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RISK MANAGEMENT IN THE CEMENT INDUSTRY - IMPROVING THE RISK ASSESSMENT OUTCOMES BY DEVELOPING OF A NEW METHODOLOGY FOR PRIORITIZING THE TREATMENT OPTIONS

Constantin-Cristian DEOPALE, Liviu Daniel GHICULESCU, Bogdan-Ionut CRISTEA

Abstract: *In the context of an accelerated transformation of cement manufacturing, the efficient allocation of limited resources for risk treatment becomes a critical business-decision factor. The FMEA is a risk assessment method widely used in the manufacturing industry, but has some obvious limitations, among them the difficulty of establishing in an objective and efficient manner the priorities for implementing the risk treatment. To overcome these limitations, the study proposes new factors that estimate the efficiency of risk treatment actions, based on a combination of Action Efficiency Number and Risk Priority Number. The results of the case study carried out at an automatic bulk cement loading plant show significant improvement compared to a classical approach based only on Risk Priority Number.*
Keywords: *FMEA, RPN, risk assessment, risk treatment, action priority, cement manufacturing.*

1. INTRODUCTION

The new focus of the organizations in cement manufacturing on green manufacturing and Industry 4.0, observed over the last decade, emphasized the need for risk identification and analysis to properly respond to these challenges. On the other hand, it can also be observed in the scientific world an increasing concern of researchers to enhance and improve existing risk assessment methods or even develop new methods, in order to achieve better results in risk management.The actual scientific literature offers numerous instruments for risk assessment, used in many manufacturing fields [1-3].

Failure Mode and Effects Analysis *FMEA* is a classical technique for prioritizing the failure modes based on the Risk Priority Number (*RPN*) factor, but there are authors who propose other criteria that refer to the operating time required for the specific activity or the frequency of occurrence of defects, with all these estimates being based on the general opinion of a group of experts [4,5].

The integration of the *FMEA* method with other complementary methods, like *AHP*, *the Entropy method for risk factor weighting*, or *VIKOR*, can be good alternatives for risk classification, while offering the possibility of obtaining more competitive results compared to the classical approach [6-9].

With all the improvements which were made in the last decades, the *FMEA* method continues to predominantly use the *RPN* to estimate and rank risks and prioritize the risk treatment actions [10-12].

On the other hand, the assessment of failure modes can be performed by using alternative methods, such as fuzzy *AHP* or *fuzzy MULTIMOORA*, *The Lab Criticality Index*, or *The Logistic Regression Model*, which allows calculating the failure rate based on multiple criteria such as the return of investment, implementation cost, or implementation duration [13-16].

Other studies give some possible alternatives to avoid the problem of the equal weighting of the RPN calculation criteria, such as the use of other methods like *The best-worst method*, *The Analytical Hierarchy Process*, *The Full Consistency Method,* or *The Decision-Making Trial and Evaluation Laboratory* [12,18].

Even if the classic *FMEA* method is widely used in the manufacturing field, one of the main weaknesses that remain is the excessive use of the *RPN* as the only criterion for setting priorities in the implementation of risk treatment, which is itself a risk for the organization, because it would not consider many highly important aspects, such as their economic effect.

The ongoing transition to Industry 4.0 of the organizations in cement manufacturing, and the need to become a green manufacturing industry bring about many changes including in terms of managing the new specific risks. The speed at which this transformation needs to be made, as well as the appropriate allocation of the limited resources available, where they are most needed, are challenges that the organizations in cement manufacturing must find a rapid response to.

The combination of different methods, unlike the classic use of the *RPN*, can lead to improving the results of the risk assessment by using the relative importance of assessment criteria [17,19,20].

The use of the costs generated by the failure together with severity and detectability criteria can be a solution, since the cost is a characteristic easier to understand, and they can be analyzed together to determine the *RPN* [21,22].

In the classical use of the *RPN* as part of the risk assessment processes through the *FMEA* method, another disadvantage would be the difficulty to consider the expert opinions in a consistent way, and not having a proper instrument to effectively prevent the risk of poor allocation of the limited resources available for implementing the necessary treatment actions [23].

As it can be observed, there are many approaches for conducting the *FMEA* studies, but once the risks are identified and assessed, the success or failure in risk management is largely influenced by how the risk treatment is implemented, especially in real economic conditions, where the top priority is the efficient use of limited resources.

