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Opportunities for the applications of FMEA Model in logistics processes in Bulgarian enterprises

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***Abstract* — The article explores the use of FMEA method in the logistics processes in manufacturing plants in Bulgaria. The surveyed enterprises have a system ISO 9001 and apply different methods of analysis and assessment of logistics processes. The purpose of this study is to present a model for improving the reliability of logistics processes through the FMEA (Failure Mode and Effect Analysis) method.**

An inquiry among 14 organizations in the implementation of FMEA was conducted. The results show that FMEA is not used for assessment in logistics processes and provides useful insights for decision-making to improve the reliability of supply. A framework based on the survey is presented for determining the reliability of logistics processes in manufacturing plants. The study demonstrates the applicability of the method in logistics processes and the role FMEA can play in assessing logistics processes.

***Key words* — Failure Mode Effects and Analysis (FMEA), Logistics process, Quality.**

I. INTRODUCTION

Uncertainty in supply and problems of logistics processes can pose a serious obstacle to achieving the goals of the business. Uncertainty of supply could have a significant impact on the success of the companies, but it has received relatively little attention in the scientific literature. This question is of great importance for any commercial or industrial organization in order for them to be able to meet the requirement to supply the right amount of product in the right place at the right time. This requires a reliable supply process, which usually consists of many intermediate stages, starting from the production of products from supplier through to the store shelves of the retailer.

Understanding the impact of supply uncertainty and the value of improving supply reliability is therefore among one of the major keys to achieving the final goal of matching supply and demand. Studies have shown that a variety of supply chain glitch (e.g., unexpected supply disruption, incorrect shipment quantity, transportation delays) can cause severe stockout situations (Hendricks and Singhal, 2005, p.4-7). Also, a careful selection of suppliers and proper management of supplier relationship can be important in reducing uncertainty in the supply channel.

The purpose of this study is to present a model for improving the reliability of logistics processes through FMEA (Failure Mode and Effect Analysis) method. A survey, which included 14 organizations that have certified systems ISO 9001 was conducted. Production enterprises of the clothing industry, production of lighting fixtures and furniture industry are included in the survey.

II. LITERATURE SURVEY

FMEA was formalized in 1949 by the US Armed Forces by the introduction of Mil-P 1629 *Procedure for performing a failure mode effect and criticality analysis*. The objective was to classify failures "according to their impact on mission success and personnel/equipment safety. There are a number of business reasons to implement an effective FMEA Process. When done well, FMEA is a proven tool to reduce life cycle warranty costs. [3, p.4]

Failure Mode and Effects Analysis is a method designed to Identify and fully understand potential failure modes and their causes, and the effects of failure on the system or end users, for a given product or process; assess the risk associated with the identified failure modes, effects and causes, and prioritize issues for corrective action; Identify and carry out corrective actions to address the most serious concerns.

There are several studies on security in the supply chain and reliability of supply, which raise more questions. The number of empirical studies is still insufficient in addressing issues related to the process of managing the reliability of logistics processes and supply.

Marek Šolc Briefly describes the process FMEA (Failure Mode and Effect Analysis) methodology in logistics. It is then applied procedural FMEA methodology and finally article by defining risk numbers for possible faults in the process of material flow in the organization, we then pay proposal, whose task was to eliminate faults and reduce their effects on the overall process functionality. [11, p.1906]

According to Šolc application of the FMEA tool in logistics processes is certainly a step in front of the perception of risk, but if we want to maximize the effect of this instrument, the application of the other departments of logistics is needed.

Agung Sutrisno, Jiun-Shen Lee suggest that other researchers to widen discussion on the role of FMEA in enhancing six sigma-oriented service systems, focus on human error issues, application of service FMEA in virtual setting, and its role in creating value within collaborative business framework. [12, p.25-38]

Stefan Schmidt discribes preventive methods in logistics poka-yoke and failure mode and effect analysis (FMEA). This paper presents two examples of preventive methods currently in use, Poka-Yoke and FMEA (Failure Mode and Effect Analysis). The implementation of Poka-Yoke, the mistake proofing methodology, has been shown to drastically reduce the enormous warranty costs, including logistics costs, while FMEA, implemented for the purpose of assuring the smooth execution of industrial processes, has already been successfully applied during the early planning phase of a new packing centre under construction. [13, p.27]

