaluation of the model and presenting the findings obtained as a result of the model
- Tracking the model

The goal of data mining is to search for previously unknown relationships and to compare the appropriate methods for analysis. The most suitable data mining tool may not be the tool with the best data mining algorithms or the most advanced tool that gives the best accuracy in prediction (Nisbet et al., 2017). Some of the most used data mining programs in the world; IBM SPSS Modeler (Clementine), R, Python, Knime, Weka, SAS Enterprise Miner, Statsoft Statistica Data Mining & Predictive Analytics, Mozenda's Data Mining Software, RapidMiner, Tanagra, Oracle etc. (Ersöz, 2019).

3. DESIGN/METHODOLOGY/APPROACH

In this study, data from the company established in Ankara in 2007 was used. The company provides services to leading organizations in the defense and aerospace industries (Tübitak-Sage, Aselsan, Roketsan TAI) by carrying out machining of critical structural parts. The company, which carries out manufacturing activities in accordance with aviation standard (AS/EN9100:2016), has the capacity to produce an average of 10,000 pieces per month, offers a total of 38 personnel, 13 CNC counters and 3 CMM counters, including 6 white collar personnel in an area of 1400-meter square. This business, which provides services to its customers by machining, also carries out all stages from the supply of raw materials to the product it will produce, from the production of the finished product to the delivery of it in accordance with customer requests. In this study, a team was created in the enterprise for FMEA, which was carried out as a team work. The members of the created team are selected from people in units that can directly affect production. These team members are: technical manager, business development and productivity engineer, quality management engineer, purchasing officer, quality control chief, CAD-CAM personnel, manufacturing chief, production operator and team house personnel. With the FMEA team created, failures that occurred or may occur during the manufacturing process were determined by brainstorming. The measures taken with the FMEA team cover all company personnel.

In the study, failure analysis was carried out with FMEA technique by addressing the faulty parts of a business that produced in the machining sector first and then investigated the factors that affected the failure of the staff in the business through IBM SPSS Modeler and Weka data mining programs. As a result of the analyses, measures and improvements were presented to prevent the appearance of faulty parts.

For this study, a manufacturing business in Ankara connected to OSSA defense and aviation clustering was discussed. An application team of experienced personnel has been established for this work within the business. The data used in the study are the data obtained by analyzing the main processes of the business using brainstorming technique, together with the non-compliance records kept in the business in 2018.

2018 non-compliance records contain descriptive information about all non-compliance in the business within a year. For example; type of failure, root cause of failure, type of production, number of scraps, shifts, personnel, etc. can be given as information. Research in the FMEA method, the risks / threats obtained as a result of analyzing both 2018 data and business processes with the brainstorming technique were discussed. In data mining, records for 2018 were used. As part of the FMEA application, existing and possible failures were detected primarily in the business, and then action was proposed to bring the RPN value to an acceptable level after the RPN values were detected.

As part of data mining, IBM SPSS Modeler data mining C5.0 and Weka J48 classifier algorithms were used and 2018 record and factors that affected staff to make mistakes were analyzed. The methodological approach created for FMEA and data mining applications discussed in this study is included in Figure 1 as a flow diagram.