The fourth industrial revolution may also include different challenges to deal with new and complex risks, since new manufacturing technologies must be more economically reliable, greener, and based on digital transformation to better analyze the interconnected data.

Organizations in cement manufacturing have to face growing pressure from society as a whole for the adoption of technological solutions that are less polluting and greener. For this reason, it is necessary that the assessment method used facilitates a fast transition process, at optimal cost, and with the lowest possible level of risk.

In this context, the main objective of this paper is to provide an improved risk assessment method based on *FMEA*, as a viable alternative for organizations in cement manufacturing, which ensures:

- Solving the *FMEA* weakness regarding the use of the classical *RPN* as the main instrument for prioritization of risk treatment.
- Improving the risk assessment outcomes by using the action efficiency factor, together with the severity, occurrence, and detectability, as better ranking criteria to establish the order in which the treatment actions are implemented.
- Sustainable and swift reduction of the global risk level by implementing with priority the treatment actions generating a maximum benefit to the organization in terms of severity reduction and positive economic impact.
- Optimizing the process of resource allocation to implement risk treatment actions to support the transition of the organizations from cement manufacturing toward green and sustainable manufacturing.

2. METHODS

In order to achieve the set objectives, a new improved structure of the *FMEA* has been designed, which is briefly outlined in figure 1.

The improved *FMEA* starts with setting the scope and the main goals, followed by a clear definition of what is to be assessed, as well as the directions to be followed. These steps are then followed by rigorous planning of the assessment, while also setting the limits between which the whole process takes place. In order to identify the component parts of the system assessed, up to the level of structural

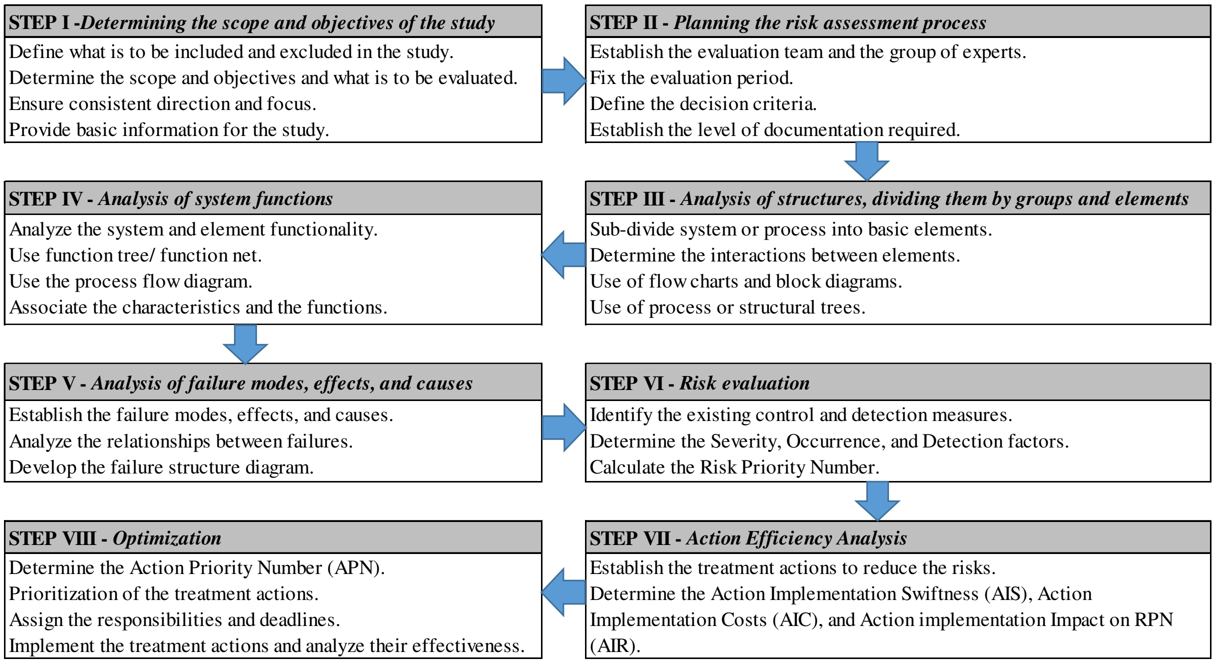

Fig. 1. The main steps of the improved FMEA method.

basic elements, a detailed analysis must be carried out using flow or process diagrams, or tree diagrams.

