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# INTEGRATION OF THE ENVIRONMENTAL DIMENSION IN MAINTENANCE DECISION SUPPORT TOOL FMEA: CASE OF A MOROCCAN FOUNDRY

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**KEYWORDS:** ENVIRONMENT, EMS, MAINTENANCE, FMEA.

## ABSTRACT

Nowadays, more and more companies communicate on their commitments concerning the protection of the environment, and seek to integrate environmental criteria in their management. As part of our research project which aims to integrate the environmental aspect into maintenance using the environmental management system, we offer a green Failure Mode and Effect Analysis (FMEA) that respects the environment during all of its implementation stages. We start in this article by defining the environment, environmental management system (EMS), maintenance and its relevance, and the relationship 'maintenance-environment'. Then we define the improvement process of maintenance FMEA, and how can the integration of environmental aspect be done, we will end up an industrial application of our proposal in a Moroccan foundry.

## INTRODUCTION

Companies are now evolving in an economic context marked by competition increasingly intense and always more demanding customers. To differentiate them from the mass, nothing beats a certification. And to go further, nothing beats an environmental certification. Moroccan companies have finally understood and are thus more likely to take the plunge.

The challenges of competitiveness, profitability and environmental protection call out the maintenance function and make it one of the pillars of an environmental management system.

In this paper, we present at first the environment and environmental management system (EMS), as well as maintenance function and the implicit link that gather them. We will then define Failure Mode and Effect Analysis (FMEA) and detail the integration of the environmental aspect in this approach, Finally, we will present a part of the industrial application of this integration in a Moroccan foundry.

## Definition of Environment and OF EMS

- The definition that interests us in the context of our research, it is these of ISO 14001: 2004. This reference defines the environment as "ambience in which an organization operates, including air, water, soil, natural resources, flora, fauna, humans and their interrelationships".

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- The international standard ISO 14001, defines EMS as "Component of the organization management system used to develop and implement its environmental policy and manage its environmental aspects. A management system is a set of interrelated elements used to establish policy and objectives and to achieve those objectives. A management system includes organizational structure, planning activities, responsibilities, practices, procedures, processes and resources. "

## ANALYSIS OF THE ENVIRONMENT/MAINTENANCE RELATIONSHIP

### Definition of Maintenance

According to the literature, the maintenance term, from Latin manu (hand) and tenerer (hold) appears a long time ago in the French language vocabulary (XII century). However, he was more dedicated to a military sense more than industrial one. He then pointed to the maintenance of the normal number of staff and equipment of a combat troop. Industrial connotation of the term comes from the Anglicism 'maintenance' dated on the middle of the twentieth century: Holding of technical equipment in function state; all set of maintenance ways and of their implementation.

For industrial activities, the most commonly and originally used term was maintenance: Care, repairs, expenses required to hold in good condition (Small Robert).

Before 1900, the term repair or fixing of equipment once it has failed. The goal was to have a quick restart.

From 1900 to 1970 the maintenance concept is used with the development of railways, automotive, aviation and armament during the two world wars. The majority of maintenance operations consisted of troubleshoots and repairs after failure [1].

From 1970, the development of risk sectors and modern tools leads to the implementation of maintenance. Indeed, for the responsible of these areas, to maintain the equipment undergoing his behavior is becoming inadequate to the risks incurred: it was necessary to master these automated systems, preventing incidents to avoid accidents, while avoiding prohibitive extra costs [2].

Maintenance is the optimization of upkeep parameters. If the upkeep was not considered productive yesterday, today's maintenance becomes [3].

We can make the sub-maintenance or over-maintenance. In one case, the process will lead to premature degradation of equipment, in the other case the overflow of useless interventions brings to a waste of money for the company.

It can be considered henceforth that "maintenance becomes a productive activity and not a cost for the company. Maintaining ensures availability of production, then assurance of the quantity but also the quality "[4]. And the slogan "Caring is undergoing, maintenance is to master" sums up the attitude changing[1]. Maintenance can be defined as "the set of all what helps maintain or restore a system in working order."

[1] French Association for Standardisation (AFNOR), Comment réussir votre maintenance, p. 21.