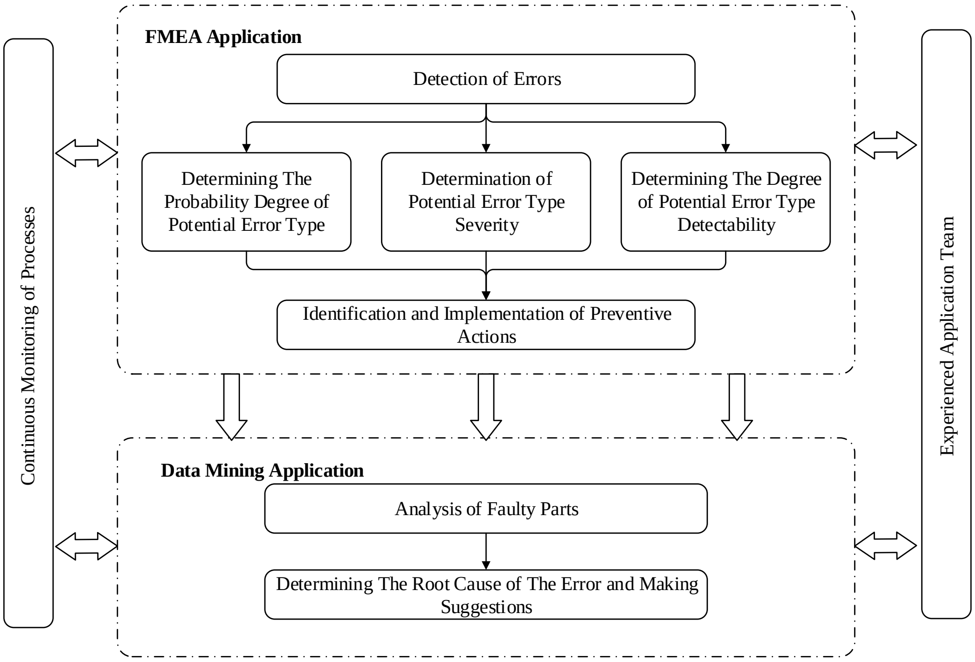

Figure 1. FMEA and data mining application flow diagram

The processes discussed have been constantly observed and the application team consisting of experienced personnel has been supported at every stage of the application. In this context, primarily FMEA application and then data mining application were performed.

4. FINDINGS

In this study, first of all, the fault analysis was made with the FMEA technique for the faulty parts that occur in an enterprise. During the machining process, non-compliance caused by human, machine, method, environment, materials and measurement may occur in the operation, and the underlying failure causes of these improprieties are different for each component. The components that are effective in the occurrence of failures in machining enterprises related to the manufacturing process are mentioned in Appendix 1 with the fishbone diagram.

Within the scope of the application, the auxiliary processes are evaluated under eight processes that directly affect production, and these processes are: purchasing process, raw material acceptance process, process of production of raw materials, machine processing/manufacturing process, leveling process, measurement control process, external process and shipping process.

In 2018, the numbers of parts shipped by the enterprise on monthly basis classified according to customers by performing the above mentioned eight processes are given in Table 6.

Table 6. Number of parts shipped monthly for 2018

Months	A Enterprise	B Enterprise	C Enterprise	D Enterprise	E Enterprise
January	1753	3488	1436	73	-
February	1377	4519	1348	146	57
March	1096	7549	1292	-	16
April	2707	4926	2895	30	472
May	1221	10305	521	-	1247
June	699	5252	120	7	2243
July	558	4684	2707	52	2030
August	597	3211	2182	-	1600
September	230	7039	1323	-	180
October	7845	9000	1155	-	-
November	4587	11223	341	-	-
December	889	4465	299	-	-

In 2018, it is observed that the total number of parts shipped to all customers of the business were 122987, while the average monthly shipment of 10248 pieces was shipped. When the company's failure records are examined, it is observed that the total number of scrap pieces during the production of 2018 is 968 units, which amounts to an average of 80 scraps per month.

Failures occurred during 2018 were analyzed with FMEA and 11 failure types were found as a result of the analysis. Among the types of failures, it was determined that the most scratched failure was the large hole diameter with 349 units. Table 7 includes types and number of failures that occurred in 2018.

