

THE ROLE OF THE OVERALL EQUIPMENT EFFECTIVENESS AS A DECISION SUPPORT TOOL FOR STRUCTURING THE ROADMAP OF A TFS TRANSFORMATION (CONSTRAINT THEORY, SAFETY OF OPERATION, AND SIX SIGMA).

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ABSTRACT

The purpose of this article is to explain how the overall equipment effectiveness (OEE) is used to initiate and structure reflection on a new approach called "TSF transformation", that can improve the performance of the means of production combining the theory of Constraints (ToC) and its translation to identify machine-specific bottlenecks, Six sigma method to avoid variability of key maintenance parameters such as reliability and maintainability, availability and security, and (Such as survival law, reliability diagrams, etc.) that could be integrated into the Six Sigma method, like MSP (Statistical Process Methods) methods.

Keywords: *Bottlenecks, Overall Equipment Effectiveness, Reliability-Based Maintenance, FMECA Analysis, Operational Safety, Theory Of Constraints, Six Sigma.*

1. INTRODUCTION

Given the importance of reliability, availability and safety of machines in improving the performance of production systems. The efficiency of these machines has become an inevitable criterion of judgment. But in order to improve this efficiency, it would be important to identify a relevant indicator to measure it properly, such as the OEE (Overall Equipment Effectiveness) in order to determine all factors of influence and to understand what it can not be achieved only through a rational and coherent use of an operational transformation of improvement which aims at improving performance in this case six sigma, safety of operation as well as the theory of constraints. Through this article, we intend to show how the OEE can be a tool for decision-making. And how can it structure a reflection around a new transformation of the operational performance of a production system that we have named "TFS" integrating the Theory of constraints, the Safety of Operation, and the Six Sigma approach?

2. LITERATURE REVIEW

We will present a general overview of methods for addressing the "efficiency, reliability, availability and safety" aspects of production equipment. These approaches can be divided, according to the analysis tools adopted, into three categories:

- ✓ Continuous improvement approach, particularly the new ToC (Constraint Theory) approach as well as Six Sigma;
- ✓ Empirical approach, we mainly mention maintenance based on reliability (RCM);
- ✓ Analytical approach: safety of operation;
- ✓ Standard approach: for NF E 60-182, which describes how operational indicators are calculated.

2.1 ToC: Theory of Constraints

Among the main steps of continuous improvement to develop the performance of industrial companies, we can cite the Lean, the Six Sigma and the Theory of Constraints (TOC). The latter is the result of the work of Goldrat, the approach

(ToC) has been the subject of a series of publications, but remains very unknown in the world of maintenance in the same way as the method Six Sigma. In general, the ToC makes it possible to concentrate progress in the right place, that is to say, bottlenecks which are production resources whose real capacity does not satisfy the need Customers [1] presenting a constraint penalizing the total capacity of the production. The Theory of Constraints makes it possible to increase performance faster, the approach of which is to show that bottlenecks completely determine the rules and conditions of production. It is based on two main steps:

- ✓ Identify bottlenecks: Initially, the analysis of the plant must make it possible to locate the bottleneck (s). Generally, the identification of the constraint is easy because the outstanding and the fall of the capacities accumulate before the bottlenecks.
- ✓ Rhythm the factory to the "sound" of the bottlenecks to balance the capacities and flows : The flows of the plant must be put under control and piloted according to the capacity of the bottlenecks, following the so-called "drum-buffer-rope" approach:
- ✓ Drum: optimizing the scheduling of bottlenecks to maximize production.
- ✓ Buffers: establishment of a buffer stock in front of these resources and only these resources in order to avoid the forced shutdown of production and following the failure of a non-bottleneck equipment (c That is to say non-critical), and setting up a second stamp before the expeditions to ensure compliance with the delays.
- ✓ Rope: adaptation of production start-up rules according to the program of the bottleneck to avoid the accumulation of unnecessary work in progress.

