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Enhancing Drinking Water Production Efficiency through Total Productive Maintenance Optimization

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Abstract: ***A drinking water company in Côte d'Ivoire is going through a critical period in its history. Facing chronic production failures, this company struggled to fulfill its mission of reliable water supply, prompting public discontent and operational inefficiencies. These failures inconvenience populations, who frequently express their frustration. A diagnosis of the company's situation shows that there are technical and organizational problems, marked by a further deterioration in the production apparatus, inadequate maintenance management practices and insufficient investment in maintenance for equipment and facility renewal. This leads to increasingly irregular service for customers. To respond to the many complaints, the general management is undertaking a comprehensive restructuring with priority emphasis on the maintenance system which appears to be the main problem area. This study analyzes technical and organizational shortcomings, including deteriorating equipment and poor maintenance practices, and details a restructuring effort prioritizing maintenance optimization. Implementing Total Productive Maintenance (TPM) across the company, with a pilot station as the initial focus, yielded significant performance gains, reducing downtime and enhancing service reliability. These findings pave the way for broader application across the company's network, offering a scalable model for maintenance-driven operational recovery.***

Keywords: drinking water, maintenance, TPM, optimization, SYR.

1. Introduction

In the current context of economic recession and fierce competition, all companies are constantly concerned about optimizing their production structure and resources. The challenge is to increase the performance of the production equipment, reduce operating costs, and improve productivity in order to maximize the overall performance of the company. This is how the company can be competitive and withstand several market fluctuations (competition, customer requirements, financial market constraints, etc.).

One of the most important factors influencing a company's performance is the occurrence of repetitive failures in the production apparatus. Indeed, industrial plants and equipment are disrupted during their operation by malfunctions that affect the quality of products, expected quantities, compliance with delivery times, production costs, safety of workers, the image of the company, etc. It is to deal with all these dysfunctions that the maintenance function sees its importance. It seeks to prevent breakdowns, limit them to the strict minimum and make repairs when they occur, in order to ensure that equipment is safe to operate. The concept of operational safety covers aspects of reliability, security, maintainability and availability. It represents the set of capabilities of equipment that allow it to have the specified functional performance, at the appropriate time, for the intended duration, without harm to itself and its environment.

The maintenance function therefore strongly conditions the performance of equipment, and consequently that of the company. Its optimization is complex, because it must take into account different criteria, sometimes antagonistic ones such as availability and costs. There are also multitudes of ways to maintain equipment. Managers can adjust the type of maintenance, task variety, frequency, and intervention levels, among other factors.

To optimize the performance of the maintenance system, managers no longer just monitor it and make repairs. They seek to predict all internal or external events of the company that influence the operation of equipment and to evaluate the various alternatives for making the best use of them, taking into account technical and budgetary constraints. However, making strategic choices and maintenance methods to optimize the performance of production systems is always difficult. The complexity of equipment and the behaviour of its components lead to maintenance strategies which are equally complex, consisting of different types of tasks chosen from a number of options. Furthermore, the random nature of the phenomena of deterioration and failure of equipment makes it difficult to make a quantitative assessment of the various maintenance strategies and requires expert judgment, qualitative data to make decisions.

This study aims to enhance the maintenance system of a drinking water production company through TPM, minimizing production stoppages and improving service reliability. This work is significant as it addresses a critical public health issue - access to reliable drinking water - while offering a practical framework for maintenance optimization in resource-constrained settings.

Due to public dissatisfaction, the drinking water company faces chronic equipment malfunctions in its production apparatus, characterized by production shutdowns ranging from a single day to several weeks. To overcome this problem, at the request of those responsible for production and maintenance, it is necessary to optimize the maintenance system in an approach that best suits the difficult situation facing the company. The ultimate objective is to limit to a strict minimum the production stoppages due to repetitive outages, and consequently to revitalize the production activity, to put an end to the inconvenience caused by drinking water shortages and to increase the profitability of the company.

To achieve this objective, in view of the state of advanced degradation of the production apparatus and the inappropriate maintenance management style, TPM (*Total Productive Maintenance*), which is a method for optimizing maintenance, is applied throughout the company. In choosing the TPM, we were inspired by the work of WASIM. S. HANGAD & Dr. SANJAY KUMAR (2013), Ranteshwar Singh et al. (2013), Kitalu Ricin Ngoy & Kipendo Israel (2021), who did not fail to highlight the benefits and merits of this method in terms of increased productivity, quality and satisfaction at all levels, reaching out to the firm's customers. Indeed, through this globalizing method, all the company's staff has been involved in maintenance optimization activities.

Whether it was administrative, production or maintenance staff, everyone was directly or indirectly responsible for solving the various maintenance problems. Thus, the chances of success in implementing TMP were increased as all problems were scrutinized through a thorough analysis of their causes and appropriate solutions were immediately implemented collaboratively.

Problematic

The drinking water production company is responsible for the production, transport and distribution of drinking water throughout the country. In recent years, it has been the subject of repeated criticism by both the media and the public following numerous cuts in drinking water. This regular water shortage is a flagrant violation of the right to safe drinking water and a healthy environment. It has consequences that affect both the population and large-scale drinking water companies.

In terms of populations, chronic water shortages are at the root of many well-being and health problems (sometimes endemic). The first victims are children, pregnant women, sick people and low-income groups more exposed to serious hygiene problems and water diseases (dehydration, diarrhea, cholera, skin ruptures, etc.). Other inconveniences caused by water scarcity are: the loss of time spent in search of water, exhaustion due to long distances travelled for this purpose, disruption of domestic tasks, etc. Indeed, to have access to water (whether or not it is available), the populations (mostly women and children) rush to the few points of availability of water (tankers, fountains, wells, rivers...) around which the queues are longest. They will be served after several hours of waiting. Time lost reduces the amount of time available to do housework, business or even field work. Reaching water points is not so easy, as people are forced to spend a lot of energy not only to travel long distances but to carry large bowls or 20-litre water cans on their heads, on bicycles, in wheelbarrows or even in the back of cars.

Figure 1: Challenges of accessing drinking water in Africa (Source: public domain image).