Table 7. Failure types and numbers for 2018

Failure Type	Number of Failure
Large Hole Diameter	349
Thickness Out of Tolerance (Thin)	307
Setting Part is Incorrect	139
Hole Position is Incorrect	56
Awarding wrong NC Program to the Clerk	41
Misinformation to the Operator	30
Decrease in Measure	28
Burr in the Piece	13
Running the Old Revisioned CMM Program	2
Coating is not Suitable for Technical Document / Damage to the Part	1
Other	2

When the failures encountered were observed, 95% of the process was found to occur in the manufacturing/machine processing activity. All processes were evaluated by brainstorming with the FMEA application team and in addition to the types of failures available for each process, potential types of failures were determined and the RPN values related to them were determined. A total of 31 types of failures have been identified, including the current and potential for the eight processes evaluated under FMEA. Possible types of failures that are above the acceptable risk level with FMEA application, respectively; the thickness is out of tolerance (thinner), the diameter of the hole is large, the position of the hole is wrong, the size is reduced, the wrong NC program is given to the machine, the operator is given wrong information, running the old revisioned program, the coating-painting process is not done in accordance with the technical document / damage to the part and burrs on the piece. In accordance with the determined failure types, the RPN values (RPN≥100) related to the most probable types of failures for the enterprises are given in Table 8.

Table 8. Failure types determined by FMEA application and RPN values

Types of Failures	RPN
Thickness Out of Tolerance (Thinner)	280
Large Hole Diameter	280
Incorrect Hole Position	200
Decrease in Size	200
Giving the Wrong NC Program to the Machine	175
Giving Wrong Information to the Operator	175
Running Old Revised Programs	160
Coating-Painting Process not Compliant with The Technical Document / Damage to the Part	150
Burrs on the Piece	120

When the value of RPN is considered to be 100 or higher, the types of failures are divided according to the processes as follows. Fault types for machine processing/manufacturing process; the fact that the thickness is out of tolerance (thinner), the hole diameter is large, the hole position is faulty, the machine is given the wrong NC program, the operator is given incorrect information. Types of failures related to the leveling process; is the decrease in size and burr in the piece. Dimensional control process failure type is the operation of the old revised program. The type of failure related to the external process is that the coating-painting process is not done in accordance with the technical document/damage to the part.

The potential failure type determined by the FMEA implementation team, the effect of the potential failure type, the severity, the causes of the potential failure, the degree of probability, the current control activity, the degree of visibility and the RPN value are given in Appendix 2.

4.1 Determination and Implementation of Preventive Activities

For these types of failures with a RELAY value of 100 or more, preventive activities taken in conjunction with the FMEA application team are given in Appendix 3. New risk priority number values are given in Table 9 in accordance with the preventive actions taken by evaluating the existing and potential types of failures by the FMEA implementation team using the brainstorming technique.

Table 9. Failure types and new RPN values

Types of Failures	**RPN**	**NEW RPN**
Thickness Out of Tolerance (Thinner)	280	100
Large Hole Diameter	280	100
Incorrect Hole Position	200	100
Decrease in Size	200	80
Giving the Wrong NC Program to the Machine	175	75
Giving Wrong Information to the Operator	175	75
Running Old Revised Programs	160	20
Coating-Painting Process Not Compliant With The Technical Document / Damage To The Part	150	30
Burrs On The Piece	120	48

The following are preventive activities related to the thinner production thickness, i.e. non-tolerance, large hole diameter and faulty hole position.

- Production of the operator in accordance with the operation plan,
- Displaying the values that the operator should measure on the part in the operation plan and recording the found value,
- Awareness training for the personnel and implementation of the reward system,
- Keeping quality control measurement intervals short on risky parts and
- There are activities to provide vocational training to the personnel, and these activities have started to be implemented in the production enterprise.

With the introduction of preventive activity, the RPN values of 280,280 and 200 respectively for failure types were reduced to 100.

The preventive work on the issuance of the wrong NC program to the production machine is given below.

- Approval of the NC program to be used by the operator by the production chief,
- Vocational training for CAD-CAM staff and
- Activities to create and follow up NC program list have been implemented.

With the introduction of preventive action, the RPN value was reduced from 175 to 75.

Preventive work on misinformation to the operator is given below.

- Transferring information to the operator with the operation plan has been implemented.

With the introduction of preventive activity, the value of RPN has been reduced from 175 to 75.

