International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

Vol. 43 No. 1 February 2024, pp. 105-121

Multi-Criteria Optimization Of Textile Production By Analysis Of Machine Stoppage

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Abstract — This article presents the application of multi-criteria optimization in textile production. Indeed, with globalization and technological development, only industries that manage to maximize their production and minimize the lost of time are competitive. This work then relates the application of multi-criteria optimization combined with the FMEA method which is the analysis of failure modes, their effects and their criticalities as well as the Analytic Hierarchy Process (AHP) method to maximize production in the field textiles and reduce machine downtime. To do this, we considered 3 sub-objectives which are economic viability, the service provided to the consumer and the impact on the environment. From these 3 sub-objectives, 11 criteria are studied at level 2 of the objective hierarchy tree, namely the cost of fabric, the cost of energy, costs linked to the unavailability of systems, maintenance costs and repair, the cost of replacing components, the quality and quantity of fabrics produced, the delivery time.

Keywords— Optimization, textile, FMEA, desirability, multi-criteria.

I. Introduction

The technological evolution of the 20th century era as well as the globalization imposes a spirit of creativity and innovation and thus allows companies to distance their productivity from their competitor. Therefore, due to the fluctuation in demand combined with customer requirements, industries in the textile field have a primary need to minimize machine downtime and optimizing too their maximum production. This work proposes an alternative for optimizing production in the textile field by applying multi-criteria optimization combined with the method of prioritizing criteria in order to have the best compromise and the optimal solution which meets both the needs of society, industry and customers.

In this work, 3 main criteria are developed at level 1 of the objective prioritization tree in order to have a better vision of a textile industry with optimal performance. These criteria concern the 3 main players in the field of industry and entrepreneurship, namely the economic aspect of the industry, the services provided to the consumer and respect for the environment.

Then, this article focuses at level 2 of the criteria hierarchy tree on the 11 objectives linked to the 3 main criteria. In order to satisfy the economic viability of the company, our study will develop 5 sub-criteria, namely the cost of fabrics (CT), the cost of replacing components (CRC), the cost of maintenance and repair (CMR), the cost linked to system unavailability (CIsys) and energy cost. Furthermore, the service provided to the consumer is evaluated on 3 sub-criteria, namely the quality of the fabric delivered (Q1), the quantity of fabrics delivered (Q2) and the delivery time (T). Satisfaction with respect for the environment will be evaluated on 3 sub-criteria, namely the parameters of chemical products during the treatment of fabrics (Xc), the management and reprocessing of wastewater (Eus) and CO2 emissions.

II. METHODOLOGY

2.1. Optimization method

The multi-objective optimization method adopted in this work is an optimization method employing the desirability function for the treatment of our problem. This method allows us to find the best compromises, and consequently to find the multi-objective optimum. In this case, the search for the best compromise is carried out in four stages, namely [1]:

2.1.1. The transformation of the performance variables studied via the individual desirability functions

Desirability is defined as the degree of agreement between the objectives set in the problem and the level of modeled responses. In other words, it represents a percentage of satisfaction based on the response calculated by the model, in relation to the objectives set for this response. Therefore, the desirability function evaluates a percentage of satisfaction of the compromise with respect to the objectives.

For an objective function f_m, we associate a desirability function d_m which takes values between [0, 1] and measures the level of satisfaction:

- ❖ A desirability of 0, that is to say an elementary desirability taking the value zero, represents an unacceptable solution for the chosen objective;
- ❖ A desirability 1 indicates the maximum desired performance so no improvement is possible.

The desirability function is defined by the relation 1:

$$\begin{cases} d_m : [f_{min}, f_{max}] \rightarrow [0,1] \\ f_m \rightarrow d_m(f_m) = \gamma_m \end{cases} \tag{1}$$

An improvement of the desirability function proposed by Harrington was developed and proposed in references [2] – [3] in which the principle is:

- ➢ When we must maximize the objective, the value of the latter must be the greatest in the interval [ALC, LSL]. This principle is presented by the relation 2:

$$d(f_m) = \exp\left(-\exp(\beta + \alpha . f_m)\right) \tag{2}$$

$$\begin{cases} \alpha = \dfrac{\ln\left(\ln(0{,}99)/\ln(0{,}01)\right)}{LSL - A} \\ \beta = \ln(-\ln(0{,}99)) - \alpha . LSL \end{cases} \tag{3}$$

- ➢ In the case of targeting, the objective value must be as close as possible to f^* in the interval [ALC, AUC]. The desirability function is then written :

$$d(f_m) = \exp\left(-\left|\left(\frac{2.f_m - (USL + LSL)}{U - L}\right)^n\right|\right) \tag{4}$$

$$n = \frac{\ln\left(-\ln(0{,}99)\right)}{ln\left(\left|\left(\frac{2.LSL - (U+L)}{U-L}\right)\right|\right)} \tag{5}$$

- ➢ When minimizing an objective, its value must be as small as possible in the interval [USL, AUC]. The desirability function is written as follow:

$$d(f_m) = \exp\left(-exp(\beta + \alpha . f_m)\right) \quad (6)$$

$$\begin{cases} \alpha = \frac{\ln(\ln(0{,}01)/\ln(0{,}99))}{AUC-USL} \\ \beta = \ln(-\ln(0{,}99)) - \alpha . USL \end{cases} \quad (7)$$

$$\begin{cases} U = \frac{AUC+U}{2} \\ L = \frac{LSL+A}{2} \end{cases} \quad (8)$$

Où :

- LSL : Lower limit value for the objective function f_m (Lower Soft Limit) :
- USL : Upper limit value for objective function f_m (Upper Soft Limit) ;
- ALC : Threshold or lower tolerance for the objective function f_m (Absolute Lower Cutoff) ;
- AUC : Threshold or upper tolerance for the objective function f_m(Absolute Upper Cutoff) ;
- d : Desirability associated with the objective function f_m.

