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Shipbuilding pipeline production quality improvement

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ABSTRACT

Purpose: The pipeline production is one of major processes in shipbuilding industry. Quality improvement and risk assessment in this process can yield significant savings, both in terms of internal quality costs as well as in terms of customer satisfactions.
Design/methodology/approach: Shipbuilding pipeline production quality improvement has been carried out by application of FMEA (Failure Mode and Effect Analysis) method. For the successful implementation of FMEA method it is necessary to identify process failure modes or possibility of the appearance of non-compliance, as well as their possible causes. For qualitative analysis of key input variables of the process, in the paper is used Ishikawa diagram and p-chart.
Findings: It is shown that proposed approach to risk assessment in shipbuilding pipeline production is applicable to real casa scenario. The analysis has identified the points in the process with the highest probability of occurrence of nonconformities, or the highest risk for error.
Research limitations/implications: As the experimenting has been conducted in shipyard, within production process, research schedule must have been set in accordance with production pace. Also, due to character of production process the data collecting was adopted to the production plan in that particular moment.
Practical implications: Dealing with causes of potential nonconformities in the process can significantly contribute to the reliability and robustness of the process. Corrective actions that have been taken based on results of analysis significantly contributed to the level of quality in the pipeline production process.
Originality/value: The pepper is dealing with a well known method applied in different production environment that are mostly conservative in production approach. It was shown that successful application of proposed approach can yield benefits especially in improved quality of produced pipelines within shipbuilding industry.
Keywords: Quality assessment; FMEA; Pipeline production

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1. Introduction

Failure Mode and Effect Analysis (FMEA) is a systematic method to detect and prevent problems in the product or in the manufacturing process before they arise [1]. The FMEA method focuses on prevention of errors and on reducing the possibility of their occurrence.

The objective of this study is to point out the ways of quality improvement in the Marine Pipe Workshop by applying the FMEA method. The effectiveness of the FMEA method depends on its sensitivity to recognize possible causes of errors as well as on identification of the points in the manufacturing process which have different characteristics than the other points in the process. An Ishikawa-diagram is used to identify such points, and p-control charts are used to show the situation before and after the application of the FMEA method. A period of three months has been taken as the time necessary to notice the effect of the corrective measures taken. The measurements were taken in the Pipe Workshop of 3. May Shipyard in Rijeka.

2. Quality management methods applied in shipbuilding piping design

Application of the FMEA-method in marine piping design reduces the number of products with errors or inconsistencies, but its most valuable quality is its ability to show 'spots' in the manufacturing process with a higher risk of error [2].

The piping design process consists of several steps: cutting the pipes to length, bending, welding the flanges, assembling the pipe. By using the results obtained after the FMEA method was applied, points of higher risk have been located. *Cutting the pipes to length* has been evaluated as the step with the highest Risk Priority Number (RPN). In that way it was possible to see with precision characteristics of different points in the piping design process and identify the points of higher risk of error than others.

The practical value of the *FMEA* method consists in identification of the problem areas and suggesting corrective measures in order to avoid the problems even before they appear [3]. The results obtained from an FMEA analysis are not effective unless the corrective measures are taken. Therefore, it is crucially important to re-evaluate the severity, occurrence and the possibility of detection since by re-calculating the RPN it is possible to discover whether the corrective actions taken resulted in reducing risk of error [4].

2.1. The FMEA method

The FMEA Method is carried out through 15 basic steps [1]: (1) the decision-making by the Management, (2) the analysis of the products, processes, services or systems, (3) drawing up or modifying the FMEA form, (4) collecting ideas about all the potential errors that might occur, (5) identifying possible effects of each error, (6) estimating the scale of the potential effect of an error, (7) searching for all the possible causes of an error, (8) estimating the probability of occurrence of an error, (9) listing all the existing monitoring procedures, (10) estimating the probability of detecting an error/effect, (11) calculating the RPN for each effect, (12) classifying the potential errors by priority, (13) suggesting and taking preventive measures in order to eliminate or reduce the risk of occurrence of an error, (14) calculating the RPN assuming that the errors have been eliminated or reduced and (15) submitting a report to the Management.

