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PETRI MODEL OF RECYCLING LEAD-ACID BATTERIES

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ABSTRACT

The use and disposal of lead-acid batteries are increasing every year. Several strategies for their treatment have been put in place, some for the recovery of materials and others for the regeneration of batteries. The latter, which has been practiced for a very long time, has been revolutionized, saving management of the battery parks and reducing harmful waste, although it does not seem to be valued. It is a perfect ecological alternative. The mismanagement of failed batteries can be toxic, threatening water, soil, and the atmosphere, and the health of humans in the profession and the surrounding populations. This study presents all the solutions for managing the faulty batteries that are ecological. A review of the different types of lead recycling methods was carried out, and an experimental survey was carried out in the field with different craftsmen blacksmiths, car mechanics, and companies to identify the different methods resulting from failures. Then, we modeled Petri networks to manage used batteries by highlighting all the possibilities of the recycling process and subsequently proposed a generic recovery of materials by craftsmen. This work is a new management of faulty lead batteries highlighting safely the various players in society in contact with these faulty batteries.

1. Introduction

The fleet has seen unprecedented growth in recent years. This growth consequently results in significant waste generation, and its materials have a big impact on society [1]; vehicles end-of-life have very toxic components, among which batteries. Lead-acid batteries used contain materials harmful to the environment and also to humans. Its recycling process can be dangerous if it is not safely done because it can threaten water, soil, atmosphere, and human health; for this reason, recycling must be carried out continuously. Recycling is creating new materials or the renewal of initial materials through waste treatment [2].

This article is putting down the framework that other lead-acid recycling batteries which exist are not well valued and highlighted in the link of the management of faulty batteries, except these thus make it possible to preserve and manage the number of faulty batteries. However, there is poor management of these batteries, loss of material and energy, and poisoning since lead is a heavy and toxic metal. Recycling has two main objectives: the concept of sustainable development and the economic aspect as a whole (saving energy and raw materials, cost of emissions) [3]. These involve recycling the waste generated during the recycling process. Recovery considers the type of material, the sorting criterion, the size of the recovered item, and the deposit (density and logistics) [4]. However, it is crucial to finally conduct a deep study to know the benefits and limits of its different methods.

The main objective of this work is to propose a recycling approach for lead-acid batteries using the Petri Dish. This objective involves collecting and analyzing existing methods for lead-acid recycling batteries in the literature and by recyclers in Cameroon and identifying their failures. Faced with this vast field of investigation, this article will explore several avenues to define our expectations and our motivations, the approach adopted for the development of our work is logically organized around several steps: The first step introduces the presentation of the materials and methods where we define our questionnaires relating to our experimental survey which we will carry out with recyclers in order to define the management of battery. We carry out in the second step a review of the methods of recycling of lead batteries existing in the literature and those identified during our investigation: case of Cameroon while defining their limits and advantages which will bring the problem associated with the search for more ecological methods. Then we will devote ourselves to the use of the Petri net to improve these kinetics, upsetting established ideas and finally, there the result will be a proposal for a used battery management strategy that will be applicable by blacksmiths.

2. Methods of analysis

The lead-acid battery in question at a nominal voltage of 12V is generally used in vehicles. The survey is based on lists of questions asked to blacksmiths, car mechanics, and companies involved in recycling used batteries to understand the recycling process stages. Two sectors were identified, bringing together stakeholders related to the management of used batteries. These sectors include those which collect materials and the car mechanical structures which regenerate the batteries.

The questionnaire was designed to meet the specific objectives of the study. We structured our questionnaire in six parts: the first part identifies the respondents' sector of activity, their function within the organization or the company. The second part of the questionnaire concerns the measures before recycling used lead-acid batteries. The third part makes it possible to schematically and coherently describe the recycling chain and associate it with the equipment or materials with the timing. The fourth step concerns the protection of people and the environment during recycling; it highlights the protection and control measures adopted by recycling during their process. The fifth step presents the traceability and continuous improvement of the product and finally, the sixth part shows the problems encountered by recyclers in purchasing or supplying batteries during the recycling and sale of products.

