

# The Role of Organizational Failure Mode, Effects & Criticality Analysis (FMECA) in Correcting, Implementing and Achieving Corporates' Goals in HSE

Hezla Lokmane\*<sup>1</sup>, Avdotin Vladimir P<sup>1</sup>, Gurina Regina R<sup>1</sup>, Derouiche Laid<sup>2</sup>

<sup>1</sup>Peoples Friendship University of Russia (RUDN University, Moscow, Russian

<sup>2</sup>Human capital training- Manchester UK.

Corresponding author: E-mail: Lokmanehzla@gmail.com.

**Abstract**—This work tackles the measurements of health, safety and environment at work (HSE) which is closely related to developing the HSE indicators. The main aim of the research that has been proposed in this work is to suggest solutions that allow companies to achieve their objectives in an appropriate time, to develop product quality, and to improve the image of the company by determining the failures of the Health and Safety Management System using organizational FMECA. To improve HSE performance, the companies and industrial institutions need to understand the role of the managerial system, and its relationship with all institution's details, in which the importance of understanding the policy and organization in the enterprise helps directly or indirectly to achieve the aims through implementing specific methods. In this study, we will apply the Organizational FMECA on different levels in the field of institution management system, also on the level of Health and Safety Management System. Moreover displaying the extent of its contribution to reveal the failure points on the level of managerial system, in addition to present possible solutions in order to improve and develop the performance.

**Keywords:** System managerial, FMECA, organization, safety, policy, risk

## 1. Introduction:

Currently, a lot of companies and industrial establishments operate with objectives that can be very different in their natures [1]. The goal is a set of activities that can be achieved in order to get a well-defined and well-targeted managerial system. It is essential for this system because it is compared to the results that are obtained through some criteria [2]. Indeed, experience shows that a large number of companies do not achieve the fixed objectives within the same company, the results could be very different from one objective to another [3].

At the same time, industrial activities generate adverse or undesirable effects on workers, facilities, and

the environment that provides a general idea about the companies. Even more, it can impact on the ground, and workers that may suffer from various health problems [4].

So, how can companies attain a high level of management quality, which allows them to achieve their cyclical goals?

To solve this problem and answer this question, we need to answer the following questions:

How to extract information to reach the goal?

How to maximize performance?

What methods and tools are used to achieve this goal?

Our study highlights the importance of using a managerial system that extracts information and uses it to provide solutions to achieve goals. Certain techniques or methods must be used to achieve a maximum level of performance.

However, the implementation of the managerial system is often complex and it requires the evaluation of this problem [5]. This evaluation can be done by using tools called Organizational FMECA ( Failure Modes, Effects, and Criticality Analysis is a method designed to identify and fully understand potential failure modes and their causes, and the effects of the 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 and identify and carry out corrective actions to address the most serious concerns [6]. The Organizational FMECA method confronts the knowledge of all the activity sectors of the organization to obtain good results that allow the company to develop and to improve its external image.

In our study, we will demonstrate how the management system failures impacts on the company's failure to achieve its objectives, also, on the performance, and safety of workers, where we will provide scientific answers and effective solutions that help companies to reach their aims and improve their external image using of health and safety performance indicators at work and by the application of organizational FMECA.

## 2. Previous related work

In this study was used FMEA like a method for Modeling failure propagation is presented in the context of producing a failure mode and effect analysis from SysML with a critical infrastructure system example [7]. In another study, the FMEA was classified in stochastic quantitative methods and the qualitative reliability assessment methods, the results also show in this study that the method can be used to assess the quality and quantity, as the method can be used in more than one specific field [8]. In this study, [9] they provided an effective tool to solve the quality problem in the manufacturing process by FMEA. The study aims to identify and eliminate potential problems in the company's manufacturing process, by applying (FMEA) to improve the reliability of subsystems, in order to ensure quality that boosts the end result of manufacturing.

