MANAGEMENT BY PROCESS AS CLEAN ALTERNATIVE FOR BIOREMEDIATION PROJECT MANAGEMENT

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Abstract

The purpose was to implement the management by process in the rehabilitation project of a zone polluted by hydrocarbons. There were implemented the eight steps in the problem solution and the study method of production management. There were identified deficiencies in the performance of the process and it was evaluated as steady and incapable. It was simulated and improvement proposition, where the results showed its feasibility. It was diminished the 53.33 % of the productive cycle time and its stability was achieved. There were diminished the costs in a 10.57 %. It was contributed to the achievement of cleaner productions.

Keywords: bioremediation projects, production management, capability, stability, simulation

1. INTRODUCTION

The Cuban Environmental Strategy identifies oil pollution as one of the most significant environmental problems in the country, considering that the oiled residues are classified as hazardous and have a pronounced negative effect on the physical, chemical and microbiological contaminated areas [1].

One of the more widely used technologies for the treatment of the oil residues worldwide is bioremediation [2-4]. This practice is a natural process enhanced by man through the implementation of projects, to detoxify different environments from various pollutants, strategically using microorganisms, plants or their enzymes. Regarding oil pollution bioremediation techniques are systematized in Cuba led by the Ministry of Science, Technology and Environment (CITMA, Spanish acronym), introduced through the implementation of environmental rehabilitation projects of hydrocarbons contaminated areas (PRAZCH , Spanish acronym).

One of the principles for achieving quality in projects is to manage the processes and activities that apply scarce resources to obtain the objectives set; within certain time intervals and bounded costs, working with the general direction in its strategic management [5]. In this sense, the present research is developed through a case study in order to identify and diagnose the condition and performance of PRAZCH critical process, regarding quality standards. Another goal was the correction of the deficiencies identified in the diagnostic phase, through the development of an improvement project and a simulation of scenario.

Researches allowed reducing the response time to oil pollution contingency and decreasing the costs. It also helps to reduce the time of operations and make better use of technical capacities implicated, which corresponds to a decrease of the energy , the physical and the mental fatigue of the workers involved in the project.

2. METHODS

2.1. Background

The object of study was the rehabilitation project of a low mangrove zone nestled in Santa Maria Cay, Villa Clara, Cuba. The Basic Business Unit (UEB, Spanish acronym) "Santa Maria Cay" (belongs to the Cuban National Electrical Union), is located in the southern- central part of the Cay. In 2009, as a result of improper operations and design problems of the primary system of separation of oil sludge and oily water of the UEB, there was an environmental pollution of 20 500 m^2.

2.2. Identification of critical process

The identification of the critical process was performed from the application of the Delphi method to the weights of experts, regarding the quality levels of each of the eight PRAZCH macro-process components. Then, the capability and the steadiness (statistical control) were evaluated. In addition, its performance was analyzed as an independent productive system, meeting the required technical and organizational requirements.

A methodology was used to implement a project to improve the "eight steps in problems solution" [6]. Table 1 shows a relationship between the steps of the methodology, the main techniques used and their references.

2.3. Diagnostic Process

To classify the state of the process, the *concentration of microorganisms* of each bioproduct batch before being applied to the environment was analyzed as a variable. This quality variable, is of the type " the biggest is the best" and the lower limit specified for the bioproducto is: $1 \cdot 10^8$ Cel $\cdot$ mL^{-1}. By using capability indices and descriptive statistics, a comprehensive study of capability was made. The stability was monitored by an individual's control chart. To corroborate the supposed inherent to the used techniques, nonparametric hypothesis testing were performed. One observation was extract, because it was classify like atypical with a 95 % confidence level.

2.4. Technical and organizational requirements [7, 8]

For the low capacity, the performance of the bioremediation campaign was evaluated like a productive system. The determined organizational and technical requirements are described below.

