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DIAGNOSIS OF OPERATIONAL MALFUNCTIONS AND FAILURES BY THE FMEA METHOD IN THE INDUSTRIAL ROBOTS SECTOR

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Abstract: Failure modes and effects analysis (FMEA) is commonly used by organizations for the assessment of the risks associated with the planned production, construction and manufacturing. The application of this method allowed to determine the importance of the malfunctions and failures by point estimating, taking into consideration such criteria as: I – importance of defects, R – risk and D – detectability. The aim of the article was the analysis of the failures, their causes and effects in the process of institutional client's order fulfillment in a selected company from the industrial robots sector.

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1. INTRODUCTION

Realization of customer order is one of the basic processes, that is essential for the functioning of the entire supply chain. Order is the basis for information flow in the logistics system. The order's relation consists of creating, completing, delivering and handling the order. The order realization process incorporates both operational and strategic elements (Odlanicka-Poczobutt & Kulińska, 2015).

Systemic thinking about logistics is based on finding links between its various aspects and it results from the nature and tasks of logistics (Kulińska, 2005). Realization of orders according to the target is related to the search for solutions that will enable faster response to the needs of the market. Logistics plays an important role in speeding up the execution of customer orders, by integrating processes and systems across the enterprise and supply chain, and in a comprehensive approach to customer order realization process (Sweeney, 2004). A comprehensive approach makes it possible to capture such irregularities as long production switching times, "bottlenecks", accumulation of excessive stocks, sequential order preparation and insufficient visibility of individual steps in order realization (Towill, 1999).

Due to the large variety of irregularities, it is important to sort out the causes of the disturbance so that it is possible to identify directions for improvement. The main interest of enterprises is the total (the shortest) duration of the order execution cycle (Radziejowska, 2012). Looking for solutions to eliminate the causes of interruptions that lengthen the order cycle, reduce or bridge the gaps between logistical cycles and order realization

The aim of the article is to analyze the failures, their causes and effects in the process of institutional realization of client’s order in a selected company from the industrial robots sector. The scope of the article covers activities in the field of production logistics, related to the search for solutions eliminating the causes of disturbances that lengthen the order cycle. The application of the FMEA should allow the reduction or elimination of gaps between logistic cycles and the execution of orders.

2. INDUSTRIAL ROBOTS SECTOR

Since 2010, the demand for industrial robots has been steadily increasing due to the ongoing trend of automation and continuous innovation in the industrial robots sector. Between 2010 and 2014, the average increase in robot sales was 17% of the cumulative annual growth rate (CAGR) per year. This is an increase of about 48% and a clear sign of a marked increase in demand for industrial robots in the world. The growth of the automotive industry was the main driver of growth. Sales of

industrial robots increased significantly in the Czech Republic and Poland, while other markets in central and eastern Europe reported a decrease in 2014 (www3).

In 2014, 1267 new industrial robots were installed in Poland, compared to 692 units in 2013. It indicates that between 2010 and 2014, 22% of the cumulative annual growth rate (CAGR) was obtained. After this increase Poland was ranked 16th in the world ranking of the robot market.

In Poland, robots are mainly used in handling operations (47%) and welding (16%). Most of the robots are used in the Automotive industry (44%) and in the plastics and chemicals industries (22%). At present, the number of used robots in Poland is about 8500 units, which is about 22% more than in 2013. Significant growth of the industrial robots market in Poland results from investments made by car manufacturers and suppliers of automotive parts as well as plastics, metal and food industries (www1).

In 2014, compared to 2013, the percentage of industrial enterprises with installed means of automating production processes, including robots and manipulators, increased by 1.8 pp and amounted to 26.9%. The number of installed robots and industrial manipulators in 2014 was 13052 units, including 8513 industrial robots (Raport GUS).

Audited company – KUKA Poland – deals with the sale and service of robots, as well as the organization of trainings. Branch Offices store at company headquarters located in Augsburg. The company's offer includes robots tailored to different industries and applications. Sample products are shown in Figure 1.

Fig. 1. Sample products of the researched company, Source: http://www.kuka-robotics.com/poland/pl/products/industrial_robots

The activity of KUKA Roboter in Poland focuses on sales of industrial robots, their service, training and sale of spare parts. All processes related to formal aspects of the process and information flow between the branch and the central office are carried out with support of the SAP ERP system. KUKA Roboter Branch is responsible for analyzing the request, preparing the offer, creating a sales order, monitoring its implementation and contacting the customer to obtain the necessary

information for the correct preparation of the offer and confirmation of the delivery date. Head office realizes processes related to the procurement, storage, picking, packing and shipping of ordered parts. External executive is responsible for the transportation process (Natora, 2016).