For businesses where water is an essential input, the shortage of water leads to a considerable shortfall in income at several levels. Water shortages are the cause of many production shutdowns, resulting in: inability to produce enough to meet customer-ordered volumes, failure to deliver on time and associated penalties the increase in production costs due to numerous stoppages and restarts of the production apparatus, the non motivation of staff, chronic technical unemployment, the increase in turnover, and overall, the decline in performance and return of the company.

For the drinking water production company itself, the irregularity of the supply of drinking water linked to the malfunction of its production system creates: a tarnishing of its image with the whole population, significant productivity losses due to increased production maintenance costs, unease and non motivation within work teams, etc.

In response to complaints from households and businesses that use large quantities of water, the government has ordered the company to comply with its specifications as part of the lease agreement between them. In response to all these numerous complaints, the company is faced with an urgent need to answer the question: "*what strategies, methods and means to implement in order to optimize the whole maintenance system in order to improve the availability rate of the production apparatus, and consequently, to ensure the regularity of the service of supplying drinking water to the customer, in a relatively short time?*". To answer this question, our mandate is to rationally rethink, restructure and improve all the functional and operational processes of the entire company maintenance system.

2. Methodology

The optimization of maintenance, while limiting the dangers and the number of interventions on equipment, contributes greatly to the increase in performance of the production system, provided that it is adapted to the situation of the latter. The goal is to determine for each piece of equipment the correct maintenance to be performed and to identify the frequency at which it should be carried out to meet regulatory requirements, reliability and availability objectives. Maintenance optimization also represents the balance between costs and benefits of maintenance tasks or timing of maintenance tasks.

In this work, the optimization method chosen and deemed appropriate to the situation of the drinking water production company was the TPM (Total Production Maintenance). This method is based on a search for consensus and a continuous improvement process. The effectiveness of TPM in dealing with human errors can be highlighted by the introduction of rules and procedures or the installation of decoders on equipment. With TPM, we find a desire to involve manufacturing personnel in maintenance and to give a voice to those involved in improving existing systems.

However, due to the absence of very strong technical foundations, its application can call upon complementary techniques such as the use of the 5S method and the calculation of the SYR (Synthetic Yield Ratio) also called OEE (Overall Equipment Effectiveness). These techniques allow for the continuous improvement of the performance of the maintenance system. Moreover, they have shown their relevance and effectiveness in cases of machine performance optimization in several companies, when we read the articles of authors such as: Anand S. Relkar & K.N. Nandurkar (2012), Faria Aktar Tonny et al. (2023), Hamzeh Soltanali, et al. (2021), KADA Mohammed (2019), Sayuti M. et al. (2019), Timothée KOMBE et al. (2006), Xiaoyan Li et al. (2021).

The following criteria were used to support the choice of TPM:
- The complex and disparate nature of the company's problems, both at the operational level and in terms of management and supervision;
- The size and geographical distribution of the company: the company is a set of several drinking water production stations spread throughout the national territory, mainly in the most populated agglomerations;
- The complexity of its operational structure, which is the source of the difficulties in effectively coordinating production and maintenance activities as a whole;
- Centralizing maintenance management that is not adapted to the company's broken structure;
- The need to build capacity and re-motivate employees, especially those in maintenance and production;
- Difficulties in controlling maintenance costs;
- The company's catastrophic economic situation;
- The budget for maintenance is restricted;
- The lack of control over tools and optimization methods by production/maintenance managers.

To lead the project, our approach consisted of:
- Establish the project pilot team;
- Discuss with branch management on overall objectives and clarify expectations;
- Seek its firm commitment to the mobilization of material, financial and human resources;
- Select a pilot station to launch the project;
- Develop a plan of action and follow-up for the project;
- Hold regular review meetings;
- Gradually extend the project to the whole company.

3. Results

To address the company's catastrophic situation, several actions and recommendations were implemented at organizational and operational levels.

3.1 Organizational level actions

3.1.1 Corporate performance audit

To address the company's challenges, a comprehensive audit - covering accounting, tariffs, finances, and technical aspects - was conducted. The function concerned is primarily the production function, of which maintenance is an important component.

The audit reveals that the company has failed to meet its obligations under the concession and/or has not followed good practice, particularly in relation to the installations:
- Constantly deteriorating technical performance on the audited installations, both in electromechanical and water treatment trades;
- Technical staff's lack of motivation in the face of stressful and stressful situations that prevent the normal conduct of production and maintenance activities, thus promoting the risk of accidents and additional failures;
- Insufficient investment for the renewal of equipment and installations at all levels (production, transport and distribution), with the consequences of aging equipment, a decrease in their reliability and performance, and the degradation of service quality (repeated water cuts);
- Tariffs on the rise due to a considerable increase in production costs;
- Administrative and financial management that reveals shortcomings and requires adjustments;
- Lack of a well-structured and coherent organization facilitating the management and monitoring of maintenance activities;
- Lack of a preventive maintenance program to allow for each equipment to be serviced to ensure its availability;
- Lack of a maintenance policy within the company;
- Lack of continuing education, especially to update knowledge, introduce new practices in trades and build capacity at all levels.

3.1.2 Maintenance policy defined

The company did not have a formal maintenance policy. With the participation of the Technical Director and the Maintenance Manager, a new policy consistent with the company's objectives was formulated. This policy has focused on four main areas of progress, namely: (1) the restructuring of the maintenance function to alleviate administrative burdens and make operations more fluid and direct; (2) the multiplication of training actions to integrate more new methods and tools, to increase the skills of production and maintenance personnel; (3) a significant financial investment compared with the gradual renewal of equipment and installations, which are very old, followed by the long-term construction of new production units; (4) finally, control of production and maintenance costs. The implementation of such a policy should increase the efficiency of production units, improve company performance, but above all relieve populations from untimely water cuts. Our intervention was articulated in the straight line of implementing this policy.