## 3. Methods and Materials:

A qualitative methodology has been used when conducting this research with a special focus on safety and quality aspects in order to determine all aspects that directly or indirectly affect the quality and safety at work. According to the requirements of the scientific research methodology, official information and data were collected from various sources (official documents in quality assurance, safety and health, data and statistics on the number of annual injuries and losses, worksites visits, interviews with workers when they are working, and with administration officials). Through the extracted informations, we have had a general idea of the level of health (occupational diseases, accidents at work, etc.) Safety (wearing protective equipment, accident statistics ...) and Environment (waste storage at the level of companies, pollution ...).

As already mentioned in the introduction, our goal is to enable the company to identify clear and precise objectives through the extraction of errors in the HSE management system (the policy) and to provide possible solutions through the application of the organizational FMECA method. A transition phase, therefore, seems necessary before considering the establishment of organizational FMECA, the first step is to achieve a state of identification of the managerial system of the company (in our case it is the policy) according to international

standard. We relied on our results on the evaluation tools of the existing system and we used it in our work of synthesis, the observation, the investigation by the interview, the data of the company. We have used all the extracted information from the field study to take advantage of our company consulting study to show the points that have been hurting organizations that have been doing methods for many years, without reaping the full benefits. We applied the FMECA method to the research policy for the modes of policy failures, the effects and the causes of non-achievement of the objectives assigned to the policy. Organizational FMECA allowed us to work preventively because Prevention is an integral part of the safety culture, and we want by the results obtained, that prevention becomes a priority for the company.

## 4. Organizational FMECA

### 4.1. The history of the FMECA method (Failure Modes, Effects and Criticality Analysis).

Originally was the analysis of potential problems, the generic format that allowed to work on any planning and identify what could have gone wrong. This basic logic was taken over, then specialized for products, processes, machines, and services, the table 01 presented the four basic questions of FMECA ... [10].

FMECA was established in the United States by Mc Donnell Douglas in 1962. It consisted of listing the components of a product and accumulating information on failure modes, their frequency, and their consequences. The method was developed by NASA and the armaments sector as FMEA to evaluate the effectiveness of a system. In a specific context, this method is a reliability tool. It is used for systems where reliability and safety objectives must be met. In the late seventies, the method was widely adopted by Toyota, Nissan, Ford, BMW, Peugeot, Volvo, Chrysler, and other major automakers [11].

Despite the fact that the FMEA is developed by the military, this method is widely utilized in several industries such as: food services, semiconductor processing, plastic, Aeronautics, healthcare, and automotive [12].

Potential failure modes	Possible effects	Possible causes	Surveillance plan
Monitoring plan	What could be the effects?	What could be the causes?	How to see it?

Table 01: The four basic questions of FMECA (Landy, 2007).

### 4.2. Organizational FMECA

Applies to the different levels of the companies' process: from the first level which includes the management system, the information system, the production system, the personal

system, the marketing system, and the finance system, up to the last level as the organization of a work task.

For the functional study, we will use the Organizational FMECA method, which allows us

to understand the functioning of some management components within the company, to estimate cases of occurrence of failure as well as their consequences on the proper functioning of the management system much more health and safety at work, and to initiate the necessary preventive actions.

The results obtained allow us to increase the level of the company to a good performance, to have more productivity and good management of the health of the workers. We present in the table 2 reminder questions of organizational FMECA and the priority determination questions of organizational FMECA in the table 3.

**Table 2: Reminder questions of Organizational FMECA**

Potential failure modes	Potential effects	Possible causes	Surveillance & Mesures
What could go wrong?	What could be the effects?	What could be the causes?	How to make that?

**Table 3: Priority Determination Questions of Organizational FMECA**

Severity	Occurrence	Undetected	Criticality
What are the gravity effects?	What is the probability relative appearance to causes?	What is the effectiveness on controls?	What are the priority points listed?

#### 4.3. Objectives of FMECA

- There are a number of business reasons to implement an effective FMECA Process. When done well, FMECA is a proven tool to reduce life cycle warranty costs. When done well, FMECAs will reduce the number of “oops” during product development. It is much less expensive to prevent issues early in product development than to fix them after launching. FMECAs can pick out and address safety problems before a potential disaster [13].
- Assist within the selection of design alternatives with excessive reliability and high safety ability during the early design stage.
- Ensure that all possible failure modes and their consequences on the system's operational success have been thought of.

