Developing a new method "PKPGA" by using a combination of the ABC method Knapsack Problem and Greedy algorithm as a tool for decision support

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Abstract— *Among major concerns of industry leaders are low production performances due to stoppages and unplanned and spontaneous breakdowns of the machines. To remedy this, they must take the optimal and adequate decisions using a specific technical approach that takes into consideration a reasonable budgetary cost.*

In the present article, we present a solution to this problem by elaborating a method of good procedure. It is based on the combination of three tools: Pareto, knapsack Problem and Greedy Algorithm "PKPGA".

To validate this method, we treat a case study via the use of these three tools of decision support then treat the same case study with a new method that combines all three of the tools. This new tool "PKPGA" enables those responsible for industrial maintenance to better identify the anomalies, classified according to the degree of their negative impact on production. This method limits production breakdowns, saving time and money for companies.

Keywords—Greedy Algorithm, Knapsack Problem, Pareto, PKPGA.

I. INTRODUCTION

Recent studies on the effectiveness of maintenance management showed that more than a third of maintenance costs come from unnecessary or poorly performed operations. Poor maintenance policy can have disastrous consequences on the quality of products. The primary cause of this inefficiency is the lack of real information that would determine the immediate needs for repair or maintenance. Maintenance costs are often the majority of operating costs in many production units. These costs can be significantly reduced by taking the most suitable decisions.

In this paper, we propose a new method for decision support. We begin by presenting three decision support tools: Pareto [3][4][5], knapsack [1]–[2]–[6]–[7]–[8] and Greedy algorithm[9]–[10]–[11]–[12]. Subsequently a case study of a carbonated drinks company will be developed by using the three tools of study. Finally, a new method of decision support is presented based on a combination of these three tools. This method treats the same production line and gives the best results [13]–[14].

II. THE PARETO (ABC METHOD)

Without hierarchisation, any action of organization can be long and tedious. By using the Pareto law [3] [4] [5] we can highlight the most important elements of a problem to guide our action. Because of this, the elements having little influence on the criterion studied will be eliminated.

The ABC method is a tool for decision support, which defines priorities for action. This means that the Pareto chart shows the most important causes that are causing most effects.

The elements will be ranked by order of importance indicating the percentages for a given criterion. This study requires a three-step approach:

• Defining the nature of the elements to be classified: the classification of these elements depend on the criteria studied.

These elements can be: physical, causes of failures, types of failures, work orders, items in stock, etc…

• Choosing the classification criterion: The most common criteria are costs and time, but according to the character studied, other criteria can be used, including: The number of accidents, the number of incidents, the number of rejects, the number of operating hours, the number of kilometers covered etc..

• Defining the limits of the study and classifing the elements

The Pareto chart is a column chart that presents information in descending order and thus brings out the most important elements, which explain a phenomenon or situation. Generally, 20% of the number of elements represents 80% of the studied criteria: this is class A; 30% of the number of elements represents 15% of the criteria studied: this is class B; and the remaining 50% of elements represents only 5% of the criterion studied: this is class C.

By cumulating the decreasing values of the criterion studied, the ABC curve shows three classes, hence it is named "ABC" See Fig 1.

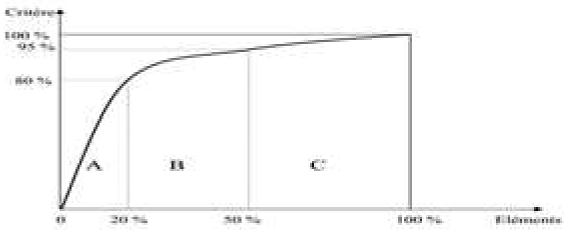

Fig. 1: Pareto (ABC)

III. MAN RESULT

1. Introduction

This work aims to propose an easy and effective methodology for selecting the most reliable evidence for an optimal solution. This method is based on the Pareto, the Knapsack Problem and the Greedy algorithm. At first, we begin with a case study that will be solved using the simple problem analysis tool "Pareto", then we will integrate the Knapsack Problem to the problem of Pareto and finally the Greedy algorithm.