The NF X 60-010 has defined maintenance in June 1984 to be "All actions to maintain or restore a property in a specified state or to provide a specific service". This definition has been supplemented by specifying the nature of the maintenance function activities and the introduction of the concept of dependability in the definition of December 1995, 'all activities to maintain or restore in a state or in given conditions of security operation, to perform a function. These activities are a combination of technical, administrative and Managerial ones'.

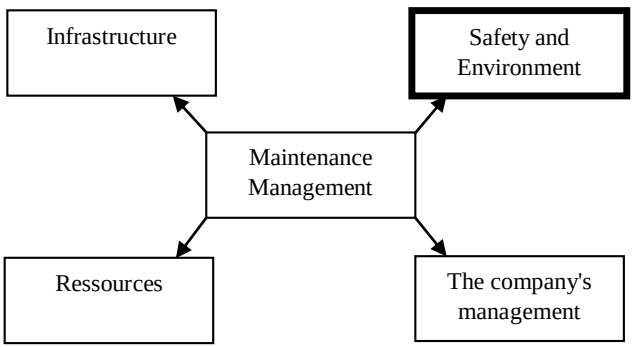
Thus, we find the standard AFNOR NF X 60-000 definition (February 1985) that incorporates the economics of the maintenance function "Well maintained is to ensure the optimal operation overall cost" As part of our research we use the definition of the standard EN 13306: maintenance is "The set of all technical, administrative and management activities throughout the life cycle of an asset intended to maintain or restore it to a state in which it can perform a required function. "This definition introduces the concept of maintenance throughout the life cycle of a material, the thing that was absent in that of the NF X 60-010.

The objective of this section is to reveal all the areas and concepts that are included in this function, and during this analysis we noticed that the environmental dimension is absent in all definitions of the maintenance function but it does not reject our assumption that the link Maintenance & environment is obvious. We will try to find this link by analyzing the objectives of maintenance or by following the maintenance activities on the life of the equipment.

**The relevance of the maintenance management:**
The relevance of the maintenance management was demonstrated in several books ([5], [6], [7], [8] ....). Indeed, a good maintenance management can help the company remain competitive both nationally and internationally.

A maintenance management implemented properly has a positive impact at different levels: infrastructure, resources (human and material), company's management (spare parts, inventory, etc.), safety and environment (figure 1). This is what we will detail in what follows.

***Figure 1: the impact of the maintenance management***




On the infrastructure side, maintenance management allows ([9], [10], [11] and [12]):

- Protect investments by providing the machines and buildings prolonged life through regular and effective Maintenance;
- Ensure return on these investments by making maximum use of the equipment and thereby minimizing downtime (unplanned) production system.

On terms of resources, the effect of maintenance management is also well situated to human resources nival as material resources. As regards the first component, the maintenance management allows ([13], [14], [11] and [15]):

- Supervise and direct service maintenance personnel to improve to the maximum the use and allocation of resources;
- Ensure effective staff technical training, so that mastery stains it is trying to accomplish.

As regards the material aspect, maintenance management allows ([7], [14], [11] and [15]):

- Improve the use of these resources (equipment, tools and spare parts);
- Optimize their allocation (to avoid waste);
- Reduce production costs.

At the company's management, it allows ([8], [14], [11] and [15]):

- Record spending, and many estimate the cost of upkeep work ,and maintenance to try to reduce them;
- Check the upkeep costs to keep accounts for the establishment of future budgets.

In terms of safety and environment, maintenance management allows at the first part of ([5], [6] [11]):

- Establish an accident prevention system, ensuring the safe functioning of equipment, building safety;
- Have a working climate within in the company, thus creating a safe working environment;

In terms of environment, maintenance management allows ([16], [17], [18]):

- Extend the lifetime of the property;
- Reduce noise (eg. A vibration motor).
- Reduce consumption of matter and energy (eg. Water and electricity)
- Reduce solid and liquid waste (oil leakage ...).
- Reduce air pollution (gas leak ...).
- Reduce costs related to the environment (the penalty cost due to the impact of the deterioration of the production system on the environment).