3.1.3 Maintenance function restructuring

In response to the dysfunctions observed, a restructuring is undertaken by modifying the organizational chart with major changes at the maintenance level. On the occasion of this redrafting, it was decided to eliminate the centralized management of maintenance, because it is too cumbersome and complex in relation to the number of drinking water production stations. Each production site now has autonomy in setting up and managing new maintenance management procedures. As a result, the scope of responsibilities, missions, objectives and priorities has been clarified. This empowerment approach has proved to be relevant: technicians close to the equipment, flexibility in decision-making and maintenance planning, increased efficiency of intervention workers, Time savings, increased availability of equipment, etc.). But it must be accompanied by an upgrade of all maintenance technicians.

3.2 Operational level actions

3.2.1 Selection of a pilot station to launch TPM project

A drinking water treatment plant, which will supply the neighborhood, was selected as a pilot station for the launch of the TPM project. It is the largest, by size of plant and production capacity. It must cover the daily drinking water requirements of approximately 300 000 m^3/day for the residents of this district. The know-how and feedback on this station, in terms of TPM, should be deployed and generalized to all other stations within the country.

3.2.2 Establishment of the TPM project steering team

The steering team was composed of the Director of maintenance and two assistants, six production agents initially assigned to the operation of the pilot station, a representative of the financial and accounting management, the quality control officer and two expert consultants who act as coaches, a heterogeneous team of 13 people. Assisted by the two experts, the maintenance Manager was appointed as project leader to plan and coordinate the implementation of all project operations.

3.2.3 Goal definition

Several objectives have been defined at the operational level:

- Improve product quality (water);
- Avoid any water breakage in subscribers;
- Achieve the maximum equipment efficiency measured by the Synthetic Yield Ratio (SYR);
- Reduce production costs to increase business productivity;
- Ensure staff safety and better working conditions;
- Train staff in the different operating procedures and maintenance implementation tools;
- Protect the environment.

3.2.4 Modeling of the pilot station's operational processes

Process maintenance is inspired by the management of quality by process and consists in representing the production unit as a set of interrelated processes according to the logical sequence of operations. Thus, the pilot station is modeled by processes (Figure 1 below) for each of which it becomes easy to:

- Identify equipment and facilities and know how they work
- Identify potential malfunctions, anomalies and failures, their causes and their effects on the efficiency of production activities;
- Deciding on changes and improvements to processes;
- Evaluate and improve working methods;
- Facilitate the management of relationships and interfaces;
- Facilitate communication and information flow;
- Facilitate process documentation;
- Develop preventive maintenance plans;
- Implement, as part of remedial maintenance, a rapid intervention device (highly skilled workers, adequate tools, spare parts available);
- Control costs;
- Implement a security system for each process;
- Have a simplistic view and total control of the water treatment process.

Figure 1 below illustrates the principle of operation of the process composed of the Pi processes:

P1: Pump sends raw spring water to P2 and P5;
P2: Raw water is analyzed for its characteristics and the doses of reagents required for coagulation-flocculation (test);
P3: Preparation of reagents in quantities;
P4: Transfer of reagents into the coagulation-flocculation basin by pumps;
P5: Mixing of raw water and reagents followed by coagulation-flocculation;
P6: Mineral precipitation reagent mixture;
P7: Water resting in a pond for settling of the flocs;
P8: Water filtration to separate the flocs particles;
P9: Transfer of filtered water to the storage tarp;
P10: Transfer of filtered water into storage tarpaulin;
P11: Sludge transfer to the environment.

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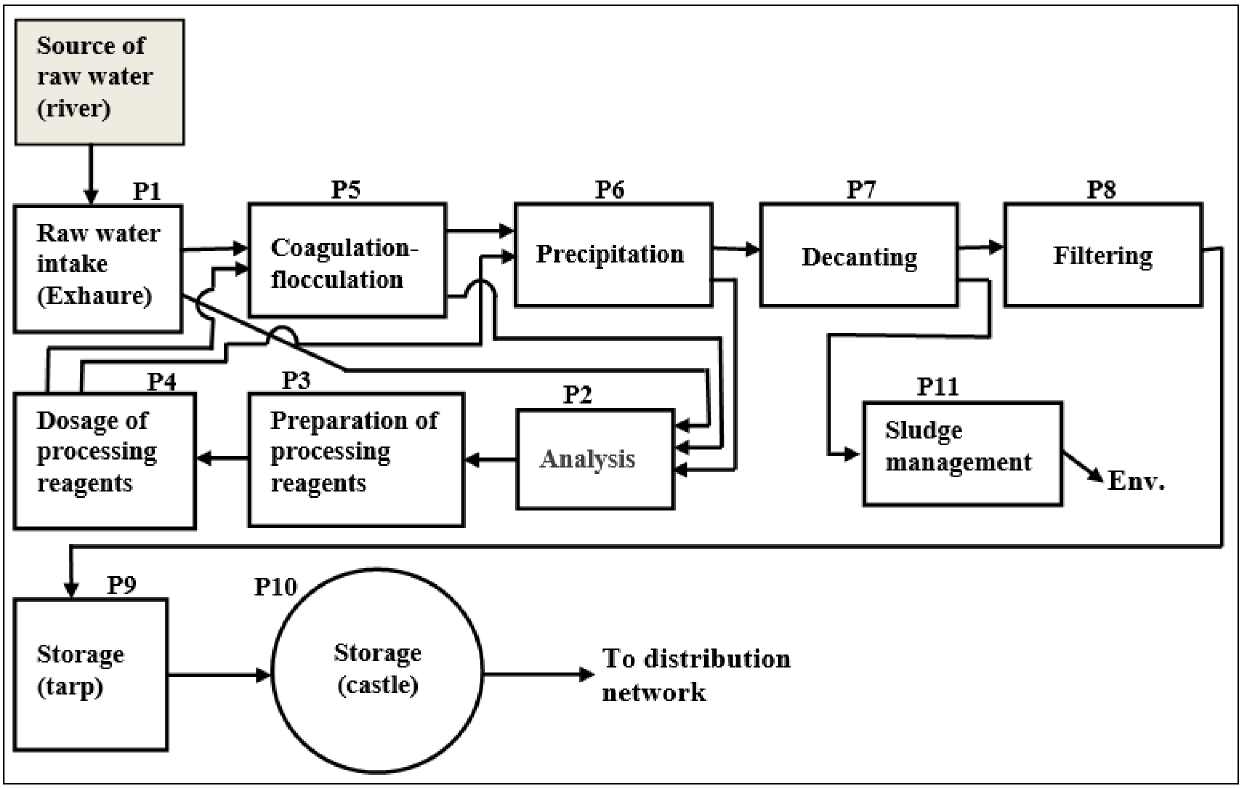

Figure 1: Pilot station operational processes.