Table 1 - Methodological summary of eight steps in the problem solution

Steps	Description	Techniques & References
1	**Select and characterize the problem**	Delphi Method [9], {Check sheet, Individual control chart, Histogram, Capability rates, Hypothesis Testing [6]}, Determination of technical and organizational requirements
2	**Find the possible causes**	Cause and effects diagram [10]
3	**Analyze the most important causes**	Failures modes and effects analysis (FMEA) [11]
4	**Make an improvement plan**	Critical analysis (5W& 2H) , Control Plan
5	**Implement the plan**	Simulation [12]
6	**Check results**	Nonparametric hypothesis test, Period average payback [13]
7	**Prevent recurrence**	Documentation and standardization
8	**Conclusions**	

Dynamics of Performance: The demands that the production management adopted ensure systematic growth efficiency indicators. The economic indicator "gain per pesos"(national unit of currency), of each projects implemented to date was used to evaluate this exigency.

Reliability: The number of failures, interruptions and waste that occurred during the production of each batch of bioremediation campaign was analyzed because each time there is a stop, it will affect the outcome variables such as: cost and volume of production and process quality. To obtain data, a check sheet was used as well as the card process that was as bioremediation campaign registration form of this project.

Stability (Es): For its calculation the following equation was used:

$$Es = \left[1 - \frac{\sigma}{X_{media}} \right] \quad (1)$$

Where:

X_{media} : Average production per interval

σ : Standard deviation of this average production.

Nonparametric tests were used to check the supposed of randomness and adjust for production volume of each bioproduct batch (m^3). Specifically for randomness runs above or below the median, runs up and down, Box-Pierce test were used. The Kolmogorov-Smirnov test was used to test the normality of this variable.

Flexibility: This indicator shows the level that the productive system has, to accept the challenges imposed by the environment when it is producing. Only flexibility from the working force (FFT , Spanish acronym) was calculated. All the processes or activities that take place in the bioremediation campaign was listed and all the workers who participated in it.

$$FFT = \frac{\sum_{i=1}^{n} (1 - \frac{1}{Ft_i}) * W_i}{\sum_{i=1}^{n} W_i} \quad (2)$$

Where:

Ft_i = number of functions that can be handled by the worker i

n = number of workers

W_i = Rate of importance, in this case, all activities should be able to cover the worker i

Reaction capacity ($Tr\alpha$): This requirement is successful, as it is able to provide the delivery times of batches shorter. To do the calculations fermentation times of each batch of approximately 4.5 m^3 were interpreted as the delivery period.

$$Tr\alpha = t_{med} + b' \cdot \sigma$$

(3)

Where:

t_{med} : Average delivery

b' : Standard deviation of this average delivery.

$Tr\alpha$ was applied compared to Tr plan. If $Tr\alpha \leq Tr$ plan it implies that the reaction capacity is satisfactory. The bacterial cluster scheduled times in the closed system, as production in m^3 volume, was estimated from bacterial growth models described in [14].

2.5. Simulation

The alternative was to introduce a new reactor with the same technique characteristics of the existing, but with a gap of 15 minutes in generating their items. The workload or volume to produce was 100 m^3 of bioproduct (patented like BIOIL-FC). The model is defined below.

Source generating: fermenters

Time inter arrivals of two consecutive batches: the time needed for fermentation 4.5 m^3 of byproduct (batch), where growth of microorganisms reaches concentrations required for application to the medium. The time between consecutive arrivals follow an exponential distribution adjusted to the expression "38 + EXPO (36.8)".

Service time: It corresponded to the time required to perform the extraction and application operations. This variable follows a Poisson distribution fitted to the following expression "POIS (17.8)". As a resource for the service, a tanker truck (server) with a volume capacity of 9 m^3 was used.