The structure analysis is followed by an analysis of the operating modes. To better understand the interactions between the distinct functions of the elements, the function structure networks, matrixes, and tree diagrams can be used.

To determine the level of risk, the entire risk chain (failure mode, causes, and effects) is analyzed, and the value of the following factors must be estimated:

- Severity *(S)*, which estimates how severe the effect is.
- Occurrence *(O)*, which estimates how likely it is that the potential causes of failure will materialize.
- Detectability *(D)*, which estimates the possibility of anticipated detection of failure.

To determine the *RPN*, factors such as *S*, *O*, and *D* are used, estimated based on individual expert opinions, using a scale from 1 to 5, where 5 is the most unfavorable situation.

The Risk Priority Number is calculated using the formula (1):

$$RPN = S \cdot O \cdot D \tag{1}$$

The next step is to perform an analysis regarding the efficient allocation of resources using the following factors:

- Action Implementation Swiftness (*AIS*), which estimates how quickly the action is implemented.
- Action Implementation Costs (*AIC*), which estimates how low the implementation cost is.
- Action implementation Impact on reducing the RPN (*AIR*) which estimates how quickly the *RPN* is reduced.

To determine the values of the three factors, a scale from 1 to 5 is used, where 5 is the most desirable situation. The Action Efficiency Number (*AEN*) is calculated using the formula (2):

$$\mathrm{AEN} = \mathrm{AIS} \cdot \mathrm{AIC} \cdot \mathrm{AIR} \tag{2}$$

To solve the problem of equal weights of the opinions expressed by experts regarding the estimation of the factors *S, O, D, AIS, AIC,* and *AIR*, the formula (3) is used to calculate a weighted average of the individual opinions.

$$\overrightarrow{\gamma_{\mathrm{exp}}} = \frac{\sum_{i=1}^{n} \epsilon_i p_i}{\sum_{i=1}^{n} p_i} = \frac{\epsilon_1 p_1 + \epsilon_2 p_2 + \cdots + \epsilon_i p_i}{p_1 + p_2 + \cdots + p_i} \tag{3}$$

where,

$\overrightarrow{\gamma_{exp}}$ – the weighted average of the opinions expressed by experts,

ϵ_i – individual opinion of expert i, p – the weight of the opinion of the expert i.

Finally, the ranking of treatment actions and the estimation of the Action Priority Factor (*APF*) is done based on the following criteria:

- **Tier I criterion** – used to group treatment actions into three priority categories depending on the level of *RPN*. Thus, treatment actions in the category "High Risks" will have the highest implementation priority, followed by treatment actions in the category "Medium Risks", and finally, those in the category "Low Risks".
- **Tier II criterion** – used to prioritize the treatment actions from each risk category, based on the *AEN* value, starting from the highest to the lowest calculated value.
- **Tier III criterion** – if, after using the Tier I and II criteria, there are still treatment actions left for which the same *AEN* value has been calculated, the following differentiation criteria will be the values obtained for *S, O,* and *D*.

3. METHOD VALIDATION – A CASE STUDY CONDUCTED IN A CEMENT FACTORY

In order to validate the methodology proposed and detailed in chapter 3, a case study was carried out for a process of transferring bulk cement from the storage silo to the special transport vehicle, using a loading machine.

Due to the limitations regarding the volume of information that can be included in this research paper, the details related to assessment planning, structure analysis, functional analysis, failure modes analysis, and analysis of causes and effects, will not be detailed here.

The study used a rating scale of 1 to 5 for the factors *S, O,* and *D* to evaluate the risk level. Thus, each of these factors received a preliminary estimate from the group of experts, with the final results retained being calculated as a weighted average of the individual opinions using the formula (3).

The formula (1) was used for the calculation of the *RPN*. As is shown in figure 2, the results and the spreading of the risks into three risk categories:

I. HIGH RISKS – risks of unacceptable level. That means immediate action is required. This category includes the risks R-02, R-06, R-11, and R-13.

II. MEDIUM RISKS – risks that can be accepted only under certain conditions following a thorough cost-benefit analysis. This category includes the risks R-01, R-03, R-04, R-05, R-07, R-08, and R-09.