3.2.5 Diagnostic and repair at the control station process level.

The equipment in each process was diagnosed to identify any failures and malfunctions. This diagnosis revealed an advanced ageing of equipment and installations (use beyond the expected service life), with the consequences of frequent production shutdowns due to repeated outages, and thus frequent shortages of drinking water for consumers. In some specific processes, the following failures were identified and corrected:

P1: At the pump, the motor of the pump assembly frequently failed, causing a service irregularity. The cause was that the thermal protection was not properly adjusted. After adjustment, the pump returned to normal operation.

P4: Chlorine pump was making an abnormal noise. After disassembly, the bearing was found to be deteriorated due to aging. This failure resulted in an incorrect chlorine dosage, and thus insufficient disinfection of the water, which then presented risks for the consumer. The pump was repaired by replacing the damaged bearing.

P8: The booster control circuit was down due to improper tightening of some components in the control cabinet. It was repaired at the same time as all small failures of the entire electrical circuit.

P9: The metal staircase leading to the top of the storage tarpaulin had undergone very advanced corrosion in its fastenings, with the risk of it collapsing one day with the operator and causing an accident at work. Call was made to a welder to replace corroded parts. All minor failures were corrected and the station returned to normal operation. This has resulted in a regular provision of services and relief for consumers. But there is uncertainty about the reliability of some vital equipment that could not be replaced with new equipment and for which the history indicates a high failure rate.

3.2.6 Capacity building of production and maintenance staff

As recommended by one of the 8 pillars of TPM, staff training is a guarantee for improving the performance of a production unit. Capacity building engaged all production and maintenance staff at the pilot station. The aim was to equip them and took place in three phases:

Phase 1: Acquisition of knowledge and know-how

It was based on lessons relating to the transfer of knowledge and the acquisition of management methods and practical implementation of industrial maintenance. It was organized in 8 sessions of training regularly spaced 2 weeks apart:

- Session 1: Operations and production management;
- Session 2: Piloting a production line;
- Session 3: Methodological approach to industrial maintenance;
- Session 5: Mastering the maintenance diagnostic tools;
- Session 6: Management and quality assurance approach;
- Session 7: Animation and coaching of a work team;
- Session 8: Development and management of a maintenance project.

Phase 2: Management and follow-up of existing

It aimed to enable learners to demonstrate their ability to conduct structured reflection on a real problem identified in their work environment, and to build or apply relevant solutions, using knowledge, the methods and tools covered in the training. In other words, it was mainly for them to have a critical look at their daily work environment, to extract a particular problem, to carry out a fine analysis of it in terms of strengths and weaknesses, then to identify the areas of progress from this analysis: improvement in the flow of activities, increase in the reliability of equipment, reduction of costs, motivation of staff, improvement of overall performance. This phase proved to be very useful, as it allowed each learner not only to fully understand his or her mission in the organization, but also to master all the processes at the technical and administrative level.

Phase 3: Autonomy in the practice of the trade

The third phase consisted of providing the trainees with a framework to enable them to take on production/ maintenance activities in all their aspects. Indeed, another pillar of TPM is self-maintenance. It is to give the machine operator the ability to perform small preventive or corrective maintenance tasks (cleaning, lubrication, inspection, minor repairs, application of 5S, etc.). The challenge is to involve the operator in the maintenance activity by becoming responsible for the good condition of his equipment and contributing to the increase of its optimal performance.

In our case, given the more pronounced aging state of the pilot station equipment, we instead converted operating agents to maintenance agents and vice versa. This has resulted in a homogeneous team of versatile agents combining maintenance and operation activities, to increase the knowledge of equipment by all, to reduce the time required for diagnosis and repair, Facilitate communication and interface management, improve machine availability and increase overall water treatment plant efficiency.

During this three-month phase, the learners were put into a real situation at the pilot station to organize and manage all production and maintenance activities themselves, under the supervision of the two experts. Expert coaching was essential to correct and perfect certain aspects of the practice of the trade, including:

- The operation of certain diagnostic devices such as: laser lineage apparatus, infrared thermograph, vibratory analysis and ultrasonic analysis apparatus. These devices were available but nobody knew how to use them;
- The preparation and use of documents that they had no knowledge of, such as: work order, supply order, store exit order, shipping order, intervention report;
- The constitution of machine files (manufacturer's documents, history sheets of interventions, list of special tools, safety instructions, etc.);
- Application of methods and tools for maintenance planning and management, problem solving and cost optimization.

At the end of this phase, the evaluation of participants showed that they have appropriated the know-how of the trade and are ready to be redeployed to other stations to become production/maintenance managers.

3.3 Maintenance optimization by using the Synthetic Yield Ratio (SYR)

Given the importance of maintenance and its impact on machine performance, optimization methods have been developed. The one we used is the calculation of SYR or OEE (Overall Equipment Effectiveness). It is an indicator expressed in ratio (%) and allows measuring the yield of a production means (machine), of a cell or even of a complete chain. It enables continuous improvement of the performance of the production system. In other words, it allows us to trace and quantify the efficiency of a machine and then identify areas for improvement to increase its productivity.

Calculating SYR helps boost production yield without requiring new equipment investments. The SYR measurement uses data that must be collected on each line or production medium. The analysis of SYR losses consistently highlights the actions to be taken to improve the performance of production facilities. Indeed, the "non-SYR" or complement of the SYR allowing to obtain 100% represents the installed capacity but not used to produce; it is a waste that Lean aims to eliminate through continuous improvement.