The preventive studies on the operation of the old revisioned program are given below.

- Creation of CMM program list,
- Revision monitoring and
- Awareness training to the staff has been implemented.

The RPN value has been reduced from 160 to 20 with the introduction of preventive action.

Preventive works related to the type of failure of coating-painting process not being in accordance with the technical document / damage to the part is given below.

- Purchase of external process services from companies that have a customer approval or a high-quality assessment score,
- The quality control chief checks the parts coming from the external process for the second time and
- Decisions taken by the quality control chief to approve parts coming from the external process with a stamp on the work order were put into practice.

The RPN value was reduced from 150 to 30 with the introduction of preventive action.

Preventive studies for burrs on the part and size reduction failure types are given below.

- After leveling, the parts are checked by the experienced leveling staff and approved via the work order file and
- The decision to provide vocational training to levelling personnel has been implemented.

With the introduction of preventive activity, The RPN values of 120 and 200 were reduced to 48 and 80 respectively.

With the implementation of preventive activities in the operation, RPN values have decreased to acceptable risk levels, but are kept under constant control. As a result of the implementation of preventive activities in 2019, it has been determined that the quality improvement studies have benefited from the evaluation made at the end of the first four months.

4.2 Analysis of Failures with Data Mining Method

The analysis of the factors that affect the personnel's mistake in data mining and business was performed using IBM SPSS Modeler and Weka and the findings were evaluated.

The data to be analysed for the application are faulty parts records for 2018. The application uses 448 non-compliance (production failures) records. As a result of examining the records of non-compliance, it was observed that 17 variables were found to be important criteria for detecting failures. These variables are; "Failure type", "Root cause of failure", "Type of production", "Number of failures", "Shift", "Month of failure occurrence", "Day of failure occurrence", "Staff", "Staff age", "Staff "experience", "Training status of staff", "Marital status of staff", "Number of children of staff", "Professional certificate of staff", "Customer to which the faulty part belongs", "Effect of the failure on the quality score" and "Material type for the faulty part".

Factors that affect staff's failure were analysed in the IBM SPSS Modeler data mining program with the C5.0 Decision Tree Algorithm and the J48 Decision Tree Algorithm in the Weka data mining program.

Classification of factors that affect staff to make mistakes; while the dependent variable is personnel, the arguments are; failure type, failure root cause, type of production (FAI/Seri), failure number, shift, the day of the failure and month, staff age, experience, education status, marital status, number of children, whether the personnel have a professional certificate, material type, impact of the failure on the quality score and customers. Model achievements related to classifier models made in IBM SPSS Modeler and Weka programs are given in Table 10 below.

Table 10. C5.0 and J48 algorithms accuracy rate

	IBM SPSS Modeler	**WEKA**
Algorithm	C5.0 Decision Tree Algorithm	J48 Decision Tree Algorithm
Right	430	422
False	18	26
Total	448	448
Accuracy rate	98.98%	94.19%

The accuracy ratio of analyses made with data mining programs is reliable and closely values with each other. However, the accuracy of the C5.0 result in the IBM SPSS Modeler program was higher.

C5.0 Decision Tree Algorithm Analysis

When the C5.0 algorithm examined the factors that affect staff's failure, it was observed that the personnel certificate was the most important factor in making mistakes for the personnel. C5.0 decision tree model finding screenshot is given in Figure 2.