2. Case study

All enterprises have a lucrative purpose that is to say "producing more" and consequently downtime must be minimized; for that purpose enterprises reserve the budgets allocated to improve their productivities. In our article we look at a case study of the packaging of soft drinks.

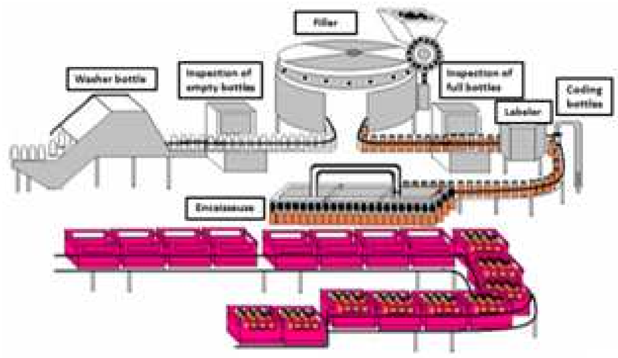

Fig. 2: Schematic illustrative of the different steps of the preparation of soft drinks

To improve the efficiency of a production line (called line 2) and maintain the majority of its equipment in good condition during production (Fig. 3), a budget of 300,000.00 MAD is proposed. To do this we will study the downtime and the maintenance costs during 2 months for each machine on line 2, given in the following table:

Table.1: The cost of maintenance and downtime for each machine of line 2

The elements of the line 2	Downtime(h)	The cost of maintenance (MAD)
FILLER O + H L2	7,24	72400
VISSEUSE L2	6,73	67300
CONVEYOR BOTTLE L2	6,02	60400
ENCAISSEUSE KETTNER L2	5,59	56400
CAPPING L2	4,47	44300
CONVEYOR CASIERS L2	4,14	41900
PALLETIZER L2	3,73	18000
WASHER BOTTLES O + H L2	3,3	33100
LABEL KRONES L2	2,41	24200
DECRATER KETTNER L2	2,4	24300
DEPALETISOR L2	1,51	15500
INSPECTOR L2	1,12	11900
DATEUSE L2	1,03	10900
MIXER L2	0,26	3300
Total	49,95	483900

3. Resolution by the method of Pareto:

The method Pareto consists in classifying machines in order of severity which is calculated by (downtime of the machine / Total downtimes)*100

The table below represents the percentage of downtime for each machine of line 2 during two months:

Table.2: Percentage of breakdowns of each machine of line 2

Machines	Downtime(h)	% Downtime	%Cumulative
FILLER O + H L2	7,24	14,49	14,49
VISSEUSE L2	6,73	13,48	27,97
CONVEYOR BOTTLE L2	6,02	12,05	40,02
ENCAISSEUSE KETTNER L2	5,59	11,19	51,21
CAPPING L2	4,47	8,96	60,17

CONVEYOR CASIERS L2	*4,14*	*8,29*	*68,46*
PALLETIZER L2	*3,73*	*7,47*	*75,93*
WASHER BOTTLES O + H L2	*3,3*	*6,61*	*82,54*
LABEL KRONES L2	*2,41*	*4,82*	*87,36*
DECRATER KETTNER L2	*2,4*	*4,80*	*92,16*
DEPALETISOR L2	*1,51*	*3,02*	*95,18*
INSPECTOR L2	*1,12*	*2,24*	*97,42*
DATEUSE L2	*1,03*	*2,06*	*99,48*
MIXER L2	*0,26*	*0,52*	*100,00*

According to the Pareto diagram, we find that 82.52% of the problems which cause the stopping of line 2 are due to the stopping of the FILLER, the NUTRUNNER, the CONVEYOR BOTTLE, the ENCAISSEUSE, the CAPPER, the CONVEYOR CASIERS, the PALLETIZER and the WASHER BOTTLES, provoking downtime taking a sizeable proportion of the working time and consequently stopping the production.