Five repetitions of the simulated model were run; the average and standard deviation were estimated. With these parameters, the number of samples necessary (n) to compliment the follow statistics conditions was determined (Table 2):

Table 2 - Statistics conditions to contrast the replicas thrown by the model

α	1-β	Alternative hypothesis	Hypothetic standard deviation	Hypothetic Average	Average to contrast	n
0.05	95 %	>	3.441 h	21.368 hours	24 hours	34

3. RESULTS

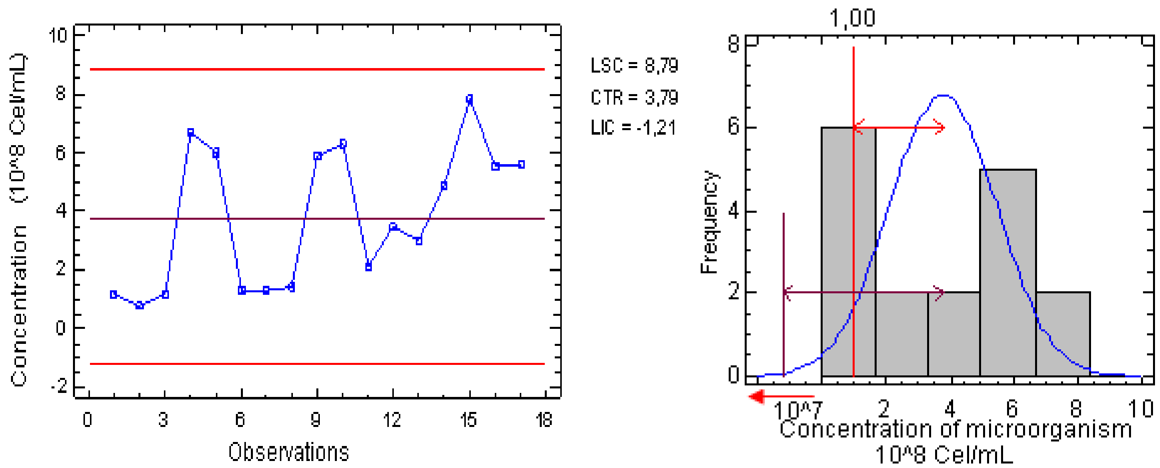
3.1. Selection of the problem

The method of experts found that the critical process regarding quality levels was the "bioremediation campaign"; this process also coincides with the constraint operation within PRAZCH following Goldratt criteria [15]. During execution, at industrial scale operations such as scaling, production, application and fermentation control overlap. Frequency

3.1.1. State of the process

The variable concentration of microorganisms turned randomness and normality assumptions, although valid highlight which must be removed by two observations constitute significant outliers. This occurs because during the fermentation cycle, various phases of the bioproduct growth occur. With responses to different laws of distribution, the drawn observations belonged to the exponential and deceleration phases. Figure 1 shows the control chart for the stability analysis (a), and the histogram to analyze capacity limits (b), the specified limit in red and real in black.

As shown in Figure 1 a), there were no special causes in the process so it is under in the statistical control with respect to the analyzed variable. Regarding the histogram (Figure 1 b), in spite of the bars do not correspond precisely with the Gaussian distribution, the standardized bias and standardized kurtosis are in the interval [-2; 2] (Table 3), it mean that the variable is normally distributed; also the Kolmogorov-Smirnov test confirmed this statement. The results of the comprehensive study of capability are shown in Table 3.
Based in the previous results, like any points are out of the control limits (Figure 1 a) the process was classified as steady; and it is incapable, because the histogram shows batches under the lower specified limit.



a) b)

Figure 1 – a) Individual control chart for the concentration of microorganisms of the bioproduct, b) Capability histogram for concentration of microorganisms (the frequency axis is in order of 10^8 $Cel{\cdot}mL^{-1}$).