2.2 Reliability Based Maintenance (RCM):

Reliability based maintenance (RCM) emerged in the 1960s in the aeronautical field, in particular to reduce the maintenance costs of B747 aircraft, or preventive maintenance was very expensive at the time. It was taken over by EDF in 1990 for the maintenance of the nuclear fleet and tends to be applied in many complex industrial sites where maintenance operations are carried out. Reliability-based maintenance is considered to be a systematic method for identifying the most efficient preventive maintenance tasks [3] and pursues three goals:

- ✓ Reduce maintenance costs without degradation of reliability;

- ✓ Improve the safety and availability of installations (by being more relevant to the periodicities and elements to be maintained);
- ✓ Master the life of the equipment;

In order to improve the availability of production equipment. It is based on the following three major steps:

- ✓ Identify critical equipment;
- ✓ Prioritize system failures using feedback from experiments (typically workshops with experts, possibly using data from a CMMS system and / or manufacturer's documentation for each Equipment) to identify past failures to focus maintenance on the least reliable components;
- ✓ Developing FMEA analyzes (analysis of failure modes of their effects and criticality) for each critical equipment. A failure mode, according to the standard NF EN 60 812, is an effect by which the failure of a component of the system is observed. This definition shows that the method is based on the decomposition of the system into elements. The data collection makes it possible to know the behavior of each element. The system's hardware and functional architecture makes it possible to induce all the effects of all the failure modes of all the elements of the system [2].
- ✓ The resolution of the failure modes of production equipment requires that one knows its production mission, the various components, and their modes of failure. The resolution methods must be chosen according to the complexity of the equipment. In this context, the FMECA analysis is important, particularly in the case where digital data are not available.
- ✓ Develop maintenance plans that focus primarily on the most critical components that can cause failures.

2.3 Safety of Operation:

The safety of operation is a concept, which is de-cline in four quantifiable quantities; they depend on each other. These four quantities must be taken into account for any safety study. At times, the initials of its four characteristic magnitudes, FMDS, denote safety:

- ✓ Reliability: probability the system is not failing on $[0, t]$.
- ✓ Maintainability: probability that the system is repaired on $[0, t]$.
- ✓ Availability: probability the system is running at time t .

- ✓ Safety: Probability of avoiding an event catastrophic.

2.4 Presentation of The French Standard NF E 60-182

In the industrial world, sources of disruption to production processes are generally multiple. This is the reason why real productivities are lower than expected. "... The theoretically achievable quantity is a function of the time allowed or considered, hence endless debates on the reference time: maximum theoretical opening (365 days × 24 hours per year, for example), or the time actually worked according to the company's schedule, or the time theoretically necessary to carry out the production ". Standard N FE 60-182 describes the procedures for calculating OEE. These are the formulas for calculating this performance indicator taking into account the configuration of the system which distributes the different state times of a production means. The analysis of the OEE can be carried out from two different viewing angles: taking into account the productivity aspect as well as the functional safety aspect, that is to say taking into account only the functional or dysfunctional behaviors of Machines.



Figure 1: Decomposition of OEE [4]

- ✓ Total time (Tt): initial time, which brings together all the possible states of the means of production. In the case of a year, the total is 8760 h.
- ✓ Opening time (To): The total time which corresponds to the part of the working time, while eliminating the closing of the workshop, which leads to the disengagement of the means of production (holiday periods...).

$$T_o = (T_t) - \text{time (close factory)} \quad (1)$$

- ✓ Required Time (Tr): The length of the opening time corresponding to the part of the working hours while eliminating stoppages related to

preventive maintenance or load tests of the means of production.

$$T_r = (T_o) - \text{time(planned shutdown)} \quad (2)$$

- ✓ Operating Time (Tp): The time period during which the means of production is ex-ploited in production, which does not include unexpected downtime and consequent breakdowns, change of series, absence of personnel.

$$T_p = (T_r) - \text{time(availability losses)} \quad (3)$$

- ✓ Net time (Tn): The period of time during which the means of production is exported without taking into account the duration corresponding to the fall in the rate, during which the means of production would have produced good products and bad, referring to the criteria of quality.

