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Improvement Analysis of the Maintenance Policy of a Civil Engineering Equipment: A case study of the graders in Cameroon

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ABSTRACT: *The work carried out in this paper focuses on "Improvement analysis of the maintenance policy of a civil engineering equipment: A case study of the graders in Cameroon". The aim is to analyze the improvement of the maintenance policy of this equipment, in order to reduce the number of failures that occur at the building sites and thus increase their availability. To achieve this objective, the methodology adopted begins with a diagnosis of the current maintenance policy carried out using an evaluation questionnaire called the Lavina questionnaire, which identified the weaknesses of the policy in place. Then, the use of the Ishikawa diagram revealed several causes of unavailability such as: lack of preventive maintenance plans, the unsuitable working methods, the insufficient stock of spare parts. Finally, the use of the usual maintenance tools such as ABC analysis, functional analysis and FMECA, has enabled us to highlight the critical elements of the gears, namely the engine and the injection pump. To establish a preventive maintenance plan for these equipment as well as an annual maintenance schedule, to develop preventative maintenance sheets and contingency sheets, to establish a list of critical spare parts, and to set up a file to record the history of failures and interventions. This work will not only increase the availability of the gears, but also keeps them in a good working condition and prolong their life span.*

KEYWORDS: *civil engineering gear, availability, building sites, maintenance policy, graders.*

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I. INTRODUCTION

With a view to develop the country, many shipyards are underway in Cameroon, including the building of bridges, dams, hydroelectric power plants, ports, roads and highways. On the other hand, a large part of these projects are the civil engineering works. Building and public works companies were responsible for the realization of these projects, to carry out these activities there is a need for good equipment. However, the machines undergo several failures during their use at the building sites, which slowdown the work as well as financial losses. In addition, failures occur due to the poor quality of maintenance applied on these machines. How to reduce the number of failures that occur at the building sites and increase the availability of these machines? How to improve the maintenance strategy applied to these machines? The overall objective of this work is to analyze the improvement of the maintenance policy, in order to reduce the number of failures that occur at the building site and thus increase their availability. To achieve the objective and answer the two questions above we present this work. The first part is the "Material" which consist of the generalities on the constitution and the use of the machine. The second part is the "Methods" which consist the different stages of the methodology used to analyze the improvement of the maintenance policy. The last part is the "Results and Discussion", where the results obtained are presented and discussed by succinctly applying the methodology presented in the previous section.

II. MATERIALS

1. General Constitution of a Civil Engineering

According to [1], heavy equipment has an architecture that presents itself as shown in Fig. 1. below.