Table 3 – Interesting parameters in the analysis of process capability

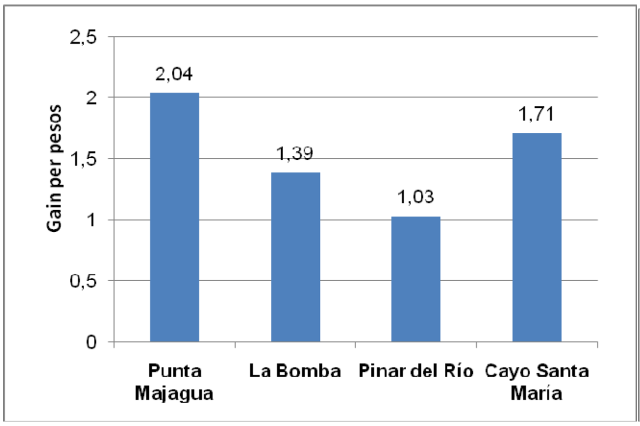
Statistics	Values	Discussion
Average	3.791 18	The measurements of central tendency are relatively similar. The process is centered, although the frequency of the central value is not predominant.
Standard deviation	1.667 77	Dispersion is seen between the observed values.
Standardized bias	0.211 012	It's a fairly symmetrical distribution although few observations exist.
Standardized kurtosis	-1.38891	There is neither flattening nor high elevations of data corresponding to a normal distribution with that approach.
Cpk (lower)	0.56	The process is a Class 4 (Cpk ≤ 0.67). Unsuitable for work. It requires very serious modifications (according to Table 5.1 of "Statistical Quality Control and Six Sigma" Authors: Gutierrez and de la Vara [6].
% out of specification (OOS)	5.882353	As shown in the histogram, there is a defective fraction below the lower specification
Z Rate	1.6736	The process is approximately working to 1.67 sigma it resulting in poor performance.
Parts per Million out (PPM)	74 824.096	With the current process control, lots of batches out off specification of batches produced per million.

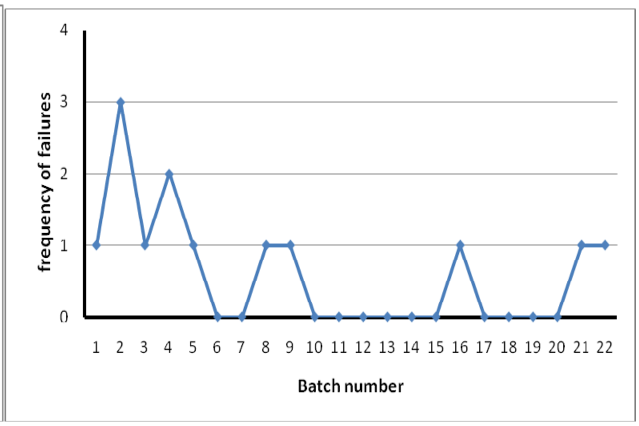
3.1.2. Performance of the productive system

Dynamic of Performance: fluctuation indicators shown in Figure 2 a) are in dependence of the magnitude and circumstances in which each project has occurred. It is valid to emphasize that despite the observed oscillations, the gain per pesos, remains greater than unity, indicating the feasibility of the studied projects.

Reliability: Figure 2 b) shows the behavior of the system's failures during the bioremediation campaign, we can see that at least, there is an interruption for some special cause in 10 of the 22 batches produced. This is considered a bad result.

As shown in Figure 2 b), there are twelve observations without failure in a total of twenty, this means that the reliability of the productive system under the concepts covered is approximately 55%, which is considered as a low magnitude. This means that in 45% of the lots, there are errors that affect the quality of the product, its volume or overall cost.





a) **b)**

Figure 2 – a) Gain per pesos of each one of the PRAZCH carried out,
b) Reliability of the productive system.

The calculation of the stability proves that Es ≈ 90% (pretty good), but rejects that requirement because it violated the assumptions of normality and randomness to the output variable.

The levels of flexibility of the work force were 0.7582 and 0.8101 real and ideal respectively. This indicates that the productive system was found to work about 94% respect to the ideal level that it can reach. The results in this indicator are interpreted as appropriated and presented consistency with those issued by Hernandez [16], in a similar productive system of drug production, where the percentage of the FFT from the ideal was 95.79%.