For the budget (300 000.00MAD), we note that with the Pareto method we can solve the problems of the following machines:

- FILLER O+H L2
- NUTRUNNER L2
- CONVOYOR BOTTLE L2
- ENCAISSEUSE KETTNER LV2

This solution allows us to minimize up to 51.2% of downtimes with an amount of 258 500.00 MAD, but the questions that arise are:

- Is this the most optimal solution?
- Can we exploit the rest of the budget to get a better solution than this?

To answer these questions, we will use the knapsack problem.

IV. KNAPSACK PROBLEM

The knapsack Problem (KP) or rucksack problem is a problem of combinatorial optimization: Given a set of elements, each with a mass and a value, it determines elements to include in a collection so that the total weight is less than or equal to a given limit and the total value is as large as possible. It derives its name from the problem faced by someone who is constrained by a fixed-size knapsack and must fill it with the most valuable elements [1]–[2]–[6]–[7]–[8].

The data of the problem can be expressed in mathematical terms. Objects are numbered by index "i" varying from "1 to n". Numbers "Wi" and "Pi" are respectively the weight and the value of the object numbered "i". The capacity of the bag will be noted "W". There are many different ways to complete the knapsack. To describe one of the way, we must indicated for every element whether it is taken or not. We can use a binary coding: the state of the element "i" will have the value "xi = 1" if The element is in the bag, or "xi = 0" if it is left out. A way of filling the bag is fully described by a vector called vector content, or simply content: X = (x1, x2, ...,xn), and the associated weight and value to this filling can then be expressed as a function of the vector content.

$$z(X) = \sum_{\{i,x_i=1\}} p_i = \sum_{i=1}^{n} x_i p_i$$

For a given content X, the total value in the bag is naturally:

Similarly, the sum of the weights of the selected objects is:

$$w(X) = \sum_{\{i,x_i=1\}} w_i = \sum_{i=1}^{n} x_i w_i$$

The problem can then be reformulated as the search for a content vector X = (x1, x2, ...,xn) (which components have the value 0 or 1), achieving the maximum total value function under duress (1) :

$$w(X) = \sum_{i=1}^{n} x_i w_i \leq W \qquad z(X)$$

This is to say that the sum of the weights of objects selected does not exceed the capacity of the knapsack.

In general, the following constraints are added to avoid singular cases:

$\sum_{i=1}^{n} w_i > W$: We can not fit all the objects ;

$w_i \leq W, \forall i \in \{1, \ldots, n\}$: no object is heavier than the bag can carry ;

$p_i > 0, \forall i \in \{1, \ldots, n\}$: any object has a value and brings a gain ;

$w_i > 0, \forall i \in \{1, \ldots, n\}$: any object has a certain weight and consumes resources ;

Terminology:

$z(X)$: is called objective function;

Every vector X satisfying the constraint (1) is said to be feasible;

If the value of $z(X)$ is maximum, then X is said optimal.

1.1. Resolution of the case study by the method of Knapsack Problem

The method of Knapsack Problem consists of putting objects in a bag without exceeding its capacity, until the saturation of the knapsack, if the object i is in the bag we have xi = 1, if not xi = 0.

The application of the method of Knapsack Problem on the results given by the Pareto method leads to a new solution illustrated in the following table:

Table.3: Results of the application of the Knapsack Problem on the results obtained by Pareto

Machines	% downtime	The cost of maintenance (MAD)	xi
FILLER O + H L2	14,49	72400	1
NUTRUNNER L2	13,48	67300	1
CONVEYOR BOTTLE L2	12,05	60400	1
ENCAISSEUSE KETTNER L2	11,19	56400	1
CAPPER L2	8,96	44300	0
CONVEYOR CASIERS L2	8,29	41900	1
PALLETIZER L2	7,47	18000	0
WASHER BOTTLES O + H L2	6,61	33100	0
LABEL KRONES L2	4,82	24200	0
DECRATER KETTNER L2	4,80	24300	0
DEPALETISOR L2	3,02	15500	0
INSPECTOR L2	2,24	11900	0
DATEUSE L2	2,06	10900	0
MIXER L2	0,52	3300	0

From the results of Knapsack Problem applied to Pareto, we see that we can solve the problems of the following machines:

FILLER O+H L2
NUTRUNNER L2
CONVOYOR BOTTLE L2
ENCAISSEUSE KETTNER LV2
CONVEYOR CASIERS L2

This solution allows us to minimize up to 59.49% of downtime with an amount of 298,400 .00MAD, but does a more optimal solution exist?