EunJi Kim and HwanSeong Kim proposed a methodology for assessing the reliability of transportation model. By analysing and measuring transportation failure event applied FTA and FMEA, it resulted in numerical values of reliability in the link. In addition, it could be resulted in the total network reliability value. Considering literature related with the reliability, this study contributed to describing the quantitative reliability of practical transportation model. [6, p.256]

Samir Ben Abdallah, Maher Aidi, Alaeddine Zouari, and Aref Maalej focus on the study of the logistics function integration in product design phases. We have treated these problems in order to establish the bases of an enriched approach using a process of systems engineering in particular requirements engineering. This integration will be able to improve the quality of the product and reduce the time and cost of its development as well as its manufacturing costs. [1, p.185]

Sime Curkovic, Thomas Scannell and Bret Wagner describe the reasons why FMEA is not used in the supply chain. The general lack of knowledge regarding how to apply FMEA in a supply chain context seems to be the biggest challenge to more widespread adoption.: There is no noticeable "explicit" value yet; It is not recognized or required by our industry; FMEA is too time-consuming; It is difficult for us to estimate failure modes using tools such as the FMEA model. [5, p.251]

III. METHODOLOGY

The study is based on data from manufacturing enterprises in the garment industry, production of lighting fixtures and furniture industry. The survey was conducted using a structured questionnaire on the application of the method FMEA in logistics processes. All questions included are of closed type, as they are divided into questions requiring evaluation in five-Likert scale, numeric data and respond with "yes" and "no". Respondents are authorized representatives of the management.

The analysis applied basic statistical methods for processing and analyzing the information from the survey. After analyzing the data, a model for the implementation of FMEA evaluation of logistics processes was presented. The method "Failure Mode and Effect Analysis" (FMEA) is based on the risk assessment of potential errors and revealing the reasons associated with the proposed solution. This method can detect potential risks during delivery, and through ordering these risks to be determined the sequence of activities needed for their prevention. In this study the method is adapted for systematically analyzing the reliability of logistics processes by analyzing the possible problems that may arise during the delivery of the product. The purpose of FMEA in logistics processes is to ensure that product delivery will reach the consumer without problems.

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The application of the method FMEA in logistics has great application to ensure quality and safe delivery of products. The analysis is based on consistent detection of possible risks, risk assessment of its release and determine the sequence of preventive measures to avoid. The procedure for implementing FMEA takes the following sequential steps: Step One: preparation of a list of possible risks in product delivery. During this step, identify all potential risks, which may, but should not occur during delivery. Also, errors are detected that can occur under extreme conditions. Step Two: Presentation of the results of the occurrence of possible risks associated with the delivery. Any potential effects on the occurrence of errors in the logistics system are identified, describing the adverse consequences of the emergence of risks concerning the user, such as delayed schedule for production or production interruptions due to untimely delivery.

Step Three: an analysis of the causes of the risks during delivery. Possible reasons that cause errors in the logistics system during delivery and the mechanisms by which these potential hazards may occur are identified. Step Four: analysis of the likelihood of supply risks. After analyzing the likelihood of risks during delivery proceed to step Five: analysis of the consequences of the risks associated with the delivery of the product.

Step Six: assessment of the likelihood of risks during delivery to be discovered. During this step the likelihood is estimated for potential risks to be detected prior to delivery of the product. Step Seven: calculating risks in product delivery. The priority number of risk for each defect is calculated by multiplying the valuation steps: four, five and six. The final step - Eight is: drawing up proposals to improve the reliability of supply.

IV. OPPORTUNITIES FOR THE APPLICATION OF FMEA IN LOGISTICS SERVICE

The sample of respondents includes enterprises as follows: 42.86%of the furniture industry, 35.71% of the garment industry and 21.43% manufacturers of lighting fixtures. The distribution of companies is represented in Figure 1.