- Assist within the target evaluation of design necessities associated with diffusion, detection systems' failures, fail-safe qualities, and manual as well as automatic override [13].
- The FMECA will: highlight single point failures requiring corrective action; aid in developing test methods and troubleshooting techniques; provide a foundation for qualitative reliability, maintainability, safety and logistics analyses; provide estimates of system critical failure rates; provide a quantitative ranking of system and/or subsystem failure modes relative to mission importance; and identify parts & systems most likely to fail [14].
- Contributes to improved product and process designs.
- Contributes to cost savings.
- Contributes to the development of control plans, test requirements, optimal maintenance plans, reliability growth analysis and related activities [5].

#### 4.4. Applications of FMECA:

An FMECA is simple to conduct. It does not require any advanced analytical skills of the personnel performing the analysis. It is, however, necessary to know and understand the purpose of the system and the constraints under which it has to operate [13].

To carry out an FMECA effectively, a systematic approach should be followed. The general procedure for conducting an FMECA can be divided into several steps as shown in Figure 1.

**Step 1.** Determine the range of FMECA analysis: according to the definition, the FMECA is a specific methodology to evaluate a system, design, process, or service for the possible ways that failures can occur. So, the first step is to select the specific scope of an individual FMECA in order to narrow the project focus [15].

**Step 2.** Gathering the FMECA team: FMECA is an activity based on group (team), it cannot be based just on one person [15]. The FMECA should act as catalyst to the motivating ideas between the design engineer, operations manager, maintenance manager, and a representative of the maintenance personnel (technician). The members of FMECA team must have a comprehensive understanding of the systems processes and the mission's requirements [14].

**Step 3.** Understand the system to be analyzed: Understanding the system that is used is one of the most important steps in FMECA. This needs to divide description of the operational patterns of the system

and the later breakdowns into subsystems that can be dealt with effectively [13].

**Step 4.** Brainstorm failure modes of each component and their impact Once each member of the FMECA team understands the system, here a series of brainstorming sessions must be held in order to determine all the possible failure modes [15].

**Step 5.** Determining the O, S, and D for failure modes usually: the three risk factors O, S, and D are classified based on a 10-point scale, as the following: the number 1 is the lowest and number 10 is the highest. It is essential to establishing clear and concise descriptions for the points on each of the three risk factors, so that, all the team members understand the rankings at the same level. Also, it is important to adapt the risk ranking scales with the organization-specific applications [15].

**Step 6.** Calculating the RPN for every failure mode: To computing the riskness in FMECA method, risk consists of three components that are multiplied to produce a risk priority number (RPN):  $RPN = S \cdot O \cdot D$  [5].

**Step 7.** Giving the priority to the failure modes for the protective actions: Now it can prioritize the failure

modes by arranging them in descending order under the terms of the RPN. Then, it must put recommended actions for the high-risk failure modes in which they should be advanced to improve the system performance. Usually, these actions are used in three categories(cases): eliminating failure modes, increasing the detection of the failure, and reducing the losses in the of case failure [15].

**Step 8.** Preparing a report for FMECA through making a summary to the analysis results: The FMECA process must be documented by using an FMECA worksheet [15].

**Step 9.** Calculating the revised RPNs where the failure modes are reduced or canceled: Once the recommended actions have been used to develop the system, the FMECA team must re-evaluate all the risk rankings for O, S, and D, also, follow all the improvements again. It is very important to re-evaluate the risks, because this shows how quality of eliminating the risk related to each failure mode is reduced as a result of the specific actions from the FMECA. There are two goals, the long-term goal which is the full elimination of all failures, and the short-term goal that is to decrease the failures if not get rid of them [15].