To answer this question, we will use the Greedy algorithm in order to compare the results to better exploit the budget by minimizing downtime in line 2.

V. GREEDY ALGORITHM

As for most decision problems, it may be enough to find workable solutions even if they are not optimal. Preferably, however, the approximation comes with a guarantee on the difference between the value of the solution found and the value of optimal solution [10]–[11].

The terminology adopted is "Efficiency of an object" which is the ratio of its value over its weight. If the value of the object is large compared to what they consume, then the object is more efficient.

The idea of greedy algorithm as illustrated in “Fig.2” is to add in priority the most effective objects until the saturation of the bag [9]–[10]–[11]–[12] :

1- sort the objects in decreasing order of effectiveness
2- w_conso: = 0
3- for i = 1 to n
4 - if w [i] + w_conso ≤ W then
5 - x [i]: = 1
6 - w_conso: = w_conso + w [i]
7 - else
8 - x [i]: = 0
9 - end if
10-end for

2. Resolution of the case study by the Greedy algorithm

Greedy algorithm makes a classification of objects by their efficiency; the latter is calculated by dividing the cost of maintenance by the downtime. The choice of machines to be corrected is made through the method of filling the knapsack; the use of this algorithm in our case study provides results that are illustrated in the following table:

Table.4: Application results of the Greedy algorithm

Machines	The cost of maintenance (KMAD)	Efficience (KMA D/h)	xi
MIXER L2	3,3	12,69	1
INSPECTOR L2	11,9	10,63	1
DATEUSE LV2	10,9	10,58	1
DEPALETISOR L2	15,5	10,26	1
DECRATER KETTNER L2	24,3	10,13	1
CONVOYOR CASIERS L2	41,9	10,12	1
ENCAISSEUSE KETTNER L2	56,4	10,09	1
LABEL KRONES L2	24,2	10,04	1
CONVEYOR BOTTLE L2	60,4	10,03	1
WASHER BOTTLES O + H L2	33,1	10,03	1
FILLER O + H L2	72,4	10,00	0
NUTRUNNER L2	67,3	10,00	0
CAPPER L2	44,3	9,91	0
PALLETIZER L2	18	4,83	1

After the application of the Greedy algorithm, we find that we can solve the problems of the following machines:

- MIXER L2
- INSPECTOR L2
- DATEUSE L2
- DEPALETISOR L2
- DECRATER KETTER L2
- CONVOYOR CASIERS L2
- ENCAISSEUSE KETTER L2
- LABEL KRONES L2
- CONVOYOR BOTTLE L2
- WASHER BOTTLES O+H L2
- PALLETIZER L2

This solution allows us to minimize over 63.07% of downtimes with an amount of 299 900 .00 MAD.
There are many methods and decision support algorithms; in our study we are interested in the following methods: Pareto, knapsack and Greedy algorithm. Our case study shows that the Pareto method allows choosing the most critical elements based on a single criterion. Greedy algorithm is used to select the most effective elements based on two variables. Adding the knapsack method to remedy more of the elements; thus, to exploit the maximum resources (in our case study exploiting the budget provided by the direction).
Our synthesis is summarized in the following graph which represents the choice of the method according to the number of criteria to study:

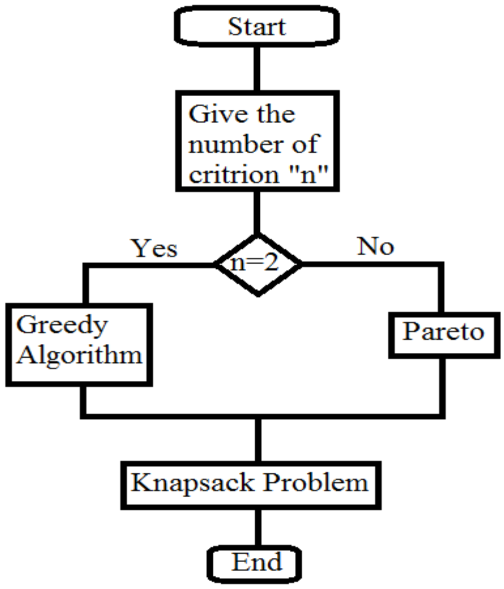

Fig 3: The choice of the method according to the number of criteria to study

To improve a production line we seek the number given. If the number is equal to 2 we use Greedy algorithm and after apply the knapsack method. If the number is not equal to 2 we use the Pareto method and after apply the knapsack method for the most optimal result. But the question that arises is: Is it possible to combine all three tools in an algorithm to have even better results?

VI. METHODOLOGY

The methods applied in our case study give more optimal and efficient results of the development of an algorithm allowing us to:

- Calculate the percentage of cumulative gravity (downtime) and the percentage of the cost of intervention of each machine;
- Calculate the efficiency value for each element from Greedy algorithm by the following formula: ((percentage of gravity) / (percentage of the cost of intervention));
- And finally, apply the method of the Knapsack Problem.

3. Application of our algorithm

The application of our algorithm gives the results presented in the following table:

Table.5 : Application of the Knapsack problem to the Pareto method

Machines	% Downtime	% of The cost of maintenance	Efficience	xi
PALETISEUR LV2	7,47	3,73	2,00	1
CAPSULEUSE LV2	8,95	9,17	0,98	1
VISSEUSE LV2	13,47	13,93	0,97	1
SOUTIREUSE O+H LV2	14,49	14,99	0,97	1
LAVEUSE BOUTEILLES O+H LV2	6,61	6,85	0,96	1
CONVOYEUR BOUTEILLES LV2	12,05	12,51	0,96	1
ETIQUETEUSE KRONES LV2	4,82	5,01	0,96	0
ENCAISSEUSE KETTNER LV2	11,19	11,68	0,96	0
CONVOYEUR CASIERS LV2	8,29	8,67	0,96	0
DECAISSEUSE KETTNER LV2	4,80	5,03	0,95	0
DEPALETISEUR LV2	3,02	3,21	0,94	0
DATEUSE LV2	2,06	2,26	0,91	0
INSPECTRICE LV2	2,24	2,46	0,91	0
MIXEUR LV2	0,52	0,68	0,76	1

This solution allows us to minimize over 63.56% of downtimes with an amount of 298 800 .00 MAD.

The results of four tools: Pareto, Knapsack Problem& Pareto, Greedy algorithm and our methodology are shown in the following table:

Table.6:The percentage of downtime corrected and the cost of intervention for the four tools

	% downtime corrected	The cost of intervention (MAD)	Value remedied in 2 months (MAD)
Pareto	51.20	258500	92160
Knapsack Problem & Pareto	59.49	298400	107082
Greedy algorithm	63.07	299900	113526
Our methodology	63.56	298800	114408

The comparison of downtime percentage corrected by the methods is shown in the following table:

Table.7:The percentage of downtime corrected for each tool compared to other tools

	Pareto	Knapsack Problem & Pareto	Greedy algorithm
Knapsack Problem & Pareto	8.29%	-	-
Greedy algorithm	11.87%	3.58%	-
Our methodology	12.36%	4.07%	0.49%

The application of our methodology provides the most optimal result compared to the three other tools. The gains in MAD from our methodology compared to other tools are shown in the following graph:

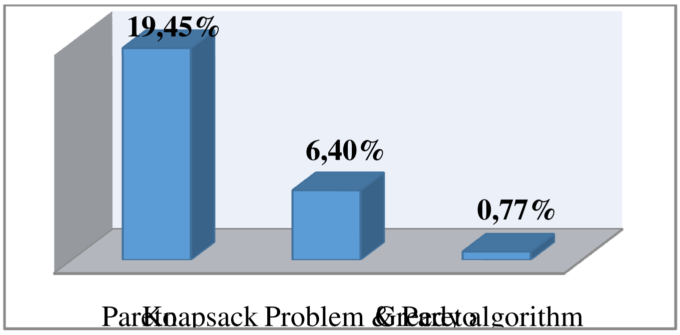

Fig 4: Quantification of monetary gains of our methodology compared to the other three tools

VII. CONCLUSION

In our article, we have developed a new method of selection of elements with the objective of improving a production line. This method combines characteristics of three decision support tools: Pareto, Knapsack Problem and Greedy algorithm. This new decision support tool gives the most optimal results compared to those obtained by applying the three methods mentioned before.

Also, this tool allows the maintenance managers to take the most optimal decision to improve the production efficiency. This is gained by reducing the period of machine breakdowns concerned and respecting the budgetary cost specified by the company.

REFERENCES

[1] H. Kellerer, U. Pferschy, D. Pisinger, "Knapsack problems," Spinger, 2004.

[2] M. Hifi, H. Mhallah, S. Sadfi, "Adaptive algorithms for the Knapsack problem," European Journal of Industrial Engineering, 2 (2), 2008, pp. 134-152.

[3] Chad Brooks," What Is a Pareto Analysis? ", Business News Daily Senior, March 29, 2014

[4] Renato Cirillo, "The Economics of Vilfredo Pareto", Routledge, 12 nov. 2012 - 148 pages

[5] Mahdi Doostparast, Narayanaswamy Balakrishnan, "Pareto analysis based on records", A Journal of Theoretical and Applied Statistics,Volume 47, Issue 5, 2013, pages 1075-1089

[6] X. Song, R. Lewis, J. Thompson, and Y. Wu, "An incomplete m-exchange algorithm for solving the large-scale multi-scenario knapsack problem," Computers & Operations Research, vol. 39, no. 9, pp. 1988–2000, 2012.

[7] Pezhman Sharafi, Lip H. The, Muhammad N. S. Hadi, "Conceptual design optimization of rectilinear building frames: A knapsack problem approach", Engineering Optimisation, Taylor& Francis, DOI: 10.1080/0305215X.2014.963068, 2014.

[8] F. Furini, M. Iori, S. Martello, M. Yagiura, "Heuristic and exact algorithms for the interval min-max regret knapsack problem", INFORMS Journal on Computing, 2015. INFORMS. DOI:10.1287/ijoc.2014.0632

[9] Babacar Diop, Dame Diongue, Ousmane Thiaré, "Greedy Algorithms for Target Coverage Lifetime Management Problem in Wireless Sensor Networks", International Journal of Control and Automation Vol. 8, No. 2, pp. 232-250, 2015

[10] Zhi-qiang Zou, Ze-ting Li, Shu Shen, Ru-chuan Wang, "Energy-Efficient Data Recovery via Greedy Algorithm for Wireless Sensor Networks", International Journal of Distributed Sensor Networks, Article ID 856764, 2015.

[11] Lara Turner, Matthias Ehrgott, Horst W. Hamacher; "On the generality of the greedy algorithm for solving matroid base problems", Discrete Applied Mathematics, 2014

[12] Fred Glover, "Advanced greedy algorithms and surrogate constraint methods for linear and quadratic knapsack and covering problems", European Journal of Operational Research, Volume 230, Issue 2, 16 October 2013, Pages 212-225.

[13] Amal Boukili, Mohamed Fri, Mohammed El Hammoumi, Fouad Belmajdoub, "Comparative study of Pareto, Knapsack and Greedy Algorithm in the field of industrial Maintenance", International Journal of Scientific and Engineering Research, Volume 7, Issue 4, April 2016 .

[14] Amal Boukili, Mohamed Fri, Mohammed El Hammoumi, Fouad Belmajdoub," Elaboration of a new method in the science of decision", International Journal of Scientific and Engineering Research, Volume 7, Issue 4, April 2016.