2.1.2. The definition of the desirability index

The desirability index is defined as an element that makes it possible to combine the individual desirabilities of the objectives in order to find an overall desirability. We note DOI (Design Objective Index). The desirability index is expressed by the relation 9 according to Scott and Antonsson [4] which is an aggregation with an aim to identify all the points of the Pareto frontier:

$$DOI = \left(\frac{w_1.d_1^S+\cdots+w_M.d_M^S}{w_1+\cdots+w_M}\right)^{1/S} \quad (9)$$

- w_m : the weights assigned to the objectives;
- d_m : the individual desirabilities associated with each objective;
- S : the level of compensation

2.1.3. The definition of the global objective function

In this work the multiobjective problem requires the aggregation of desirability indices in order to have the global objective function OF. To each level 2 objective function, we associate its desirability function d_m, and its weight v_m. Then, we aggregate the individual desirabilities obtained with regard to each level 1 secondary objective to obtain the DOI_i desirability indices. To complete the process, we aggregate the desirability indices together to obtain the overall objective function of the system. So, we have the following aggregation relations:

$$\begin{cases} \text{With regard to } Ob_I : DOI_1 = d_1^{v_1}.d_2^{v_2}.d_3^{v_3} \text{ with } v_1+v_2+v_3=1 \\ \text{With regard to } Ob_{II} : DOI_2 = d_4^{v_4}.d_5^{v_5}.d_6^{v_6} \text{ with } v_4+v_5+v_6=1 \\ \text{With regard to } Ob_{III} : DOI_3 = d_7^{v_7}.d_8^{v_8}.d_9^{v_9} \text{ with } v_7+v_8+v_9=1 \end{cases} \quad (10)$$

For the main objective, we have the relation 11:

$$OF = DOI_1^{w_1}.DOI_2^{w_2}.DOI_3^{w_3} \quad (11)$$

The desirability index retained is the geometric mean obtained with the use of the weighting coefficients that we will define in the following section. They are important because they reflect the choice made by the decision maker.

2.1.4. Search for the optimal function

During multi-objective optimizations, sometimes some objectives are contradictory, hence the need for the weighting coefficient which favors certain objectives over others depending on the main objective of the user. We choose the AHP method for the weighting of the objectives which we will associate with the FMEA method (failure modes and effects analysis). This method is useful for constructing the judgment matrix or relative importance matrix because it provides a precise ranking of objectives and facilitates consequently peer comparison of objectives when applying the AHP. Figure 1 then illustrates the optimization method used:

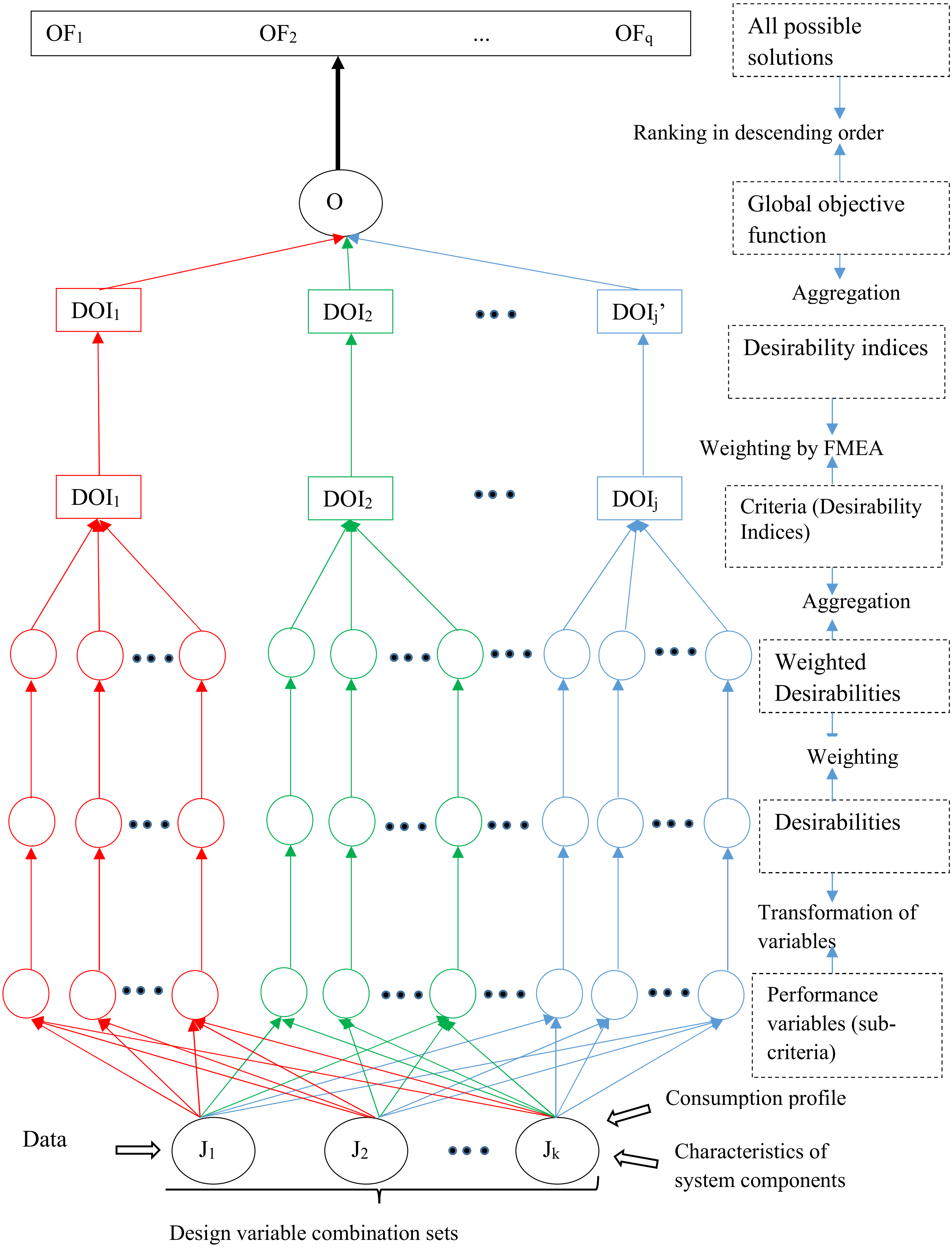

Fig. 1. Optimization method used

2.2. FMEA method

In a multi-objective problem, the problem lies in classifying the objectives and identifying the important one among the multitudes of objectives. Therefore, a rational evaluation of the objectives allows you to have a fairly satisfactory result and to be able to find the ideal solution.