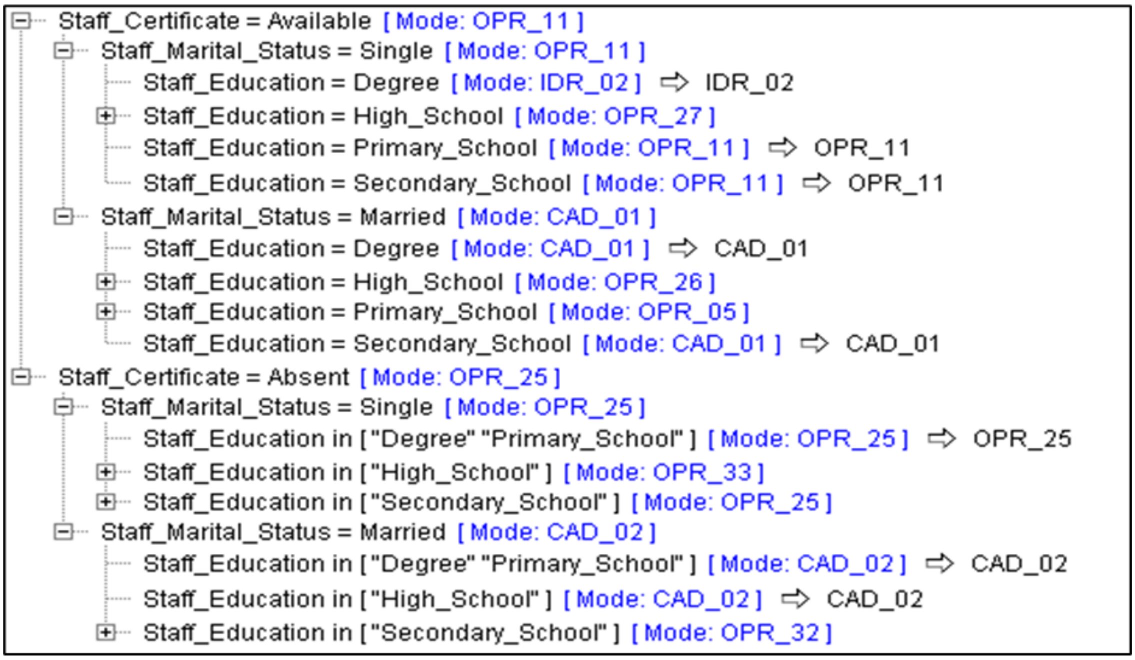

Figure 2. C5.0 Decision tree model finding screenshot

OPR 25 staff were the most failure-making personnel in the decision tree model finding.

The C5.0 algorithm model result is visually included in figure 3 image of the decision tree.

