METHODOLOGY FOR THE DETECTION AND PREVENTION OF FAILURES IN INDUSTRIAL PRODUCTION EQUIPMENT

Wellens A.[(a)], **Esquivel J.**[(b)]

[(a)]Facultad de Ingeniería, UNAM-MEXICO
[(b)] Dínamo Value Partners, MEXICO

[(a)]wann@unam.mx, [(b)] esquivelvillar@hotmail.com

ABSTRACT

This paper constitutes a methodological proposal in the area of industrial maintenance. It combines maintenance philosophies and techniques, elements of statistical process control and statistical data analysis to obtain two methodologies: the first one for the detection of chronic failures in industrial equipment and the second one to prevent sporadic failures in the same equipment.

Both methodologies are intended to be applied to production processes, as data acquisition is relatively easier than in service processes. However, they can be easily adapted to service processes as well. Their goal is to increase production equipment availability in order to improve product quality and quantity, increasing in this way the competitiveness of the company in the market.

The methodologies were applied to a cosmetics production facility with favorable results.

Keywords: failure prevention, reliability

1. INTRODUCTION

At present, the perception of management on industrial maintenance has shifted from considering it a cost to valuating the investment in maintenance of assets as a business opportunity.

The strict quality norms that have to be satisfied and the competitiveness between industries of the same type have forced the management to stop considering the maintenance department as a “fire department” to solve problems, and change its perception to a strategic unit that contributes to assure the facilities production level, including higher product quantities and qualities at lower costs.

Quality philosophies as Lean Manufacturing or TQM would have no sense in a company where the machinery presents a poor performance.

Maintenance costs are a fundamental part of the added value of whatever facility or business, and should be lowered as much as possible without failing to guarantee the availability of the productive actives. To stay competitive, facilities should consider maintenance as the fundamental pillar of management, and techniques should be developed for detection, control and execution of activities that guarantee an appropriate performance of production machinery.

The methodology for the detection of chronic failures in industrial equipment emphasizes especially on detection, as this is the main problem in solving chronic failures. Once the root cause is detected, the solution to be applied is immediate. No special analysis is needed. Although the methodology was designed for industrial equipment, it can be applied in the services area with some adaptations.

The second methodology, used to prevent sporadic failures is an alternative proposal of proactive maintenance, as it intends to identify the failure before it occurs and thus would interfere with the productive process. An inconvenience is that the major part of existing facilities (at least in Mexico) lack to have failure statistics. Some indicators, as for example mean time between failures (MTBF) should be measured as soon as the methodology is being applied to improve the results with gained experience.

2. PROPOSED METHODOLOGY

To be efficient, a productive system should achieve the equipment to operate effectively during the major time span possible (Cuatrecasas 2002). To obtain this, it is necessary to discover and eliminate factors that diminish the ideal operating conditions of the equipment. In general, six types of losses can be distinguished and these can be divided in three categories, according to the effect they have on the output of the production equipment (Figure 1). From the maintenance point of view, failures are the type of loss that has the biggest impact on the production process, as they can originate the other types of losses, such as quality defects, reduced velocity, process stops or breakdowns.

Advanced production systems pretend to optimize their efficiency through the elimination of wastes, which implies the use of the minimum possible quantity of all resources and to produce only the necessary items. Maintenance, specifically the total productive maintenance methodology, intends to use the same basic principle to optimize the process performance and output, eliminating the losses in production equipment.

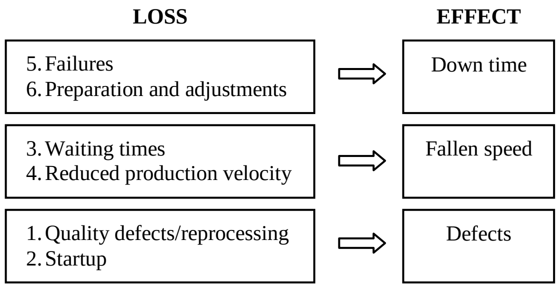

Figure 1. Types of losses and their effect on production equipment.

The aim of the proposed methodology is to reduce failures in industrial equipment. These can be of two different types:

- Chronic or continuous failures, which do not interrupt the operation of the equipment, although they reduce its performance and therefore the product quality.
- Sporadic failures, where the equipment suddenly looses one of its fundamental functions and stops operating. These failures occur unexpectedly and have to be solved urgently.