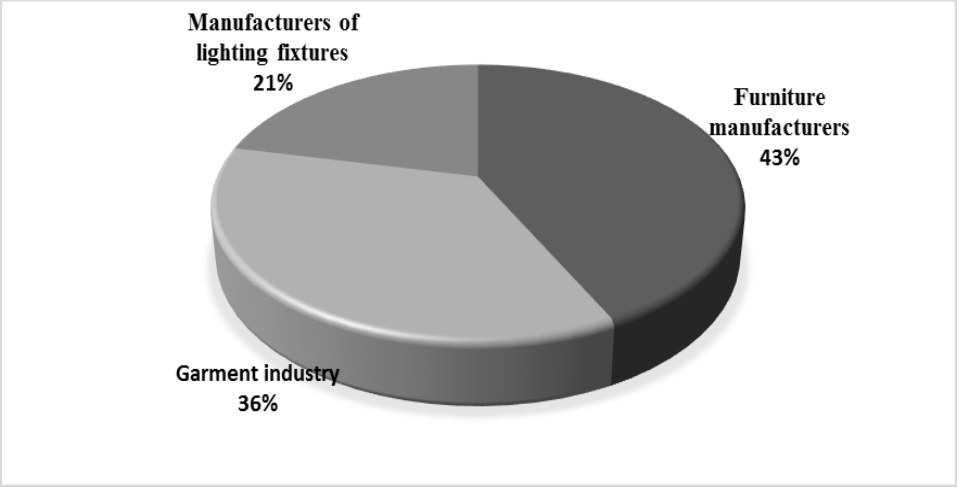

Figure 1. Distribution of surveyed organizations according to industry
Source: author‘s calculations

According to the number of staff 57.14% are small enterprises and 42.86% are medium enterprises. The number of settlements where there are manufacturing activity, the organizations surveyed showed that 81% of them operate in the locality in which they work and the remaining businesses operate nationwide. In the largest scale is presented equipment for streaming production (64.28 %), followed by highly specialized equipment (28.57%).

All surveyed manufacturing companies marketed a wide range of product types, indicating a predominantly outbound logistics. For the production and distribution of these products a

combination of logistics activities is necessary involving the supply of raw materials, production, transport and consumption. In terms of sources of supply in the country so far, 71.42% of the enterprises supply directly from the manufacturer. Supply through intermediaries by country marked significantly less than those from the manufacturer - 28.57%. At the sources of supply of imported directly from the manufacturer supplied 14.20% of the surveyed enterprises, and in the next three years this percentage increased to 44.80%.

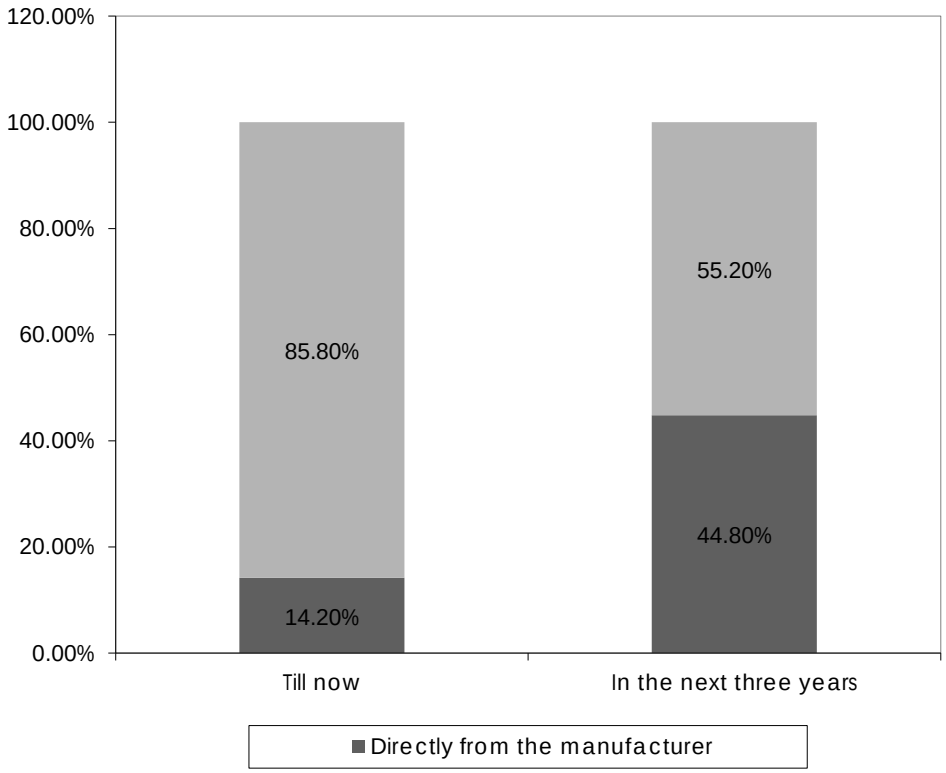

Figure 2. Sources of supply from imports (% of respondents)
Source: author's calculations