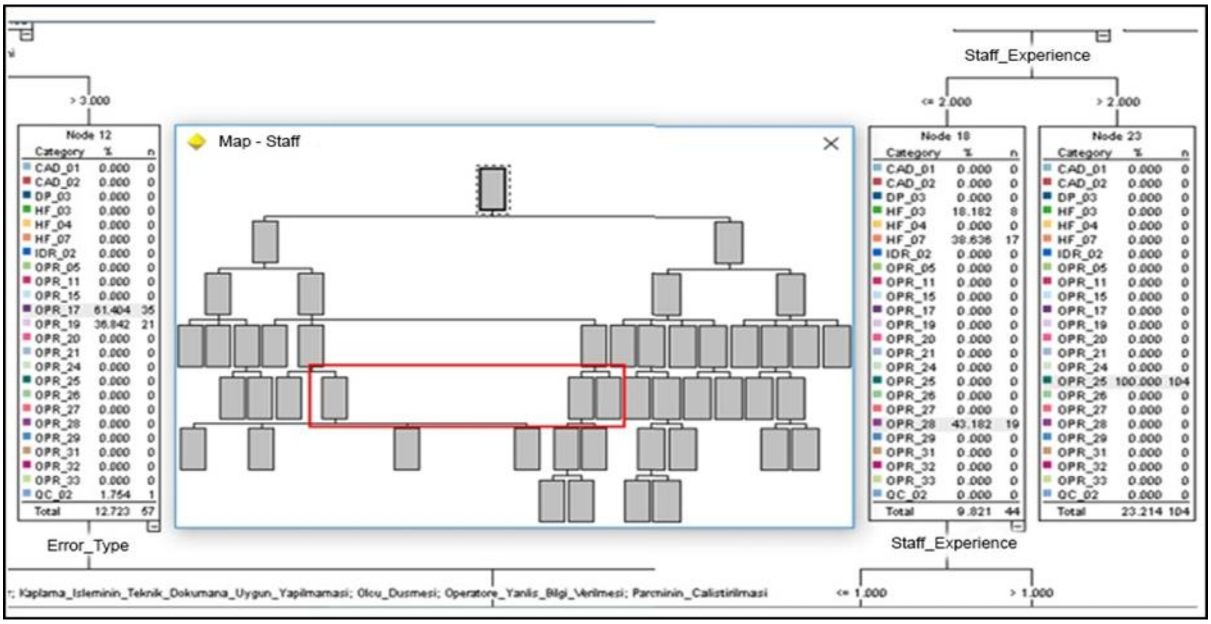

Figure 3. 5th level screenshot of decision tree model

When the findings obtained in the analysis conducted by the C5.0 decision tree algorithm were examined; it has been observed that the most important factor that affects the personnel making mistakes is the personnel certificate. Among staff who do not have a certificate, it has been found that staff with marital status are more likely to make mistakes. It was seen that middle school graduates, who do not have certificate and single personnel, made more mistakes. In addition, it has been concluded that the experience is prominent in single and middle school graduates who do not have a certificate, and those with more than two years of experience make more mistakes.

J48 Decision Tree Algorithm Analysis

It was observed that the variable that most affected the personnel's failure was the "Personnel Training Status", followed by the civil status of the staff, the professional document, staff experience, staff age, failure type and production type. It was observed that the root cause of the failure, the number of failures, the shift, the day and month of the failure, the type of material, the effect of the failure on the quality score, and the customer independent variables had no effect on the staff's mistake. The decision tree screenshot for the J48 algorithm is given in Appendix 4.

5. DISCUSSION

This study maintains its uniqueness in terms of the fact that FMEA process and data mining techniques have not been previously applied in the workshops (order-based) that provide services to the defense and aerospace industry with machining operations.

Factors in the occurrence of failures in machining enterprises were investigated by Dağcı and Ersöz in 2018 with logistic regression management. As a result of the research, it was concluded that the most important factor affecting the failure of a part produced in an enterprise operating in the machining sector is "personnel failure" (Dağcı & Ersöz, 2018). In this study, it was concluded that the factors that affect the mistakes of the personnel were "lack of theoretical knowledge", and the study that Dağcı and Ersöz was developed.

Factors that were effective in the formation of the wrong part in manufacturing enterprises from the past to the present have been analysed with various techniques. Using the FMEA method in the machining industry (Pantazopoulos & Tsinopoulos, 2005), pump manufacturing industry (Konguraja & Gobi, 2015), automotive industry (Sönmez & Ünğan, 2017), with a qualitative study in the food industry (Arvanitoyannis & Savelides, 2007), a qualitative study in the automotive industry (Fore, 2011), using statistical quality control techniques in glass manufacturing (Yee et al., 2014), they observed that the failures occurring were human-induced and concluded that manufacturing failures could be prevented by training and increased controls to be given to staff.

6. CONCLUSIONS

By keeping customer satisfaction high in the modern quality approach, reducing costs is at the forefront. In order to ensure the quality, enterprises must present the manufactured product to the customer with just-in-time and zero failures, therefore, enterprises should recognize themselves and learn from past mistakes. Enterprises that want to get results from past mistakes and improve their processes by constantly controlling them are taking advantage of a variety of techniques, and FMEA and data mining are techniques that provide convenience to Enterprises. FMEA; is an effective technique in the analysis and improvement of the current situations of processes. Data mining contributes to a more objective and reliable analysis of the current state of processes.

In this study, an FMEA application was carried out for the process from raw material supply to product shipment, so that faults do not occur in an enterprise operating in the machining industry in Ankara, and that if it occurred, it would not be reflected to the customer. Measures have been taken for failure types that are not acceptable in practice, i.e., high risk priority, and measures taken as of 2019 have been implemented. In addition, in 2018, data mining was carried out with the help of failure records encountered in the enterprises and factors that affect the failure of enterprises personnel were investigated.