Let us consider the set of objectives $\{O_1, \dots O_i, \dots, O_n\}$ where we are looking for the weighting coefficient. The objective in prioritization is to have a ranking where O_1 is more important than O_i and which is more important than O_n. Furthermore, the importance relationship is not strict so it is possible that the objectives O_1 is smaller than O_n and vice versa, hence the need for objective evaluation methods such as the FMEA method. The FMEA method (failure modes and effects analysis) is an analysis method which makes it possible to identify possible failures as well as critical components and the consequences of these on a project from his first step.

In this work, a failure is considered to be the non-satisfaction of an objective, which implies an identification and a fairly precise definition of the most critical objectives in the design of our system. We are mainly interested in estimating the criticality index of the trio cause – mode – effect of the failure. The determination of this index can be carried out using several criteria but in practice, the importance of a failure is assessed by 3 factors, namely:

- The extent of its consequences ;
- The frequency of its repetition;
- The probability that it will not be detected.

In front of with these factors, a score was assigned for each trio (cause – mode – effect), each of which is defined on a scale of 1 to 10:

- Grade G: severity of effect – consequences on the system;
- The O note: the probability of occurrence – the frequency of appearance ;
- Grade D: probability of non-detection – the risk of non-detection by the user.

Tables 1, 2 and 3 illustrate the evaluation method for each rating [5]:

TABLE I. SEVERITY REFERENCE VALUE SCALE.

Criteria	***Definition***	***Mark***
Very weak	*The nature of the defect cannot cause any perceptible effect on the performance of the product. It is likely that the customer will not be able to detect the defect.*	*1*
Weak	*The minor nature of the defect may constitute a slight inconvenience for the customer. The latter will not be able to note any deterioration in the performance of the product.*	*2* *3*
Moderate	*Failure that causes customer dissatisfaction. It causes embarrassment or discomfort. The customer will notice a degradation in product performance.*	*4* *5* *6*
strong	*Customer dissatisfaction, product not in working order, subassembly inoperative. Failure that can contribute to reducing compliance with certain regulations, without reaching non-compliance.*	*7* *8*
Very strong	*Potential security issues. Non-compliance with regulations.*	*9* *10*

TABLE II. OCCURRENCE REFERENCE VALUE SCALE.

Criteria	*Definition*	*Mark*	*Probability*
Very weak	*Very low probability of failure. It would not be reasonable to predict a failure.*	*1*	*0*
Weak	*The low probability of failure can be assessed on similar products, already used, in which failures were low in relation to the number sold.*	*2* *3*	*1/20000* *1/10000*
Moderate	*Moderate probability of failure. Occasional failures observed in small proportions on similar components*	*4* *5* *6*	*1/2000* *1/1000* *1/200*
strong	*High probability of failure. Notorious failures on similar components.*	*7* *8*	*1/100* *1/20*
Very strong	*Very high probability of failure. Virtual certainty of high failure rate.*	*9* *10*	*1/10* *1/2*

TABLE III. DETECTABILITY REFERENCE VALUE SCALE

Criteria	*Definition*	*Mark*	*Probability*
Very weak	*Very low probability that the defect will reach the customer or be detected during testing. 100% verification.*	*1*	*0 à 5 %*
Weak	*Low probability that the defect will reach the customer or be detected during testing. 100% verification but poorly adapted sampling.*	*2* *3*	*6 à 15 %* *16 à 25 %*
Moderate	*Moderate probability that the defect will reach the customer or be detected during testing. 100% verification but insufficiently controlled validation process. Poorly adapted sampling, conditions different from the specifications.*	*4* *5* *6*	*26 à 35 %* *36 à 45 %* *46 à 55 %*
strong	*High probability that the defect will reach the customer or be detected during testing. Little known validation process. Ineffective means, poorly adapted sampling, conditions different from the specifications.*	*7* *8*	*56 à 65 %* *66 à 75 %*
Very strong	*Very high probability that the defect will reach the customer or be detected during testing. No validation program is planned.*	*9* *10*	*76 à 85 %* *86 à 100 %*

According to references [6] and [7], the criticality index C is the product of the scores of the three previous criteria, namely severity, occurrence and detectability. It is given by the relation 12:

$$C = G.O.D \tag{12}$$

2.3. Definition of performance evaluation criteria

The choice of objectives is an important step in the formulation of a multiobjective optimization problem. The literature offers us several performance criteria that have been used. We can quote among others: the traditional criterion of economic cost, the criterion of physical models which simulate the behavior of the different components of the system and the transfer of energy flows, the type of storage, the impact of the consumption profile on the sizing, etc. To summarize these different themes we arrive at 3 main criteria which are:

- The economic viability illustrated by the economic costs namely the fabric cost (CT), the energy cost (CE), the cost linked to the unavailability of the system, the maintenance and repair cost (CMR), the cost Component Replacement (CRC);
- The service provided to the consumer is illustrated by the Quality of fabric delivered, the Quantity of fabric delivered and compliance with the delivery time of the fabrics;
- Ecological viability defined by wastewater reprocessing, environmental impact indicator and CO_2 emission.