3. METHODOLOGICAL BASIS AND RESEARCH METHOD

FMEA – failure modes and effects analysis – is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service (Tague, 2004). This useful tool, in practice, allows to realize the qualitative approach of "zero defects" as well as the need of "continuous improvement" (Goble, 2012). The essence of the FMEA method is the analysis of a possibility of the occurrence of a product failure, its causes and effects, as early as at the designing stage or at the stage of developing a technological process, in order to eliminate failure before the product is ready (Vinodh & Santhosh, 2012).

The FMEA method allows for continuous improvement of product or process through further analysis, on basis of which further improvements and solutions that effectively eliminate the source of defects are introduced. The objectives of the FMEA analysis are: lower probability of occurrence of defects, increased detectability of errors emerging at the manufacturer and increase in customer satisfaction with purchased product or services provided (Rychły-Lipińska, 2007).

The main reasons for the use of this analysis are: meeting customer expectations, adapting to the requirements specified by the regulations, eg related to safety of production, responsibility for the product, lowering the cost of quality, reducing the time needed to implement new technologies, introduction of new products to the market, production of high complexity products and introduction of innovations (Rychły-Lipińska, 2007). FMEA is a tool that allows for: (1) identification of various types of errors and their effects, (2) finding solutions to the problems, (3) early detection of product or process weaknesses and elimination of them, (4) indication of areas that require advanced supervision, (5) elimination of repetitive errors, (6) control planning (www2).

FMEA analysis consists of three stages (Hamrol, 2007):

STAGE I – Preparation. Identification of the problem and its causes.

At this stage a team is set up to conduct the analysis, define the problem and its effects, and the areas to be covered by the FMEA analysis. Boundaries of the system in which the problems will be analyzed are determined. Elements and functions of the product or process in the process to be analyzed are selected.

STAGE II – Proper analysis. Calculation of numerical indicators to define couses.

At this stage potential defects are indicated for the selected product or process, including their cause and effects. The actions used to detect the defects identified and their causes are described. Defects, effects, and causes creating mutual relationships are assigned to integers from 1 to 10, that define: I – importance of defects, R – risk, D – detectability. Rate risk RPN is calculated as the product of these factors from the formula (1).

$$RPN = I \times R \times D \tag{1}$$

STAGE III – Introduction and Supervision of Preventive Measures.

Defects and their causes are ordered starting with those whose RPN ratio is the highest. With regard to defects, which RPN is the highest preventive measures are planned, which are then implemented (Odlanicka-Poczobutt & Kulińska, 2016).

FMEA of the process gives the opportunity to know the distractions that can hinder or disorganize the planned processes in the enterprise. These interruptions can be caused, i.e., by incompatible deliveries, incorrect machining parameters, by control and measuring devices, improper work of the organization etc. (Hamrol, 2007).

4. COLLATION OF THE RESEARCH RESULTS

In order to detect potential defects in the order realization process, FMEA analysis was performed. Customers of the process of order for elements of industrial automation realization are institutional ones. The table 1. lists customer requirements related to the process and potential defects that were observed during the researched period.

The following defects were identified in the process of order fulfillment:

At the inquiry stage:

- incorrect name or article number,
- unavailability of the article,

At the stage of preparation of the offer:

- wrong customer number,
- incorrect delivery conditions,
- wrong article number,

At the stage of creating a sales order:

- wrong type of order,
- incorrect field order,
- reference to invalid offer,
- wrong number or quantity of article,
- wrong recipient,
- incorrect delivery conditions,
- spare parts inaccessibility.

Table 1. Customer requirements and potential defects, Source: developed on the basis of company materials

Customer of the process	Customer requirements	Potential defects
Institutional customers KUKA Roboter	Punctuality Completeness Product delivered in proper condition Complete documentation	Errors in documentation - quantitative, generic, time-related, incorrect customer Incomplete documentation Spare parts inaccessibility Errors in creating a sales order System error Terminals failure Goods damaged in transport Load of the wrong commodities Employee error Lack of packaging Delays in the transmission of information Lost shipment Refusal to accept goods

At the shipping stage:

- load of the wrong part,
- lack of packaging,
- too late submission of a transport order,

At the transport stage: damage of shipment, lost shipment and at the reception stage – refusal to accept.