2.1. Detection of chronic failures

An appropriate diagnostic of a failure corresponds to 80% of the solution and its solution depends directly on its correct detection. An important part of chronic failures start as sporadic failures that were not solved adequately or due to the fact that they are of minor importance, were "solved" with provisional solutions, waiting for production stops or time availability to be able to propose a final solution. The main problem with this kind of solutions is that, generally, these provisional solutions will remain eternally due to the lack of time to fix them in an appropriate way, and the deficient functioning of the equipment is seen at the end as a "normal" and expected functioning.

The aim of the detection of chronic failures is to eliminate them, or, if this is not possible, to minimize their effects in the performance of the equipment. Table 1 shows the losses on which the detection of chronic failures has an effect and the corresponding aim to pursue:

Table 1: Aims of the chronic failure detection.

LOSS	AIM
Failures	Eliminate
Short stops	Reduce as much as possible
Reduced velocity	Eliminate
Quality defects	Eliminate

The following scheme summarizes the proposed methodology for the detection of chronic failures:

1. Give maintenance to the assets
2. Leave all assets functioning in normal operation
3. If an opportunity of improvement is detected (product error), then:
    3.1 Define the problem to solve
    3.2 Identify the main cause of the problem
    3.3 Apply the corresponding solution
    3.4 Compare the new performance
    3.5 If the new performance is better, then:
        3.5.1 Standardize the improvement as best practice for similar equipment
        3.5.2 Repeat from step 1
    3.6 If the new performance is not better, then:
        3.6.1 Start again from step 3.2, as the identified cause was not the main cause or the only one
    3.7 Repeat from step 1

Techniques and or methodologies as flow diagrams, checklists, histograms, Pareto diagrams and pyramids, cause-effect diagrams, dispersion diagrams, control charts, FMEA, hypothesis testing, fault tree analysis and process capacity are used to carry out the previous steps.

2.2. Prevention of sporadic failures

The prevention of sporadic failures implicates the creation of a pessimist scenario, trying this not to occur. It makes use of a *what-if* analysis considering all possible alterations the process can have, identifying its consequences.

Taking the product as the main indicator of the equipment's health, its quality characteristics can be used to deduce where the equipment is failing to produce the desired defect.

The proposed methodology to prevent sporadic failures is similar to the previous one, however, considering as second step the identification of the potential failure modes of the equipment, and looking afterwards for the main cause of each potential failure. Figure 2 indicates a flow diagram for this detection methodology.

Its main aim is to identify the potential failure modes that need to be monitored and eliminate their causes to minimize their effects. The following table shows the losses on which the detection of chronic failures has an effect as well as its corresponding aim:

Table 2: Aims of the sporadic failure detection.

LOSS	AIM
Failures	Eliminate
Long stops	Reduce as much as possible

As in the chronic failure methodology, it is important to emphasize the first step, corresponding to general maintenance. A cleaning and lubrication plan will detect minor failures, equipment ware out, bad fitting and possible fractures among others, which should be corrected before starting the prevention of sporadic failures.

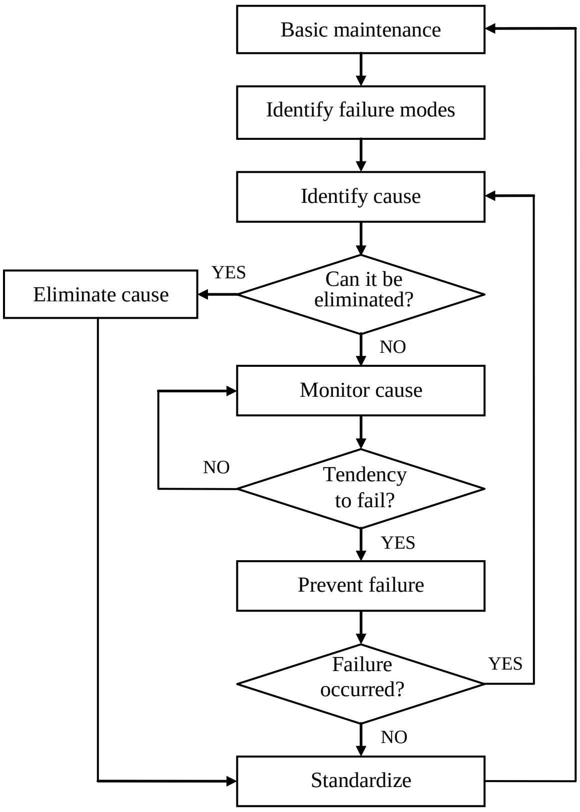

Figure 2. Proposed methodology for the prevention of sporadic failures.