2.4. Determination of weighting coefficient

With multiobjective problems, we are led to find the best possible compromise while considering all the objectives. Sometimes some objectives are contradictory, hence the need for the weighting coefficient which favors certain objectives over others depending on the main objective of the user. In our work, we choose the AHP (Analytic Hierarchy Process) method or the hierarchical analysis process [8] because its particularity is that it supports the decision maker in the methodology of formulating his problem and also that it proposes a method evaluation of important parameters. Its principle is divided into four steps:

- Hierarchy of criteria and sub-criteria by importance from most important to least important.
- Construction of a matrix from the two-by-two comparison of the criteria according to the numerical notation of the previous step. This matrix is called the judgment matrix or the binary comparison matrix or the relative importance matrix, it is expressed by the relation 13 :

$$A = \begin{bmatrix} a_{11} & \dots & a_{1i} & a_{1j} & \dots & a_{1n} \\ \dots & & \dots & \dots & & \dots \\ a_{i1} & \vdots & a_{ii} & a_{ij} & \vdots & a_{in} \\ a_{j1} & \vdots & a_{ji} & a_{jj} & \vdots & a_{jn} \\ \dots & & \dots & \dots & & \dots \\ a_{n1} & \dots & a_{ni} & a_{nj} & \dots & a_{nn} \end{bmatrix} \tag{13}$$

$a_{ij} = \frac{w_i}{w_j}$ et $a_{ii} = 1$

- a_{ij} : Intensity of importance of goal 0_i over 0_j ;
- w_i : Weighting coefficient associated with 0_i ;
- A : Relative importance matrix.
- Determination of the weights associated with each objective: In our study we chose the matrix normalization method [9], this method consists, after the formation of the matrix A, in finding the vector of the weighting coefficients $w = \{w_1, \dots, w_n\}$. We divide each a_{ij} by the sum of the values in the corresponding column. Then, we perform an average per line.

$$w = \begin{bmatrix} \dfrac{\frac{a_{11}}{\sum_{k=1}^{n} a_{k1}} + \dots + \frac{a_{1i}}{\sum_{k=1}^{n} a_{ki}} + \dots + \frac{a_{1n}}{\sum_{k=1}^{n} a_{kn}}}{n} \\ \dots \\ \dfrac{\frac{a_{i1}}{\sum_{k=1}^{n} a_{k1}} + \dots + \frac{a_{ii}}{\sum_{k=1}^{n} a_{ki}} + \dots + \frac{a_{in}}{\sum_{k=1}^{n} a_{kn}}}{n} \\ \dots \\ \dfrac{\frac{a_{n1}}{\sum_{k=1}^{n} a_{k1}} + \dots + \frac{a_{ni}}{\sum_{k=1}^{n} a_{ki}} + \dots + \frac{a_{nn}}{\sum_{k=1}^{n} a_{kn}}}{n} \end{bmatrix} = \begin{bmatrix} \dfrac{\sum_{m=1}^{n} \left[\frac{a_{1m}}{\sum_{k=1}^{n} a_{km}} \right]}{n} \\ \dots \\ \dfrac{\sum_{m=1}^{n} \left[\frac{a_{im}}{\sum_{k=1}^{n} a_{km}} \right]}{n} \\ \dots \\ \dfrac{\sum_{m=1}^{n} \left[\frac{a_{nm}}{\sum_{k=1}^{n} a_{km}} \right]}{n} \end{bmatrix} \tag{14}$$

Each coefficient w_i is obtained by relation 15 and its expression is:

$$w_i = \frac{\sum_{m=1}^{n}\left[\frac{a_{im}}{\sum_{k=1}^{n} a_{km}}\right]}{n} \tag{15}$$

The sum of w_i must be equal to 1.

- Checking the consistency of the result

During this step, we calculate the consistency ratio which is a parameter to ensure better judgment made by decision-makers. This procedure is important because the user can make errors in the assessments, that's why the need for consistency measurement in order to detect errors which can greatly affect the result of the final analysis.

The first step in calculating the consistency ratio consists of multiplying the initial matrix of judgments. It is then necessary to add up the values for each of the lines of the new matrix and divide the vector resulting from this operation, that is to say consisting of the total of each of the lines, by the value of the priority vector associated with it. The average of the elements of this last vector obtained is represented by λ_{max} (the largest eigenvalue). This method is illustrated by relations 16, 17, 18, 19 and 20. Let the vectors $[\lambda'_1 \cdots \lambda'_i \cdots \lambda'_n]$ and $[\lambda_1 \cdots \lambda_i \cdots \lambda_n]$ be such that:

$$\begin{bmatrix} \lambda'_1 \\ \cdots \\ \lambda'_i \\ \cdots \\ \lambda'_n \end{bmatrix} = \sum_{k=1}^{n} \left[w_k * \begin{bmatrix} a_{1k} \\ \cdots \\ a_{ik} \\ \cdots \\ a_{nk} \end{bmatrix} \right] = \left[w_1 * \begin{bmatrix} a_{11} \\ \cdots \\ a_{i1} \\ \cdots \\ a_{n1} \end{bmatrix} + \cdots + w_i * \begin{bmatrix} a_{1i} \\ \cdots \\ a_{ii} \\ \cdots \\ a_{ni} \end{bmatrix} + \cdots + w_n * \begin{bmatrix} a_{1n} \\ \cdots \\ a_{in} \\ \cdots \\ a_{nn} \end{bmatrix} \right] \tag{16}$$

$$\lambda_i = \frac{\lambda'_i}{w_i} \tag{17}$$

$$\lambda_{max} = [\, \textstyle\sum_{i=1}^{n} \lambda_i]/n \tag{18}$$

The consistency index IC is defined by the relation 19:

$$IC = (\lambda_{max} - n)/(n-1) \tag{19}$$

n : Number of criteria or sub-criteria considered.

The coherence ratio (RC) is the ratio between the coherence index (CI) and the random index (AI) illustrated in Table IV [10] of a matrix of the same dimension depending on the number of given objectives.

$$RC = \frac{IC}{IA} \tag{20}$$

TABLE IV. TABLE OF RANDOM INDEXES

Matrix size (n)	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***
IA	***0***	***0***	***0,58***	***0,9***	***1,12***	***1,24***	***1,32***	***1,41***	***1,45***	***1,49***	***1,51***	***1,53***	***1,56***	***1,57***	***1,59***	***1,61***

For a matrix is perfectly consistent, its maximum eigenvalue is equal to its dimension : $\lambda_{max} = n$ et $IC = 0$.