Application of the FMEA Method in risk analysis begins with detection of flaws in the existing manufacturing process. Before evaluating the risk it is necessary to identify and describe the points where potential errors can occur. The most time consuming part of the FMEA Method is the identification of possible errors. It is necessary to check for all possible error types in all the elements of the system because in practice all potential types of errors will occur sooner or later [5].

2.2. Analysis of the current situation in the Pipe Workshop

Decision was made to start applying the FMEA method in the Pipe Workshop of 3. Maj Shipyard, a systematic quality monitoring of the cut pieces of pipes was introduced in the cutting-to-length phase in order to collect data for statistical analysis. In compliance with the quality management system based on ISO 9001 standard, required quality levels of products and processes were established. In order to meet the requirements and reduce the manufacturing costs, a good quality management requires a careful statistical analysis [6].

The basic concept of statistical process control through the use of control charts consists of comparing the data obtained from the process with the calculated control limits, based on which conclusions are drawn about the process itself. Statistical process control of piping design is used in order to ensure the product quality so as to meet the requirements with minimal likelihood that the final product will have to be reworked and with minimal scrap.

The Pipe Workshop daily makes a certain number of pipes for marine pipelines. Piping design quality is systematically monitored according to pre-set parameters. The monitoring system is carried out on four key points of the process:

- Band saw blade - which includes selecting and cutting the pipes according to a given design. Dimensions and the external appearance are checked.
- Checking if the tools are in order.
- Checking the documentation.
- Checking the workplace.

Statistical quality control includes a group of methods and procedures for gathering, processing, analysing, interpreting and presenting data. It is used in order to ensure the quality of products and processes. Appropriate use of statistical quality control can reduce the manufacturing costs. Statistical process control of shipbuilding piping design includes defining tolerance limits of product quality or degree of variation from a standard or required measurement. If the product quality is within such limits, it means that its quality is satisfactory. The reasons for the use of statistical quality control are the following [7]:

- Defining the capabilities of the manufacturing process which meets the requirements,
- Monitoring the process in order to discover the variations due to which the process runs out of control,
- Taking the corrective actions in the process in order to keep it under control.

The statistical process control can only point to the changes that have occurred. The sources of such changes, however, have to be identified subsequently as it does not look for the sources of variations or points to what needs to be done in order to eliminate the variations.

2.3. The use of a control chart - cutting to length

Control charts are the main tool that is used to carry out the statistical product or process control. The main role of control charts is to differentiate common from special variation causes and enable the visualisation of defective quality of a product.

Control charts as a tool to improve quality are used in Pipe Workshop as an indicator of product quality. Besides control charts with numerical properties by which common variation causes differ from special variation causes of product quality, *p*-charts are also used to monitor quality improvement or deterioration. P-charts are control charts used to monitor the percentage of faulty products. They are less accurate than control charts for monitoring continuous properties and require a larger number of samples over a longer period of time. Therefore they are suitable for comparison of monthly, quarterly or annual product control analyses. It is especially useful to use *p*-charts when new corrective actions for quality improvement are about to be taken as the results from different periods of time before and after the implementation of the new corrective actions can be compared and the changes can be presented visually for different periods of time.

Control charts for monitoring the percentage of designed pipes with an error are made based on daily product controls over the period of 22 working days in a month in the Pipe Workshop. Fifty inspections are made daily in four piping design workshops checking the accuracy of pipe cutting based on the design. As it is the first step of the designing process, the number of errors in a product is limited to one. If the pipe is cut longer than required the error is rated as + (it is possible to rework the product), and if the pipe is cut shorter than required the error is rated as - (the likelihood that it will be possible to rework the final product is diminished and it is more likely that there will be scrap). The results of the controls that were carried out are shown in Table 1.

