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Experimentation of the Failure Mode Analysis method of their Effects and Criticalities: Case of a network of maintenance actors

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Abstract This study consists in testing the method of Analysis of Failure Modes of their Effects and Criticality (FMECA) on the maintenance of equipment of small agri-food processing units in Burkina Faso. The maintenance of the said equipment still in the traditional stage, is carried out by several networks of maintenance actors with an informal organization. Thirteen players in the maintenance network of a cotton seed press were brought together to carry out the experiment. At the end of the test, it appears that the criticality indices do not have the same perception as those of a large, well structured company. For these small units, the priority is access to on site spare parts at an affordable cost. In addition, discussions have shown that reliability and maintainability are not a major concern for equipment users.

Keywords: FMECA, Network of maintenance actors, Small agri-food processing units, Readiness, Burkina Faso.

1. Introduction

In Africa, and more particularly in Burkina Faso, the agri-food sector is considered to be a driving force for agro-pastoral development and food security. An approximate calculation on the main pieces of small equipment such as the Engelberg sheller for shelling cereals or the cotton seed press for crushing oilseed oil shows that operational availability varies between 89 and 97 percent: the rapid recovery of failures at an affordable cost and the availability of spare parts are possible thanks to the advantages offered by the network of service providers that justify this result [3]. In fact, the networks offer service providers proximity to equipment users, which in the event of a breakdown reduces the cost of travel and the time it takes to supply spare parts [4]. However, these players often do not have a history or a traceability of measurable maintenance values. Bationo et al. (2009) used the network of maintenance actors to characterize the operational availability and repair costs of equipment in small agri-food processing units in Burkina Faso [6]. Several works in Africa have confirmed the presence of networks of maintenance actors as a logistical support to maintenance [1-4-6-15-21]. In these networks, relevant indicators are identified, namely the cost, the duration of supply and the lifespan of the parts to assess the maintenance of equipment [7].

We have chosen to test the FMECA method a priori which is interesting in the context of small units without traceability, because it is a method of giving rise to a quantitative value, the result of a qualitative consensus assessment on equipment maintenance. The experiment made it possible to observe the relevance of the concepts and the interest of the FMECA method in the networks. We will also see the possibility of bringing together a team of field actors and designers to collaborate on the maintenance of equipment. This is done through an analytical and structured method usually used in large industrial companies with a specific maintenance department with internal organization and budgetary resources. Moreover, since January 2005 in Europe, traceability has become mandatory for the agri-food sector [8]. The FMECA method is used to propose diagnostic elements and solutions to highlight its interest and reduce the informational risk associated with management information systems in a multi-site group in the field of mechanics [9]. It is now recognized as a quality process (ISO 9000) for the control of industrial installations. It is generally used in large companies with a specific maintenance service with internal organization and budgetary resources. The literature review confirmed the widespread application of FMECA, but the few contributions in small agri-food units organized in maintenance networks are limitations related to the use of its use. We chose the case of the cotton seed press with a capacity of three (03) to five (05) tons per day, because of its development in the country during the fifteen (15) In recent years there has been an example of successful diffusion of equipment to the point where there is today competition between different local suppliers. In addition, Burkina Faso is a Sahelian country emerging in oilseed processing.

2. Materials and Equipment Used

FMECA has been used in northern countries and Africa, in small, medium and large industries for the design, continuous improvement, maintenance and failure analysis of equipment [9-10-11-14-18-21-20-23].

We are using these results to see how FMECA could be tested in a network of small and medium-sized enterprises in developing countries. The maintenance network is a structured set of entities representing actors or objects distributed in a region (city, country, etc.), articulated to each other by links in order to ensure the maintenance of the equipment. These links are based on exchanges of information, products (spare parts, currency) and services (repair) [5-6]. The FMECA method was carried out by initially specifying the initial criteria (frequency, severity, non-detection) in order to ensure that their meaning is well understood in the context. We know that these criteria can be used to characterize a failure, but the question is whether they are valid in the context of small units. This is one of the few experiments involving researchers, manufacturers and several users of the equipment. This was carried out on a cotton seed press at the premises of the West African Foundry Company (WAFC) in Bobo-Dioulasso, Burkina Faso. It has a staff of about sixty agents and is specialized in the local manufacture of presses, crushers, crushers, spare parts and offers maintenance services on demand.