III. CLASSIFICATION OF MACHINE STOPPS

Our study will focus particularly on the analysis of machine downtime in the finishing department of a textile industry in order to maximize production. As we said before, there are two categories of stage in the Dyeing Printing Primer Finishing (TIAF) department, namely the main stage which deals with the printing and dyeing operation and the finishing stage which deals with the dyeing operation. priming and finishing. The machines used for each operation are respectively: for printing we have the rotary, for dyeing there is the batch pad, the hot flue and the Kusters scarf, for priming and finishing there are the RAMs and the sanforizer.

In the following table V, we illustrate the type of stoppage and downtime assessment of machines in the finishing department:

TABLE V. STOPS ON EACH MACHINE AND THEIR RATES

STOP FAMILY	***ROTARY 3***	***PB_HF***	***KUSTERS***	***WASHER 6***	***RAME 6***	***RAME 8***	***RAME 9***	***SANFO 1***	***Grand total***	***Rank***
ABSENCE (A)	0%	0%	0%	0%	6%	1%	5%	8%	**3%**	**6**
WAITING FOR FABRIC ON MACHINE (ATM)	1%	9%	2%	43%	2%	17%	11%	2%	**13%**	**4**
CHANGE OF BET (CM)	56%	8%	35%	9%	34%	23%	21%	7%	**31%**	**1**
MAINTENANCE (E)	3%	3%	1%	1%	2%	4%	0,5%	0,5%	**2%**	**7**
LACK OF SMALL EQUIPMENT (MPM)	0%	0%	0%	0%	1%	2%	1%	0%	**1%**	**8**
FOCUS ON THE FABRIC (MPT)	22%	61%	48%	3%	22%	11%	43%	26%	**25%**	**2**
BREAKDOWN (P)	5%	2%	2%	6%	9%	11%	4%	33%	**7%**	**5**
MACHINE PREPARATION (PM)	14%	16%	12%	39%	24%	31%	15%	24%	**18%**	**3**

IV. PRESENTATION OF THE RESULTS

4.1. Multiobjective optimization

4.1.1. Principle:

Our job is to find the combination that reflects the best possible compromise to best meet the different objectives simultaneously. So, we structured the optimization problem into a hierarchical tree with 4 levels illustrated in Figure 2.