$$T_n = (T_p) - \text{time(speed loss)} \quad (4)$$

- ✓ Useful time (Tu): The period of time during which the means of production is operated with the subtraction the time necessary to correct all problems related to non-quality (scrap, recycling, etc.).

$$T_u = (T_n) - \text{time(quality loss)} \quad (5)$$

Based on figure 1, the standard NF E 60-182 defines the main performance indicators, in particular, the Economic yield rates, it is the strategic indicator of commitment of the means of production, it allows the managers to evaluate the industrial strategy of organization of the company. The Economic yield rate is defined as:

$$\text{Economic yield rate} = T_u / T_t \quad (6)$$

Overall yield rates: It is an indicator of the productivity of industrial organization. An economic indicator integrates the effective load of a means of production. It is the tool to measure the productivity gain of the company. It is used in the majority of cases in manufacturing industries. It answers many strategic questions (actions to optimize production, efficiency of the organization, need of

investment ...). It expresses the reality of operation in relation to an ideal of operation and it allows to visualize the various losses of efficiency of use, performance and quality. The Global Rate of Return is a ratio between two quantities of time, or two quantities of coins produced. There are two types of weather: the time needed to produce good parts (useful time) and the available time (or opening time). The Overall yield rate is defined as:

$$(7) \quad \text{Overall yield rate} = Tu/To$$

Overall equipment effectiveness: The optimization of production processes is based on a good appreciation of the performance indicators. The OEE has become, through the standard NF E 60-182, one of the performance indicators of production systems. The OEE primarily measures equipment performance [5]. It is a relevant means of measuring technical causes of non-performance in order to improve the efficiency of machines.

$$(8) \quad \text{Overall equipment effectiveness} = Tu/Tr$$

2.5 World Class Performance

Each model of the system (according to the criteria already mentioned) makes it possible to calculate the value of the OEE at the SDF angle, referring to operating states [6]. The value obtained then makes it possible to evaluate the efficiency of the system taking into account the values of the World Class Performance, which defines the thresholds based on three modes in which a system can be found:

- ✓ The mode on (m) if the value Of TRS is $\geq 85\%$.
- ✓ Degraded walking (md) if $25\% \geq OEE \geq 85\%$.
- ✓ Out of service if $OEE \leq 25\%$.

As a result, the value of the Overall equipment effectiveness (OEE) of a machine can tell us about its operating states "on", "degraded" and "out of service" whose thresholds are set according to the World Class Performance. In this context, switching from one state to another is linked to events such as failure or premature degradation of components. This corresponds to the safe viewing angle of operation; the value of the OEE largely depends on the type of system (serial system, parallel). For a simple system, this value corresponds to the product of three indicators: Performance, Quality and Operational Availability.

If we take into account the notion of "reliability diagram" which is considered one of the

important concepts and foundations of operational safety, the evaluation of the OEE of a system comprising, for example, several elements mounted in parallel depends on several Elements. It depends on the type of redundancy [7], the reparability of the components (repairable system or not), the number of components in the system. A parallel system in the case of active redundancy. For passive redundancy, two cases can be envisaged: first, if the system is not repairable, which means that the faulty elements are not restarted, and if the system is Repairable, and that any component that breaks down can be repaired and put on hold for another boot, the OEE will be defined by the formula.

3. CASE STUDY

3.1 Presentation of the Case Study

The types of production can be classified into three categories, continuous production, discontinuous or by project, knowing that many mixed types could be found. The standard in question is essentially adapted to discontinuous production. The calculation of the OEE according to the standard NF E 60-182 can be initiated under two different approaches, namely, productivity and safety of operation. The notion of productivity is rather adapted to the discontinuous industry in which one can count the number of products realized, that is not the case for the continuous industry (chemistry or parachemistry, ..) whose term In question means the pace of production constituting an already integrated loss in order to evaluate the net time (Tn). The example below illustrates the calculation of the OEE for a total time of 24 hours and does not take into account the safety aspect of production for the following reasons:

Table 1: Status Time Values

Time	Value of time	Loss	Value of loss
Tt	24		
To	20,6	Close factory	3,4
Tr	16	Planned shutdown	4,6
Tp	12,3	Availability losses	3,7
Tn	11,8	Speed losses	0,5
Tu	11,6	Quality losses	0,2

The availability indicates the fraction of the time planned for the production (load time), in which the equipment is actually producing [8].