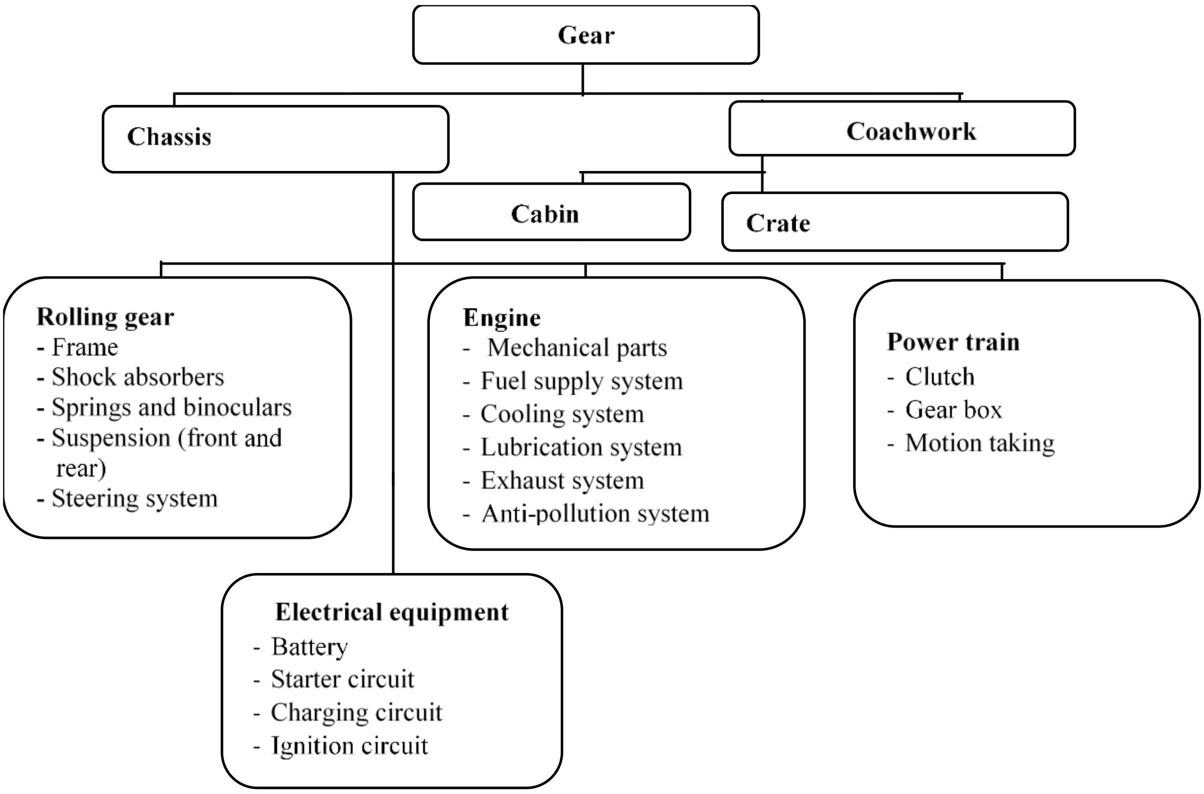

Fig.1. Architecture of a heavy equipment

There four main groups are identified as follow:

- The Engine: It is the source of energy that allows the vehicle to move. It allows the transformation into mechanical energy, the chemical energy released by the reaction that takes place within it between air and fuel.
- The Rolling gear: It is the whole of the rolling part of the vehicle with all the associated elements which ensure a reliable handling.
- The Power train: These are all the components whose main function is the transmission of power to the wheels of the vehicle.
- Electrical equipment: These are all elements which have the function to produce the electric current necessary to start the engine and to turn on the electrical devices.

2. Operations carried out by Graders

The role of the grader is as its name implies to regulate the surface of a soil and to allow the adjustment of this surface following cants and very precise slopes. This equipment is more or less large depending on the surface to be treated. A grader can work in the horizontal plane but also with a certain slope. In any case, a grader is used primarily to surface the floor as much as possible in road applications particularly in:

- The landscaping of airports and sports fields
- The construction of parking lots and industrial areas

The ground to be worked must be free of important obstacles such as stumps of trees, remnants of roots, large stones, etc. At the moment, a grader is a kind of tractor under which a grader blade is mounted, the hydraulically operated blade can rotate vertically and horizontally.
The Fig. 2. below shows a road grader, which is in the process of flattening a surface for the construction of a route in a village around Yaoundé in Cameroon.

Fig. 2. Grader operating in a building site

As can be seen from the Fig. 2. the graders are rather cumbersome machines compared to conventional vehicles, with a length of 9.4 meters in this case, a width of 2.8 meters and a height of 3.5 meters. They weigh about 17 tons and have a six-cylinder engine of 229 hp running at 2000 rpm at rated power.

III. METHODS

There are now a very large number of maintenance improvement tools. The best known are the ABC analysis, functional analysis, FMECA, maintenance plan, Hoshin method, Ishikawa diagram, TPM, PDCA and CMMS.

According to [2], these tools can be grouped into two categories, the diagnostic tools and improvement research (Hoshin method, PDCA, Ishikawa diagram); the tools effectively lead to solutions to be implemented (TPM, CMMS, ABC, FMECA and others). Each of these tools has pros and cons which makes it possible to choose the ones that are best suited for the resolution of the problem posed.

- For the first group: The Ishikawa diagram is the most appropriate in the present case because it allows to break down a situation according to several factors and to highlight the causes leading to the problem, which is the first thing necessary before starting to years looking for solutions.
- For the second group: ABC tools, functional analysis, FMECA and maintenance plan are the most appropriate as the ABC analysis will focus on critical elements, which will alleviate the study, functional analysis and FMECA will be used to analyze these elements and to propose solutions that will be implemented through a preventive maintenance plan.

Thus, the methodology to be followed consists of three main parts: the diagnosis, consisting of an analysis of the existing maintenance policy, followed by the representation of the different causes of the problem on a Ishikawa diagram; the determination of critical elements to highlight the most punitive elements of the spacecraft through ABC analysis; and finally the analysis of failures, thanks to the FMECA, in order to highlight the modes, causes and effects of failures, to prioritize them and propose corrective actions.