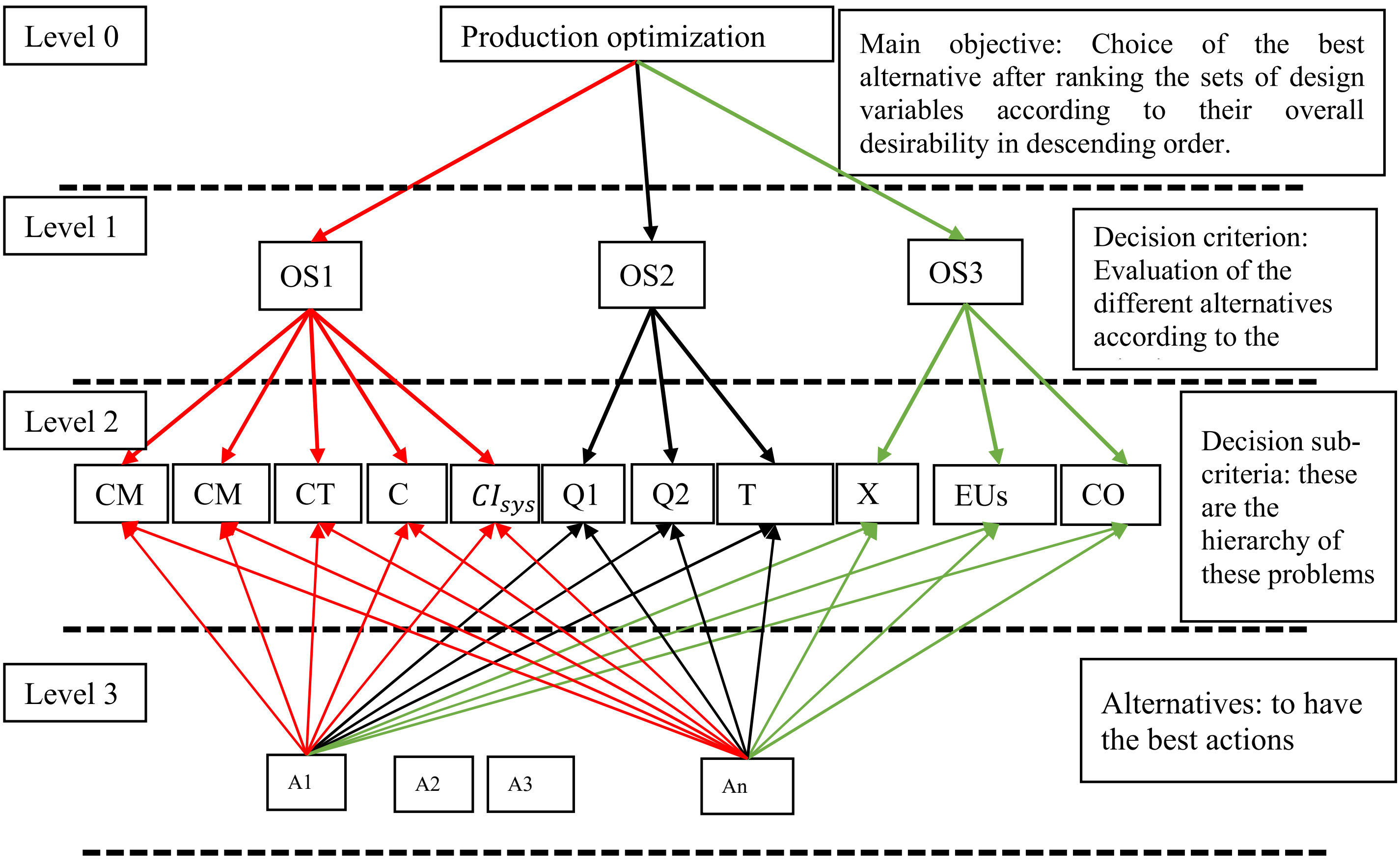

Fig. 2. Hierarchical tree for multi-objective evaluation

4.1.2. Evaluation of objectives

Therefore, the result of the sensitivity of each criterion is then translated into the criticality index which is the product of the three factors (severity – occurrence – detectability). Table VI illustrates a survey carried out in Benin [4] in the field of energy supply which we adapted according to the context of our work. From this table we see that users favor criteria linked to the services provided to the consumer, which is understandable. The advantage with the FMEA method is its flexibility because we obtain a completely different result by putting ourselves in the place of producers and environmentalists. However, each criterion has limits, regardless of point of view.

TABLE VI. CRITERIA CRITICISM INDEX

Decision criterion	***Severity (G)***	***Occurrence (O)***	***Detectability (D)***	***Criticality (C)***
Economic viability threshold (OS1)				
Fabric cost (CT)	***8,1***	***7,2***	***5,6***	***326,59***
Energy cost (CE)	***6,5***	***6,5***	***6,5***	***274,63***
Cost of replacing components (CRC)	***8,1***	***6,5***	***5,6***	***294,84***
Maintenance and repair cost (CMR)	***7,2***	***6,5***	***4,6***	***215,28***
Cost linked to system unavailability (CIsys)	***7,2***	***5,6***	***4,6***	***185,47***

Service threshold provided to the consumer (OS2)				
Fabric quality (Q1)	***8,1***	***8,1***	***6,5***	***426,465***
Fabric quantity (Q2)	***8***	***8,1***	***6,5***	***421,2***
Delivery delay (T)	***7,2***	***6,5***	***6,5***	***304,2***
Environmental impact threshold (OS3)				
Wastewater reprocessing	***7,2***	***5,6***	***5,6***	***225,792***
CO2 emission	***7,2***	***7,2***	***3***	***155,52***
Parameter due to treatment chemical	***8,1***	***6,5***	***3***	***157,95***

Based on Table VI, we obtain the classification of the criteria and sub-criteria according to their order of priority. In table VII below we illustrate the ranking of the main criteria according to their importance:

TABLE VII. RANKING OF CRITERIA IN ORDER OF IMPORTANCE

Decision criterion	***Criticality***	***Rank***
Economic viability threshold *(OS1)*	*259,36*	*2*
Service threshold provided to the consumer *(OS2)*	*383,96*	*1*
Environmental impact threshold *(OS3)*	*179,75*	*3*

4.1.3. Calculation of weights linked to criteria

The weight calculation for each criterion is done in 3 steps, namely:

- Pairwise comparison of the relative importance of objectives with regard to the domain of the main criteria and objective;
- Creation of the judgment matrix for each criterion ;
- Checking the consistency of the matrix.

The results for calculating the weights are grouped in Tables VIII to XI.

The weighting coefficients for the sub-criteria linked to the economic criterion are presented in Table VIII:

TABLE VIII. WEIGHTING COEFFICIENT OF SUB-CRITERIA 0S1

Objective	CT	CE	CRC	CMR	CISys
Weight (%)	0,42	0,22	0,20	0,10	0,06

The consistency ratio is equal to 0 because the largest eigenvalue $\lambda max=5$ which is equal to the dimension of the matrix, therefore, matrix is perfectly coherent.

The weighting coefficients for the sub-criteria linked to the criterion of service provided to the consumer are presented in Table IX:

TABLE IX. WEIGHTING COEFFICIENT OF SUB-CRITERIA 0S2

Objective	*Q1*	*Q2*	*T*
Weight (%)	*0,54*	*0,30*	*0,16*

The consistency ratio is equal to 0 because the largest eigenvalue λmax=3 which is equal to the dimension of the matrix and the number of criteria, consequently, the matrix corresponding to the criterion of services provided to the consumer is perfectly coherent.

The weighting coefficients for the sub-criteria linked to the impact on the environment (OS3) are presented in Table X:

TABLE X. WEIGHTING COEFFICIENT OF SUB-CRITERIA 0S3

Objective	*EUs*	*CO2*	*XC*
Weight (%)	*0,55*	*0,21*	*0,24*

The consistency ratio is equal to 0 because the largest eigenvalue λmax=3 which is equal to the dimension of the matrix and the number of criteria; therefore, the matrix corresponding to the criteria linked to the impact on the environment is perfectly coherent.

The weighting coefficients for the criteria linked to the main objective are presented in Table XI:

TABLE XI. WEIGHTING COEFFICIENT OF THE CRITERIA OF

Objective	*OS2*	*OS1*	*OS3*
Weight (%)	*0,54*	*0,30*	*0,16*

The consistency ratio is equal to 0 because the largest eigenvalue which is equal to the dimension of the matrix and the number of criteria, therefore, the matrix corresponding to the main objective is perfectly cohere

4.1.4. Multiobjective equation:

By considering the weights linked to each criterion that we calculated previously, we then obtain the desirability functions in relation to the secondary objectives, namely:

The desirability function of the secondary cost objective presented by equation 21:

$$dOS1 = dCI^{wCT}.dCMR^{wCMR}.dCR^{CR}.dTCE^{wCE}.dCIsys^{wCIsys} \quad (21)$$

Relationship 22 illustrates the desirability function of the secondary objective linked to the service provided to the consumer:

$$dOS2 = dLQ1^{wQ1}.dQ2^{wQ2}.dT^{wT} \quad (22)$$

Equation 23 represents the desirability function linked to the impact of the environment:

$$dOS3 = dEUs^{wEUs}.dCO2^{wCO2}.dXc^{wXc} \quad (23)$$

After aggregating the criteria and taking into account the weights linked to each criterion, the overall desirability function of our work is expressed as:

$$\begin{cases} min_x f(x) = \prod_{i=1}^{3} \prod_{i=1}^{11} (exp(-exp(\beta x_i + \propto x_i^2)))^{wdx_i})^{wOS_i} \\ \sum_{i=1}^{11} USL_i \leq \sum_{i=1}^{11} x_i \leq \sum_{i=1}^{11} AUC_i \\ 0 < f(x) < 1 \end{cases} \quad (24)$$

x_i : Represents the 11 sub-decision criteria

4.2. Optimization results

4.2.1. Evolution of objective functions

The evolution of the overall objective function F in relation to the objectives linked to economic viability OS1 and the objective linked to the service provided to the consumer OS2 is illustrated in Figure 3:

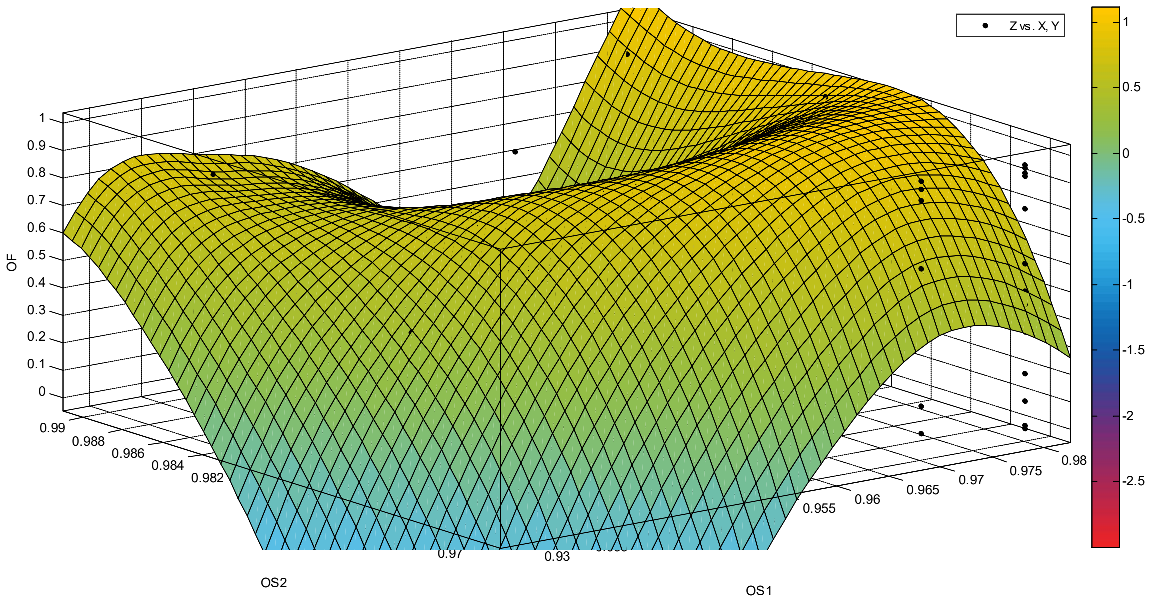

Fig. 3. Evolution of the OF compared to OS1 and OS2

We note that the overall objective function oscillates in the 96% satisfaction rate and that the average satisfaction rate of the OS1 objective is 96% while the satisfaction rate of the OS2 objective is around 99%. Remember that in our study during the rankings and rating we favored the criteria linked to the service provided to the consumer.

Knowing that the upper limit USL for the two sub-criteria which are the quality and quantity of fabrics delivered to customers is 95.4% and that the upper tolerance AUC is 99%, in this scenario the result is 98.83 % consequently we notice the two criteria are satisfied which illustrates the satisfaction rate of 99% of the OS2 objective.

For the OS1 objective the USL upper limits of the CE and CRC criteria are respectively 0.1 and 0 Dollars/m in this scenario we had a result where the value of CE is equal to 0.19 dollars/m and that of CRC is 0.05 dollars/m.

Figure 4 illustrates the evolution of the overall OF function according to the objectives linked to economic viability OS1 and that of environmental impact OS3:

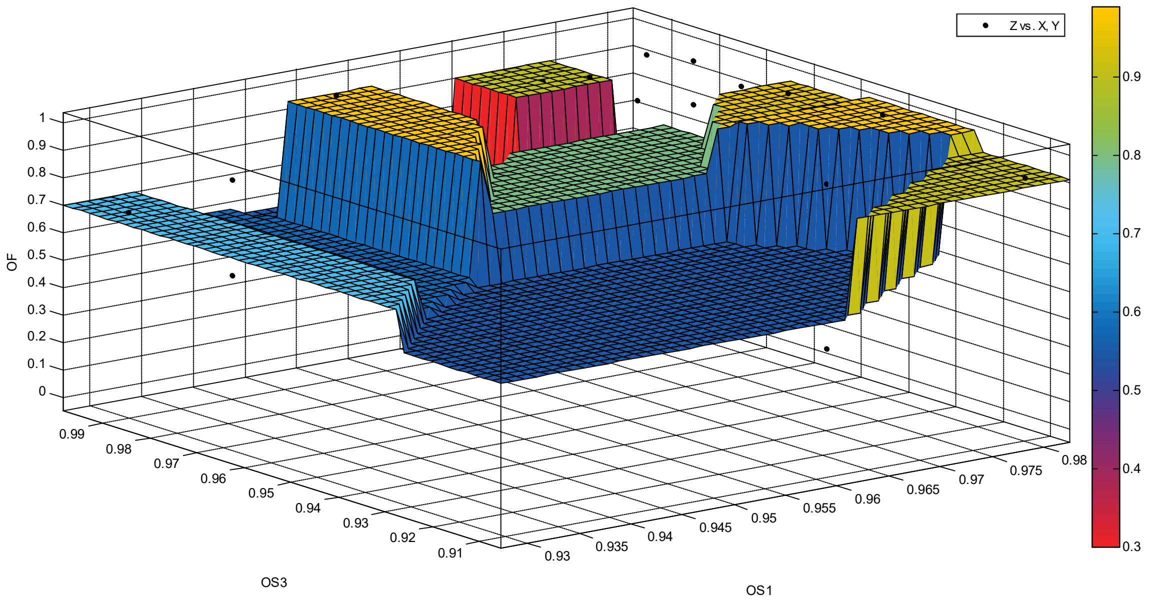

Fig. 4. Evolution of the OF compared to OS1 and OS3

In this scenario the average value of the main objective is 0.97 while that of the two secondary objectives which are economic viability and environmental impact is 0.96.