The modeling of production systems is challenging because of the number and diversity of parameters to consider and the complexity of the relationships between its parameters. We chose the Petri Dish because this modeling tool is particularly well suited to the representation of production systems. It lends itself to modular construction and allows the whole model obtained to identify all the sub-assemblies.

A Petri net is a 5-tuplet (P, T, F, M0, W), where: P is a finite set of places and T is a finite set of transitions ($P \cap T = \emptyset$, $P \cup T \neq \emptyset$), F defines one or more arcs (arrows) p P; an arc cannot connect two places or two transitions. It can only connect place-transition pairs; more formally: F $(P \times T) \cup (T \times P)$, M0 P called initial Marking, where, for each place p P, there are tokens, W called a set of primary arcs, assigning to each arc f F a positive integer, indicating how many tokens are consumed from a place to a transition, or if not, how many tokens are produced by a transition arrived for each place.

To bring out a lead battery management model, we used the Petri Net application, which is software allowing the creation and analysis of Petri networks, to bring out the models described in graphic or textual form and generate the graphs. It works on Windows PC and it is very flexible and easy to work. The Petri Net Editor toolbox is modular and includes a graphic editor (of networks, of automata), including functions for drawing networks or automata, a textual format tool, and a structural analysis tool.

3. Results and Discussions

3.1 Critical Analysis of existing recycling methods in the literature

In the literature, the much more developed methods in recycling batteries are called recovery methods [5]. In fact, we distinguish three methods: hydrometallurgy, pyrometallurgy, and the mechanical process [6] [7] [8].

Pyrometallurgy is a technique of recovering materials using a high temperature. This process includes pyrolysis, smelting, distillation, and refining. His advantage is that it generates less waste and has many disadvantages such as excessive energy consumption, the low lead recovery rate because the electrolytic Pb powder oxidizes rapidly in the atmosphere and is volatile, the use of toxic substances (chemicals), and the severe corrosion of metallic components [9] [10].

The hydrometallurgy process is a technique for recovering metals using acids or bases to leach metals into a solution, which is later purified to extract the materials; this process is preceded by a mechanical process such as crushing, shredding, to release the materials. His advantage is that it consumes less energy and has many disadvantages because it generates waste that must be treated later, also the low solubility of lead compounds in solvents and the ineffective desulfurization in the aqueous solution[10] [11] [12].

The mechanical or pretreatment process separates different materials by fractions and subsequently removes sulphuric acid [13]. It is the first process when recycling lead-acid batteries. It consists of two phases: crushing and sorting. The first step is to disassemble the battery and release the components. The second step consists of separating the crushed components and grouping the materials according to their physical properties. This process can include magnetic separation, ballistic air, separation, and sieving [11]. The benefits of this mechanical process are low energy cost and less expensive, while disadvantages are the risk of lead poisoning during grinding and the risk of skin burns, irritation of the respiratory tract during the extraction of sulfuric acid.

3.2 Critical Analysis of existing recycling methods in Cameroon

This section presents the recycling chain for lead-acid batteries in Cameroon. After an investigation carried out in two regions of Cameroon, the Littoral and the West regions, two kinds of recycling emerged: among ten recyclers, (80%) regenerates while (20%) recoveries materials from batteries. We have subdivided the regeneration method into two sub-groups (traditional and modern). Those who practice traditional regeneration are generally car mechanics (mechanics) since they are in contact with the batteries; when it is impossible to regenerate its used batteries (totally sulfated), these car mechanics collect them to resell to structures or individuals (are in recovery).

3.2.1 Battery regeneration method

This method (Fig. 1) is essentially electric, and it concerns all types of batteries (open, sealed, or frozen). Lead sulfate is removed through the high-frequency electrical pulsation process sent by the battery regenerator.