Authors who have introduced the environment among the pertinence of maintenance management are very rare, which explains the implicit form of the relationship ‘maintenance environment'.
Based on this literature review, we conclude that: improving maintenance of a good, service or process reduces its environmental impacts, where the relationship can be extracted (1) described below (see Figure 2).

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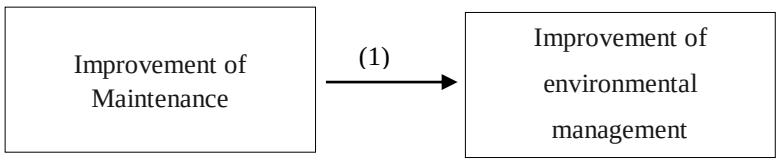
***Figure2: The implication relation Maintenance/ Environment***




**The relationship 'maintenance-environment'**

The 'environmental' dimension is absent in all definitions of maintenance, even after the awareness of the issue of protecting the environment and international multilateral actions between states in this regard that are being in place, such as:

- Kyoto Protocol: protocol to reduce the effects of global warming and reducing certain gases that contribute to global warming. It is signed on 11 December 1997, ratified[2] by 37 countries[3].
- Montreal Protocol[4]: protocol that aims to remove certain gases contributing to the destruction of the ozone layer, approved on September 16 1987 and applied in 1 January 1989[5], ratified by 197 countries.
- Etc.
  Nationally, Morocco has:
- Developed a national global environmental charter, which is available in Law No. 99-12,
- Ratified the Kyoto Protocol in 2002 [19].

In the time when the environment became an international scale policy and maintenance is an essential function in an industry, there is very little research work which deals with the relationship between maintenance and the environment.

All maintenance definitions have a common point which is 'to ensure a good functioning', the latter remains incomplete if a machine for example works without fail and consumes much energy. The good functioning includes also the respect for the environment, so the proper functioning means working without breakdown, without failure, without energy overconsumption and no air, soil or water pollution.

[2] www.commaissancedesenergies.org
[3] Kyoto protocol to the united nations framework convention on climate change. Technical report, United Nations.
[4] The Montreal Protocol on substances that deplete the ozone layer. Technical report, Programme des Nations Unies pour l'Environnement.
[5] http://ozone.unep.org

Although the link "Maintenance-Environment" is obvious, it remains implicit. Our objective seeks to strengthen it and make it more explicit through its integration in all strategies of maintenance function and its decision support tools including the FMEA approach, which we have presented in this article.

## FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

The FMEA made its appearance in France in aeronautics (Concorde and Airbus) in 1960. Introduced in manufacturing series since the 1980s, its application remains there today widespread [20]. Initially FMEA techniques was mainly used for product failures analysis modes only in the nuclear, aerospace, automotive, chemical, mechanical industries, but with the passage of time, FMEA becomes widely used in the analysis fault industries softwares: [21] [22] and in the information security [23].

The FMEA helps to identify the potential failure mode and its causes, effects, and it's Risk Priority Number (RPN) which is traditionally defined as the product of the occurrence (O), severity (S) and detection (D).

Maintenance can act on a product, service or process. And as we have mentioned before, maintenance actions can be technical, administrative or managerial and must be implemented throughout the lifetime of a material (equipment). Some of these actions are situated at the conception of equipment, others are actions of surveillance and monitoring, end of life, maintenance of equipment offers a decommissioning [17]. This is why in the rest of our research we treat FMEA generally, without considering its types (e.g. Process FMEA, Design FMEA, System FMEA, Product FMEA, etc.).

## THE ADDED VALUE OF THE PROPOSAL FOR A GREEN FMEA

Among the benefits that the company can gain by integrating environmental criteria into the continuous improvement process FMEA:

- Improving the conception of the good, service or process to the 'environmental' objective.
- The integration of the environmental dimension in maintenance allows for monitoring and reassessment of environmental performance since the FMEA is an approach based on the principle of continuous improvement.
- Taking into account the direction of the company in terms of environmental management and response to the requirements of the ISO 14001 standard "The organization shall establish, implement and maintain one (of) procedure (s) to identify potential emergency situations and potential accidents that can have (the) impact (s) on the environment, and how to react 'and' use practices process, materials, products, services or energy to prevent , reduce or control (separately or in combination) the creation, emission or discharge of any type of pollutant or waste '.
- Continuous improvement of environmental performance required by the implementation of an environmental management system[6].
- Look for potential failures or malfunctions which may affect equipment, machine, process, or the environment.
- Analyze the consequences of these failures, identify situations that would result.