The reaction capacity of the productive system is not adequate, as the scheduled times for batch fermentation byproduct are lower than the actual time (Tr plan = 124.52 y Tr real = 138.54).This would breach the fundamental condition for this indicator. Therefore, the system doesn't ensure the delivery of the lots in the times demanded, this prolongs the duration of the campaign of bioremediation.

Failure to comply with the demands posed by the environment to a productive system, means that the internal organization to be taken to achieve maximum satisfaction don't be correct. This way will break the methodological basis for the achievement of an adequate organization of production, which may be acting directly on the capability process. This problem affects the planning of time in the bioremediation campaign and has direct impact on the cycle time and process capability, therefore, also influences production costs. With wastes, not only quality is affected but the physical integrity of workers too, because they are forced to make extra efforts.

3.2. Find the possible causes and analyze them

Figure 3 is shows a cause and effects diagram. The FMEA, tossed potential failures that affect the productive system were: Lack of some measuring equipment, insufficient logistical planning, and problems with the extraction system.

3.3. Make and implement an improvement plan

A set of measurements to counteract the main causes that affect system performance was proposed. The proposal to introduce a new fermenter with the same characteristics of the existing, but out of phase respect to the first, was the most viable alternative to implement. The execution of this variant was simulated.

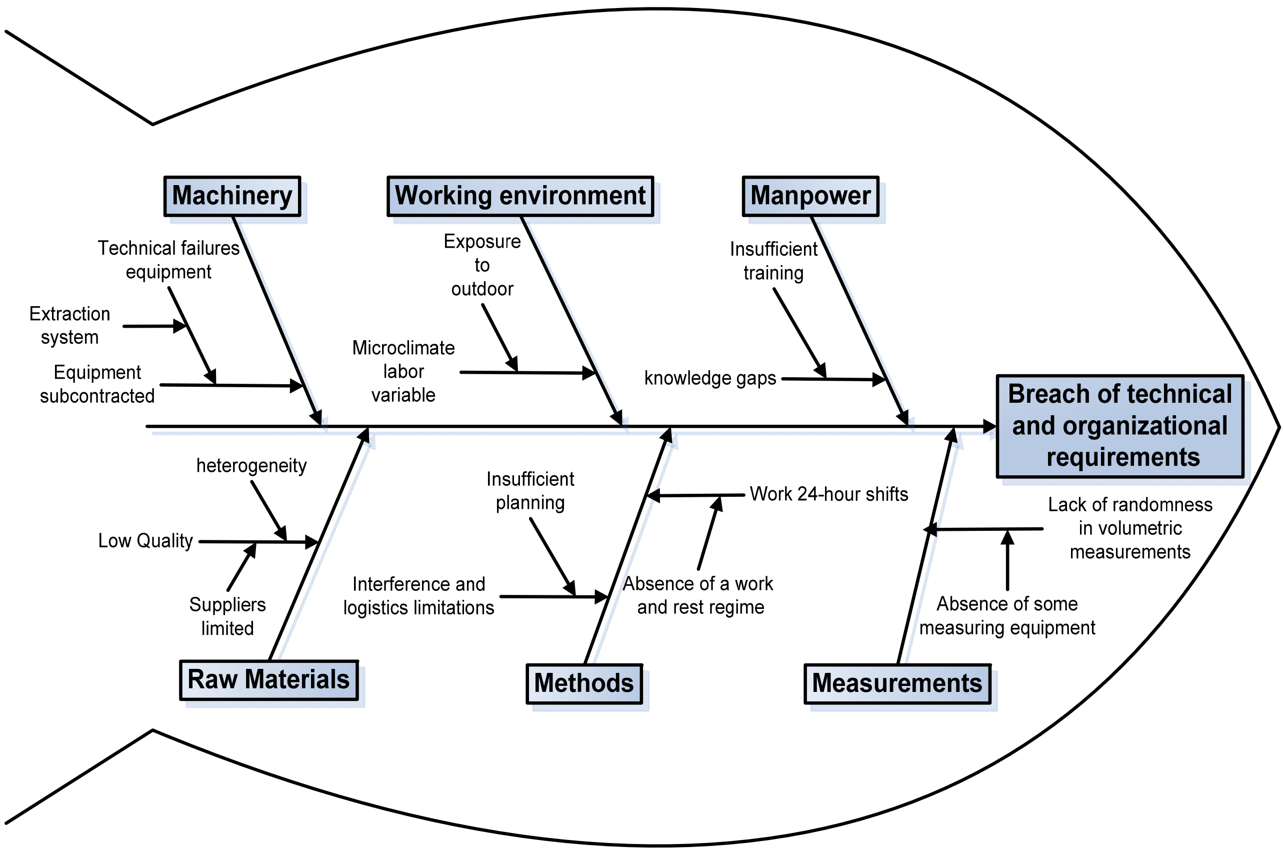


Figure 3 – Cause and effect diagram for breach of technical and organizational requirements.

3.4. Check results and prevent recurrence

The feasibility of the proposal was evaluated from the technical and economic dimensions as shown in Table 4.

Table 4 – Economic and technical feasibility of the evaluated proposal.

Variants	Campaign resources		Using the server (%)	Reaction capacity		
	Hours	Pesos ($)		Time inter arrivals (min)	*Tr* real	State
One reactor	45.00	18 300.00	16.00	75.47	138.54	Non conforming
Two reactors	22.00	16 366.48	33.00	19.90	36.53	Conforming

The hypothesis test (Test-t), demonstrated that the proposal of two reactors, diminish the cycle time of the bioremediation campaign less than 24 hours with a 95 % of confidence level. As it can be observed, when contrasting the failure reaction capacity, before and after the proposal it is seen how the technical and organizational analyzed demands go from a state of nonconformity to a state of approval.