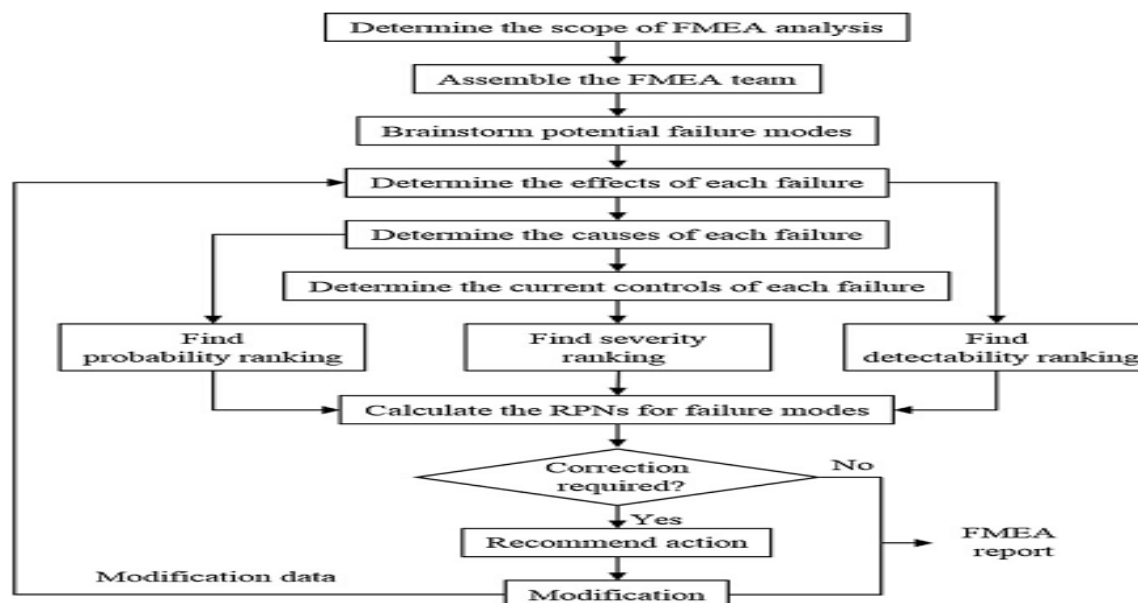


Figure 1 Main steps of FMEA using

## 5. Results and discussion :

After our analysis of this policy paper and its comparison with the criteria for writing global policy paper, we have discovered that: The information written on this paper is unclear and needs more accuracy, the company's goal is generally written and the absence of periodic targets leads to the lack of the right information

for the workers and ;thus, lack of knowledge of what is required of him in fact, and this is what causes the absence of the spirit of diligence and responsibility for them. As the worker's understanding of the goal, purpose and the requirement of the institution, gives an addition and a strong push for the company to achieve its goals and develop the quality of its product and improve the external image of the institution and as a confirmation of our opinion. We notice in the policy paper that we have the

presence of old goals that have not been updated yet, and this is evidence that the written goals were not actualized. The institution is still working on achieving these goals and this is due to points of failure that have not been corrected. Figure 2 presents the company policy of our case. We present in table 04 the modes failures of policy which presents in figure 2. We have summarized the discovered failures by the organizational FMECA, and the possible solutions to correct or to remove it in table 5



Figure 2: HSE policy of the company

Table 4 modes failures of policy

Political content	Commitment	Objective
Policy unclear and ill-defined; Absence of an update for the policy; HSE policy not based on 14001, OHSAS 18001.	Lack of respect for legal and regulatory requirements; Absence of the means of HSE protections; Fuzzy commitment directed towards flora and fauna	General and unclear objective; Very old goal.

The general management defines and determines the company's occupational health and safety policy, controls the functionality of the health and safety management system and adapts it as needed. It provides the resources required and sets the organizational arrangements. The security policy is implemented at the operational level by a security charter which lays down the general rules and principles of security to be respected by all the personnel. The policy and the security charter are displayed on different panels in the company. They are reviewed and updated as needed annually [16]. It includes the commitment of the management, the current situation, the guiding axes, the objectives (quantified) and the means necessary to obtain them. It must be adapted to the purpose of the company and understood by all staff. The environmental policy is appropriate to the environmental impacts of the organization and available to the public [17].