[6] norm iso 14001 :2004

- Assess the level of severity, criticality or acceptability of these situations,
- Know how and what action, consider what steps, if these unacceptable situations appears.

## INTEGRATION OF ENVIRONMENTAL CRITERIA IN FMEA

Several research works have used the FMEA approach as a potential risk analysis tool on a system, we cite the research of [24], [25], [26], [27], [28], [29] etc ... others have made the process FMEA their research object and they criticized the Risk Priority Number (RPN), and his traditional method calculates, which is given by the product of three parameters: occurrence (O), severity (S) and detection (D) by assigning to each parameter an integer from 1 to 5 for example, they have proposed a new method based on fuzzy numbers as works of [21], [30], [31], [32], [33] etc ... but the number of researches that analyze the criticality of a system on the environment or dealing relationship FMEA / environment is very limited, we quote in this direction the research of [34], [35] and [36] who proposed the FMEA method as a tool for impact analysis of a system on the quality, safety and the environment, so the research work of [37] which analyzed the impact of maintenance activities on the environment and safety by using the FMEA. In this paper, we propose the integration of the environmental dimension in the FMEA approach; we will analyze and treat the introduction of environmental criteria in maintenance in the following three steps: calculates RPN matrix, action plan and monitoring and verification step.

**Risk Priority Number (RPN) taking into account the environmental dimension:**

Each failure is usually judged on three criteria: their occurrence (O), the severity of their consequences (or their effects) (S) and detection (D) .We therefore proposes for each failure to add the criterion 'environment'(see Table 1).

***Table 1: FMEA after the integration of environmental criteria E.***

| Function or operation of the process | Failure mode | Failure Effect | Failure cause | S | O | D | E | RPN |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

The following equation shows the Risk Priority Number (RPN) after the integration of the environmental criteria:

$$RPN = O \times S \times D \times E \quad (1)$$

E: Environmental criteria

It represents the effect of the failure mode on the environment. Rating scales which vary between 1 and 4 are based on the effects caused by the failure, in terms of environment and on the applicable law (see Table 2).

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***Table 2: Matrix of result of failure mode on the environment***

| note | Failure mode effect on the environment |
|---|---|
| 1 | minor effect<br>No significant impact on the environment / the applicable law threshold is not exceeded |
| 2 | major effect<br>Significant impact on the environment / the applicable law threshold is exceeded by 10% to 15% |
| 3 | critical effect<br>potential damage to the environment / the applicable law threshold is exceeded by 20% to 25% |
| 4 | Catastrophic effect<br>damage to the environment / the applicable law threshold is exceeded by 50% to 55% |

- The number of marks on the scale is generally limited; it is not necessary to provide a scale with 20 levels, it becomes difficult to distinguish between level 14 and level 15 for exemple.
- It is not necessary that the scales for the different criteria comprise the same number of [20] levels.
- It is proposed to grant a corrective action automatically if $E \geq 3$.

**Action Plan**

An action plan aims to reduce the Risk Priority Number (RPN) which is the product of four parameters O, S, D, and the effect of the failure mode on the environment E, thus, one of the objectives of an action plan is to decrease E, that is to say improving the management of the environment, which enhances the relation (1) described in figure 1.

In other words, Corrective and preventive actions aim to reduce the Risk Priority Number (RPN) of failures, also acting on management environment. So the improvement of environmental management helps, to reduce the RPN and consequently, to improve the maintenance management within an industry (see Fig.3).