The economic feasibility of the investment was determined by using the "period average payback" (PRIp, Spanish acronym); showed that asset is recovered in 2.75 years, or what is the same, 33 months. Even though the indicator does not fall in the short-term (one year), it is necessary to note that the fermenter is an equipment of long-term durability and the medium-term (3 years) is adjusted with the interests of the team implementing the PRAZCH.

With the introduction of the proposal other benefits of environmental and social nature were obtained but they were not estimated quantitatively, but as might be perceived, the main ones are: Reduction of the physical and mental workload of the workers present in the campaign, increased job satisfaction, reduced electricity consumption by concept of less time of laboratory and office use, increase customer satisfaction by faster performance of the service. The procedure was carried out for the analysis of the campaign bioremediation process each time that a new PRAZCH run.

4. CONCLUSIONS

The implementation of the process approach was positively related to the achievement of the objectives to improve the management of environmental rehabilitation projects of hydrocarbons contaminated areas. The bioremediation campaign was identified as the critical process regarding quality levels.

The diagnosis of the state of the bioremediation campaign process allowed the classification as steady and unable to meet specifications. Once identified the technical and organizational requirements, it was demonstrated that the performance of the productive system presented difficulties with their reliability, stability and reaction capacity.

The proposal to include a new fermentation in the productive system was simulated, confirming its technical and economic feasibility, with direct impact on the quality of the byproduct. With it, a 17% increase in the efficiency of resource utilization (tanker truck). In addition, a considerable reduction of execution time of a bioremediation campaign was obtained, for a load of 100 m^3 of BIOIL-FC. For the same volume, the proposal achieves 10.57% saving of the costs.

The results are related to the improvement of project management quality in environmental rehabilitation projects with hydrocarbons contaminated areas. They also offer theoretical and practical generalizations on the usefulness of using management by process, as a clean alternative in bioremediation campaigns, - no known background-. This demonstrates the need for further professional work in this field, in order to optimize quality in sanitation campaigns.

5. RECOMENDATIONS

Systematize in detail compilation of failure modes of the productive system, to implement an improved project for the reliability of it.

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