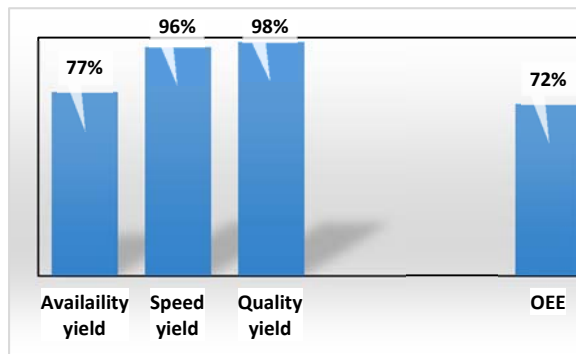


Figure 2: Calculation Of Yields According To NFE 60-182

3.2 Result

Through this example, one can conclude the value of the OEE from a "safe operating" point of view corresponds to the product of three indicators, which are performance, quality and operational readiness. This calculation mode is particularly suitable for continuous production. The OEE because it takes into account even the losses due to the planning aspect such as preventive maintenance. As for continuous production, the petrochemical industries, cement plants are typical examples, machines or installations are dedicated to the product to be manufactured, which generally does not allow great flexibility. In addition to avoiding creating bottlenecks and fluidizing the flow of products, the balance of production of each of the machines must be cared for. We believe that the calculation of the Economic yield rate and Global yield rate indicators is essential for the case of an integrated platform, these indicators allow us to measure only the intrinsic performance of a production, but also performance related to extrinsic events associated with inevitable interactions in the upstream production workshops (production of the raw material). The Global yield rate in this case shows where the time is lost and categorizes both the internal and external losses as well as the axes of improvement that result.

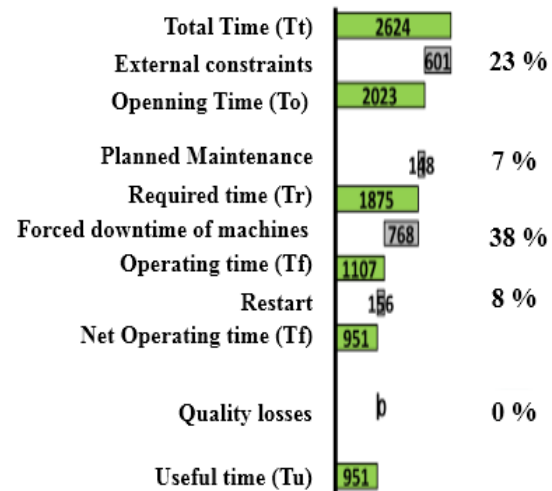


Figure 3: Decomposition Of Losses

The case study deals with a facility that was designed to run 3.5 months (total time is in the order of 2624).

- ✓ *Rethinking the industrial strategy:* The calculation of the economic yield rate (formula 6) gives us: $TRE = Tu / Tt = 36\%$, it shows that the commitment of this installation as means of production is very low if only for the seasonal period of operation. If we take the total standard time ($365 * 24h = 8760$) into account, the ERR will be even lower (11% only). This requires a call to question the industrial strategy (Review the return on investment).
- ✓ Introduce a constraint management approach as an integrated approach that can include other approaches (Lean, Six Sig-ma, and operational safety).
- ✓ We note from Figure 4 that the constraints represent 23% of the time lost; this is due to a time lost for the reconstitution of the stock in order to replenish the plant. This really constitutes two extrinsic bottlenecks, which totally determines the rules of operation of this production installation.
- ✓ The actual capacity of the facility (upstream) to meet the demand for the facility that is the subject of our case study.
- ✓ Integrated planning is lacking in this case.