Table 2. The criteria of the assessment of the I, R and D factors, Source: developed on the basis of company materials

I importance of defects		**R** risk (probability or frequency)		**D** detectability	
1	Lack of influence	**1**	Very small/ hardly perceptible	**1**	Very easy
2-3	Significant	**2-3**	Low	**2-3**	Average detectability
4-6	Medium	**4-6**	Medium	**4-6**	Medium detectability
7-8	Serious	**7-8**	High	**7-8**	Small detectability
9-10	Very serious	**9-10**	Very high	**9-10**	Low detectability

The criteria of the assessment of the I – importance of defects, R – risk, D – detectability factors were presented in Table 2. The analysis the importance of

defects was presented by means of point estimating and the following criteria in Appendix 1.

5. DISCUSSION OF RESEARCH RESULTS

As a result of the conducted FMEA analysis of the process of customer order fulfillment for elements of industrial automation, 18 defects were identified, in which 44 relational links were identified: cause-effect-effect. Figure 2 shows a summary of values of RPN before and after the implementation of corrective actions. It was assumed that serious errors were considered those with a risk level above 115.

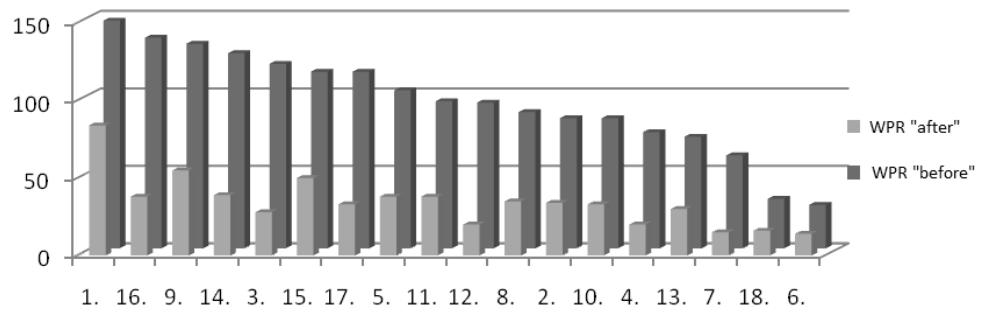

Fig. 2. Summary of the CAP indicator before and after corrective action, Source: Self-reported data

On this basis, 5 defects were identified as hazardous due to various factors. These defects include:

- incorrect name or number of the article at the inquiry stage, CAP = 147, the index was reduced to 84,
- damage to shipment during transport, CAP = 136, reduced to 38,
- wrong number or quantity of article at the stage of creating a sales order, CAP = 128, the index was reduced to 55,
- lack of packaging at shipment stage, CAP = 126, reduced to 39,
- incorrect client number at offer preparation stage, CAP = 119, reduced to 28.

The defects that will require further corrective actions are:

- too late submission of the transport order at the shipment stage, CAP = 114, the index was reduced to 50,
- loss of shipment at transport stage, CAP = 114, the index was reduced to 33,
- incorrect article number at the offer preparation stage, CAP = 102, the index was reduced to 38.

In accordance to the aim of the article - analyze of the failures, their causes and effects in the process of institutional realization of client's order we can say that most of the serious defects arose in the area of soft skills of KUKA Roboter employees who are responsible for the customer order realization process.

In this area, the following preventive measures were proposed, in order not to counteract defects emergence in the process of order realization: staff trainings, contact with the customer before shipping, determining the due time for placing an order that will be sent on a given day and contact with the customer to confirm delivery. Defects related to hard skills of KUKA Roboter's employees were also identified, including the knowledge of SAP ERP and the expertise of industrial automation. In this area the company should pay attention to raising the qualifications of employees and trainings in SAP ERP and product offer. Increasing employee knowledge will allow them to support customer in creating technical documentation.

The customer order realization process is very well supported from the technical side. Using the ERP class system, allows to automate the exchange of information while optimizing the use of enterprise resources. In order for the ERP system to fully support the process, it is important to maintain the database. FMEA analysis identified errors in the maintenance area of the database.

The following corrective actions were proposed: Assigning correct delivery terms to the customer; Blocking inactive numbers of materials; Removing duplicate data in the system; Periodic control of correctness of the documentation and Introduction of data on available discounts on customer's account.

In the technical area there were defects indentified due to insufficient number of packages and delays in transport. Proposed actions are: creation of packaging guidelines for each material and analysis of data sent by customers about the state of the shipment status.

Due to the transport realization by an external company, it is important to monitor the quality of the services it provides, as it directly affects the fulfillment of the customer's expectations with respect to the order realization process.