3.3.1 Graphic illustration of SYR elements

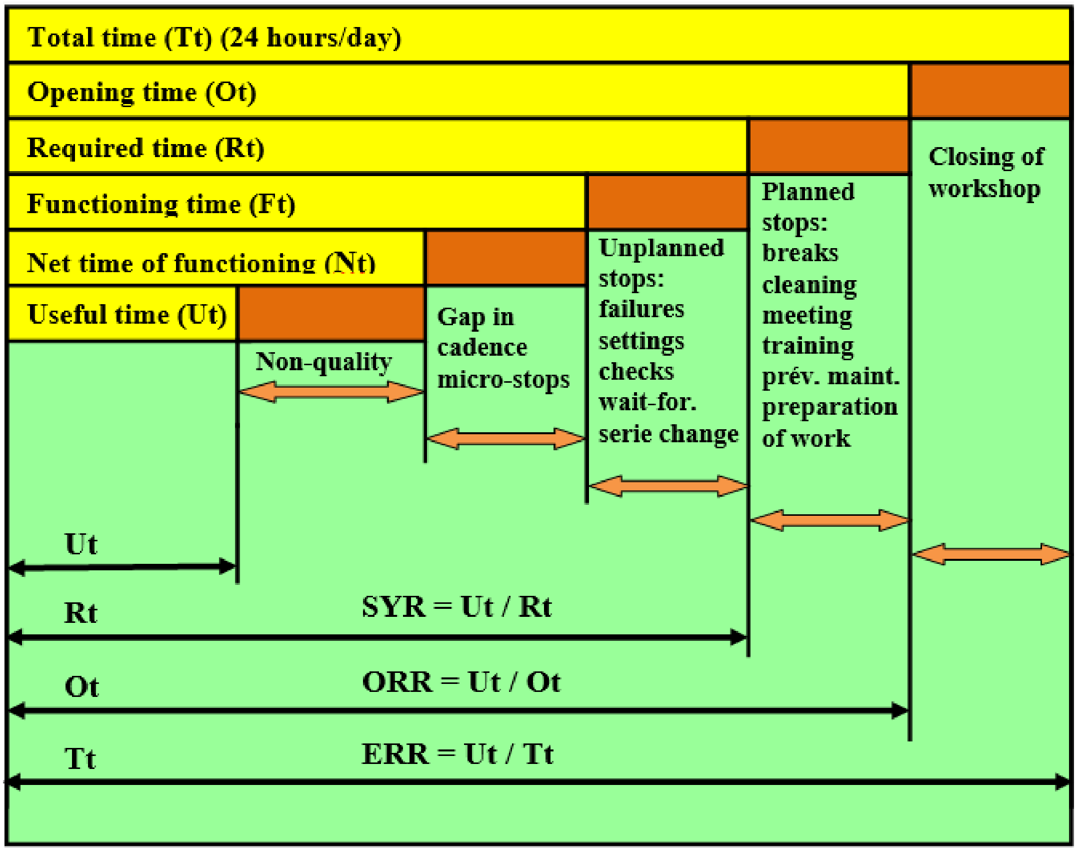

Figure 2: Arrangement of different elements to calculate SYR

3.3.2 Description of SYR components

Total time (Tt): It is the total time of possession of the medium. Time during which it is theoretically usable (24h for a day, 168h for a week...), this is actually the duration of the analysis period.

Opening time (Ot): This is the time during which the manufacturer has decided to open the means. (1 shift, 2 shifts... on 5 days for example).

Ot = total time – workshop closure.

Required time (Rt): Time during which the means of production is engaged with the will/ability to produce according to the organization.

Rt = opening time – time (break, meeting, maintenance, cleaning...).

Functioning time (Ft): Time during which the medium manufactures products.

Ft = required time – (failures, adjustments, changes in series...)

Net time (Nt): The reference time during which the medium produces in accordance with the reference cycle time (or theoretical cadence).

Nt = operating time – cadence deviations

Useful time (Ut): Time during which the medium produces good quality products.

Ut = net time – time spent doing non-quality.

3.3.3 Expression of SYR

The SYR states:

SYR = (number of good quality pieces produced) / (number of theoretically feasible pieces during the required time)

SYR = Useful time (Ut) / Required time (Rt)

The SYR can be broken down into three sub-indicators:

SYR = Quality Rating (Qr) x Performance Rating (Pr) x Operational availability (Oa)

= Qr x Pr x Oa

With:

- Quality rate (Qr) = Number of good quality pieces produced / Total number of actual pieces produced;
- Performance rate (Pr) = Total number of pieces actually produced / Number of pieces that should have been produced during the time spent on production;
- Operational availability (Oa) = Number of parts that should have been produced during the production time / Number of parts theoretically achievable during the required time.

3.3.4 SYR expression versus time

The three rates that make up the SYR can be expressed in terms of time ratios (see figure 2) rather than as ratios of number of coins. The principle is to measure, starting from the opening time (Ot) of the machine, all non-productive times (planned or not, changes in series, important or not (micro-stops), times spent on producing products of poor quality), and to establish the ratios below:

Quality rate (Qr) = Ut / Nt

Performance rate (Pr) = Nt / Ft
Operational availability (Oa) = Ft / Rt

SYR = Qr x Pr x Oa= (Ut / Nt) x (Nt / Ft) x (Ft / Rt) = <u>Ut / Rt</u>
With:
Quality rate (Qr) = Useful time to manufacture good parts/ Net operating time.
Performance rate (Pr) = Net production time / Machine running time.
Operational availability (Oa) = Functioning time / Required time.
Functioning time (Ft) = Time required- stops (clean and induced).
Required time (Rt) = number of theoretically achievable parts x theoretical Cycle time (Ct).

Note
The SYR of a production line composed of several machines whose individual synthetic yield rate is **SYR_i (Qr_i, Pr_i and Oa_i)** is defined by:

SYR = Qr x Pr x Oa
With:
Qr = $\prod Qr_i$ (product of the Qr_i)
Pr = $\prod Pr_i$ (product of the Pr_i)
Oa = $1/[\sum 1/Oa_i - (n-1)]$, if the values of the Oa_i are close to 1, $Oa \approx \prod Oa_i$

If the required time (Rt) does not correspond to the opening time (Ot), a SYR with respect to the required time Rt and a Overall Rate of Return (ORR) with regard to the opening time can be calculated separately. This can happen especially when the plant is overcapacity (compared to market demand: production is constrained on a lower required time in order not to produce waste (by overproducing).