Our analysis of Figure 4 also allowed us to identify other bottlenecks on the same installation with losses in terms of durations represented in %. But we can see from the outset that forced stops of machines as bottlenecks is the most penalizing, therefore more "constraining" than the others, and

therefore it represents the major constraint of steering production. In this case, if we want to improve the reliability and maintainability of the machines (source of 38% losses) by implementing a Six Sigma project, on what type of machine does it A priori without holding the constraints. Why? and in a management approach by constraints? Why. In a logic of constraint management, we will choose to carry out the Six Sigma project on the machines representing bottlenecks in terms of capacity [9] and actually penalizing production, even if they are not often broken down. The goal is to save production time. So to gain in capacity. This is the case of a metalworking company in Belgium producing steel sheets and which implemented the management not the constraints through the control of the drum-buffer-rope flows. The whole approach of a Six Sigma project to improve both the reliability (improvement of the MTBF) and the maintainability (decrease of the MTTR) must be reviewed in the way of management by constraints and by privileging the bottlenecks. At this level the TRS (overall performance time) can be a CTQ (Critical to Quality) indicators with double impact compared to capacity and safety:

- ✓ With regard to capacity, by adopting the WCP classification (World Class Performance), the calculation of the OEE makes it possible to identify the machines which are really bottlenecks and have the smallest capacity that does not allow To meet production requirements in terms of output flow, which determines both a new penalizing output rate and unexpected inventory levels. This is the case Implementation of the piloting of the Drum-Tampon-Cord flows. Increase of more than 80% of the flow of the gou-lot workshop. Increased productivity by more than 40%. Reduction of the manufacturing cycle by 50%.
- ✓ In a safety logic, a system can occupy three states by referring to the principles of safe operation. In addition to the normal operating state that can be defined by a $OEE \geq 85\%$, compared to the degraded step ($25\% \geq OEE \geq 85\%$), two degraded Combining the failure with safety) according to the figure: The ability of the machine not to pass to the incorrect and dangerous state of operation (state C, see Fig. 4) represents the parameter the safety which deserves This situation can lead to a potential

bottleneck in the event of a technological accident (the notion of an industrial catastrophe), which will have the consequence of material and human damage and a Long term, such as the case of the explosion which took place on September 21, 2001 at 10:17 am, which occurred at the AZF plant belonging to Grande Paroisse, a subsidiary of Total Fina Elf. "... The plant manufactures ammonium nitrate fertilizers. Such an event produced a shock equivalent to an earthquake of 3.4 degrees on the Richter scale. The industrial site was immediately ravaged for hundreds of meters, the shock wave spread in the city, blowing and damaging many homes, public buildings, blowing up windows even miles from the site. A toxic cloud rose above the plant and moved to the northwest of the agglomeration with medium- and long-term health consequences (beyond the initial record of deaths and the wounded of the first days) "[10].

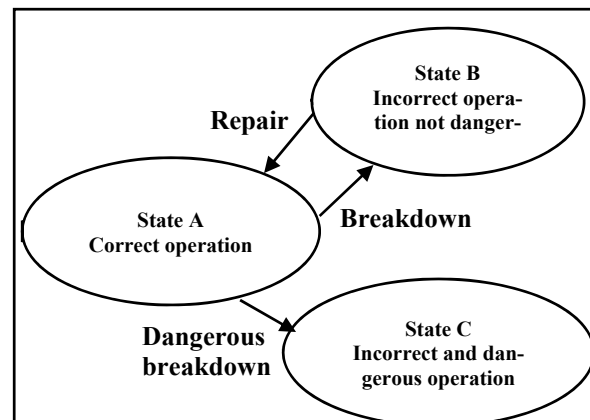


Figure 4: The Three States of a System

4. DISCUSSION

4.1 Different View on the Concept of Capacity

We have seen that a bottleneck is defined as a production resource (machine, workstation,) whose capacity does not allow satisfying the demand. It is precisely the actual or demonstrated capacity that is different from the theoretical capacity. In this context, it will be interesting to carry out a Six Sigma project to improve the capacity of which the Six Sigma level will be linked to the desired (theoretical) capacity.