The company should pay attention to improving the qualifications of employees, their training, contact with the customer at every stage of order fulfillment, securing transported goods, and maintaining data in the system. In a long term, these actions should significantly reduce the defects occurring in the process of order realization.

6. CONCLUSION

In accordance to the aim of the article – analyze of the failures, their causes and effects in the process of institutional realization of client's order we can say that most of the serious defects arose in the area of soft skills of KUKA Roboter employees.

In conclusion, conducted FMEA analysis of factors causing the occurrence of defects and failure to meet customer requirements in the process of institutional customer order realization for industrial automation elements has revealed 5 factors that affect the quality of the process and customer satisfaction to a great extent. Identified areas of defects in the customer order realization process are i.e. soft skills, hard skills, maintenance of the database and technical areas in the field of transport and packaging. Actions were proposed in order to increase detection and reduce frequency of defects occurrence in the process of order realization. Also the CAP indicator was re-calculated. For all factors, the cap index fell below 115, which was considered critical.

The application of the FMEA should allow the reduction or elimination of gaps between logistic cycles and the execution of orders in the presented scope.

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Appendix 1. The FMEA analysis of the process of institutional client's order fulfillment in a company from the industrial robots sector

Failure number	Operation	Kind of failure	Effects of failure	Causes of failure	Undertaken control measures	I	R	D	RPN	Recommended corrective actions	Results			
											I	R	D	RPN
1	Analysis of the inquiry	Wrong name or article number	Invalid identification of the offer	Incorrect preparation of the inquiry	Clarification of the inquiry by the contracting authority	7	3	2	42	Customer support for technical documentation	7	2	2	28
			Incorrect price	No communication between the requester and the person preparing the query	Contact the person who requests	7	3	3	63	Identification of article no. Based on images uploaded by the client	7	2	2	28
			Present an invalid offer	Lack of knowledge needed to identify parts	Contact with the customer before preparing the offer	7	2	3	42	Consult with the head office or service department	7	2	2	28
Sum									147					84

2	Analysis of the inquiry	Article unavailable	Article Retraction	Finish of production	Inventory control	9	2	2	36	Identification of the replacement	9	2	1	18
			Item not available from stock	Rare reporting of article requirements	Contact with head office	8	3	2	48	Identification of the replacement	8	2	1	16
Sum									84					34
3	Offer prepara tion	Invalid customer number	Invalid customer address data	Incorrectly established customer account	Data control	7	4	2	56	Removing duplicate data in the system	7	2	1	14
			No data about discounts	Unreleased discount data	Control of rebates granted	7	3	3	63	Introduction of data entitled discounts on customer account	7	2	1	14
Sum									119					28
4	Offer prepara tion	Incorrect delivery conditions	Error on customer order	Incorrectly entered data in customer account	Data control	6	1	2	12	Correction of erroneous data	6	1	1	6
			Non-delivery			7	3	3	63		7	2	1	14
Sum									75					20

5	Offer preparation	Incorrect article number	Incorrect customer order	Incorrect data provided by the customer	Data control	9	1	2	18	Choice of person responsible for control	9	1	1	9
			Delivery of the improper part	Inadequate employee knowledge	Employee training	10	1	3	30	Organization of courses, training	10	1	1	10
			Incorrect price	Documentation error	Data control	6	3	3	54	Support for clients in the creation of technical documentation	6	2	2	19
Sum								102						38
6	Creating a sales order	Incorrect type of order	Reduce the stock of a branch	Employee‘s error	Employee training	5	2	1	10	Conducting training of operating system	5	1	1	5
			Not delivering the order	System error	Data control	9	2	1	18	Draw employees' attention to data control when creating orders	9	1	1	9
Sum								28						14
7	Creating a sales order	Incorrect field of order	Not delivering the order	System error	Visual inspection	9	2	2	36	Preparatory training	9	1	1	9
			Elongation of time of order fulfillment	Employee’s error		6	2	2	24	Familiarizing the employee with the system	6	1	1	6
Sum								60						15