In a month a total of 1100 controls were conducted and the total of 135 errors was detected, which means that the proportion of products with errors was 12.27 %. The ratio of the errors including the pipes cut too long to those cut too short is 69:66, which means that there is almost an equal number of both types of error.

The control chart central line (CL) is at 0.123, while the control limits are as follows: upper control limit (p) = 0.262, and lower control limit (p) = 0, the border of the upper zones B and C is 0.169, the border of the lower zones B and C= 0.076, the border of the upper zones A and B = 0.216, and the border of the lower zones A and B = 0.03. A *p*-control chart is drawn up based on the aforementioned calculation as shown in Fig. 1.

Besides the fact that a control chart has to be drawn up accurately, it is also very important to interpret it correctly. The control charts in which the process is 'not in control' are the easiest to interpret. That is the process in which some of the measurements are beyond the control limits. That means that the process contains a special variation cause and adjustments need to be made. However, the fact that all the points are within the control limits i.e. a control chart indicating that the process is ‘in control’ does not necessarily mean that the process really is in a state of statistical control.

Table 1.
The results of the product control measurement taking - current situation

Day	The number of controls	The number of errors	+ errors	- errors	%
1	50	10	5	5	20%
2	50	6	4	2	12%
3	50	5	1	4	10%
4	50	6	3	3	12%
5	50	8	5	3	16%
6	50	5	2	3	10%
7	50	11	3	8	22%
8	50	6	6	0	12%
9	50	7	2	5	14%
10	50	4	1	3	8%
11	50	6	4	2	12%
12	50	7	4	3	14%
13	50	4	2	2	8%
14	50	9	4	5	18%
15	50	5	3	2	10%
16	50	4	4	0	8%
17	50	8	7	1	16%
18	50	8	3	5	16%
19	50	5	2	3	10%
20	50	5	3	2	10%
21	50	2	0	2	4%
22	50	4	1	3	8%
	1100	135	69	66	12.27%

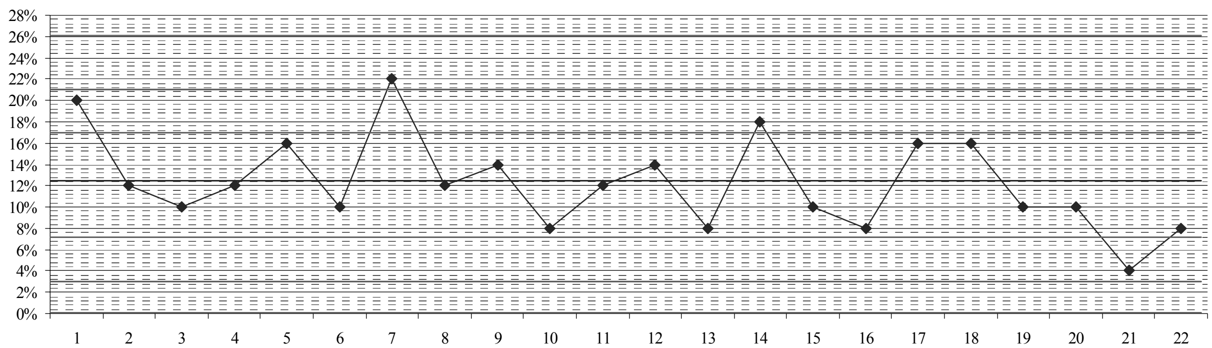

Fig. 1. p - chart - current situation; x-axis - working days during one month

In control chart interpretation a series of terms are used in order to describe a certain situation on the control chart showing a process 'in control' [8]:

- Run - seven points in a row are on the upper or the lower side from the central line, but within the control limits.
- Trend - there is a sequence of points on the control chart the measurements of which are constantly rising or falling.
- Periodicity - there are periodical cyclical changes in the process.
- Hugging - the characteristic measurements are either very close to the central line or beyond the control limits.