**Table 05: Organizational FMECA for company policy**

Organization operation		Potential failure mode	Failure effect	Possible cause of failure	Evaluation				Preventive actions	Results			
					O	D	G	C		Recommended			
					O	D	G	C	O	D	G	C	
Policy	Political content	Unclear and ill-defined policy	<ul style="list-style-type: none"> <li>- Objectives not achieved</li> <li>- Waste of time</li> <li>- Some workers do not understand the Objectives</li> </ul>	Old methods and difficult words	3	2	4	24	Redefine a well- targeted policy, well defined with new methods	2	1	2	4
		The lack of an update for the policy	<ul style="list-style-type: none"> <li>- Development delays</li> <li>- Loss of the value of the policy</li> </ul>	- Bad training on policy	3	3	3	27	- Regular and continuous trainings for the company officials who set the company's policy	2	1	2	4
				- The company has a single policy	2	1	3	6	- An annual or semi-annual policy update	1	1	2	2
				- The absence of a culture based on policy at the direction	3	3	4	36	- Adapted a culture based on policy among the direction	1	1	3	3
			- HSE policy not based on 14001, OHSAS 18001.	<ul style="list-style-type: none"> <li>- Loss of the image of the company</li> <li>- Lack standards certificates.</li> </ul>	- The uncertified company	4	4	4	64	A policy must respect the standards 14001, OHSAS 18001.	3	2	3
				- The company does not have the means to apply the standards.	4	3	4	48	Adopted procedures to obtain certifications	2	2	3	12

### 5.1. The "rules" for establishing a policy

All organizations need a clear policy and accurate goals in order to obtain the results underlined by the organization. Based on the results obtained by applying the organization FMECA which are Failure's detection at the enterprise policy level and providing possible solutions that help to build a realistic policy written according to international standards in order to provide possible addition across the enterprise.

Each policy is specific to the enterprise to which it relates, and should, therefore, be written by the needs of that enterprise. There are no special rules to follow, but the points below are provided for information only. The enterprise policy must respect the following indications [18],[19],[20],[21]:

- Define the reasons why a policy needs to be defined;
- Include in this policy its commitment to:
  - Continuous improvement;
  - Compliance with environmental standards;
  - A maintenance of public relations.
- Cover all major environmental issues facing the company and establish a priority list;
- Define good HSE management practices;
- Assign responsibilities and decision-making authority;
- Document and make public this policy [17];
- Annual objectives of health and safety at work: The general objectives for occupational safety and health are defined by management at the beginning of the year. The general objectives are constructed in such a way as to meet on the one and regulatory requirements and the other hand the "customer" requirements for health and safety. To define these objectives, the management relies notably on accident statistics and occupational diseases, audit reports, the results of the risk assessment and the annual report of the HSCT. The safety objectives are set out in an annual prevention action program. [16].

### 5.2. The general advantages of the FMECA method

The FMECA method confronts the knowledge of all the activity sectors of the organization, in order to obtain, in an order that we have sought to make meaningful, the following results:

- **Customer satisfaction** is the main objective of FMECA, an objective against which no one can rise today. If there were only this argument in favor of FMECA, it should be enough to make it essential in our organizations;
- **The continuous improvement management** through the management of action plans. The development and management of these plans will, along with the regular updates of the FMECA, be

one of the major ways to support continuous improvement and demonstrate its implementation;

- **Improving communication.** Although rarely cited as a benefit of FMECA, it is for us a major benefit. It involves placing colleagues from different departments around a table in order to make them work in groups, using the same logic and the same vocabulary to exchange information that will necessarily be useful for the rest of their work;
- **Improving product stability,** processes, services, machines ... It is a priority to act on things that hinder, destabilize, complicate ... You will use FMECA to make more stable, better controlled, better known, better understood, less dangerous ..., this on what are you working on?
- **Cost reduction.** Contrary to what some claim, the FMECA helps you to reduce the internal costs of obtaining quality, provided you also work on the internal effects (in the framework of the process FMECA, on the reduction of rejects and retouching);
- **The optimization of controls, tests, and, not strengthening of these same controls.** The FMECA helps you to make checks only on the points that require it;
- **Elimination of the causes of failures.** This is one of the major objectives of FMECA that will result in the implementation of preventive measures, or even the development of action plans;
- **The written experience based on FMECA reasoning;** some organizations will have to move from an oral culture to a written culture [10];
- **The Fault Tree Analysis is a tool used for identifying multiple point failures;** more than one condition to take place in order for a particular failure to occur. This analysis is typically conducted on areas that would cripple the mission or cause a serious injury to personnel [14].