ORR = Ut/Ot = SYR x Rt/Ot (Overall Rate of Return)

We also speak of Economic Rate of Return (ERR) when the calculation is carried out on a theoretical opening time of 24h/day (economic point of view).

ERR = Ut/Tt = ORR x Ot/Tt (Economic Rate of Return).

So we always have: SYR ≥ ORR ≥ ERR

3.3.5 Selection of SYR site

All the equipment and facilities forming the station were considered as a single SYR application cell, with special attention to viral equipment such as the motor pump assembly, metering pump and control cabinet. Any failure of these three elements results in production being stopped.

3.3.6 Data collection and SYR calculation

Sheets have been developed to record data and calculate SYR using the models below. These sheets were then entered into a computer tool (Excel) to facilitate their use: data recording, calculation of SYR, classification of causes of judgments, etc. They also served as a very didactic means for the operators who had to fill them daily, and make a weekly balance (see examples below).

The optimization was carried out over a period of 14 weeks, from 1 February to 15 May 2023, a period of high water demand due to the heat forcing the station to operate at full capacity.

Table 1: Weekly Time Off Record (1st week).

WEEKLY STOP-OFF TIMES								
Factory:		**Workshop:**				**Machine n:**		
Team:		**Agent:**				**Period:**		
LOST TIMES		Mo.	Tu.	We.	Th.	Fri.	Sat.	Sun.
Planned shutdowns (Rt)	***Opening time. (Ot)***	**18**	**18**	**18**	**18**	**18**	**18**	**18**
	Breaks	2	2	2	2	2	2	2
	Cleaning	1	1	1	2	1	1	1
	Meeting/training	0	0	1	0	0	0	0
	Preventive maintenance	0,5	0,5	2	1	1	0,5	1,5
	Preparation of work	1,5	1	1	2	1	0,5	0,5
	Lost time	**5**	**4,5**	**7**	**7**	**5**	**4**	**5**
	Required time (Rt)	**13**	**13,5**	**11**	**11**	**13**	**14**	**13**
Non-planned shutdowns (Ft)	Failures	1,5	1,5	0	2	0	1	5
	Settings	0,5	0	0	0	1	0	0
	Checks	0,5	0,5	0,5	1	0,5	0,5	0,5
	Waiting for resources	1	0	0	0	0	0	0
	Team change	0,5	0,5	0,5	1	0,5	0,5	0,5
	Lost time	4	2,5	1	4	2	2	6
	Functioning time (Ft)	**9**	**11**	**10**	**7**	**11**	**12**	**7**
Differences in cadence (Nt)	Slowdown	2	2	2	1	0,5	0,5	1
	Micro-stops	0,5	0,5	1	0,5	0,5	1	0,5
	Lost time	2,5	2,5	3	1,5	1	1,5	1,5
	Net time (Nt)	**6,5**	**8,5**	**7**	**5,5**	**10**	**10,5**	**5,5**
Non-quality (Ut)	Defects	0,5	0	1	0	0	1	0,5
	Restarts	1	0,5	0,5	0,5	0,5	1	1
	Lost time	1,5	0,5	1,5	0,5	0,5	2	1,5
	Useful time (Ut)	**5**	**8**	**5,5**	**5**	**9,5**	**8,5**	**4**

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Table 2: Weekly State Time Sheet (1st week)

WEEKLY STATE TIME REPORT							
Factory:	**Workshop:**				**Machine n:**		
Team:	**Agent:**				**Period:**		
Dates / State times	Mo.	Tu.	We.	Th.	Fri.	Sat.	Sun.
Ot	18	18	18	18	18	18	18
Rt	13	13,5	11	11	13	14	13
Ft	9	11	10	7	11	12	7
Nt	6,5	8,5	7	5,5	10	10,5	5,5
Ut	5	8	5,5	5	9,5	8,5	4

Table 3: Weekly SYR and factors scorecard (first week).

WEEKLY EVOLUTION OF THE TRS AND ITS FACTORS							
Factory:	**Workshop:**				**Machine n:**		
Team:	**Agent:**				**Period:**		
Dates / SYR factors	Mo.	Tu.	We.	Th.	Fri.	Sat.	Sun.
Qr (%)	76,92	94,11	78,57	90,90	95	80,95	72,72
Pr (%)	72,22	77,27	70	78,57	90,90	87,5	78,57
Oa (%)	69,23	81,48	90,90	63,63	84,61	85,71	53,84
SYR (%)	**38,46**	**59,25**	**50**	**45,45**	**73,07**	**60,71**	**30,76**

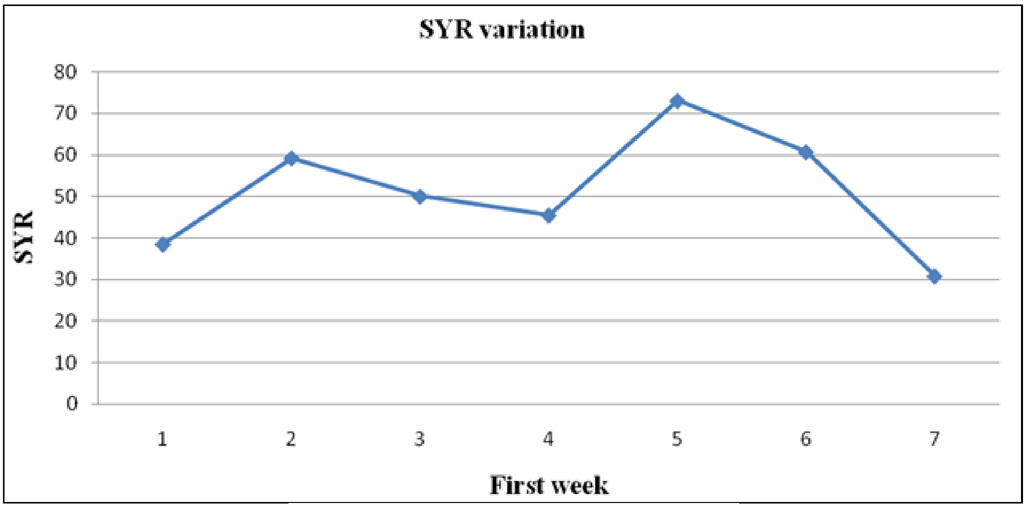

Figure 3: SYR variation in the first week.