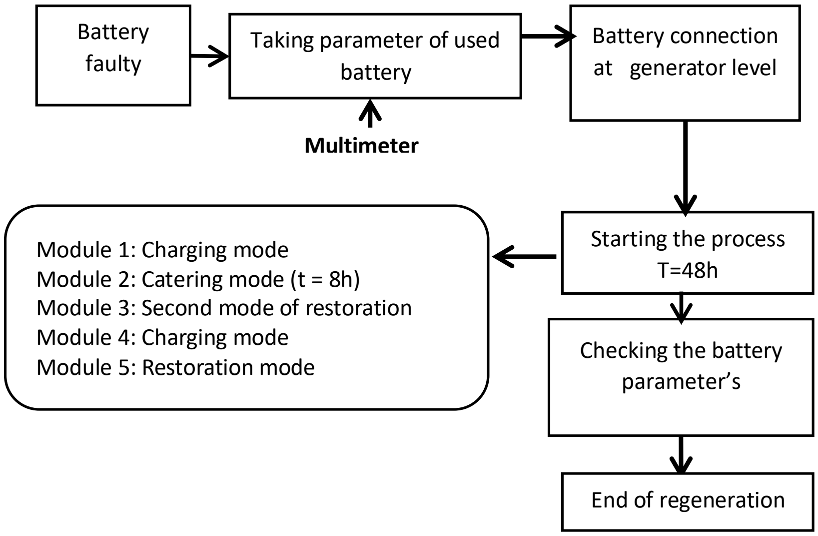

Fig. 1. Modern regeneration process of lead-acid battery

This modern regeneration method is new in Cameroon; it is simple to handle but consumes a large amount of energy by the regenerator; it is essentially electric and applicable on all types of batteries. Our recyclers are less exposed to the harmful effects of lead, and it is very ecological compared to the traditional method, which is also called the method of desulphuration of lead batteries. It must be done with much protection because the electrolyte is handled a lot, and it contains sulphuric acid, hence the importance of wearing personal protective equipment (gloves and safety glasses). The sulphuric acid recovered is poured into the toilet.

3.2.2 Recovery of materials of worn batteries

The recovery of materials of the lead-acid batteries is carried out in Cameroun by craftsmen in the following way (Fig. 2).

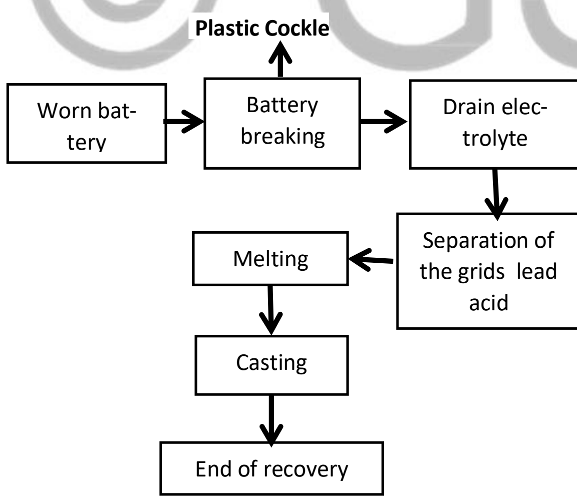

Fig. 2. Process of recovery of the lead-acid battery

In comparison with the existing methods of recovering such as pyrometallurgy, hydrometallurgy, and mechanical Processes, this method of recovery is outwards of the great organizations such as *BOCOM* and *METAFRIQUE* is made by the craftsmen inventors of antiquated Cameroon way, being done in the open air and is very polluting. The aspect of protection of the people and the environment is not taken into account. All this can be explained for the following reasons: they do not master the real dangers, the toxic and the carcinogenic effect of this component. They do not have enough financial means to be acquired furnaces and human protection equipment and the environment. The purchase of the worn batteries is competed by some investors who buy at a high price to export them in different countries. One notes an inefficient use of the instruments of protection during recycling. This is due to the financial problem of some recycler whom we met on the ground and no master of the real danger to the exposure during handling.