III. LOW RISKS – risks that can be considered negligible. The implementation of the treatment actions is optional. This category includes the risks R-10, and R-12.

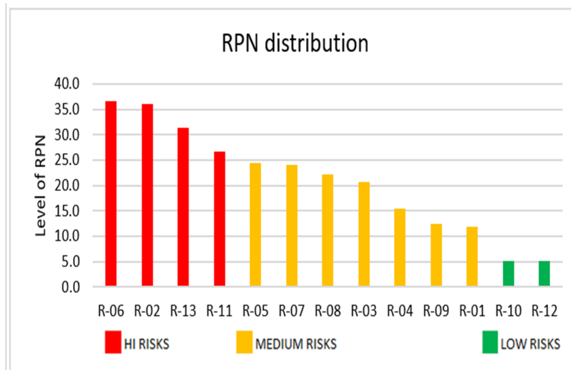

Figure 2. Distribution of *RPN* in the risk categories

Subsequently, for all 13 risks assessed, treatment actions have been established. Next, an analysis was conducted regarding the efficient allocation of resources using the Action Implementation Swiftness (*AIS*), Action Implementation Costs (*AIC*), and Action implementation Impact on reducing the RPN (*AIR*). In order to determine the values of these three factors, a rating scale from 1 to 5, where 5 is the most desirable situation.

Thus, each of these three factors (*AIS, AIC,* and *AIR*) received a preliminary estimation from each of the members of the group of experts, with the results retained being calculated as a weighted average using the formula (3). The values obtained for the factors *AIS, AIC,* and *AIR* then allowed the calculation of the Action Efficiency Number (*AEN*) using the formula (2), with the results being shown in table 1.

The final priority for the implementation of the treatment actions was established based on the Action Priority Factor (*APF*), determined based on Tier I, II, and III criteria.

Table 1

The risk assessment results and the final ranking of treatment actions.

	Risk			Action		AEN	APF
	Code		RPN	Code	Description		
I (HI RISKS)	R-02	The pressure sensor malfunction	36.0	A-04	Maintenance and quarterly check of the secondary manual roller closure system	59.2	**I.1**
	R-11	The leakage at the loading installation with cement dust spreading	26.7	A-15	Monthly inspection of seals and immediate replacement of those with a degree of wear> 30%	34.4	**I.2**
	R-06	The dust removal system was clogged with cement deposits	36.6	A-08	Carrying out monthly inspections and cleaning of the dust removal system.	31.5	**I.3**
	R-02	The pressure sensor malfunction	36.0	A-03	Replace the actual pressure sensor with a newer generation one	23.8	**I.4**
	R-13	The gear motor malfunction	31.5	A-17	Purchase a spare gear motor	8.5	**I.5**
II (MEDIUM RISKS)	R-01	The inner cone does not close	12.0	A-02	Perform monthly checks of the alignment of the inner cone guides	63.6	**II.1**
	R-01	The inner cone does not close	12.0	A-01	Perform daily checks for the inner cone and cleaning of potential hardened cement deposits	49.3	**II.2**
	R-05	The mobile lowering system malfunction	24.4	A-07	Perform daily inspections on the mobile lowering system	37.0	**II.3**
	R-07	The appearance of water condensation in the cement fluidization pipe	24.0	A-10	Carrying out daily checks on the condition of the cement translation transport aprons	24.5	**II.4**
	R-08	The improper positioning of the transport tank under the filling installation	22.2	A-11	Install a video system to facilitate the driver's visibility when positioning the vehicle	22.7	**II.5**
	R-03	The roller position sensor malfunction	20.7	A-05	Install an acoustic warning system in the control room to send an immediate alert	21.6	**II.6**
	R-04	The air pressure is too low	15.5	A-06	Carrying out daily checks of pressurized air circuits to detect leaks	17.0	**II.7**
	R-08	The improper positioning of the transport tank under the filling installation	22.2	A-12	Install a side road guides for centering the transport tank	11.1	**II.8**
	R-09	The improper positioning of the outer cone on the loading hole of the transport tank	12.5	A-13	Install visual signals to signal the loading operator the correct positioning of the cone	10.1	**II.8**
	R-07	The appearance of water condensation in the cement fluidization pipe	24.0	A-09	Drying of the air used to fluidize the cement	6.0	**II.9**
III (LOW RISKS)	R-12	Loading a larger amount of cement in the transport tank than the one ordered by the customer	5.2	A-16	Periodic metrological verification of the weighing machine installed under the loading installation	54.4	**III.1**
	R-10	Loading a smaller amount of cement in the transport tank than the one ordered by the customer	5.2	A-14	Periodic metrological verification of the weighing machine installed under the loading installation	28.9	**III.2**