3. CASE STUDY

The proposed methodology was applied at the maintenance department of a company that produces cosmetics and is characterized by direct sells per catalogue. The seller offers products which, in case of convincing a client, will be delivered at the end of the campaign, for instance two weeks. This characteristic implies that the filling equipment is changing continuously its format, and, still more important, that the products to be produced are already sold. The latter characteristic is the leading principle of the company, and demands a high availability of the production lines to avoid late delivery, money refunding and loss of clients.

To prove the effectiveness of the presented methodologies, they were applied to the production lines in charge of filling compressive tubes. Both chronic failures, on one hand in good/bad situations and on the other hand implying numerical variables, and sporadic failures were considered.

The production line for creams in cosmetic packaging tubes is composed of three workstations: manual alimentation of the tube by an operator, filling machine and transport band for inspection and packing (Figure 3).

Figure 4 shows the nomenclature of the elements of interest in cosmetic packaging tubes.

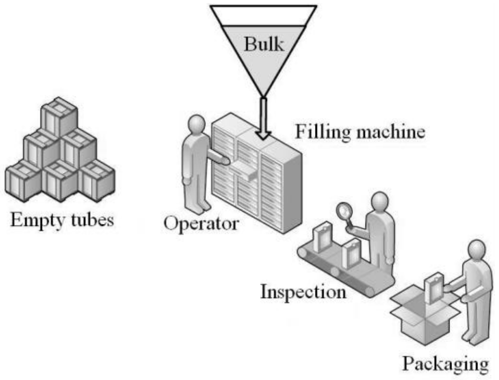

Figure 3: Tubes production line.

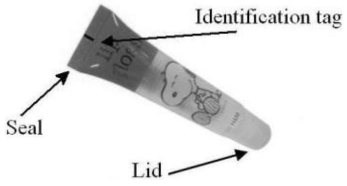

Figure 4: Cosmetic tube nomenclature.

As a first step, basic maintenance was carried out, including cleaning and lubrication of the filling machine and transport band, tightening of screws in mechanical and electrical devices and changing or repairing pieces that are in bad condition. As soon as the production line was working in normal operation, a check list was applied to a run where 5131 tubes were packed: 405 rejected pieces were detected, corresponding to a 7.9% of the run. The previous process identified both chronic and sporadic failures.

3.1. Detection of chronic failures in tube filling

The check list provided information to identify the most recurrent defect in the tubes at the end of the production line. Table 3 presents the observed defects.

Table 3: Observed defects in the production run.

Defect type	**Frequency**	
	Absolute	**Relative**
Seal	203	50.12%
Bad tag centering	116	28.64%
Product leaks	45	11.11%
Weight	41	10.13%
Total	**405**	**100.00%**

The most recurrent defect was a defective seal; this defect can be subdivided in other categories, for which the condensed information is presented in table 4.

Table 4: Observed defects in the tube seal.

Defect type in seal	**Frequency**	
	Absolute	**Relative**
Burned	126	62.07%
Bad cut	41	20.20%
With bubbles	26	12.80%
Defective	10	4.93%
Total	**203**	**100.00%**