3.3 Steps of recycling using the metamodel approach

The step of treatment of the worn batteries was elaborate under the software Petri Net. This Petri network will make it possible to identify the system, to define the behavior (what the made system), and the dynamics of the worn batteries (cycle of life) in time. For this fact, we have initiated to raise a metamodel of the battery and the flowchart.

The metamodel will make it possible to describe the various mechanisms which enter the design of a lead-acid battery and the factors causals that can carry out its failure.

According to [14], the metamodel of a product of maintenance integrates the three classes of variables of maintenance which describe the function, behavior, and structure of the product. It will be based on an approach based on the interdependence resulting from the addition (combination, analogy, and change) or the substitution (change, analogy, and emergence) of the product's variables during the design process.

Figure 3 is a maintenance metamodel of a lead-acid battery. It highlights the progressive design of a lead-acid battery taking into account three aspects: functional, structural, and behavioral. This will facilitate the maintenance, dismantling, and recycling process during the life cycle. This figure explains on the one hand the manufacturing of the elements that will be assembled to obtain the sub-assemblies that will constitute the major parts of the lead-acid battery and on the other hand the factors that can lead to the deterioration of a battery with the deterioration modes. In the structural approach of the battery, we present the constituent parts of the battery by breaking it down into sub-assemblies (electrolyte, battery shell, and lead grid), and then into elements where we list the manufacturing steps of a battery taking into account these elements. In the functional approach to the battery, we identify the main function and the elementary functions of its sub-assemblies. The behavioral approach highlights the expected behavior of a battery at the end of its life cycle and its deterioration mode.