The preparation of the design experiment for the use of FMECA was based on the approach proposed by Michel Riout (1994) according to the FMECA Practical Management Memoir and the recommendations [22] of Gérard Landy (2002) according to the FMECA practice guide [16]. The preparations consisted of :

- identify the work team (composition desired by the research team): responsible for design and manufacturing; responsible for marketing, sales and after-sales service (after-sales service); maintenance/repair ; facilitator; three users ; observer ;
- determine the work schedule: a preparatory meeting with the manufacturer in two three-hour working sessions with a thirty minutes break suspension on the first and second days;
- establish meeting invitations with objectives, dates, location and times ;
- prepare the logistical means of the meeting: room, paper boards and markers of different colours, pencil, allowances for the participants, snack for the break.

Experimentation support

The elements used for the experiment:

- the functional specifications (table 4) and the Block Functional Diagram (BFD) of the cotton seed press (figure 3) ;
- the FMECA rating tables (grid) ;
- worm press spare parts (screws, shaft, hub, bushing, vice assembly) ;
- the overall drawing in perspective of the first version press (reduction box consisting of straight gears).

Animation

The approach for the animation of the experiment consisted in:

- introduce participants and outline the objectives of the analysis;
- present the principles of FMECA and the different steps: application cases on known

equipment "the cotton seed press";

- present the press with Functional Analysis (FA);
- present the press using its BFD;
- present to the participants the FMECA criteria scoring grids;
- perform FMECA analysis.

Quotation grids

The rating grids validated by the maintenance actors of the cotton seed press are represented respectively by tables 1, 2 and 3 below.

Table 1: F Index Rating Grid (Failure Frequency)

Frequency index F		
Rating	**Frequency of onset of failure**	**Service Network Perception**
1	Failure rarely seen	Failure that occurs once every 6 months or more
2	Average failure	Failure that occurs quarterly (three months)
3	Frequently occurring failure	Failure that occurs once a month
4	Very frequent failure	Failure that occurs at least once a week

Table 2: Index rating grid G (Gravity)

Gravity Index G		
Rating	**Severity of failure (G Index)**	**Service Network Perception**
1	Minor failure	Downtime less than two hours
2	Average failure	Downtime from two hours to one day
3	Serious default	Downtime of more than one day to one month
4	Very serious failure	Downtime of more than one month or equipment out of use without the possibility of repair

Table 3: Index rating grid D (Non-Detection)

Detection Index D		
Rating	**Failure detection capability**	**Service Network Perception**
1	Possible detection	There is at least one sign that indicates failure
2	Low detection	Failure is difficult to detect
3	Cannot detect	Failure cannot be detected before the effect occurs, failure cannot be prevented

The work of the team consisted in analyzing and modifying the above grids, in order to adapt them to the needs of the context of agri-food SMEs in Burkina Faso.

3. Other FMECA adaptation work

Bibliographic research on FMECA has revealed that experts have proposed a new FMECA procedure using Proposed Structural Importance (PSI) and fuzzy theory. Severity is assessed on the basis of the PSI using an objectively fixed minimum reduction, while criticality is determined by the failure rate [17]. Many researchers and practitioners have discussed the disadvantages of calculating the criticality of conventional FMECA and to solve the problem, fuzzy FMECA is applied in a Yemeni ghee and soap industry [22]. A new integrated approach, called Priority Cost FMECA (PC-FMECA), is also proposed. This is the calculation of a new criticality and the introduction of the concept of profitability taking into account the cost of corrective actions [12].

4. Results and discussion

The experiment lasted one and a half days: four-hour sessions and three-hour sessions on the first day and three and a half hours on the second day.

Functional Analysis (FA) of the cotton seed press

In order to put all the actors of the maintenance network at the same level of understanding of the press "P3" of West African Foundry Company, the external and internal functional analysis was carried out and presented below.

- **External Functional Analysis**

This approach allows actors to become aware of the functions of components susceptible to failure and the elements of the surrounding environment (interactors).

Figure 1 below shows the results of the external functional analysis of the press "P3" of West African Foundry Company.