1. The Diagnosis of the Maintenance Policy in Place

The purpose of the diagnosis is to target the weaknesses of the maintenance policy in place in order to be able to make proposals for improvement. The diagnosis is made using an evaluation questionnaire described by [3], called the Lavina questionnaire, the questions are divided into several groups or criteria namely the general organization, the methods of work, the technical monitoring of the equipment, the management of the work portfolio, the physical organization of the maintenance workshop, the management of the tools, the management of the personnel and the technical documentation and the control of the activity. The questionnaire must be submitted to the service manager in charge of maintenance. For each question, a score is assigned based on the response (from "No" to "Yes" through intermediate levels). However, not all questions have the same range of notes. Indeed, the maximum score for a question depends on its importance in evaluating the test. For each criterion, the score obtained is calculated by summing the notes obtained to the questions asked. The general organization is noted on 250 points, the method of working on 200 points, the technical monitoring of equipment on 220 points, the management of the portfolio of works on 280 points, the physical organization of the workshop on 200 points, the tooling on 215 points, technical documentation on 190 points, personnel management and training on 320 points and control of the activity on 150 points. The entire questionnaire is therefore on 2105 points. At the end, a summary of the questionnaire is carried out showing the percentage of the score obtained for each criterion and the percentage of the score obtained in total. Areas that are considered weak points (areas that need to be improved as a priority) are areas where the percentage of the score is less than the percentage of the total score. The diagnosis also helps to highlight the different causes leading to the problem to be solved. According to [4], these causes and their effects can be represented on an Ishikawa diagram. It classifies the causes into several groups of equipment, this is all that requires an investment, equipment, premises and large tools. Manpower is the entire staff, Methods are the ranges, the instructions for use, the leaflets and the written or not statements, Material is all that is consumable and Environment is the physical and human environment, working conditions, ergonomics, relationship and clients. After highlighting the causes of the problem with the Ishikawa diagram, we can offer effective solutions.

2. The Determination of Critical Elements

Critical elements are the most punitive elements (responsible for most of the downtime) of the gears. According to [5], they are determined by an ABC analysis. ABC analysis is a method derived from the Pareto method, a histogram for classifying phenomena in order of importance. In Pareto analysis, the 20% of the causes producing 80% of the effects are very often interested. Its veracity in most situations and areas of activity has forged its fame. The ABC method proposes to distinguish three classes from the causes of failure. For the specific area of maintenance, three classes A, B and C are distinguished which are distributed as follows:

- Class A: Causes accumulating about 80% of failures
- Class B: Causes accumulating about 15% of failures
- Class C: Causes accumulating about 5% of failures

The main stages of the study are:

- The definition of the objective of the study and its limitations: these elements can be materials, causes of failures, natures of failures, etc.
- The choice of the classification criterion: it is a question of organizing the classification according to the criteria of the values selected (costs, times, waste, etc.).
- The construction of a graph: This graph will show the constituents on the situation studied.
- The determination of the ABC zones: It is a question of delineating, on the curve obtained, the zones depending on the shape of the curve. In general, the curve has two breaks, which makes it possible to define three zones:
- The first part of the curve usually straight and of high slope, determines zone A.
- The curved part following this area and less pronounced slope, determines zone B.
- The next low-slope part determines zone C.

The interpretation of the curve: The study focuses initially on the elements constituting the Zone A as a priority.

3. The failure Analysis

After determining the critical elements, a failure analysis is performed on each of them. This is done through the FMECA: analysis of the modes of failure, their effects and their criticality. This technique described [6], helps to highlight the modes causes and effects of failures, prioritize them and propose corrective actions. It is done by following the following steps:

- Functional analysis: It is a question of identifying the functions of the means of production, its subsystems and its components. According [7], it is a matter of making an octopus diagram and a FAST diagram of the system.
- Analysis of failures: this is through the identification of failure modes, identifying the causes of failure, risk assessment, and the search for detection modes.
- Prioritization of failures with the rating of the criticality: it allows to estimate for each failure, three criteria of definition namely the frequency of occurrence of the failure denoted as F, the severity of the consequences that the failure generates denoted as G, and non-detection of the occurrence of the failure, before it produces the unwanted consequences denoted as D. These three elements allow to determine the criticality of the failure, denoted as C in eq. 1.

$$C = F \times G \times D \qquad (1)$$

The evaluation of these criteria is done according to some evaluation grids. The frequency is evaluated on a scale of 1 to 4, the severity on a scale of 1 to 5 and the non-detectability on a scale of 1 to 4.