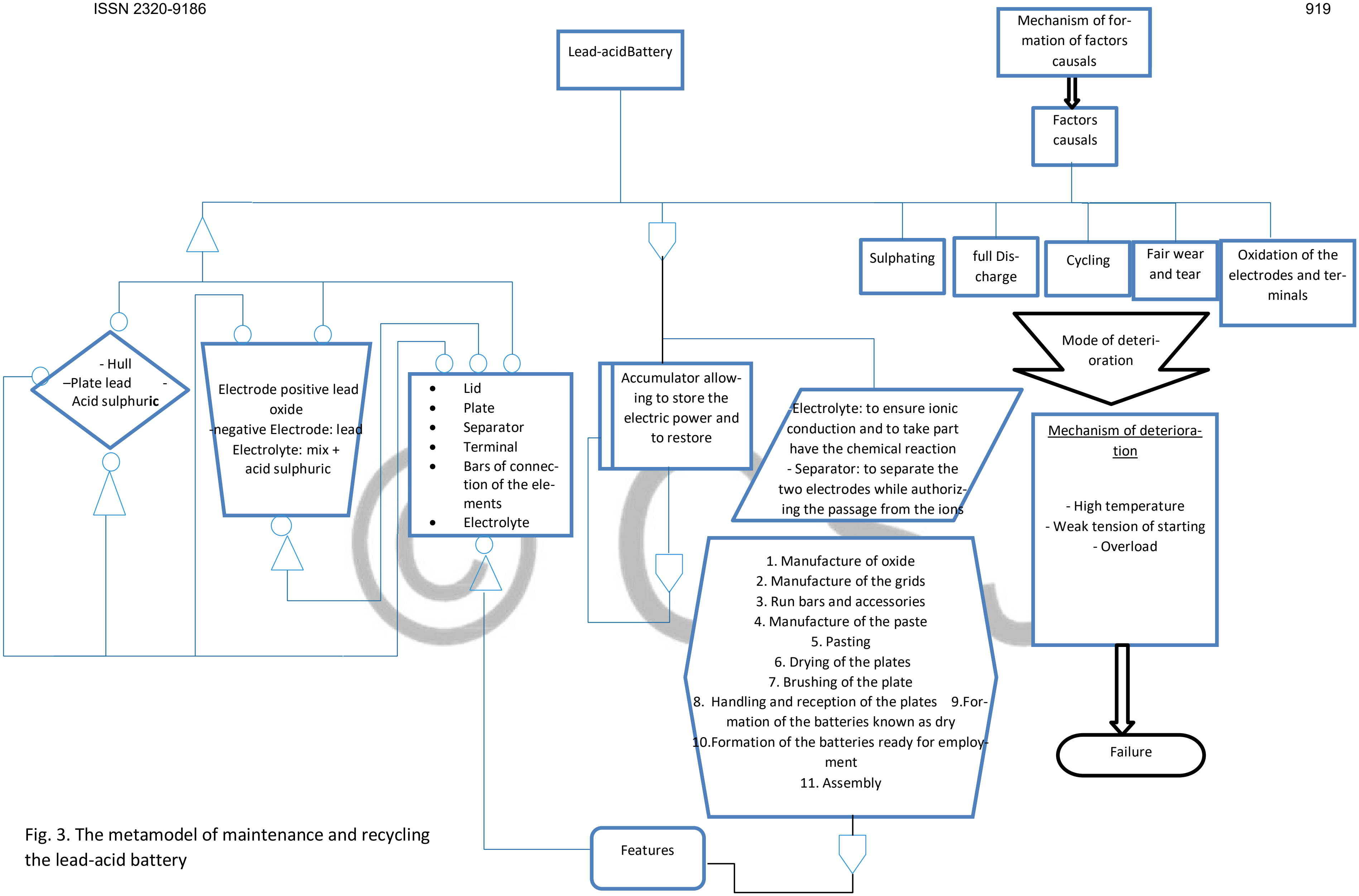

Fig. 3. The metamodel of maintenance and recycling the lead-acid battery

The flowchart below illustrates the possibilities of managing the lead-acid batteries, which can be carried out in the structures that treat the worn batteries (Fig. 4).