4. DISCUSSIONS

The Failure Modes and Effects Analysis method is rightly considered a versatile risk assessment tool, which can be used in complex systems, especially in the manufacturing field, to identify faults and prioritize risks [12]. Even if it's a well-known method, this does not mean that it has no obvious limitations, which can, fortunately, be diminished by directly improving it or even by using other complementary methodologies.

From the analysis of the scientific literature published and mentioned in the list of references, which reviews among others the different uses of the *FMEA*, it was found that experts pay less attention to how the order for implementing the risk treatment actions is established, the main focus being on prioritizing the risk based on the *RPN*.

These weaknesses of using the classical FMEA have also been analyzed by Seiti, H. et al. in their paper published in the year (2020). For example, according to the authors, the calculation of the *RPN* using the classical *FMEA* method does not usually take into account the recovery time after failure [24].

An alternative method to determine the *RPN*, which relies on causal factors, cost, the period during which the system is taken out of service in case of failure, probability of failure, and detectability was proposed by Wu J. et al. (2014). According to the authors, the value of each factor should be based on the relative importance obtained by comparing the failure mode with the most severe situation [25].

In the improved *FMEA* methodology proposed in this paper, each expert in the assessment team was able to make their own estimation of the value of the factors analyzed, the results being subsequently weighted based on criteria related to their previous experience in risk assessment, knowledge of the processes assessed, professional maturity and other relevant soft skills.

By calculating the weighted average of expert opinions, a more objective and transparent final value was obtained for the factors *S, O, D, AIS, AIC,* and *AIR*. The calculation of the *RPN* allowed for a correct splitting of risks into three levels of importance (HIGH, MEDIUM, and LOW), ranking the risks based on the product between *S, O,* and *D*. In fact, this division of risks on the three categories of importance ensures easier management of the process for communicating the results of the assessment process, being the basis from which it can start in setting the priorities for implementing treatment actions.

The results of the case study show 4 high-level risks, 7 medium-level risks, and 2 low-level risks. Moreover, certain risks, such as R-01, R-02, R-07, and R-08 have two treatment actions each, and for others, a similar level of risk has been observed, as is the case for R-02 with R-06 or R-10 with R-12. This can further complicate the evaluator's mission of determining the final ranking of risk treatment priorities if we were to stay strictly related to the classic version of the *FMEA*.

The case study also showed the use of *APF* has contributed to a more efficient ranking of treatment actions compared to prioritization strictly based on the *RPN*. This can be observed, for example, in the situation of action A-15 which, after the efficiency criteria have been applied, acquired a higher priority compared to A-03, A-08, or A-17. Although A-03, A-08, or A-17 have a slightly higher *RPN* level than A-15, all of them being in the High Risks category, the efficiency analysis provides a different ranking. Thus, the decision to implement treatment actions in orders A-15, A-8, A-3, and A-17 takes into account, in addition to the *RPN*, the estimated economic efficiency, as this generates visible results faster and more efficiently using limited resources.

However, this approach, based only on cost and *RPN*, can only be partially satisfactory since it does not consider the duration required for the implementation of the corrective action.

The methodology proposed in this paper showed the fact that the use of all three factors *AIS, AIC,* and *AIR* provides a good alternative in terms of ranking the risk treatment actions, in particular for cement manufacturing organizations operating in a highly competitive economic environment, as they must be able to obtain maximum results in the shortest possible time, with the same volume of resources, in order to face tight competition.

By combining the risk category (high, medium, and low) with the *AEN* and determining the *APF* factor, it was demonstrated that when the risk treatment actions in the same category are difficult to prioritize, they can be easily distinguished and justified in terms of economic efficiency.

If referring to the limitations of the methodology proposed and studied within this paper, it can be concluded that the most relevant is related to the complexity of the assessment process, and the relatively long time required to go through the entire assessment process.

As the direction for future research, it can further carry out broader case studies, also including other complex processes from other industries, in order to extend the scope and subsequently, the final external validation of the improved methodology proposed in this paper.