Waste and claims were analyzed by phases of the logistics process in order to assess the risk of potential errors in supply (Table 1). The surveyed companies determined that the rate of waste at the last inspection averaged 0.1% and the level of claims and products returned by customers averaged as much as 2%, indicating a high level of potential supply risks.

Table 1. Waste and claims on phases of the logistics process
(% of respondents)

Claims	Waste and claims
Claims on inputs	5%
Waste during the process of production	0-30%
Waste at the last inspection	0.1%
Claims and customer returns	2%

Source: author's calculations

To assess the risk of potential errors and detect causes of insecurity of supply it is important to analyze relationships with suppliers. In terms of length of business relationships with suppliers all

surveyed enterprises have lasting relationships. Disposable relations the enterprises have with 5% of their suppliers, 2-3 year long relationships they have with 20% of their suppliers, and over three years, i.e., long-term relationships- with 80-100% of their suppliers, indicating low risk on delivery. Overall, organizations cooperate only in traditional areas, namely in terms of exchange of information on prices, followed by exchange of information on demand forecasts.

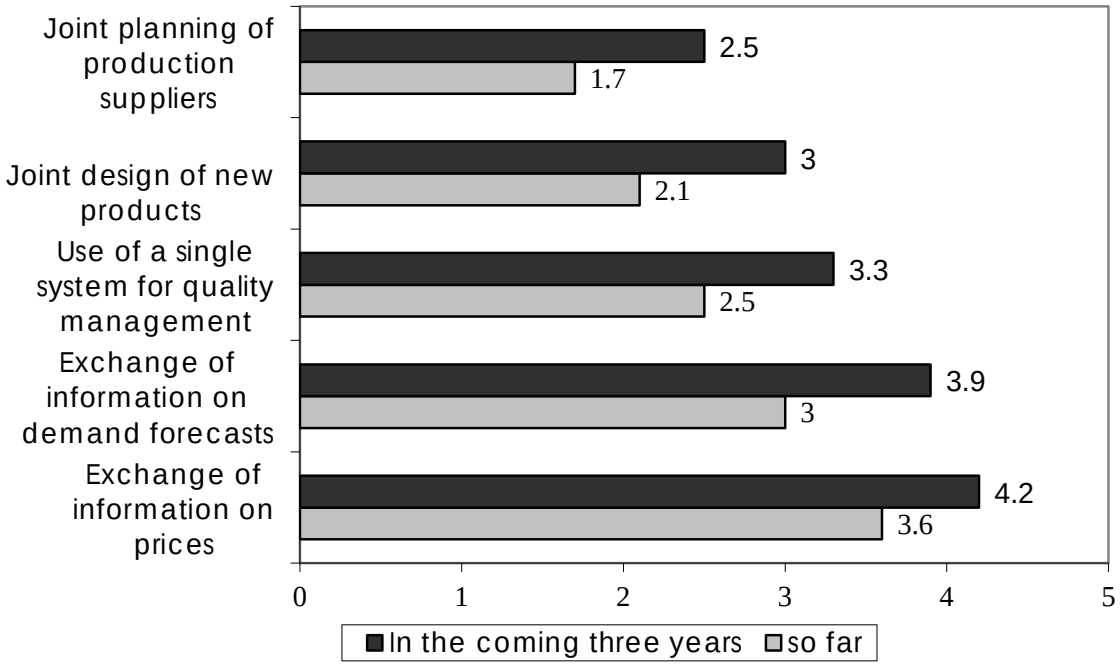

Figure 3. Areas of cooperation with partners (evaluations on five-point scale)
Source: author's calculations