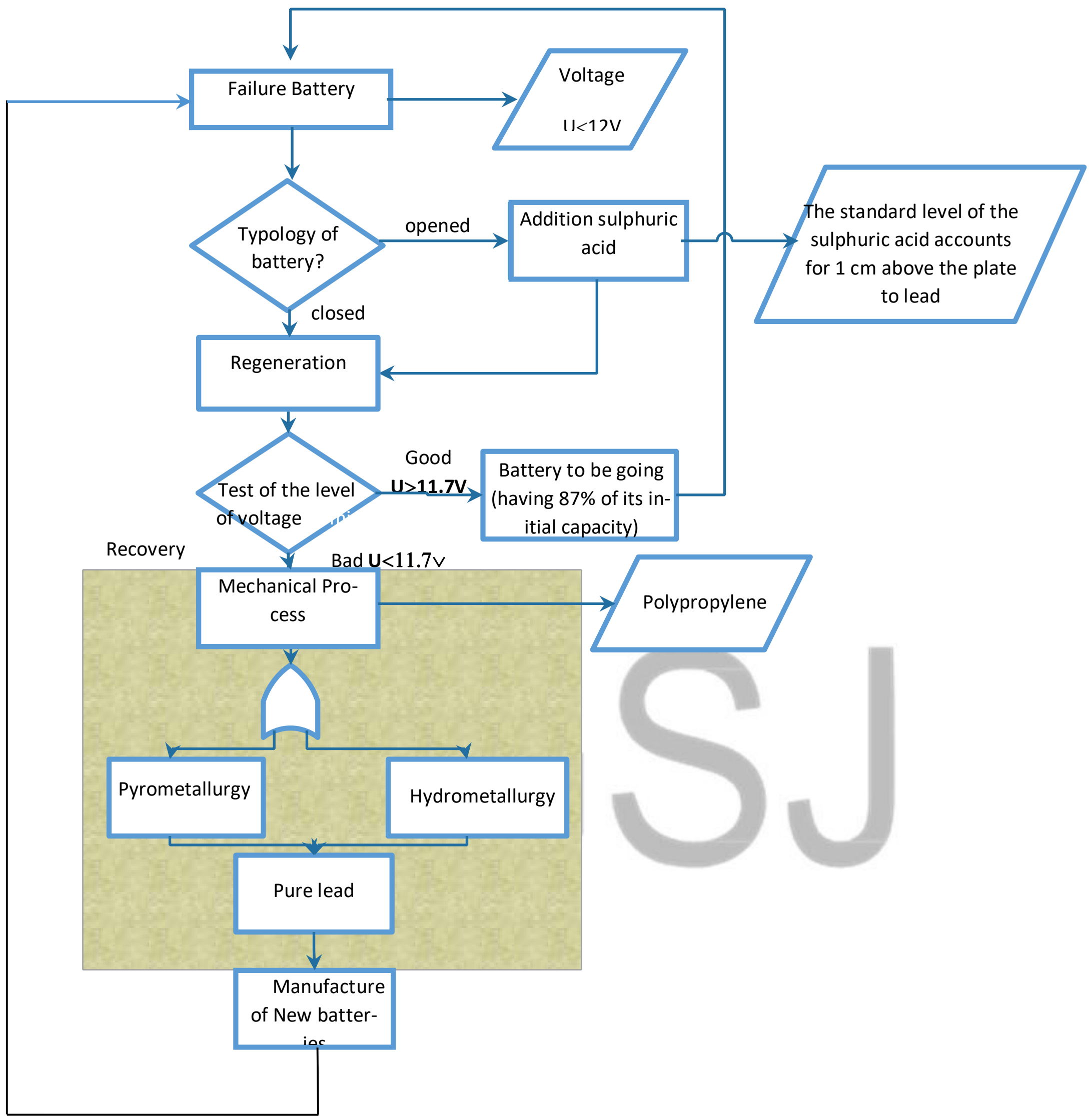

Fig. 4. Flowchart of the management of the worn batteries existing in Cameroun ¶

3.4 Petri network Model

The Petri network represented in Fig. 5 makes it possible to represent, to conceive the dynamism of the management of the worn batteries. The flowchart of Fig. 4 makes it possible to work out the Petri network below.

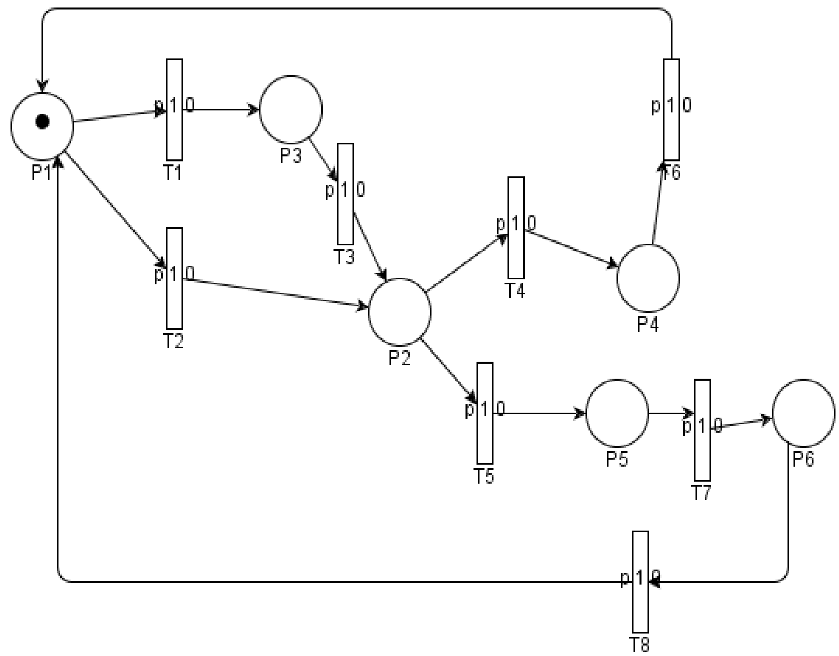

Fig. 5. Petri network proposal for the treatment of the worn batteries ¶

Four possible ranges represent these various ways. We considered two ways of management of the worn batteries: two ranges for the way of regeneration of the battery {T1, T5, T7, T8}, {T2, T4, T5} and two ranges for the way of recovery of the materials {T1, T3, T5, T7, T8}, {T2, T5, T7, T8}. Ti is the transitions from the Petri network associated with the product, transitions equivalent to the achievement from the operations of management of the corresponding worn batteries. Further interpretations of the places and transitions resulting from our model are listed in table 1.