For the case of economic viability the fabric cost is 1.05 with an upper limit USL equal to 1 dollar/m and that of system unavailability is 0.17 with an upper limit of 0.1.

Regarding the case of environmental impact, the volume of treated wastewater is 1538.48 m3/day with a USL of 1500 m3/day.

In this case we can say the overall function is proportional to the two secondary objectives, namely economic viability and that of the impact on the environment.

The evolution of the overall objective according to the objectives linked to the service provided to the consumer (OS2) and to the environmental impact (OS3) is illustrated in Figure 5:

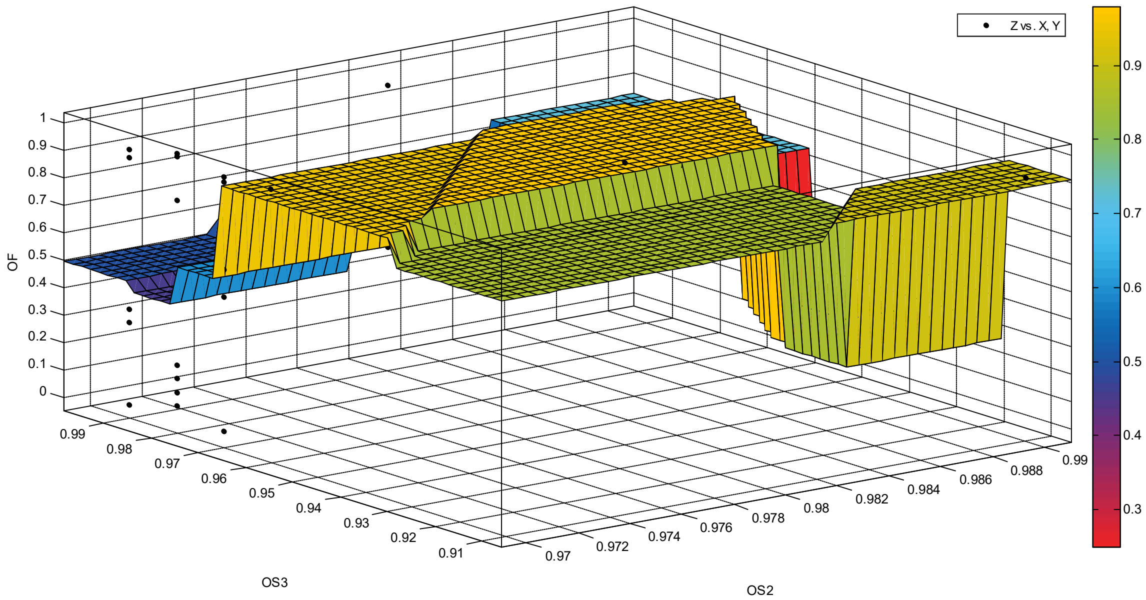

Fig. 5. Evolution of the OF compared to OS2 and OS3

The overall goal average is 0.98. Remember that the two criteria are not in contradiction, hence the high satisfaction rate. Also, we also note at the level of the secondary objectives a satisfactory satisfaction rate which is 0.98 for the services provided to the OS2 consumer and 0.97 for that of the environmental impact.

Knowing that the overall objective equal to 1 is generally solutions that are very difficult to achieve and that the overall objective equal to 0 represents mediocre solutions therefore not worth considering. Since there are multitudes of solutions because in multiobjective optimization, the goal is to find the best compromise given the plurality of criteria therefore it is necessary and essential to put hypotheses via the FMEA method in order to find the optimal solution for a case and a given point of view.

4.2.2. Decision regarding machine downtime

During our work, we considered the three (3) trains of the TIAF department which are Train 6, 8 and 9. The objective for these 3 machines being 50,000m for a running time of 1440 minutes (24 hours). With the minimization of machine downtime, the objective is almost achieved with a length of fabric produced of 49,566 m, i.e. an error of 0.8% which is largely acceptable. To do this, the effective lengths for each train are for train 6 a fabric of 14,746 m, for train 8 a length of 17,991 m and for train 9 an effective length of 16,829 m. This objective was achieved with a running time of the machines whose respective values are 429 minutes for train 6, 566 minutes for train 8 and 549 minutes for train 9. The gap between the objective time and the achievement is justified by the waiting time for cooling which is approximately 30 to 45 minutes.

V. Conclusion

This article proposes a multi-criteria optimization method with the desirability function combined with the evaluation carried out by the FMEA method. The particularity of this method lies in its flexibility because by changing the order of preference we obtain a completely different result which satisfies the user.

During the application we considered 3 secondary objectives at level 1 and 11 sub-objectives at the level. After optimization we note that the satisfaction rate of the secondary objectives are greater than 96% and in our case a preference during the survey for the objective linked to the service provided to the consumer leads us to a satisfaction rate of 98% for that this.

In the end with multi-criteria optimization we have an economically viable system with a satisfaction rate of 96%, which respects the environment with a satisfaction rate of 97% and favors users with a satisfaction rate of 98% in which objectives of the quantity and quality of fabrics delivered are respected up to 99% with a length of 49566 m/50000m of fabric produced with a reasonable time of 1544 minutes for a target of 1440 minutes. Deviations are justified in terms of cooling downtime.

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