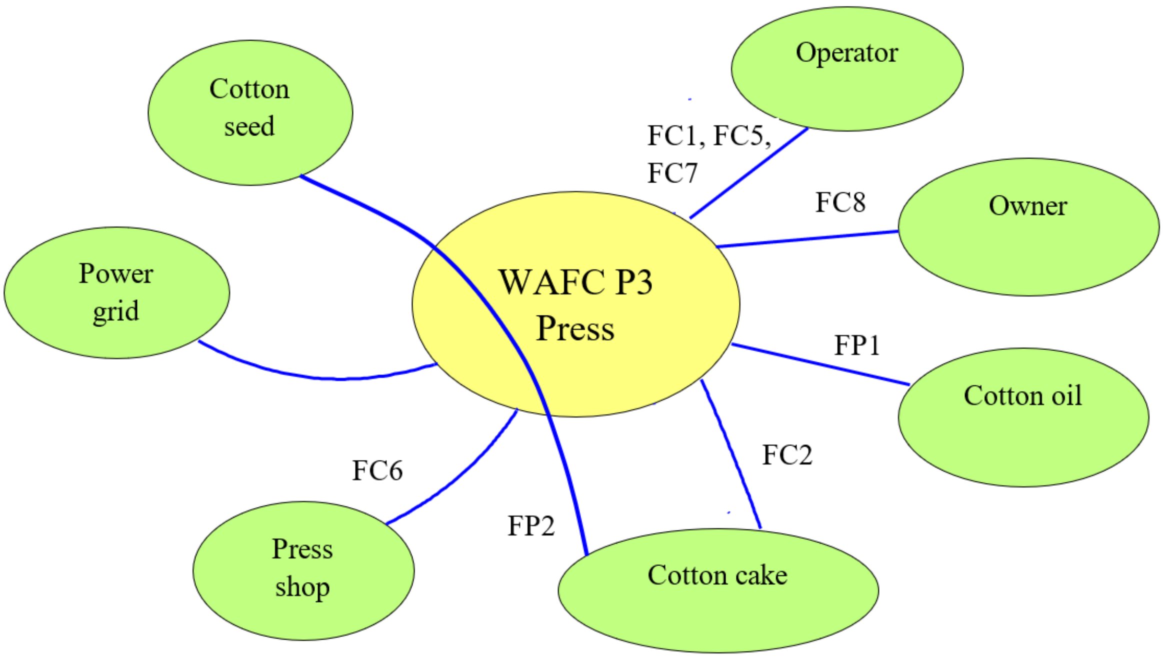

Figure 1: External functional analysis of the press

The service functions have been characterized in table 4 below. Each function related to the diagram has been defined. This allows us to have a functional representation of our equipment.

Table 4: Characterization of service functions

Function	Criteria	Level
FP1 : extract oil by pressing cotton seeds	seed flow extraction efficiency quality of the final product	2 tonnes in 8 hours ≤ 93 percent good
FP2 : produce cotton-seed meal by pressing	quality of cake	good
FC1: load the cotton seeds by the operator	loading height storage capacity	1.2 m 40 kg
FC2 : evacuate the meal	exit height	0.6 m from ground
FC3 : Using grid energy	supply voltage and frequency	380 V three phases 50 Hz
FC4 : respect the environment	environmental standards in force	-
FC5: easily maintain the equipment by the operator	use of standard tools skill level required duration of the cleaning	keys 13, 17, 19, … worker level 15 minutes

	noise level accepted	low noise
FC6: easily install the equipment in the press shop	ground congestion	1650*630*1260 mm^3
FC7: manage the operation of the equipment	control type ease of handling	electric semi-automatic
FC8: make the owner's operation profitable	purchase price of the equipment operating cost	USD 3900 low

- **Internal Functional Analysis**

The internal functional analysis is the continuation of the external functional analysis. It allows a look at the role of a product taking into account its external environment. This approach allows us to enter the heart of a product to characterize its functioning.

Thus, the block diagram of the press is illustrated in figure 3 below.