Table 1. Description of the transitions and the management model of worn batteries

Place	Description
P1	Faulty battery
P2	Regeneration
P3	Addition of the sulphuric acid
P4	Battery start off
P5	Recovery
P6	Manufacture of new batteries
Transition	Description
T1	Open battery
T2	Closed battery
T3	Acid added
T4	Success of regeneration
T5	Failure of regeneration
T6	Battery of use
T7	End of recovery
T8	Battery of use

The matrixes definitions of our model are shown in table 2. They introduce Pre and Post matrices. The matrix of incidence W of the Petri network is a whole matrix. This matrix translates the total cost of crossing a transition for each place, i.e., the difference between what is produced and what is consumed, with W = Post− Pre

Table 2. Definition of Matrixes (a) Pre-matrix, (b) Post-matrix, (c) Incidence matrix¶

(a) Pre-Matrix	P1	P2	P3	P4	P5	P6
T1	1	0	0	0	0	0
T2	1	0	0	0	0	0
T3	0	0	1	0	0	0
T4	0	1	0	0	0	0
T5	0	1	0	0	0	0
T6	0	0	0	1	0	0
T7	0	0	0	0	1	0
T8	0	0	0	0	0	1

(c) Incidence Matrix	P1	P2	P3	P4	P5	P6
T1	-1	0	1	0	0	0
T2	-1	1	1	0	0	0
T3	0	1	0	1	0	0
T4	0	-1	0	1	0	0
T5	0	-1	0	0	1	0
T6	1	0	0	-1	0	0
T7	0	0	0	0	-1	1
T8	1	0	0	0	0	-1

(b) Post-Matrix	P1	P2	P3	P4	P5	P6
T1	0	0	1	0	0	0
T2	0	1	0	0	0	0
T3	0	1	0	1	0	0
T4	0	0	0	1	0	0
T5	0	0	0	0	1	0
T6	1	0	0	0	0	0
T7	0	0	0	0	0	1
T8	1	0	0	0	0	0

Example of the computation of the Matrix evolution of Marking: ¶The evolution of marking after the shootings of the transitions is expressed:

$$¶M = M0 + W \cdot S$$

$$¶M = M0 - Pre. S + Post. S$$

With S the vector crossing. Condition crossing: A transition Tj is thru if

$\forall$ Pi $\in$ Tj, M(Pi) $\geq$ Pre (Pi, Tj)

The initial Marking of our Petri network is showcased by the matrix below:

$$M0=\begin{pmatrix}1\\0\\0\\0\\0\\0\end{pmatrix} \quad S1=\begin{pmatrix}1\\0\\0\\0\\0\\0\\0\\0\end{pmatrix} \qquad M1=M0+S1.Wt$$

$$M1= \begin{pmatrix}1\\0\\0\\0\\0\\0\end{pmatrix} + Wt\begin{pmatrix}1\\0\\0\\0\\0\\0\\0\\0\end{pmatrix} = \begin{pmatrix}1\\0\\0\\0\\0\\0\end{pmatrix} + \begin{pmatrix}1\\0\\0\\0\\0\\0\\0\\0\end{pmatrix}\begin{pmatrix}-1\\0\\1\\0\\0\\0\end{pmatrix} = \begin{pmatrix}0\\0\\1\\0\\0\\0\end{pmatrix} \qquad M1=\begin{pmatrix}0\\0\\1\\0\\0\\0\end{pmatrix}$$

Our previous Petri net from the flowchart that explains the process of dealing with faulty batteries has 02 structural conflicts. This occurs when two transitions have at least one input place in common. We have: <P1, {T1, T2}>, <P2, {T4, T5}>. Inhibitory arcs resolve this conflict and establish priorities between transitions. This inhibiting arc consists of a transition and a place. This place is connected to the two conflicting transitions linked to places P1 and P2. In each case, only one of the two transitions can be made. It is therefore necessary to make a decision as to which of the two transitions will actually be crossed. To solve the conflict problem we propose a new Petri net that has inhibiting arcs and test places. Next, we will introduce controlled transitions (Fig. 6).