The main contributions included in this paper that led to the improvement of *FMEA* are the following:

- Providing a viable alternative to mitigate the disadvantages of using *RPN* as the sole criterion for prioritizing the implementation of the treatment actions using the *FMEA* method.
- Using the Action Implementation Swiftness (*AIS*) factor which helps to scale the treatment actions based on the shortest time to produce the desired improvement. This is an important aspect from the perspective of change management and the need for a rapid transition to green manufacturing for organizations in the cement industry.
- Using the Action Implementation Costs (*AIC*) factor helps the organization in the cement manufacturing industry to better manage their limited capital flow and direct them mainly to the areas that produce the most sustainable and rapid change.
- Using the Action implementation Impact on reducing the RPN (*AIR*) factor, which focuses the attention on the treatment actions that have the greatest impact on the mitigation of partial or global risk levels.
- Weighing the opinions expressed by experts regarding the determination of *AIS, AIC,* and *AIR*, in order to increase the level of accuracy of the evaluation.

- Calculating the Action Efficiency Number (*AEN*) as a product between the values expressed for *AIS, AIC,* and *AIR*. This factor contributed to a more efficient ranking of risk treatment actions compared to prioritization strictly based on the *RPN*.
- Using the Action Priority Factor (*APF*) for the final ranking of risk treatment actions, taking into account both the *RPN* and *AEN*.

5. CONCLUSIONS

The improved method studied in this paper demonstrated in practice that it is a viable alternative and relatively easy to put into practice. The important objective of ranking the risk treatment actions in order to overcome the limitations related to the use of the *RPN* as a sole criterion was achieved.

Furthermore, the weight of individual opinions expressed by experts in determining the factors *S, O, D, AIS, AIC,* and *AIR*, with the help of criteria related to previous individual experience in risk assessment, knowledge of the processes assessed, professional maturity, and other soft skills have generated a better balancing of the final results, while also solving the problem of divergent opinions.

The three additional factors, *AIS, AIC*, and *AIR* have allowed for the decision-making process to become simpler and more transparent in terms of risk management, as the ranking of treatment actions is done now based on real economical judgments, such as speed of implementation, smallest cost possible, and the greatest impact on risk mitigation.

All these improvements in the methodology are an obvious step forward to obtaining better results from the risk assessment process for cement manufacturing. Using the additional new factors for ranking treatment actions based on the *APF* represents a novelty in the field, and a useful tool for cement manufacturing organizations, which comes to support the transition process toward green manufacturing and sustainable development.

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MANAGEMENTUL RISCULUI ÎN INDUSTRIA CIMENTULUI - ÎMBUNĂTĂȚAREA REZULTATELOR EVALUĂRII RISCURILOR PRIN DEZVOLTAREA UNEI NOI METODOLOGII DE PRIORITIZARE A OPȚIUNILOR DE TRATARE

În contextul unei transformări accelerate a procesului de fabricație a cimentului, alocarea eficientă a resurselor limitate pentru tratarea riscurilor, devine un factor critic de decizie în afaceri. FMEA este o metodă de evaluare a riscurilor utilizată pe scară largă în industria prelucrătoare, dar are însă unele limitări evidente, printre care și dificultatea de a stabili în mod obiectiv și eficient prioritățile de implementare a acțiunilor de tratare a riscului. Pentru a depăși aceste limitări, lucrarea de față propune noi factori care estimează eficiența acțiunilor de tratare a riscului, pe baza unei combinații între Factorul de Eficiență a Acțiunii și Numărul de Prioritate al Riscului. Rezultatele studiului de caz efectuat la o instalație automată de încărcare a cimentului vrac, arată o îmbunătățire semnificativă a rezultatelor comparativ cu o abordare clasică bazată doar pe Numărul de Prioritate al Riscului.

Constantin-Cristian DEOPALE, Ph D student, Politehnica University of Bucharest, cristian.deopale@outlook.com

Liviu Daniel GHICULESCU, PhD, Prof.**,** Politehnica University of Bucharest, daniel.ghiculescu@upb.ro, 313, Faculty of Industrial Engineering and Robotics, Department of Manufacturing, Splaiul Independentei, sector 6, Bucharest, Romania

Bogdan-Ionut CRISTEA, Ph D student, Politehnica University of Bucharest, cristea.ibogdan@gmail.com