In the FMEA application, a total of 31 failure types were identified in eight processes. When the RPN values of the failure types were examined, it was seen that the risk priority number value of the 9 failure types below is ≥100 and is above the acceptable risk level. In the meetings with the implementation team in FMEA application, preventive actions were taken for possible types of failures by using the brainstorming technique. Due to the fact that the process is a whole, preventive activity has been carried out not only for possible types of failures with high RPN value, but for all possible types of failures, and preventive activities taken have been implemented as of 2019. After four months of implementation of preventive activities, measures and new RPN values for possible types of failures have been re-reported.

RPN values for failure types have been reduced to 100 as a result of measures taken when the thickness of the RPN value of 280 is out of tolerance and the diameter of the hole is large. The RPN value of the failure type has been reduced from 200 to 100 because the hole position is incorrect. The RPN value for the size reduction failure was reduced from 200 to 80.

Giving the wrong NC program to the machine and giving the wrong information to the operator, the RPN value for the failure types has been decreased from 175 to 75. The RPN value of the old revision program execution failure type has been reduced from 160 to 20. With the coating-painting process not being done in accordance with the technical document/damage to the part, the RPN value for the type of failure has been reduced from 150 to 30. The RPN value for the type of burr in the piece was reduced from 120 to 48.

As a result of the measures taken, RPN values have been reduced to acceptable risk levels, but are kept under constant control. In 2019, it was observed that improvement was achieved by the evaluation made at the end of four months as a result of the implementation of preventive activities.

In this study, compared product units that are scraped by failure types in 2018 and scrap product units compared to the types of failures that occurred in the first four months of 2019; 47.05% in failure type of giving the wrong NC program to the machine, 25% in failure type of giving wrong information to the operator, 87,01% in failure type of thickness to be out of tolerance range (thinner) , 87.09% in failure type of large hole diameter, 42.85% in failure type of the wrong hole position, 71,42% in failure type of burr remaining in the piece, 62.5% in failure type of measurement and 100% decrease was observed in the failure type of old revision program.

For a more accurate and objective outcome, factors that affect staff making mistakes were evaluated by data mining using non-compliance records for 2018. The evaluation uses the C5.0 and J48 algorithms, decision tree algorithms of IBM SPSS Modeler and Weka programs.

According to the findings obtained from the C5.0 algorithm decision tree model; It has been determined that the most important factor affecting the personnel to make mistakes is the variable about whether they have professional documents or not. It has been concluded that the personnel who do not have a professional document, who are single, who are middle school graduate and having experience of more than two years, make more mistakes than other staff.

According to the findings from the J48 algorithm decision tree model; it has been determined that the most important factor that affects the personnel to make mistakes is the educational status. Secondary school graduates, single and non-professional staff made more mistakes.

According to the findings obtained as a result of two analyzes made with IBM SPSS Modeler and Weka data mining programs decision tree algorithms, C5.0 and J48 algorithms; It was concluded that the lack of theoretical knowledge underpins the factor affecting the personnel's mistakes in the enterprise. In accordance with the result, it has been decided that education is the most important activity to prevent the personnel from making mistakes, that if they have completed the training periods, the staff can be prevented from making mistakes by giving both vocational and awareness trainings, and that FMEA application should be continued for continuous improvement in the business.

Following the implementation of improvement activities and the implementation of FMEA throughout 2019, the poor-quality costs incurred in 2018 will be evaluated and the earnings provided by the improvement in 2019 will be evaluated.

As a result of this study, it was concluded that the FMEA technique should be actively implemented in order for enterprise to prevent the possibly occurring failures, that the culture of education should be adopted in the business, that intermediate control should be carried out as a result of each activity carried out, and that every activity carried out in the enterprise should be transferred to all personnel with instructions and procedures.

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