4.2 The OEE Does Not Take Into Account the Human Aspect

Production systems are quite complex because they are influenced by the human, organizational, organizational and technical aspects that directly affect the efficiency of the maintenance of the production machines forming part of the system. Moreover, the definition of maintenance, which is defined as a set of technical, administrative and management activities aimed at maintaining a good in order to restore it to a state capable of fulfilling the required function [11]. It should be noted that the term "system" means a set of elements interacting in order to achieve a common goal. The elements can themselves be sets of other elements and, ultimately in our framework, men or machines, hence the emergence of the sociotechnical approach [12] and this as a new qualification of the systems of which production systems are a part.

But maintain no longer means maintaining oneself in good condition, but achieving objectives [13]. In relation to this point precisely, the use of the OEE makes it possible to take another look at the maintenance of the means of production because it makes it easy to identify the efficiency gap between a situation and a situation- And concludes that there is a need for a decision to improve the situation by clarifying objectives, goals and objectives.

However, the OEE presents a limitation insofar as it does not take into account production systems as a socio-technical system, in particular, recognizing human faults as a discrepancy in the same way as other types of loss. If, for example, after a scheduled shutdown of a production plant for preventive maintenance, a triggering event causes a delay of three days in the restart of Production (here the duration and frequency of failures directly affects the net time T_n), the question of the efficiency of plant maintenance serves as the first reducing developer focusing solely on the technical dimension. Perhaps it would be opportune to accept the losses caused by managerial incompetence and operational skills or even the stress that potentially engenders human fault.

This situation is often encountered in the case of production information systems requiring a high level of competence, a programmer in a DCS (numerical control system) is mistaken, for example, A line of a code using a programming language to add a new program remote control of a rotating machine: it has implanted a fault [13] (which

is called "dormant" if it does not manifest itself immediately) in its program. When this line of code is executed, it writes an erroneous data in memory: one is then in the presence of an error. As soon as the operating operator manipulates the man-machine graphical interface from the control room, the DCS system supplies him with erroneous information and thus does not perform the desired function (remote machine shutdown) In accordance with what is asked of it: it is the failure, which can sometimes cost very dear.

4.3 RCM: An Empirical and Traditional Method for Improving the Availability of Critical Equipment

Reliability-based maintenance (RCM) is an approach to improving the availability of machines whose requirement to correctly set the problem and quantify it is not really defined as an important step. Before attempting to improve this parameter, it must be measured in the same way as other losses such as the deviations of the cadence, which are intimately linked to the capacity of the machines. At this level, the MBF is not based on the initial calculation of the OEE of each machine, and therefore the quantification of initial and desired performance is often difficult. To be precise, the use of the theory of constraints (ToC) by measuring the OEE of each equipment which considers themselves as bottlenecks and is interested in a first action consists in redefining the level of performance with respect to a base 100 Then, based on existing information, assess the gap with this base 100 and determine possible targets by quantifying the potential improvement by a "Six Sigma Level".

On the other hand, the approach in question considers constant failure rates, although certain phenomena of aging may occur randomly as a result of time, or physical phenomena extrinsic to equipment (eg aging of certain components electronic ...). Since the reliability approach recommended by maintenance based on reliability is often carried out on an empirical basis (AMDEC analysis, feedback, ..), they can, in the absence of adapted maintenance which is not foreseen by means of Maintenance plans developed, aggravate the frequency of failures the risk of failure in repair. However, reliability as such is a discipline remarkably mastered within the framework of the safety of operation. Based on the assumption that all bottleneck facilities were actually identified using appropriate tools. The question that necessarily comes up in order to carry out the maintenance of each equipment is:

should we choose to keep the corrective or to implement a systematic preventive? To answer this question, there are several tools (eg Noiret's charts) including the use of the Weibull law. The implementation of this law will make it possible to answer mainly the following questions:

- ✓ Is there a period of systematic intervention T such that preventive maintenance is more economical than corrective maintenance?
- ✓ If yes, what is the optimized period θ ?
- ✓ On a repairable system, of which a "fragile" constituent is interchangeable, how to determine the preventive replacement period θ .