Note
The SYR remains low throughout the first week. This is evident when we refer to the level of ageing and advanced degradation of equipment and installations, but also to poor maintenance management of the maintenance system.

3.3.7 SYR Enhancement
To improve the SYR, several actions have been taken to reduce time losses in order to increase the level of the 3 factors Qr, Pr and Oa that determine it.

3.3.7.1 Quality rate (Qr) improvement
To improve the quality of work, a system for quality assurance, self-monitoring and finding solutions to causes of non-quality has been set up. Using the Ishikawa diagram, all problems were identified and analyzed on a case-by-case basis at different levels with solutions:

- *Workforce:* training in diagnostic tools, TPM approach, operation of the TRS.
- *Equipment:* diagnosis to identify failures and malfunctions, immediate implementation of appropriate corrective maintenance actions;
- *Methods:* evolution from curative maintenance to systematic preventive maintenance
- *Environment:* improvement of working conditions and compliance with safety rules;
- *Material:* mastery of the different processing processes.

A regular drinking water quality control program has been implemented to ensure that the water meets World Health Organization standards. This program included the control of the condition and operation of measuring devices, their calibration and periodic maintenance.

The 5S method: *Seiri* (Sort), *Seiton* (set in order), *Seiso* (Clean), *Seiketsu* (Standardize) and *Shitsuke* (Maintain), at this level, has shown its full importance in creating a safer, better organized and more productive work environment, which has an influence on production yield and product quality. It has eliminated dirt and clutter, improved well-being and working conditions, promoted efficiency at all levels, minimized unnecessary time and energy losses, reduced the risk of accidents on site, and reduce the number of failures by inspecting machines during cleaning and reacting in real time.

3.3.7.2 Performance rate (Pr) improvement

A daily machine monitoring program has been implemented to detect failure symptoms and ensure that setting and operating parameters (especially chemical reagent dosing pumps) are maintained. The analysis of the symptoms detected led to the updating of preventive maintenance programs (conditional or systematic). It has triggered corrective actions to eliminate identified failures and increase equipment reliability. It is worth mentioning that the practice of self-maintenance has been a very valuable contribution in terms of saving time and improving machine availability. Because all agents were both specialized in production and maintenance, this increased the efficiency of maintenance operations, so that any malfunction detected was immediately controlled, without the need to call on a specialized maintenance engineer.

3.3.7.3 Operational availability (Oa) improvement

The restructuring of the maintenance department has made maintenance activities more efficient. Responsibilities have been clearly defined and distributed, tasks well planned, resources properly allocated, and the information and communication system improved. The effect of this restructuring was to save time at the operational level: good organization of production and maintenance, simplification of work, good use of time, good management of stocks of products, consumables and spare parts, reduction of operational stoppages (preparation of products, adjustments, controls), functional stoppages (breakdowns) and induced stoppages (lack of parts or resources, energy shortage), good coordination of programmed and unscheduled interventions (inspections, repairs, rehabilitation and renewal works, systematic operations, general maintenance operations, subcontracting) according to plans and work sheets prepared for this purpose. Production/maintenance system evaluation audits and the implementation of a safety system have contributed to continuous improvement in the organization and operation of the station. People, facilities, equipment, methods, budgets, costs, strengths and weaknesses were identified and improvement measures implemented to address identified weaknesses (improved working conditions, outdated equipment renewed, revised business planning, enhanced agent capabilities, controlled operational processes, reduced downtime).

3.3.7.4 SYR recorded as a result of improvement actions

The SYR calculated by iteration from the first week to the last week is listed in the table below. The results are due to rigorous follow-up and curative actions in a continuous improvement process, with some days of sudden drop of SYR.

Table 4: Summary of SYR calculated over the period of the 14 weeks

THE SYR CALCULATED FOR THE PERIOD (14 WEEKS)								
Weeks	**SYR** \ **Dates**	Mo.	Tu.	We.	Th.	Fri.	Sat.	Sun.
Week 1	SYR 1	38,23	59,25	50	45,45	73,07	60,71	30,76
Week 2	SYR 2	34,26	36,25	54,11	39,45	57,07	46,41	38,76
Week 3	SYR 3	40,32	41,13	**29,76**	42,26	43,11	41	43,08
Week 4	SYR 4	44,59	45,76	47,53	46,32	49,49	48,83	51,57
Week 5	SYR 5	51,02	52,22	53,46	41	54,17	56,19	55,63
Week 6	SYR 6	57,36	58;97	56,55	59,43	49,66	61,72	60,84
Week 7	SYR 7	62,48	63,51	52,12	64,44	65,07	65,99	66,37
Week 8	SYR 8	65,99	67,48	69,34	65,91	68,81	70,63	71,86
Week 9	SYR 9	70,45	69,85	71,89	68,74	66,43	72,91	72,76
Week 10	SYR 10	73,84	74,13	71,81	73,14	74,69	75,04	74,28
Week 11	SYR 11	76,83	77,45	76,89	78,26	81,27	79,91	80,76
Week 12	SYR 12	81,55	78,92	83,42	82,11	81	79,61	82,55
Week 13	SYR 13	85,61	87,51	86,57	75,45	87,57	87,09	89,34
Week 14	SYR 14	96,32	97,22	96,29	95,78	99,15	98,91	99,26