According to the analysis of the application in terms of kinds of forms of cooperation, it can be seen that real cooperation is not carried out. Regarding the use of a single system for quality management, organizations are assessing with 2.5, and in three years it increased to 3.3, as intentions for cooperation with suppliers increase. The use of a uniform system of quality management can increase the ability to detect potential supply risks and to create activities to prevent errors in the logistics system. All surveyed enterprises purchase their materials based on stocks and on the basis of the production schedule, and a small proportion of respondents use past experience. Other methods are also used to purchase materials, but to a lesser extent. Fig. 4 presents the criteria according to which the surveyed enterprises choose their suppliers. The most important criteria to consider are the quality of materials purchased (4.8), followed by reliability of supply (4.5). This reveals opportunities to improve the reliability of logistics processes related to the product delivery.

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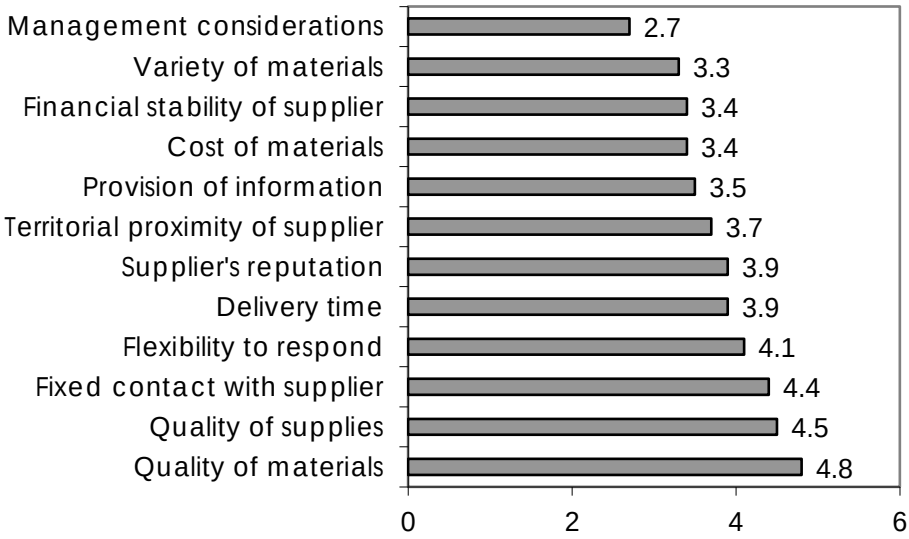

Figure 4. Criteria used for selecting suppliers (estimates by five-point scale)
Source: author's calculations

The surveyed organizations do not apply FMEA method for risk assessment of logistics processes. 64.28% of the surveyed enterprises have determined that the main risk, which may occur in the elements of the logistics system, is delayed delivery. According to 42.86% it is the lack of stock or change the quality of the stock, and 21.43% have problems servicing (before, during, after delivery). The principal adverse effects of these risks are related to the delay in the production schedule and production interruptions.

V. MODEL TO IMPROVE THE RELIABILITY OF LOGISTICS PROCESS

The main reasons for late delivery that companies cited are caused by lack of supplies, non-compliance with the schedule during transport or damage of the vehicle. The causes of defects are described so that they can be used as the basis for taking countermeasures. Fig. 5 shows a structural diagram of the logistics processes in the manufacturing plants, as the number and type of logistics activities are presented. The potential causes of risks to the supply of the product may lie in each logistics activity.

The list of possible logisticsal problems, according to the surveyed enterprises include transport problems, problems with the supplier, problems with storage, problems associated with production / operations and issues related to information and communication system (Fig. 6).

First, there are problems associated with the transport, followed by problems related to the provider. The pattern of use of FMEA for logistics processes includes an assessment of the likelihood of various issues raised in the list, then implementing new delivery schedules or changes in the logistics process. They are 10 points for defects whose probability of occurrence is highest and 1 point for those with zero probability. Table 2 shows the criteria which may be used in this assessment.