### 6. Discussion

In this study, we have demonstrated all kinds of FMECA with a precise definition of the organizational FMECA and presented a model for its application attached to the results obtained, where the owners of institutions through the study can apply the organizational FMECA and benefit from its advantages in solving the problems of institutions in improving performance and product, while we notice that in this book [11], and the end of study project [22] Organizational FMECA is mentioned only as a type, and it is explained in a very brief way.

In our study, we applied the FMECA method to the administrative system of a large company, and we applied it at the level of the company's internal policy, to highlight the most important areas of failure at the level of this document and possible solutions to correct existing errors, as we have demonstrated the contradiction between the written goals at the level of the document and the

results that exist on the ground, then institutions of various types can through this study know the extent of the strong relationship between internal policy and all the results of the institution at the level of safety, health and also the quality of the product, while in this article [8], FMECA was presented as a method usable in quality and did not explain in-depth to explain it, while we made a real presence on the possibility of using FMECA in quality by applying it to the managerial system.

Those researchers [23], [24], [25], [26], [9], apply the vague methodology of the FMEA to identify, classify and evaluate the risks that have survived in various fields, at the end of the management, In these books [13] [14], [6], they did not mention the organizational FMECA as one of the main types despite its importance, we mentioned this type, explained and applied, which shows that this is one of the important types, especially in the field of management.

## 7. Conclusion:

We used the organizational FMECA method, which allowed us to understand the functioning of some management components within the company, to estimate the cases of occurrence of failure as well as their consequences on the good functioning of the management system. a lot more health and safety at work, and to take the necessary preventive actions.

We conclude that the application of the organizational FMECA allows the company to identify clear and precise objectives through the extraction of errors in the HSE management system (the policy, the organization) and present possible solutions by giving the future impact, the causes of the damages and their preventive actions in order to achieve the continuous improvement of any management system.

The results obtained allow us to increase the level of the company to a good performance, to have more productivity and good management of the health of the workers.

We hope that we can apply the organizational FMECA to the entire management system in the future, and this is the main focus of our study.