8	Creating a sales order	Reference to invalid offer	Delivery to the wrong customer	Error in the offer number on the order	Customer order control	9	2	2	36	Training staff with system support	9	1	1	9
			Additional costs of returning the delivered goods	Employee's error	Search for submitted offers to the customer	7	2	2	28	Draw the attention of the management to control the data in the orders	7	2	1	14
			Elongation of the order processing time	System error	Control of data imported to the order	6	2	2	24	Dialog box on the system asking whether to save the order	6	2	1	12
Sum									88					35
9	Creating a sales order	Incorrect number or quantity of article	Not delivering the order	Employee's error	Visual inspection	9	2	2	36	Employee training	9	1	1	9
			Incomplete order	System error	Check article availability	8	4	2	64	Dialog box on the system asking whether to save the order	8	2	2	32
			Costs associated with re-delivery	Use of the original material number when there is a replacement	Check possible substitutes	7	2	2	28	Block inactive material numbers	7	2	1	14
Sum									128					55

10	Creating a sales order	Incorrect recipient	Not delivering the order	Employee's error	Visual inspection with data on the order	9	2	2	36	Create a delivery address on the system	9	1	1	9
			Costs associated with re-delivery	Incorrectly entered customer data		7	2	2	28	Update customer data	7	2	1	14
			Loss of customers	Error on customer order		10	1	2	20	Contact with the customer before shipping	10	1	1	10
Sum									84					33
11	Creating a sales order	Incorrect delivery conditions	Non-delivery	Error on customer order	Data control	10	1	2	20	Training employees on Incoterms	10	1	1	10
			Tax consequences	Error in the offer		5	3	5	75	Assigning the correct delivery terms to the customer	7	2	2	28
Sum									95					38

12	Creating a sales order /Confirmation of the date of order fulfillment	Part not available from stock	Failure to meet delivery deadline	Insufficient supply	Inventory control	7	5	2	70	Inventory control prior to making offers	7	2	1	14
			Elongation of the order fulfillment	Too late to order		6	2	2	24	Create a sales order immediately after receiving an order	6	1	1	6
	Sum								94					20
13	Shipment	Get the improper part	Costs related to return and re-delivery	Employee's error	Visual inspection of the completeness of the order	7	2	2	28	Appointment of an employee responsible for the inspection of completed consignments	7	2	1	14
			Elongation of the order fulfillment	Terminal failure	Control of device performance	6	2	2	24	Purchase of spare terminals	6	1	1	6
			Loss of customers	Error in the documentation	Control of documentation correctness	10	2	1	20	Periodically control of the correctness of the documentation	10	1	1	10
	Sum								72					30

14	Shipment	Lack of packaging	Delivery delay	Delayed delivery of packaging	Making an order in advance	8	4	2	64	Designation of the point of ordering packaging	8	2	1	16
			Incorrect protection in transport of materials	Improper storage	Control of storage conditions	8	3	2	48	Designation of packaging storage	8	2	1	16
			Shipping damage in transit	Lack of control of a supply of packaging	Inventory control of packaging	7	2	1	14	Regular control of the stock of packages	7	1	1	7
Sum								126						39
15	Shipment	Late submission of transport order	Delay of delivery	Late submission of order	Making an order immediately after receiving	7	3	2	42	Designated hours, in which may be submitted orders that will be sent on a given day	7	2	1	14
			Refusal of delivery	Delay in the creation of consignment notes	Information from the system about a new order	6	4	3	72		6	3	2	36
Sum								114						50

16	Transport	Shipment damage	Refusal to accept delivery	Incorrect packaging	Control of the condition of the packaging	7	2	4	56	Creation of packaging guidelines for individual materials	7	1	2	14
			Costs of complaint	Inadequate transport conditions	Rating of carriers	8	2	3	48	Selection of the carrier with the lowest percentage of damage in transport	8	2	1	16
			Elongation of the order fulfillment	Damage caused during transshipment operations	Collection of information from customers about delivery status	8	2	2	32	Analysis of data from customers about the status of shipments	8	1	1	8
Sum									136					38
17	Transport	Lost Shipment	Delay of delivery	Incorrect shipping label	Control of shipping labels	8	2	4	64	Designation of an employee responsible for checking labels of shipments	8	1	2	16
			Not delivering the order	Employee's error	Shipment tracking	8	2	2	32	Contact with the customer to confirm delivery	8	1	1	8
			Loss of customers	Carrier's error	Shipment tracking	9	1	2	18	Contact with carrier	9	1	1	9
Sum									114					33

18	Receiving orders Entering contact person data from the order	Refusal to accept	Elongation of the order fulfillment	Delay of delivery	Confirmation of delivery dates	7	2	1	14	Sending links to track a shipment after shipping from the warehouse	7	1	1	7
			Delay of use	No data of contact person on delivery documents	Entering data of contact person from the order	9	2	1	18	Entering customer contact data to the system	9	1	1	9
Sum								32						16