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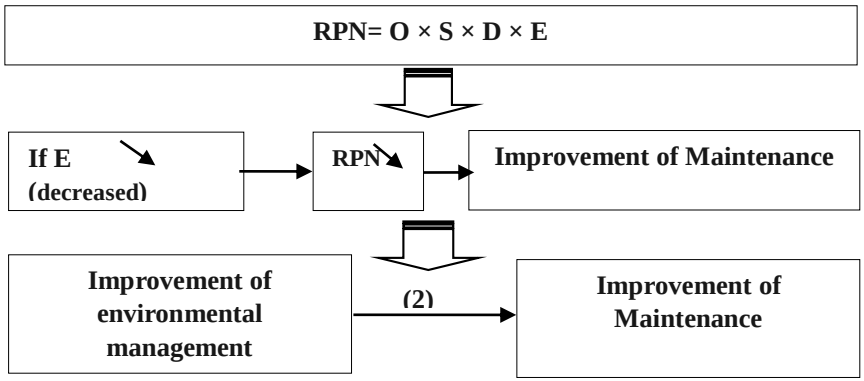
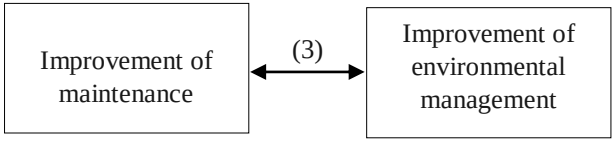
***Figure3: The implication relation Environment/ Maintenance***




And according to the relation (1) and (2) described in Figure 2 and Figure 3, we can conclude the relation (3) described below (see Figure 4):

***Fig.4: the equivalence relation Maintenance/Environment.***




**Monitoring And Verification:**

The company analyzes and evaluates its technical and environmental performance after the implementation of corrective or preventive action plan.

Assessment of environmental performance is one link in the cycle that allows measurement and synthesis, by the scoreboard of environmental performance of the system studied.

We are inspired of the PDCA methodology to present the continuous improvement process FMEA (Figure 5).

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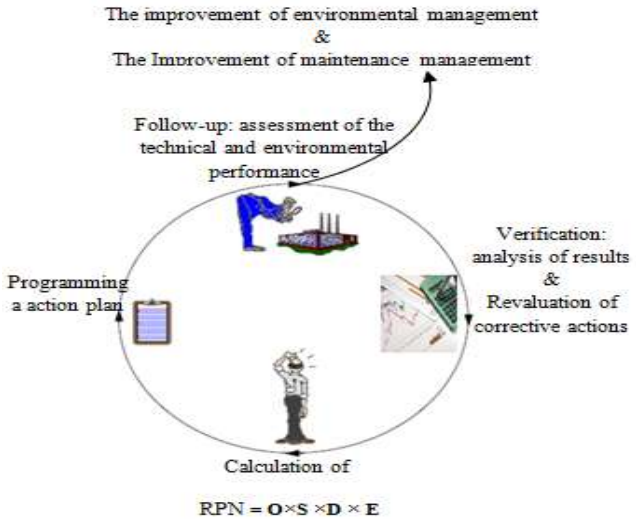
***Figure 5: Presenting continuous improvement process FMEA***




Based on results of assessment of environmental performance, the information is communicated to management of the company, it must find treatments of deviations solutions, and program an action plan. The cycle is completed by regular re-evaluation of the effects of planned corrective actions, and the opportunity to correct the action plan accordingly.

To meet the needs of the business, and for it to be able to drive the course of action towards the achievement a goal or to evaluate the result, we formalize the information later by environmental indicators.

## INDUSTRIAL APPLICATION

The industrial application of our proposal is to a Moroccan Foundry Company, which has as main activity the production of pistons, liners and automobile routes.

The working group has decided to set 16 as the threshold value for the Risk Priority Number (RPN), beyond this threshold, the effect of the failure is not sustainable, so action is needed.
Elements whose criticality exceeds 16 are combined in a preventive maintenance plan.

We will present in this article the application of FMEA on a machining center OP 50, the function of this machine is to realize finishing hole axis, its functional breakdown is as follows:
1. Hydraulics
2. Table

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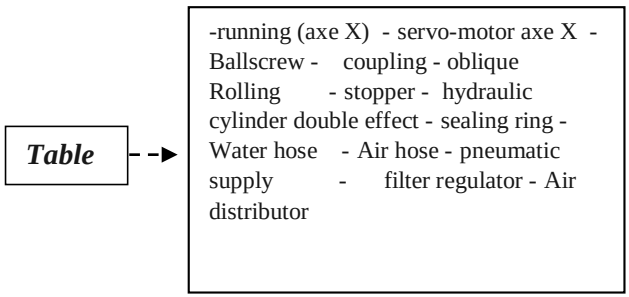
3. Pin
4. Dredge
5. Switch cabinet

We will present in this article just a part of the FMEA analysis regarding a set Table.
The most elementary decomposition of the entire table is as follows (see Figure 6):

***Fig. 6: the elementary decomposition of a set Table***




Following the presentation of the FMEA with traditional RPN.