## References:

- [1] HOYLE, D. *Quality Management Essentials*. Routledge Publications. 224p, (2007).
- [2] Hezla, L., Avdotin, V., Derouiche, L., Plushikov, V, Norezzine, A., Dokukin, P., Rebouh, N.Y. *The Relationship of Organization Failure Modes and Effects Analysis with the Safety Quality for Supply Chain Risk Management*. International Journal of Supply Chain Management. Vol. 9, No. 2, 764-771, (7p). (2020).
- [3] Lokmane Hezla., Avdotin V.P., Plyuschicov V.G., Sambros N.B., Nadjla HEZLA., Derouiche L. *The Role of Organizational Failure Mode, Effects & Analysis (FMEA) in Risk Management and its Impact on the Company's Performance*. ICBDM 2020, May 15–17, 2020, Manchester, United Kingdom © 2020 Association for Computing Machinery. 5p. (2020).
- [4] Bekefi.T., Epstein.M.J., Yuthas. K. *MANAGEMENT ACCOUNTING GUIDELINE: Managing Opportunities and Risks*. The Society of Management Accountants of Canada, the American Institute of Certified Public Accountants and The Chartered Institute of Management Accountants. 39p. (2008)
- [5] Sultan Lipol, L., Haq, J. *Risk Analysis Method: FMEA/FMECA in the Organizations*. International Journal of Basic & Applied Sciences IJBAS-IJENS Vol: 11 No: 05. 9, 49-57. (2011)
- [6] Carlson, C. *Understanding and Applying the Fundamentals of FMEAs*. Reliability and Maintainability Symposium. 35p. (2015)
- [7] Hecht,H., Baum., D. *Failure Propagation Modeling in FMEAs for Reliability, Safety, and Cybersecurity using SysML*. 17th Annual Conference on Systems Engineering Research (CSER). 153,370-377. (2019)
- [8] Leimeister,M, Kolios,A. *A review of reliability-based methods for risk analysis and their application in the offshore wind industry*. Renewable and Sustainable Energy Reviews. 12 (1065-1076). (2018).
- [9] Patel, M,T. *A Case Study: A Process FMEA Tool to Enhance Quality and Efficiency of Manufacturing Industry*. Bonfring International Journal of Industrial Engineering and Management Science. Vol. 4, No. 3, 145-152. (2014)
- [10] Landy, G. *AMDEC, Guide pratique*. Ed. AFNOR – 11, rue Francis de Pressensé. 250 p. (2007)
- [11] Kélada, J. *La méthode AMDEC*. École des Hautes Études Commerciales, Centre d'études en qualité totale. 17 p. (1994).
- [12] Fadlovich, Erik. *Performing Failure Mode and Effect Analysis [Online] 2007 [cited 2010; Available from: <http://www.embeddedtechmag.com/component/content/article/6134>*, Embedded Technology
- [13] Marvin Rausand, Arnljot Hoyland. *System Reliability Theory Models, Statistical Methods, and Applications (second edition)*. A JOHN WILEY & SONS, INC., PUBLICATION. 644 p. (2004).
- [14] *Technical Manual. Failures Modes, Effects and Criticality Analyses (FMECA) for command, control, communications, computer, intelligence, surveillance, and reconnaissance (C4ISR) facilities*. Headquarters Departement of the Army Washington. No. 5-698-4. 75p. (2006)
- [15] Hu-Chen Liu. *FMEA Using Uncertainty Theories and MCDM Methods*. Library of Congress Control Number: 2016939575. 219p. (2016)
- [16] Herbreteua, c. *Manuel santé, sécurité, Le Beon manufacturing, ver 3, 04p ISO 14001-Implementing an Environmental Management System*. 16p. (2010)
- [17] *Manuel de Management de la qualité Guide de Réduction*. Centre d'études en qualité totale. 17 p. (2000)
- [18] HILLARY. *The Eco-Management and Audit shema: A pratical Guide*. UK: Stanly Thornes (publishers) Ltd. 128p. (1994)
- [19] ISO 14001 Environmental Management System -



- Specification and Guidance for Use. Multiple. Distributed through American National Standards Institute (ANSI). 24p. (1996)
- [20] BS 7750: Specification for Environmental Management Systems. British Standards Institution (BSI). Volume 98, 119-123.
- [21] EMAS: Council Regulation (EEC) No 1836/93 June 1993 Allowing Voluntary Participation by Companies in the Industrial Sector in a Community Eco-management and Audit Scheme
- [22] Melle. BOUKHERISSI, M. AMDEC (Analyse des Modes de Défaillances, de leurs Effets et de leur Criticité) appliquée à la STEP d'Ain El Houtz). Faculté de Technologie, Département d'Hydraulique, université Abou Bekr Belkaid, Tlemcen Algeria. 182p. (2015)
- [23] Wessiani, N.A, Sarwoko, S.A. Risk analysis of poultry feed production using fuzzy FMEA. *Procedia Manufacturing*. 12, 270-281. (2015).
- [24] Renua. A, Visotskya. D, Knackstedt. S, Mockoa. G, Joshua D, Schulteb.J., 6th CIRP Conference on Assembly Technologies and Systems (CATS), *Procedia CIRP*. 6,157-162p. (2016).
- [25] Balaraju.J, Govinda Raj.M, Murthy, C.S. (2019). Fuzzy-FMEA risk evaluation approach for LHD machine-A case study. *Journal of Sustainable Mining*. 12, 257-268. (2019).
- [26] Patil. R.B, Kothavale.B, Waghmode. L. Failure Mode Effect and Criticality Analysis (FMECA) of Manually and Electrically Operated Butterfly Valve, 2nd SRESA National Conference on 'Reliability and Safety Engineering (NCRS'15). 6p. (2015).
- [27] Carlson, C. Failure Mode and Effects Analysis (FMEA), UNDERSTANDING THE FUNDAMENTAL DEFINITIONS AND CONCEPTS OF FMEAS, John Wiley & Sons, 51p. (2012)