- Definition of corrective actions: This is successively the description of the corrective actions to be implemented to definitively remedy the failures.

In practice, the implementation of the FMECA is done using a table in which the above elements are given (element, function, failure modes, causes, effects, frequency, severity, non-detectability, criticality and corrective actions). Here, the purpose of the FMECA analysis is to establish a preventive maintenance plan.

4. The Preventive Maintenance Plan

The NF X 60-010 standard defines the maintenance plan as "a document setting out the procedures, resources and sequence of activities related to the maintenance of a property". It must be able to organize the maintenance of the property and contribute to the realization of the good. So, it must contain all the information useful to its implementation. The preventive maintenance plan will define the inspection, control and visit actions to be carried out on the equipment. According to [8], the process of developing a maintenance plan can be summarized in the following Fig. 3.

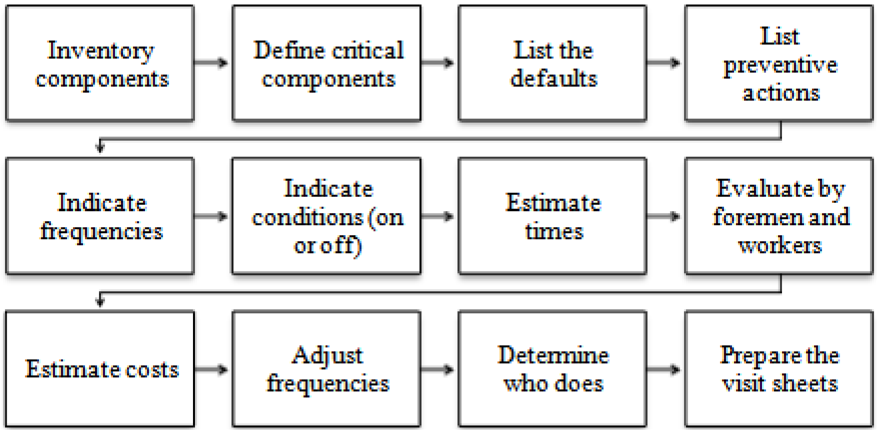

Fig. 3. Process for preparing a maintenance plan

IV. RESULTS AND DISCUSSION

1. The Diagnosis of the Maintenance Policy in Place

Assessment questionnaire results have been summarized in table 1. below. The columns respectively present areas of analysis, the score for each topic as much as possible and finally the score report within report. This table allows to identify five areas of weaknesses (or whose action is a priority). These are the areas which the percentage set out in column 4 is lower than the total score (47.60%). Its General Organization (44%), the method of work (42.5%), the works portfolio management (39.29%), management of personnel and training (40.62%) and the control of the activity (43.33%).

Table 1: Results of the evaluation questionnaire

Areas of Analysis	Scores	Max. Possible	Percentage
General organization	110	250	44
Method of work	85	200	42.5
Technical follow-up of equipment	125	220	56.82
Management of the work portfolio	110	280	39.29
Hardware organization of the workshop	140	200	70
Tooling	135	215	62.8
Technical documentation	100	190	52.63
Personnel and training	130	320	40.62
Activity control	65	150	43.33
Total score	1002	2105	47.60

The causes leading to the problem to be solved were represented on an Ishikawa diagram, shown in Fig. 4. below. This diagram shows the various causes that are categorized into several groups:

- Manpower: there are non-compliance with a schedule of maintenance activities, high response time.
- Environment: there is an inappropriate work climate.
- Equipment: the tooling is not classified.
- Material: the stock of spare parts is insufficient.
- Methods: we have no regular planning of repair activities, the lack of procedures for detecting failures, and especially the lack of a preventive maintenance program.