***Table 3: Failure Mode and Effects analysis with RPN.***

| **Analyse des Modes de Défaillances de leurs Effets et de leurs Criticités- AMDEC Moyen de production** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Atelier : Usinage** | | | | | | | | | |
| **AMDEC Du MOYEN: OP50** | | | **AMDEC N° XXXX** | | | **Crée-le** | | | |
| **Code machine : XXXX** | | | | | | **Modifiée le** | | | |
| **Ensemble : Table** | | | | | | | | | |
| **Elément** | **Fonction** | **Failure Modes** | **Failure causes** | **Failure effects** | **Détection** | **Cotation** | | | |
| | | | | | | **O** | **S** | **D** | **RPN** |
| **running « axe X »** | Reduce friction links | crack blocking (fouling) | friction poor lubrication Foreign body (grain chips) | vibration No precision | abnormal noise Warming | **3** | **3** | **2** | **18** |

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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Servo-motor « axe X »** | To train la vis à billes axe X | irregular working | - tiredness - overload | bad precision | Visual | **1** | **2** | **2** | **4** |
| | | Servomotor Stop | | no table movement | | **1** | **2** | **1** | **2** |
| **Ballscrew** | Converting the rotational movement to a translational movement | wear | Tiredness | bad precision | -Vibration - noise | **1** | **3** | **2** | **6** |
| **coupling** | Forward speed and torque between the motor and running | wear | Tiredness | bad transmission | Visual | **1** | **1** | **2** | **2** |
| **stopper** | Indicate the end of race | It does not work | Fatigue | problems of the origins of the machine and programming | Visual | **1** | **2** | **2** | **4** |
| **oblique Rolling** | Support the load carriage | wear | Tiredness | Vibration | - noise - Warming | **1** | **3** | **2** | **6** |
| **hydraulic cylinder double effect** | Transform the hydraulic energy into mechanical energy | Piston wear | Choc of piston | bad or no tightening | visual | **1** | **1** | **1** | **1** |
| | | BLock cylinder | Insufficient oil flow | | | **3** | **2** | **1** | **6** |
| **sealing ring** | Protect hydraulic components against leaks | wear | Tiredness | - Warming - Bad piece precision | Oil leak | **1** | **2** | **2** | **4** |
| **Water hose** | Direct the water lubricant on the piston | crack | Tiredness | - extraction - detachment | flight | **1** | **1** | **1** | **1** |
| **Air hose** | driving of air through the tools | crack | Tiredness | -arrachement -Détachement | flight | **2** | **1** | **2** | **4** |
| **pneumatic supply** | Discharge air | - Warming - default flow | - faulty joint -fuite | Not reached the nominal pressure | Warming | **2** | **2** | **3** | **12** |
| **filter regulator** | Removed the water bubbles | fouling | Presence of the body suspended | deterioration of the pneumatic circuit | Visual | **1** | **2** | **2** | **4** |

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| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Air distributor** | Air distribution at the piston | blocking | - overvoltage<br>- low pressure | Stopping the flow of water | Visual | **1** | **2** | **3** | **6** |

Following the presentation of the FMEA taking consideration the environmental dimension with RPN1.