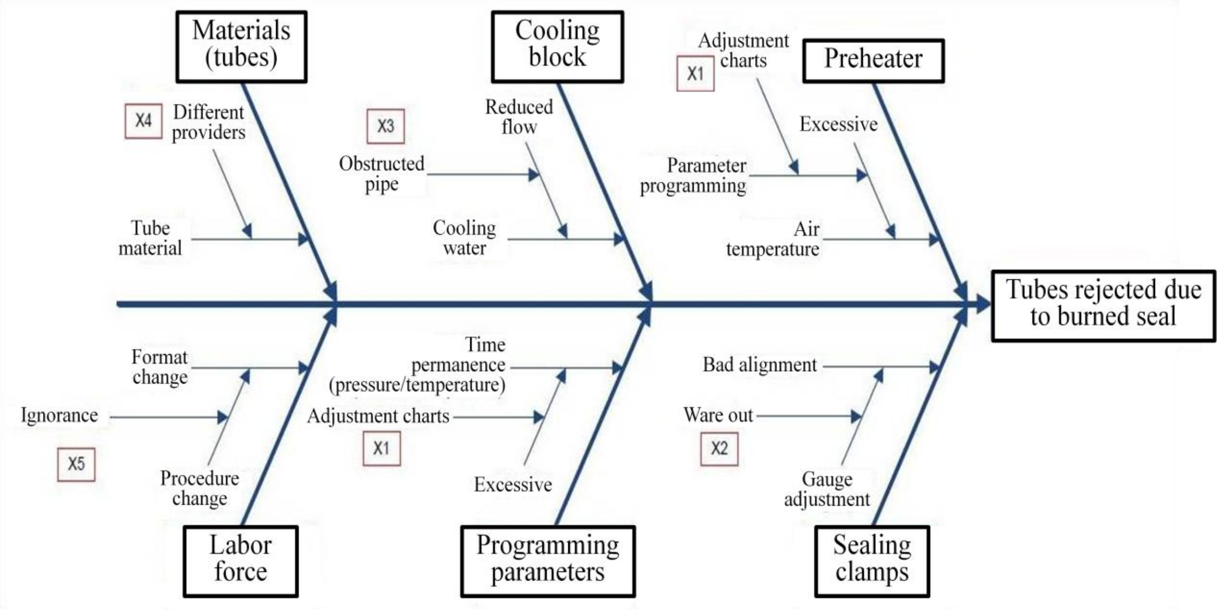

Figure 5: Cause-effect diagram for the burned seal problem.

The most important problem to reject a tube resulted to be that the seals are burned, which provides a bad aesthetic appearance. To find its cause, process maps were made, at a first level for the line, at a second level for the filling machine, and at a third and final level of the sealing mechanism. After the previous disaggregation of the process, an Ishikawa diagram was made to determine which element identified in the process map can cause the plastic seal to be burned (Figure 5).

After the diagram is finished, an AMEF table helps to determine which of the potential causes are responsible for the quality problem. For every potential cause a null hypothesis was included, and to check this hypothesis, the proposed corrective action was carried out, one at a time, and a control run was carried out to be able to quantify the number of burned seals after the corrective action. Five corrective actions were proposed, including actualization of the adjustment charts, use of only gauges and support sheets that are not worn out, to place a bypass to assure a free flow of cooling water, to buy only material of one provider and to assure that the format change is carried out according to written adjustment procedures. Carrying out the statistical procedures for null-hypothesis testing of proportions of defects before and after the corrective actions, it was found that the first three causes are significant, but the latter two are not. The corrective actions were applied provisionally in only one of the equipments to analyze its effects of the problem to be solved.

Performance of the equipment in the new conditions under normal operation was compared with the initial performance in a run with 6504 pieces produced. Table 5 summarizes the results of defects in seal in the control run.

Table 5: Observed defects in the tube seal after corrective actions.

Defect type in seal	**Frequency**	
	Absolute	**Relative**
Burned	9	8.04%
Bad cut	60	53.57%
With bubbles	28	25.00%
Defective	15	13.39%
Total	**112**	**100.00%**

As shown in table 5, the burned seal defect was reduced considerably after implementing the corrective actions. This reduction also contributes indirectly in the diminishing of total defective products, which were reduced to 360 (5.5%).

A Pareto pyramid (Wadsworth 2005) shows graphically the benefits of the proposed corrective actions (figure 6).

Figure 6: Pareto pyramid for the burned seal problem.

The previous analysis showed that the corrective actions solve almost completely the problem of burned seals, so these actions are to be made permanent in all production lines.

3.2. Weight variation of the product

The previous methodology was also applied to numerical variables, in this case the weight variation of the final product. The way to proceed is very similar, although a histogram is used instead of a Pareto diagram, summarizing weight information of 150 samples of 100 g tubes, extracted systematically (10 pieces every 30 minutes).

As lower and upper specification limits are determined respectively in 100 and 103 g, a capacity study was carried out (figure 7), indicating a potential capacity coefficient of 0.43 which corresponds to 22.8 % of pieces out of specification. Specifically, 16.5% of the tubes were found to have with weights over 103 g and although these are accepted for sale, this situation is far from optimal for the company.

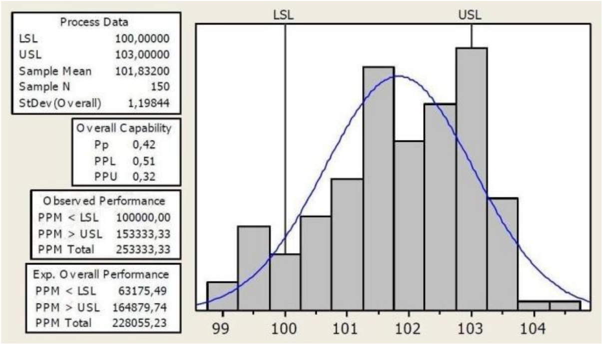

Figure 7. Process capacity for tube weights (100g).