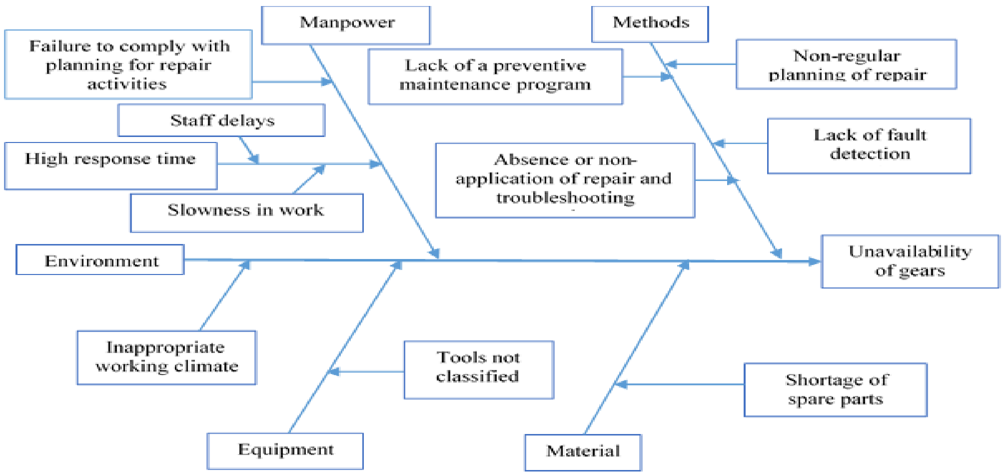

Fig. 4. Ishikawa diagram of the maintenance policy

This allowed to propose solutions to improve maintenance activities:

- For the general organization, there are strengthening of management personnel, definition (in writing) of the objectives of the service and regular control.
- For the method to work, there are preparation of work (job scheduling and forecasting the time before execution), formalization of procedures in writing.
- For the management of the works portfolio, there are establishment of a preventive maintenance plan; establishment of preventive maintenance sheets.
- For the personnel management and training, doing interviews of personnel appraisal, adjustment of staff and improve the skills (by the recycling).
- For the control of the activity, we have controls of the effectiveness of maintenance personnel.

2. The Determination of Critical Elements

It is performed by following the four steps outlined in the methods section.

- Definition of the objective of the study, the objective is to determine the critical elements of the graders.
- Choice of the classification criterion, in the present case, the classification criterion is the downtime caused.
- Construction of the graph, the graph of Pareto of downtime is represented in Fig. 5. below.
- Determination of areas A, B and C are areas defined in Fig. 5.

The actual critical elements are the elements lying in area A. Thus, the ABC analysis has identified critical elements namely the engine and the pump injection. Indeed, these two elements are responsible for 80.31% of total downtime of the machinery. They are the elements of class A, and therefore it is on these two elements that will carried out the failure analysis.

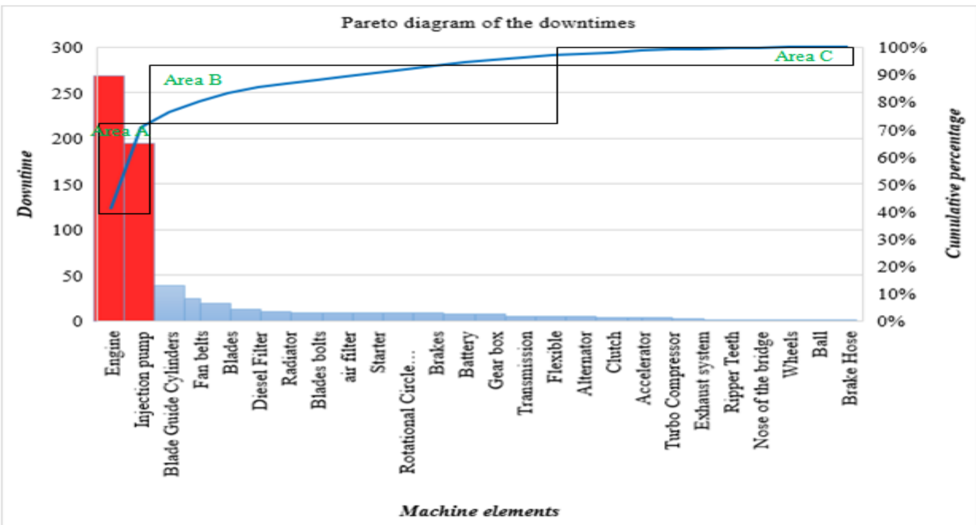

Fig. 5. PARETO diagram of the downtimes

3. The Failure Analysis

Following the procedure described in part III.3, a functional analysis and FMECA analysis were performed on the engine and the injection pump. Functional analysis consists of octopus diagrams and FAST diagrams while the FMECA is made in a table form. The octopus diagram of the injection pump is presented in Fig. 6. below.