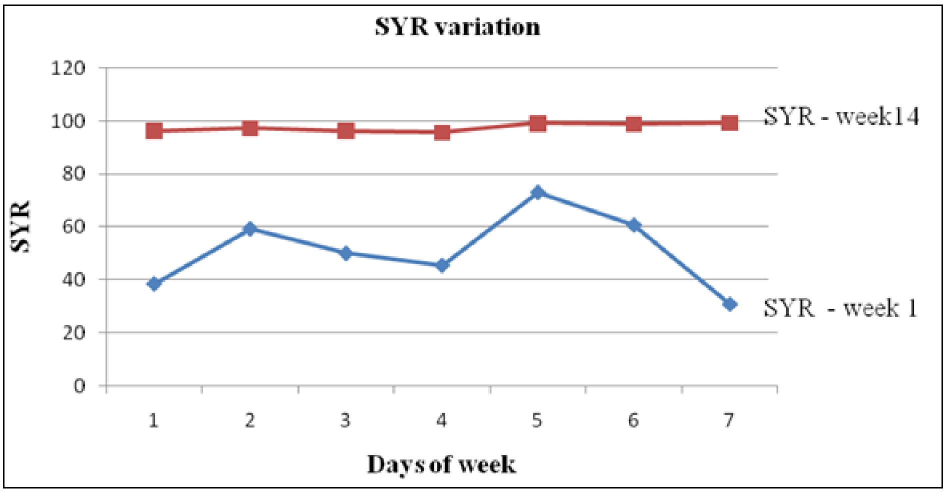

Figure 4: Comparison between SYR 1 and SYR 14 to show the gap due to improvement achieved.

3.3.7.5 Effects of SYR improvement

The actions to improve SYR have had the following effects:

- Better control of production/maintenance operational processes;
- Good business planning, and consequently elimination of unproductive time (less time wasted);
- Regular water supply to the population 24/7 (no more water cuts);
- Maintenance costs are halved compared to previous costs;
- Reduction of intervention and repair times by half for defective equipment, resulting in maximum availability;
- Improved working conditions and safety for operators;
- Motivation of production/maintenance personnel;
- Equipment and works in condition to receive a preventive maintenance program.

4. Conclusion

The objective of this work was to improve the performance of a drinking water production company's maintenance system. To do so, a pilot station was selected to launch the maintenance operational process optimization project. This station was in a very advanced state of degradation, both at the level of equipment and installations, with the result that consumers suffered from untimely water shortages.

This study demonstrates that applying Total Productive Maintenance can transform a struggling drinking water production system, as evidenced by the pilot station's leap from erratic output to near-optimal performance over 14 weeks.

By decentralizing maintenance, training staff, and leveraging SYR metrics, the company curbed water shortages and slashed costs - offering a blueprint for nationwide scalability.

While equipment age remains a hurdle, these results underscore maintenance optimization's power to bridge operational gaps and restore public trust.

References

[1] **Anand S. Relkar, K.N. Nandurkar**. *Optimizing & Analysing Overall Equipment Effectiveness (OEE) Through Design of Experiments (DOE)*; K.K. WAGH Institute of Engineering Education & Research, Nashik-422003, India. Procedia Engineering, Volume 38, 2012, Pages 2973-2980 - Elsevier.

[2] **Faria Aktar Tonny**, **Ayesha Maliha**, **Mahedi Islam Chayan**, **Md Doulotuzzaman Xames**. *Optimization of overall equipment effectiveness (OEE) factors: Case study of a vegetable oil manufacturing company.* Management Science Letters, ISSN 1923-9343 (Online) - ISSN 1923-9335 (Print), Quarterly Publication, Volume 13 Issue 2 pp. 124-135, 2023.

[3] **Hamzeh Soltanali[a], Mehdi Khojastehpour[a], José Torres Farinha[b]**. *Measuring the production performance indicators for food processing industry*; Measurement, Volume 173, March 2021, 108394. https://doi.org/10.1016/j.measurement.2020.108394.

[4] **KADA Mohammed** (2019). *Exploitation de l'analyse du TRS pour améliorer la productivité de l'usine Ain Soltane*. Mémoire de fin d'études; Département de Génie Industriel, Université Sidi Mohamed Ben Abdellah.

[5] **Kitalu Ricin Ngoy[1] & Kipendo Israel[2]**. *The Strategy of Successful Total Productive Maintenance (TPM): Implementation and Benefits of TPM (Literature Review)*; [1]Department of Mechanical Engineering Science, University of Johannesburg, South Africa; [2]Department of Mechanical Engineering Science, University of Liege, Belgium; IJIRMPS - Volume 9, Issue 6, 2021, ISSN: 2349-7300.

[6] **Ranteshwar Singh, Ashish M. Gohil, Dhaval B. Shah*, & Sanjay Desai**. *Total Productive Maintenance (TPM) Implementation in a Machine Shop: A Case Study;* Institute of Technology, Nirma University, Ahmedabad, 382481, India. Procedia Engineering, Volume 51, 2013, Pages 592-599 – Elsevier.

[7] **Sayuti M.*, Julianānda, Syarifuddin, Fatimah**. *Analysis of the overall equipment effectiveness (OEE) to minimize six big losses of pulp machine: a case study in pulp and paper industries;* Department of Industrial Engineering, Faculty of Engineering

Universitas Malikussaleh, 24351 Aceh Indonesia. June 2019, IOP Conference Series Materials Science and Engineering 536(1): 012136; sayuti_m@unimal.ac.id.

[8] **Timothée KOMBE[1]*, Eugène Désiré EFAGA[1], Benoît NDZANA[2] et Eric NIEL[3]**. *Efficience d'un système bâti sur le TRS global par poursuite du diagramme de fiabilité*. Institut Universitaire de Technologie, Département de génie industriel et maintenance, Université de Douala, Laboratoire d'Automatique Industrielle (LAI), INSA de Lyon, Bât. St Exupéry, 25 av. Jean Capelle, 69621 Villeurbanne. Afrique SCIENCE 02(2) (2006) 198 – 211.

[9] **WASIM. S. HANGAD1 & Dr. SANJAY KUMAR**. *Review paper on TPM - a key strategy for productivity improvement in medium scale industry*. Department of Mechanical Engineering, (Manufacturing System Engineering), Mumbai University; International Journal of Scientific & Engineering Research, Volume 4, Issue 11, November-2013 1248 ISSN 2229-5518.

[10] **Xiaoyan Li, Guangfu Liu & Xinyu Hao**. *Research on Improved OEE Measurement Method Based on the Multiproduct Production System*; School of Economics and Management, Tongji University, Shanghai 200092, China. *Appl. Sci.* 2021, *11*(2), 490; https://doi.org/10.3390/app11020490