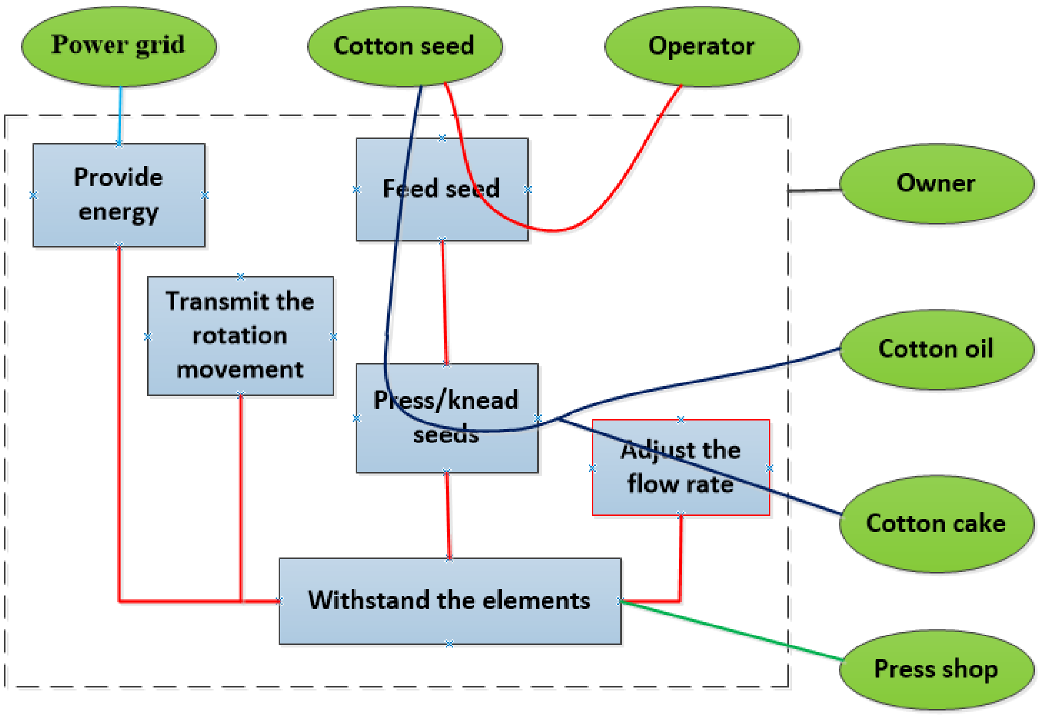

Figure 2: Simplified press diagram block

The diagram block provided a brief overview of the structure of the equipment.

Validation of rating grids

This step is essential before filling the dimension grid of the press. Indeed, the consensus sought in the FMECA index rating process can only exist if the rating grids have been validated by the team. The objective is to understand, adapt the rating grids to their context and propose other indices (criteria) to assess the failure.

The approach consisted in commenting on each grid including the purpose and meaning of each criterion. It will show the progression of the dimensions according to the intensity of each criterion and verify that the ranges that define the frequency have an equivalence with the life of the parts of the press.

- **Explanation of the meaning of the criteria**

The facilitator commented on the rating grids according to the columns and rows so that the team assimilates well. Then, he asked a series of questions focused on the team's understanding of the classic FMECA criteria, always referring to the grid and the life of the press parts.

- **Grid adaptation**

Based on the perceptions given in the grids, the facilitator asked questions aimed at confronting the perceptions given in the grids with the realities experienced by the team in terms of failure. It allowed the team to formulate the definitions and the different intensities of the criteria.

- **Grids validated by maintenance network players**

The grids are unanimously validated by the actors and are illustrated in tables 5, 6, 7 and 8 below. They are best suited in the context of the press "P3" of West African Foundry Company maintenance network and can be popularized in small and medium agri-food units in Burkina Faso.

Table 5: F Index rating grid (failure frequency)

Frequency index F		
Rating	**Frequency of onset of failure**	**Service Network Perception**
1	Very low frequency	Failure that occurs once a year and more
2	Low frequency	Failure that occurs once every three months
3	Average frequency	Failure that occurs once a month
4	High frequency	Failure that occurs once every two weeks
5	Very high frequency	Failure that occurs at least once a week

The actors referred to their own experiences, failure frequencies and conditions of use to propose new ranges of the lifetimes of the parts. The wear of the press screw is an example: it appears once or twice a month. This case prompted the creation of a new line "high frequency: once every two weeks".

Table 6: G-Index Rating Grid (Severity)

Severity Index G (Time)		
Rating	**Severity of failure (G index)**	**Service Network Perception**
1	Minor failure	Downtime less than 2 hours
2	Average failure	Downtime from 2 hours to one day
3	Serious failure	Downtime from two days to one week due to availability
4	Very serious failure	Downtime from one week to two weeks due to availability
5	Catastrophic failure	Downtime of more than two weeks to 1 month: equipment out of use without possibility of repair (management problem)

Details were added to the third and fourth lines in order to adapt the ranges initially defined with the operational lifetimes of the press parts. This is the time required by the supplier to make, for example, pressure screws, which varies from two days to a week. In addition, there is a fifth line which illustrates perfectly the extreme cases of difficulties in financing the restoration of equipment.

Table 7: Spare parts cost index (C_p) rating grid

C_p index (spare parts cost)		
Rating	**Spare parts cost level (C_p index)**	**Service Network Perception**
1	The cost is easy	Very acceptable: amount less than USD 16,33
2	The cost is Average	Acceptable: amount between 16,33 and USD 81,63
3	The cost is Difficult	Inaccessible: amount greater than USD 81,63

A cost rating grid has been proposed. It does not identify itself in the gravity grid in terms of time initially validated by the team. The team decided to rate based on this new criterion.