The role of the zones in control charts is determined by zone rules [9, 10]. There are special variation causes in the process if:

- Any of the measurements is beyond the control limits.
- Any two or three of the measurements in a raw are in the zone ‘A’ or above on the same side from the central line.
- Any four out of five measurements in a row are in the ‘B’ zone or above on the same side from the central line.
- Eight or more measurements in a row are on the same side from the central line.
- The measurements of eight or more points in a row are rising or falling.

A control chart has to be analyzed very carefully and thoroughly. The results of a control charts help improve the manufacturing process, eliminate unwanted variation causes, reduce the manufacturing costs, and thereby increase the profit. With a control chart used by competent people involved in the process, decision-making about the process is no longer intuitive but based on scientific facts.

By analyzing the p-control chart in Fig. 1 the following conclusions can be drawn:

- 14 out of 22 measuring points are below the "CL", indicating that in daily controls detected errors mostly amount to 12%,
- three measurements are in the zone "B" and one in the zone "A", indicating that the saw workers are occasionally ‘relaxed’.

Other observations are within the limits of the acceptable according to the control chart rules.

2.4. Cause-and-effect diagram of errors in Piping design

One of the seven basic tools of quality control used in cause analysis is Ishikawa-diagram developed by Professor Kaoru Ishikawa from the Tokyo University. Ishikawa-diagram leads the user to a systematic identification and description of factors that are the cause of the problem thus making it easier to eliminate the problem. It is suitable for the analysis of the root causes of a problem among a large number of causes and effects.

Therefore, in order to identify the areas causing the effect, the problem is approached through a systematic analysis of all the factors involved in the pipe cutting process. The process of identifying the cause, the scale of the effect and the person responsible for it consists of 6 steps, as shown in Table 2.

Based on the sequence in Table 2 an Ishikawa-diagram is made. The first step is to determine the most important causes. The second step is to determine secondary causes. The main causes only specify general categories. The real causes are actually secondary causes, which can be branched even further. The more detailed the branching, the more likely it is to find out what the cause is. In other words, if all the parts of the manufacturing process that meet the set criteria are eliminated, what are left are the ‘problematic’ ones.

Table 2.
The sequence of actions in order to determine the causes and effects of errors in piping design

	Step	Effect	Responsibility
I	Defining the problem	Unacceptable amount of scrap and rework	Head of the Workshop, Head of Quality Management Department,
II	Defining the main causes	Estimation of effect, ranking	Head, assistants, Quality Improvement Department
III	Defining secondary causes	Estimation of effect, ranking	Manager, cutters, controllers
IV	Branching of secondary causes	Estimation of effect, ranking	Immediate performers of actions
V	Determining the severity	Evaluation of the effect, ranking	Head, assistants, Quality Improvement Department
VI	Determining the cause	Evaluation of the effect	Head of the Workshop

The results of a brainstorming should not be taken for granted, especially if costs are an important factor or if the opinion of the head manager is likely to affect the others, but nevertheless they should be taken into consideration. The results are probably even better if the Ishikawa-diagram is made by an independent team working in a similar field of activity, which are familiar with the manufacturing process. However, should it take longer time for this independent team of experts to get acquainted with the manufacturing process, there is a threat that they become influenced by the current situation.

In this case the diagram in Fig. 2 has been made based on the procedure in Table 2.

The cause-and-effect diagram indicated the points in the manufacturing process which are possible (red) or likely (blue) cause of errors in the process of pipe cutting to length as estimated by analysts.

2.5. Evaluation of identified errors

In the error evaluation stage the following aspects of errors are estimated: the probability of occurrence of an error, severity i.e. significance of an error and the probability of detecting an error. The above characteristics are measured and assigned numeric values, and the Risk Priority Number (RPN) is the product of Severity x Occurrence x Detection. The measurement of occurrence and that of severity are proportional. If the probability of occurrence of an error is higher, the measurement will also be higher. When estimating the probability of detecting an error, the measurements are inversely proportional, meaning that the higher the probability of detecting the error, the lower the assigned measurement [7].