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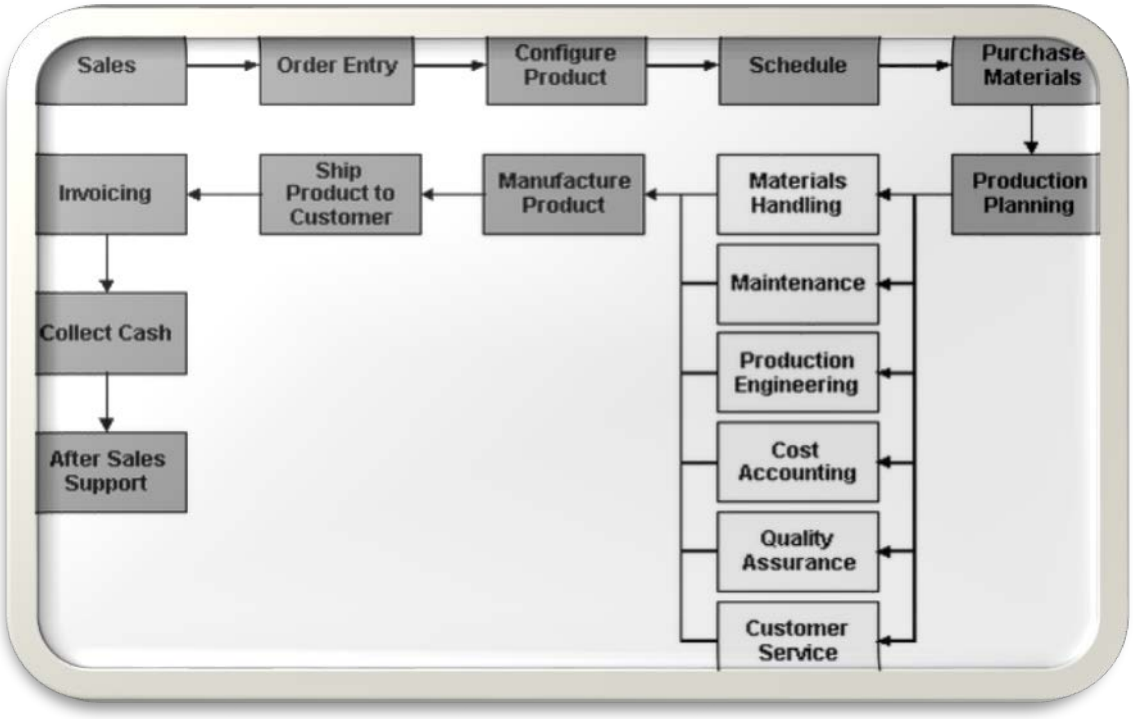

Figure 5. Scheme of the logisticss process in the surveyed enterprises
Source: https://tablo.io/ade-asefeso/lean-accounting