4.4 Necessity to Make a Compromise Between Reliability,

Maintainability, Availability and Safety which are

Some Times Contradictory Indicators

As regards the safety of operation, some of the characteristic quantities may be contradictory. Improved maintainability can lead to choices that degrade reliability. The availability is therefore a compromise between reliability and maintainability.

Similarly, security and availability may be contradictory. We have seen that safety is the probability of avoiding a dangerous event, it is often maximum when the system is stopped, but the availability is then zero, this is the case when a bridge 'collapse. Conversely, to improve the availability of their aircraft, some airlines may be tempted to neglect preventive maintenance and flight safety decreases. The determination of a system responding to the optimal compromise between safety and availability requires that these quantities can be measured at the initial state for each critical equipment, to know the target and tolerance intervals. Which will be appropriate to integrate it in a Six Sigma approach by means of the CTQ diagram (phase M "To measure" of the DMAICS approach) and to decide on the parameter (s) that would be optimized for each equipment using the voice of the (VOC) since this choice is highly dependent on experience feedback.

4.5 The Calculation of the OEE Does Not Take Into

Account the Requirements of Metrology

The Standard NF E 60-182 does not require metrological qualities when calculating yields because any indicator is a measure that must conform to the rules of metrology that are standardized (NF Standard EN 13005, OIML standard...). Hence the need to carry out the following steps:

- ✓ The value of the OEE of a machine can tell us about its operating states "degraded" and "out of service" according to the reference Word Class Performance (WCP) but not on the efficiency of the teams because behind a failure, There is always a fault and can go as far as catastrophe (the case of a very sensitive equipment like a steam turbine, the fault can lead to a catastrophe);
- ✓ Design a data collection plan;
- ✓ A study of repeatability and reproducibility (R& R);

The demerit of our research model is that it does not take into account the production system as a sociotechnical system, since it always has an interaction between people and machines and therefore our article does not propose Solutions. Because the OEE as an operational indicator highlights the losses of state times without broadening the concept of losses to cover those due to human failures and human faults which cause for example forced stops of machines (Incorrect setting of a machine, failure to observe the operating parameters, etc.). This thesis will be the subject of a PhD thesis, which will have as a perspective the implementation of a TFS transformations approach, which will deal with a real case of the strategic thinking industry up to what the deployment and the soil passing of course the state of the matter in relation to the literature.

We have also shown that the theoretical model of the OEE is essentially focused on the definition and evaluation of availability, performance and quality. We have highlighted that if it does not integrate non-security through a combination of successive deviations from safety requirements. In returning to the important dimension of this aspect in practical terms, it will be necessary to design an enriched model of the OEE taking account of deviations from safety standards.

5 CONCLUSION

Through this article we have provided answers to the first question posed in the introduction, since the EEO can be used as a decision-making tool because it allows machines with a low EEO to be considered as being Bottlenecks and consequently, this produces a synergy with the theory of constraints (ToC) with the decision to improve in priority the capacity of these machines. On the other hand, the article shows that it is possible to rethink the mission of maintenance from the "maintenance"

aspect to the achievement of objectives, because the OEE makes it possible to identify the efficiency gap of maintenance between the present situation and the projected situation. The second questioning raised during the introduction. The article highlights the possibility of integrating reliability, availability and security when improving the performance of a production system. In the "define" phase of the Six Sigma approach and using the CTQ (Critical To Quality) diagram, it will be wise to integrate the parameters of the operational safety and decide on the parameter (s) that should be optimized for each Equipment, using the statistical tools of the six sigma approach, in particular the tools specific to the "analysis" phase, as well as the tools of the theory of constraints for the increase of the real capacity of the machines. This is a tangible response to the "TFS" roadmap for improving the overall performance of the means of production by increasing production capacity, improving plant safety and reducing variability and taking into account the human aspect.

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