The calculated risk priority number has to be compared with the pre-set limit and thus it can be determined whether there is a need to take corrective measures to eliminate the error. In the example that we analyzed an RPN higher than 100 is considered significant, that ranking from 10 to 100 is considered less significant, and that below 10 is considered insignificant.

2.6. RPN calculation

To determine an RPN a modified FMEA table is used. By means of a modified FMEA table a relevant RPN is obtained. Before the FMEA table is made and filled in it is necessary to know all the entry measurements and their meaning. The sequence of actions in creating an FMEA process consists of the following steps, as shown in Table 3:

- Defining the manufacturing process (1), identifying possible errors (2) and evaluating possible effects of errors in the manufacturing process (3). When all the above factors are taken into consideration the measurement of severity is obtained (S).
- Identifying possible causes, their type and faults, and evaluating their occurrence (O).
- Analyzing the current manufacturing process monitoring system and evaluating the possibility of error detection with current monitoring and control methods (D).
- Calculating the Risk Priority Number according to the following pattern: $RPN = O \times S \times D$.

The RPN rating of all the four factors in the manufacturing process is higher than 100, which points to the need of taking certain corrective actions. The correction is based on the results obtained from the cause-and-effect diagram.

2.7. Corrective actions taken

Corrective actions were taken as soon as the analysis and evaluation process was over. The general sequence of actions from the recommendation to take corrective actions to the evaluation of results of corrective measures that were taken is shown in a Table 4 in the second part of the FMEA Form, which was made through the following steps:

- Recommended corrective actions refer to improvement of cutting machines (building in a stopper, revolution counter), more rigid control, making a list of priorities in the manufacturing process, regulating working time (double shift work and overtime), improved working conditions (lighting, noise).
- Determining responsibility and target completion date within which the corrective actions need to be taken.
- Analysis of the corrective actions that were taken.
- Re-evaluation and analysis of the results of the new corrective actions.

Due to specific manufacturing processes in shipbuilding industry, which is a large business system, corrective actions related to costs, new equipment supplies or change of personnel are taken gradually. Therefore in the Pipe Workshop in 3. Maj Shipyard the re-evaluation was done three months after the FMEA method was applied, i.e. six months after the decision about the FMEA method application was made.

3. Action result analysis

The RPN ratings obtained by re-evaluation are within the acceptable limits, indicating that the corrective actions taken were successful. In practice, whether the adoption of the FMEA method was successful or not is shown by the end product control analysis. The results of the repeated control during a month are shown in Table 5, the data from which were used to make the p-control chart, Fig. 3.

The 1100 controls were made and the total of 70 errors was detected, which amounts to 6.36 % errors. The ratio of errors consisting of pipes cut too long to those consisting of pipes cut too short is 38:32, which does not deviate much from the ratio obtained from the measuring in the first control.