Table 8: Spare parts unavailability index rating grid (Ip)

I_P Index (spare parts unavailability)		
Rating	**Spare parts availability (I_p index)**	**Service Network Perception**
1	Easy	Part available in store at the user (corresponds to cases 1 and 2 of the validated gravity rating grid)
2	Average	Part available on the market or rapid manufacture at the manufacturer (corresponds to case 3 of the validated gravity rating grid)
3	Difficult	Cast parts

This grid does not identify itself in the gravity grid in terms of time or cost above validated by the team. It therefore decided to rate it based on this new criterion.

Table 9: D index rating grid (not detecting)

Detection index D		
Rating	**Possibility of detection of a failure**	**Service Network Perception**
1	Easy detection	There is at least one sign of a failure
2	Detection quite difficult	Failure is difficult to detect
3	Very difficult to detect	Nothing can detect or access the failure before the effect occurs, it is impossible to prevent failures

The grid has been modified in the terminology used. To have a better perception of the almost impossible detection, the team proposes «very difficult detection». The actors also insert the term «access» to adjust with their realities. Indeed, according to them, failures can only be detected by signs but, it is necessary to disassemble to observe. The simple fact of reporting disassembly as a means of detection, confirms that users are mainly doing corrective maintenance.

Identification of possible criteria to characterize the failure

Particular emphasis was placed on elements defining the criteria. In the maintenance network, cost and availability are also important in the characterization of equipment failure. Thus, gravity is divided into three criticality indices namely, gravity in terms of time, gravity in terms of availability and gravity in terms of cost.

Indeed, equipment failure in Africa is characterized by the frequency of failures, repair time, non-detection, availability and cost of spare parts.

However, traditional FMECA does not take availability and cost into account. In a maintenance network in Africa, cost is an important indicator in repair. Also, the repair time does not take into account the fact that the part is available in the network. Hence the integration of the two (02) indices as part of a network of maintenance players in Africa. The criticality in this case is given by the following formula:

$$C = F*G*C_P*I_P*D \quad (1)$$

5. Discussion

FMECA is an effective tool widely used in processing industries to manage security and reliability. However, the technique of classifying failure modes using conventional criticality has several disadvantages in that it is not flexible to adapt to complex systems [2-24].

In addition, other work shows that FMECA applied to intelligent ship positioning systems has failed to differentiate severity, incidence and detection rates, but also failed to analyse the correlation of causes of failure [18]. Traditional FMECA suffers from certain deficiencies in decision-making and in the situation where the information provided is ambiguous or uncertain [13]. One of its main shortcomings is the absence of any interconnection between the classification of failures and a procedure for selecting maintenance/improvement tasks. This limits its implementation potential in real terms on the ground [19].

At an oil refinery in Italy, a new FMECA tool has been developed. The methodology is based on the integration between a modified FMECA and a Monte Carlo simulation as a method to test the weights assigned to the measurement of Risk Priority Numbers (RPN) commonly known as criticality. The proposed RPN consists of a weighted sum of six parameters (safety, importance of the machine to the process, maintenance costs, failure frequency, shutdown times and operating conditions) multiplied by a seventh factor (difficulty accessing the machine) [10].

In the end, several articles in the literature agree that classical FMECA suffers from many disadvantages if the industrial context changes.

Moreover, it did not work in a maintenance network of small agri-food units in Burkina Faso, because criticality was not determined because severity and non-detection could not be rated. The experiment would have been more successful at this level if criteria that make sense in the context such as lifetime, cost and availability of parts in the field were used.

6. Conclusion

This work offers lessons on the importance of reformulating failure analysis criteria according to the context and on the other hand, a better knowledge of the points of view of the various actors of an existing network necessary to argue the decisions, during the new design projects. We remember that the priority for these small units is above all to access parts on site in the maintenance network, at an affordable cost. Discussions have shown that reliability is not a major criterion, but its consideration is necessary to reduce spare parts costs. Maintainability is also not a major concern, as is the supply time linked to the socio-technical network.

The indices of availability and cost of spare parts could be rated by the actors of the maintenance network, because having been enlightened on the fact that:

- the availability of spare parts makes it possible to define the press downtime according to the availability of a spare part ;
- the cost of spare parts, bearable or not, the rating grid allows to accommodate the case of each part to change.

The rating of the detection was possible because the participants were able to distinguish between the detection of the warning sign of the failure and the behavior adopted by most transformers after the detection of the sign. Users of the press are able to detect failure by signs but react differently depending on the type of management of the company.

The context of small units has specificities such that the FMECA tool usually used to integrate maintenance cannot be deployed as is. For a better understanding of the quotation of the indices, it will be possible to replace on the one hand the frequency by the life of the wearing parts and on the other hand, to dissociate the downtime of repair from the gravity, the cost and the duration of supply of the wearing parts.

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