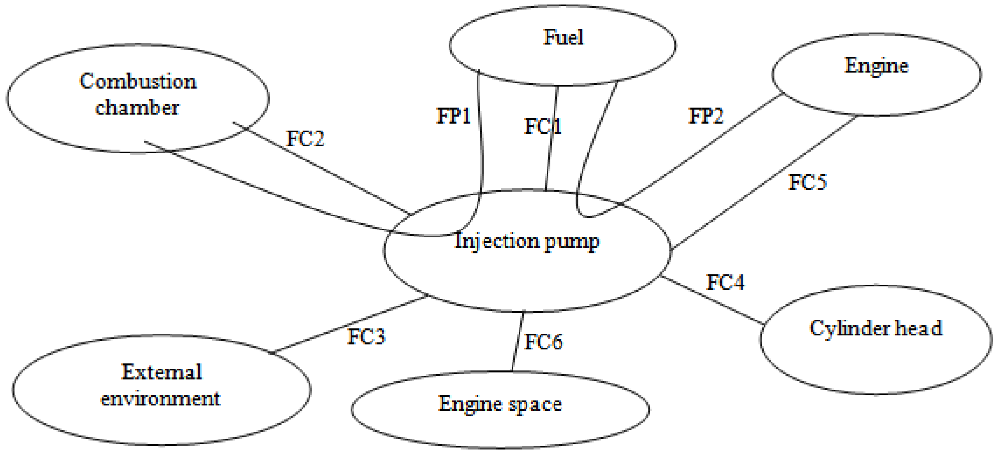

Fig. 6. Octopus diagram of the injection pump

- The main functions of the injection pump are, FP1 is to send the fuel in the combustion chamber and FP2 allows the operation of the engine.
- Constraint functions, FC1 does not waste fuel, FC2 is to be connected to the combustion chamber, FC3 does not pollute, FC4 be connected to the cylinder head, FC5 be connected to the motor and FC6 be outside the engine space.

The FAST diagram of the injection pump [2] presents the technical functions related to the main function of FP1, among which it is a FT1 which controls the injection pressure. This technical function is provided by the element « discharge connection ».

The table 2. below shows an excerpt of the FMECA of the injection pump. The criticalities are calculated by using the eq. 1.

Table2: FMECA of the injection pump

Failure Modes Effects and Criticality Analysis									
Injection pump System									
Element	Function	Failure mode	Cause	Effect	Criticality				Corrective actions
					F	G	D	C	
Discharge connection	Control the injection pressure	Wear	Cavitation	Fuel leak	2	3	2	12	Increase the controls frequency
				Reduction of the injection pressure					
		Breaking	Shocks	Fuel leak					Seal the leak

4. The Preventive Maintenance Plan

Using the results of the FMECA and following the steps in Fig. 3 (part III.4), we can set up a preventive maintenance plan. It is important to note that the process presented in Fig. 3. is the theoretical (ideal) process for the implementation of the maintenance plan. In the present case, because of the time constraints, we followed the minimal schema, which stops at the level of the step "indicate the frequency" (or periodicities in the present case). The following table 3. represents an extract from this maintenance plan. It contains mainly control, surveillance, cleaning and lubrication operations to ensure that all the elements work in conditions allowing them to carry out their mission in due course.

Table3: FMECA Extract from the preventive maintenance plan

Set	Elements	Periodicity						Observations
		J	H	M	T	S	A	
Power	Injection pump		C/N		M			Cleaning timing and various settings
	Injection nodes				N/M			Clean various settings
	Fuel filters				R			Replace systematically
	Oil filter				R			Replace systematically
	Supply and return lines		C					Visual verification of the presence of any leaks
	Check valve		C		-R			Visual check for leaks or wear
	Fittings		C					Visual verification of the absence of leakage and unwanted elbows
	Air filter			C	R			Cleaning by blowing compressed air
Engine	Engine oil			C	V			Automatic drain

<u>Notation</u>: C = control; N = cleaning; M = adjustment/setting; R = replacement; V = drain; G = lubrication; (-) = if necessary. J = daily; H = weekly; M = monthly; T = quarterly; S = semi-annual; A = annual

V. CONCLUSION

This work was carried out on "Improvement analysis of the maintenance policy of a civil engineering equipment: A case study of the graders in Cameroon". In order to achieve this, several steps were necessary to know to make a presentation of the constitution and the use of a civil engineering equipment. Then we presented the methodology used, based on the use of maintenance tools such as the Ishikawa diagram, the ABC analysis and the FMECA. Furthermore, we applied this methodology in order to diagnose the maintenance policy in place to propose solutions, determine the critical elements of the graders namely the engine and the injection pump and analyze their failures. Finally set up a preventive maintenance plan. The application of the proposed solutions can make it possible to realize a real gain in the availability of the gears, as well as an increase in their lifespan.

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