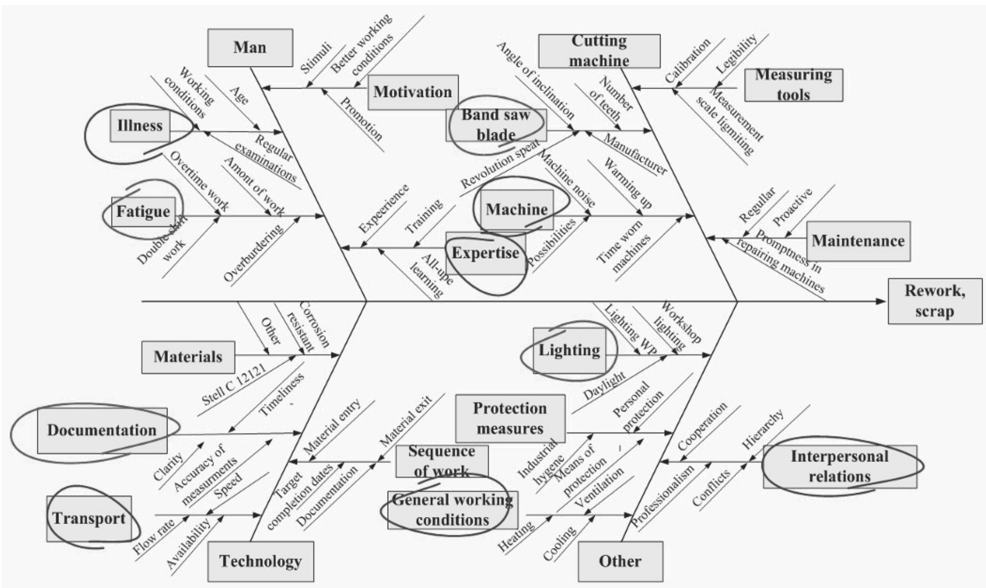

Fig. 2. p - chart - current situation

Table 3.
FMEA form I - RPN calculation

I				II		III		IV
Manufacturing process	Possible error	Possible effect due to error occurrence	S	Possible causes and type of error	O	Applied process monitoring	D	RPN
Cutting machine	Band saw blade inclination angle	Jeopardized product function	7	Human error /machine failure	4	Measuring	6	168
Band saw blade	Revolution number			Machine failure		Measuring		
	Manufacturer			Human error		Visual inspection		
Technology	Accurate measurements	Jeopardized product function	5	Human error	5	Visual inspection	5	125
Documentation	Clarity			Human error		Visual inspection		
	Timeliness			Human error		Visual inspection		
Man	Double shift work Overtime work	Jeopardized product function	4	Human error	5	Visual inspection	6	120
Fatigue	Amount of work			Human error		Visual inspection		
Maintenance Lighting	Workplace lighting Workshop lighting	Jeopardized product function	5	Workplace /Workshop Failure/ Maintenance	5	Preventive maintenance	5	125

Table 4.
FMEA Form II - Corrective Actions

	V	VI	VII	VIII			
Manufacturing Process	Recommended Corrective Actions	Responsibility And Target Completion Date	Action Taken	Action Results And Re-evaluation			
				S	O	D	RPN
Cutting machine	Build in a stopper	Foreman/expert engineer, Controller	In-built stopper	5	3	5	75
	Install revolution counter	Foreman/expert engineer, Controller	In-built revolution counter				
Band saw blade	Rank the product	Foreman/expert engineer, Controller	Ranking done				
Technology	100% visual inspection	Foreman/expert engineer, Controller	Monitoring established	4	4	4	64
	100% visual inspection	Foreman/expert engineer, Controller	Monitoring established				
Documentation	Making a list of priorities	Foreman of operational preparation /expert engineer	List of priorities made				
Man	Making a plan for : a) double shift work, b) overtime	Foreman/expert engineer, Controller	Plan made	3	4	5	60
Fatigue	Making a list of priorities	Foreman of operational preparation /expert engineer	List of priorities made				
Maintenance	100% visual inspection/workplace must meet safety requirements	Foreman/expert engineer,	Lighting adjusted Monitoring established	3	3	3	27
Lighting	100%visual control/ workplace must meet safety requirements	Foreman/expert engineer,	Lighting adjusted Monitoring established				

Based on the calculated measurements a p-control chart is made in the way that the central line (p) is set at 0.064, upper control limit (p) = 0.167, lower control limit (p) =0, the border of upper zones B and C = 0.098, the border of lower zones B and C = 0.029, the border of upper zones A and B = 0.133, and the border of lower zones A and B = 0.

From the *p*-control chart can be concluded that the variation is within the acceptable limits and does not show any significant irregularities.

A comparison of the control chart in Fig. 1 and that in Fig. 3 shows that the central line on the control chart in Fig. 3 is set lower than on the control chart in Fig. 1. Accordingly, on the control chart in Fig. 3 the zones are 'narrower', which indicates that there is less variation. The maximum proportion of errors on the control chart in Fig. 3 is 12%, and on the control chart in Fig. 1 it is 22%.

In addition, on the control chart which was made after the FMEA method was applied there are no entries into Zone A, and there are a few more entries into Zone B due to the fact that the zones are much narrower.