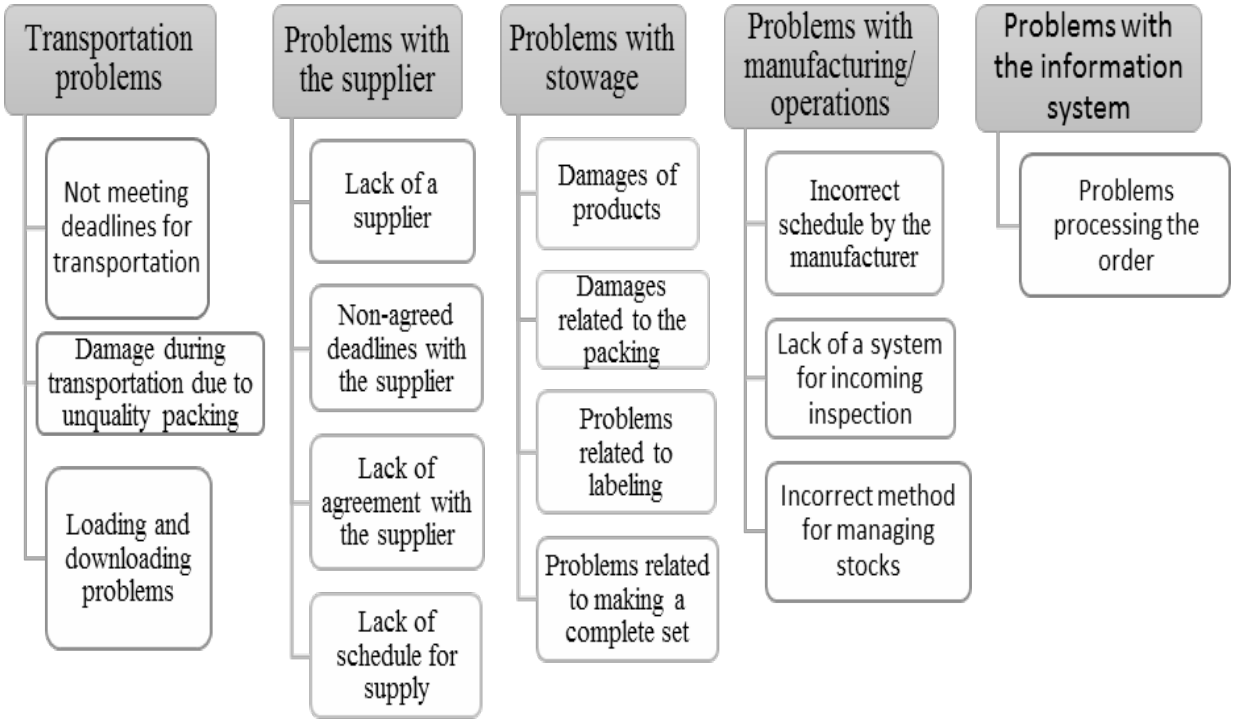

Figure 6. List of possible logistical problems, according to the surveyed enterprises
Source: compiled by author

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Table 2. Criteria for evaluating the frequency of occurrence of character defects

Probability of failure	Degree of Severity Ranking	Score
Very high (failure is almost inevitable)	≥10% 8%	10 9
High (high failure)	5% 4%	8 7
Moderate (random defects)	% 2% 1%	6 5 4
Low (isolated failures)	0.5%	3
Very low (rare failures)	0.2%	2
Remote (unknown)	≤ 0.1%	1

Source: Adapted by Curkovic, S., T. Scannell, B. Wagnerll, 2013, Using FMEA for Supply Chain Risk Management, Modern Management Science & Engineering, ISSN 2052-2576, Vol. 1, No. 2, 2013., p.11

The level of problem or damage, which is caused by defects in the list, is assessed. 10 points are given to defects whose effects could lead to serious loss and one point for those without consequences. Other defects are estimated from 2 to 9 points. Table 3 sets out criteria that can be used.

Table 3. Example of criteria for assessing the consequences of defects with time-delivery

Impact	Criteria: **severity of the consequence**	Points
Risk or violation of the established regime occurs immediately	The absence of material disrupts the working regime immediately Delivery of defective materials	10
Warning for hazard or violation of the established regime	In late delivery- warning for violating the regime Slow and unreliable transport Unreliable provider	9
Very big impact	Lack of supply schedule Long time to prepare the order in the warehouse	8
Big impact	Shipping damage due to faulty packaging	7
Medium impact	Non-agreed terms with suppliers	6
Little impact	Failure to comply terms of suppliers	5
Very little impact	Part of deliveries are timely and part untimely	4
Minimum defect	Inaccuracies in all deliveries	3
Imperceptible defect	Inaccuracies in part of the deliveries	2
No impact	No inaccuracies in deliveries	1

Source**:** Adapted by Carl S.Carlson, "Understanding and Applying the Fundamentals of FMEAs," *2014 Reliability and Maintainability Symposium*, January, 2014.

The probability for potential defects to be detected before the product gets to the customer is assessed. The nature of the defects according to their ability to be found during the examination is assessed, using methods of mathematical modeling, methods for inventory management, methods to manage operations, etc. Ten (10) points are given to defects that cannot be detected and one (1) point to those that can be detected. Table 4 indicates the criteria which may be used for this purpose.

Table 4. Criteria for assessing the detection of defects

Detection	**Probability of detection upon verification**	Points
Undetectable	Potential cause of variations in delivery cannot be detected in control or such control is not carried out	10
Very hard to detect	Potential cause of variations in delivery is very hard to be detected in control	9
Hard to detect	Potential cause of variations in delivery is hard to be detected in control	8
Very little probability of detection	Very little probability to detect the cause of late delivery in control	7
Little probability of detection	Little probability to detect the cause of late delivery in control	6
Medium probability of detection	Medium probability to detect the cause of late delivery in control	5
Sufficiently high probability of detection	Sufficiently high probability to detect the cause of late delivery in control	4
High probability of detection	High probability to detect the cause of late delivery in control	3
Very high probability of detection	Very high probability to detect the cause of late delivery in control	2
Extremely easy to detect	Extremely easy to detect the cause of late delivery in control	1

Source: Adapted by Carl S.Carlson, "Understanding and Applying the Fundamentals of FMEAs," *2014 Reliability and Maintainability Symposium*, January, 2014.