***Table 4: Failure Mode and Effects analysis with RPN1.***

| **Analyse des Modes de Défaillances de leurs Effets et de leurs Criticités- AMDEC Moyen de production** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Atelier : Usinage** | | | | | | | | | | | |
| **AMDEC Du MOYEN: OP50** | | | **AMDEC N° XXXX** | | | **Crée-le** | | | | | |
| **Code machine : XXXX** | | | | | | **Modifiée le** | | | | | |
| **Ensemble : Table** | | | | | | | | | | | |
| **Elément** | **Fonction** | **Failure Modes** | **Failure causes** | **Failure effects** | **Environmental effects** | **Détection** | **Cotation** | | | | |
| | | | | | | | **O** | **S** | **D** | **E** | **RPN1** |
| **running « axe X »** | Reduce friction links | crack<br>blocking (fouling) | friction<br>poor lubrication<br>Foreign body (grain chips) | vibration<br>No precision | noise | abnormal noise<br>Warming | **3** | **3** | **2** | **2** | **32** |
| **Servomotor « axe X »** | To train la vis à billes axe X | irregular working | - tiredness<br>- overload | bad precision | Minor effect on the environment | Visual | **1** | **2** | **2** | **1** | **4** |
| | | Servomotor Stop | | no table movement | | | **1** | **2** | **1** | **1** | **2** |
| **Ballscrew** | Converting the rotational movement to a translational movement | wear | Tiredness | bad precision | noise | -Vibration<br>- noise | **1** | **3** | **2** | **2** | **12** |
| **coupling** | Forward speed and torque between the motor and running | wear | Tiredness | bad transmission | Minor effect on the environment | Visual | **1** | **1** | **2** | **1** | **2** |
| **stopper** | Indicate the end of race | It does not work | Tiredness | problems of the origins of the machine and programming | Overconsumption of energy | Visual | **1** | **2** | **2** | **2** | **8** |

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| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **oblique Rolling** | Support the load carriage | wear | Tiredness | Vibration | noise | - noise<br>- Warming | **1** | **3** | **2** | **2** | **6** |
| **hydraulic cylinder double effect** | Transform the hydraulic energy into mechanical energy | Piston wear | Choc of piston | bad or no tightening | Minor effect on the environment | visual | **1** | **1** | **1** | **1** | **1** |
| | | BLock cylinder | Insufficient oil flow | | Minor effect on the environment | | **3** | **2** | **1** | **1** | **6** |
| **sealing ring** | Protect hydraulic components against leaks | wear | Tiredness | - Warming<br>- Bad piece precision | liquid waste | Oil leak | **1** | **2** | **2** | **2** | **8** |
| **Water hose** | Direct the water lubricant on the piston | crack | Tiredness | - extraction - detachment | liquid waste | flight | **1** | **1** | **1** | **2** | **2** |
| **Air hose** | driving of air through the tools | crack | Tiredness | -arrachement<br>-Détachement | Minor effect on the environment | flight | **2** | **1** | **2** | **1** | **4** |
| **pneumatic supply** | Discharge air | - Warming<br>- default flow | - faulty joint<br>-fuite | Not reached the nominal pressure | Overconsumption of energy | Warming | **2** | **2** | **3** | **2** | **24** |
| **filter regulator** | Removed the water bubbles | fouling | Presence of the body suspended | deterioration of the pneumatic circuit | Damage to property | Visual | **1** | **2** | **2** | **2** | **8** |
| **Air distributor** | Air distribution at the piston | blocking | - overvoltage<br>- low pressure | Stopping the flow of water | Minor effect on the environment | Visual | **1** | **2** | **3** | **1** | **6** |

For RPN1, the working group has decided to set 20 as the threshold value.

After consideration of the environmental dimension, RPN has changed value in some cases, one case has entered the preventive maintenance plan.

The case that concerns us is the case of the element 'air supply' 'who had RPN equal to 12 and spent 24 after taking into account the E criterion.

We proposed in this case a systematic maintenance: the period is 6 months and the preventive action is " change the seal'.'

**Limits of our industrial application:**

- The working group does not contain an expert environmental, this is why we found it difficult to find the most appropriate value to E, but we will try to insert an environmental expert in our group.

- The industrial application has not yet finished, we presented in this article just a part that we have partially finished, and this part can be improved thereafter.

## CONCLUSION

The improvement of the environmental management system in industry requires improved maintenance management, and our industrial application, shows how to reduce negative environmental impact by maintenance management, using the FMEA method.

The industrial application that we presented in this article is only a very small part of the study that we did in a Moroccan foundry.

In our study, we conclude that the integration of the environmental dimension in the tool of decision support maintenance FMEA increases reliability and made it more significant.

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