The proportion of errors that were detected during the monthly control before the FMEA method was applied was 12.27%, and it was reduced to 6,36 % after the corrective actions were taken which means that the process has been improved.

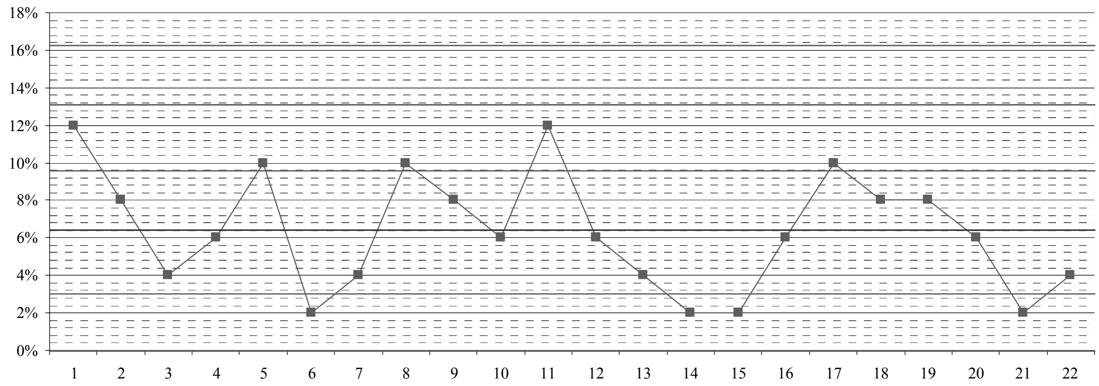

Fig. 3. p - chart - after the corrective actions were taken; x-axis- working days during one month

Table 5.
End product control measuring results - after the corrective actions were taken

Day	Number of Controls	Number of Errors	+ errors	- errors	%
1	50	6	3	3	12%
2	50	4	1	3	8%
3	50	2	2	0	4%
4	50	3	2	1	6%
5	50	5	3	2	10%
6	50	1	0	1	2%
7	50	2	1	1	4%
8	50	5	2	3	10%
9	50	4	2	2	8%
10	50	3	1	2	6%
11	50	6	5	1	12%
12	50	3	2	1	6%
13	50	2	2	0	4%
14	50	1	0	1	2%
15	50	1	0	1	2%
16	50	3	2	1	6%
17	50	5	3	2	10%
18	50	4	2	2	8%
19	50	4	1	3	8%
20	50	3	2	1	6%
21	50	1	1	0	2%
22	50	2	1	1	4%
	1100	70	38	32	6.36%

4. Conclusions

In 2009 Failure Mode Effect Analysis (FMEA) method was applied in order to study ways of improving quality assurance in Pipe Workshop in 3. MAJ Shipyard. For that purpose it was necessary to analyse the current state in order to detect and locatethe points of higher frequency of errors.Statistic Quality Control of End Products method was applied on samples collected in systematic manufacturing process control at the end of each month. By using *p*-charts daily and monthly proportions of errors were calculated as well as deviations, which showed the starting situation for the comparison. An Ishikawa-diagram was used as a tool to detect and locate the points and the time where errors frequently occurred. Evaluation of error occurrence probability, severity of the error and error detection probability were determined in the evaluation stage and the RPN was calculated for four different stages in the manufacturing process. Failure Mode Effect Analysis pointed to the need of adopting certain corrective measures, which were adopted by the Management and applied in the manufacturing process over a period of three months. The results of the corrective actions that were taken were analysed after the adaptation period was over and after the end product systematic inspection was made during a month of work. Statistical quality control showed achieved improvements in terms of reduction of monthly number of errors by 48.17 %.

In conclusion, application of the FMEA method in separate workshops can bring about expected quality assurance improvement even in individual stages of the manufacturing process, as it was analyzed in the example of cutting pipes to length, if the possible causes, their characteristics and faults, are properly analyzed and detected. Therefore, the application of the FMEA method is justified even in big metal-working industry systems such as shipbuilding.

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