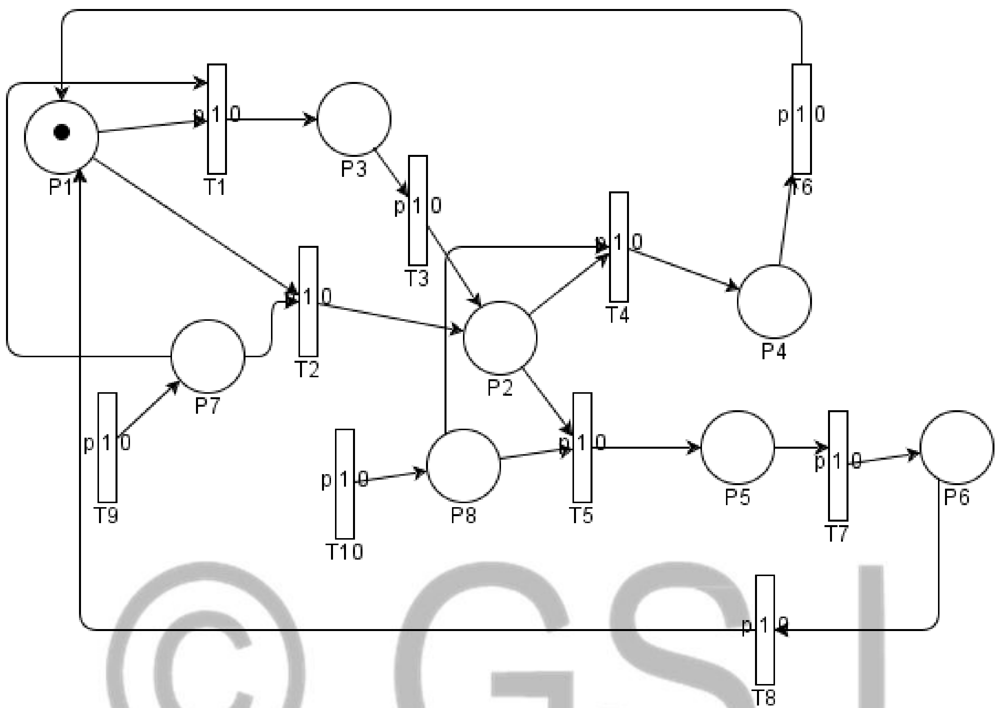

Fig. 6. New Petri network treating the case of the various conflicts observed.

The Petri network is limited. We have the finished states, and one can determine the number of Marking. It is also alive because all the transitions are possible.

4. Conclusion

The reduction of exposure of the population, the environment to the alarming harmful substances, and the rational management of these substances are the capital objectives to promote. We passed through a better knowledge of recycling methods and sources of the exposures described above to cope with these objectives. Accordingly, we develop the Model of Petri of recycling methods of lead-acid batteries. This article will contribute to the good process management of lead-acid batteries and identify the sources of exposure related to the recycling of the lead-acid batteries in the case of Cameroon.

To meet our objectives, we carried out a review of the literature on the various processes of recycling. This presentation made it possible to highlight the assets and limits of its various existing recycling methods in the literature. Thanks to the investigation carried out in situ, we considered data relating to the various management processes of the batteries used in Cameroun. In the end, we proposed a network model of Petri to manage the batteries and credits of valorization of the components during the recovery of materials by craftsmen inventors. Further work should tend to optimize the recycling process unit of worn batteries.

Acknowledgment

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