The risk of any defect is calculated by multiplying the marks obtained in steps 4, 5 and 6. So for each potential defect is obtained a Risk Priority Number (RPN), whose values range from 1 to 1000 evaluates the need for corrective actions to eliminate or reduce risk.

Reducing the incidence of defects and the severity of their consequence is done by eliminating the reasons for their occurrence. This is done through changes in the system, and the detectability of defects increases by systematic and thorough checks.

Suggestions for improvement and reduction of risks in the supply chain for manufacturing enterprises may be associated with increasing relationships with suppliers and by reducing complaints and returned by customers products. Opportunities to increase the reliability of logistics processes in the supply of the product may be creating successful partnerships in the supply chain that have integration and the ability to meet customer needs. These partnerships in the supply chain are related to the possibility of joint development of new products in the chain. Successful partnerships in the supply chain are related to the sharing of information aimed at improving and enhancing existing manufacturing capabilities.

According to international studies the application of information technologies offer great potential for expanding the scope of logistics. They are connected, on the one hand, in order to

reduce costs by increasing productivity and improving service by reducing delays in time. On the other hand, they are related to the improvement of logistics solutions through accurate input data.

Once you have taken measures for improvement, the risk of potential errors in delivery must be reassessed. When building a new logistics process potential causes are determined based on existing experience and knowledge of the logistics process. Upon optimization of existing logistics process the application of the method can improve the information available on the main problems and also help in documenting data. The new value of the RPN is assessed, called the resultant RPN, after corrective actions were taken. Improvements and adjustments should continue pending the acceptable values for RPN for each potential cause for the occurrence of delay in delivery. In each case, the analysis of the problems in the supply of products, the acceptable values are different. In this case, considered acceptable values can be considered those from 1 to 64 and 65 to 124 can be considered as widely acceptable.

VI. CONCLUSION

The presented article explores the use of FMEA in manufacturing plants and offers a model to improve the reliability of supply. FMEA systematic method that can maintain the link between logistics elements of the analysis, while respecting the logical sequence "cause - effect - measures." The method is characterized by versatility in its use for the simple and clear scale that is used for prioritization. With its preventive nature FMEA is appropriate to limit the adverse effects on the risks associated with logistics activities related to the supply. Despite the exceptional qualities of this method of pre-analyzing logistical problems in the delivery, in the surveyed enterprises do not use FMEA effectively. The reasons for this could be long time for carrying out the ignorance of the possibilities method in logistics and others. It is focusing on areas where the probability of problems occur is greatest. In any redesign of deadlines for deliveries or establishing new schedules for delivery is better to do FMEA activities that were subject to change.

The requirement increase reliability of supply in the Bulgarian industrial enterprises is a thorough coordination between customers and suppliers. According to the analysis of the questionnaire in the survey on the use of FMEA in logistics processes most commonly expressed are the risks that may occur in the elements of the logistics system associated with late delivery. According to 42.86% it is a lack of stock or change the quality of the stock, and 21.43% have problems with the service. The principal adverse effects of these risks are related to the delay in the production schedule and production interruptions.

Adopting the challenge of working in partnership between the Bulgarian manufacturers and suppliers will create numerous opportunities - for joint training and developing new products to expand market access and to jointly generate higher return on investment, especially for detection of potential supply risks and enhance the reliability of logistics processes related to the delivery of the product. The main areas of cooperation in the surveyed organizations are in terms of volume of information on prices, followed by the volume of information for forecasting demand. The final step in the process of cooperation between companies and suppliers is joint production planning and delivery scheduling.

Therefore manufacturing plants in Bulgaria need to focus on this area of partnership. Various interconnected proceedings aimed at comprehensive, rational and efficient use of raw materials and waste are the basis for the development of partnerships in the supply chain, which could be the basis for future research.

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