To fill the tubes, cyclic mechanisms are used and these are synchronized with a camshaft, which provokes the tube elevator to rise and fall. The filling valve is opened and closed by one of the cams, and finally the injection of bulk product in the tube is also controlled by the camshaft. The corresponding process maps were developed, an AMEF table was made and the resulting null hypotheses were tested, again one by one, to improve the process. It was found that two significant causes for the weight variability were the ware out of the camshaft`s lining bar and an incorrect interpretation of the adjustment graphs.

After implementing the proposed corrective actions, variability could be reduced and potential capacity was determined again, turning out to be 0.73. In this case the capacity value was still not acceptable, and on one hand the Ishikawa diagram was revised again to detect possible extra causes, and on the other hand the correct implementation of corrective actions was checked. In the revision of the provisional reparation of the camshaft it was found that the welding seam was worn out somewhat, due to the fact that the camshaft was given a thermal treatment to increase its hardness. The difference in characteristics between camshaft and welding seam impedes a perfect fusion; besides, the welding seam did not have the hardness required for the stress applied to the camshaft. As the camshaft was not available in the warehouse, the maintenance department decided to work in the meantime with the repaired camshaft.

3.3. Prevention of sporadic failures in the filling line

Although products out of specification can be due to different types of errors, the camshaft problem will be presented to illustrate the case of prevention of sporadic failures, as it was repaired but still worn out. As a consequence of the previous analysis, the camshaft will be replaced as soon it is purchased, but the maintenance department wants to prevent deterioration of the shaft and thus variability of the weight of the tubes in the future.

To identify the potential failure modes, a fault tree is developed to determine which conditions will cause failures in the camshaft (figure 8). To identify the root cause, a cause-effect diagram is used were each basic event is considered as principal cause and were the top event is the problem to solve. This diagram should be developed jointly with the maintenance department.

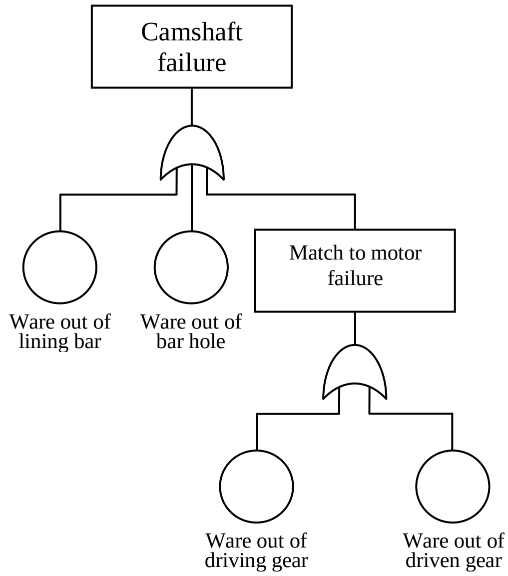

Figure 8. Fault tree for the camshaft problem.

In the cause-effect diagram, three risk conditions were detected that should be monitored or eliminated to prevent the camshaft to ware out: bad assembly, bad interpretation of provider information and non appropriate tolerance of the bar hole dimensions, the second of which is the only one that can be monitored continuously. On the other hand, a variable that can be measured is the electric current in the corresponding motor, as this is an indirect indicator of the stress that is transmitted by the camshaft. This stress generates an increment in the motor’s temperature and in the coil´s current, both of which can be measured. A control diagram for these parameters was proposed to monitor possible overloading of the camshaft.

3.4. Cost/benefit analysis

A cost/benefit analysis was carried out, considering implementation costs, costs for production of defective products, personnel training costs, salary costs for the people in charge of the implementation of the methodology and costs of the spare parts used to solve the failure. The analysis for the chronic failure in the filled tube line indicated that the implementation cost of the proposed methodologies is relatively low, and consists principally of personnel costs; however, as the level of defect products diminished drastically, these costs can easily be absorbed by the amount spilled previously in the production of defect tubes. As the number of chronic failures increases, the savings effect will be more important, as personnel costs will stay constant or increase very slightly.

Another aspect is the gain of intangible benefits, unfortunately difficult to quantify. These include reduction of the risk of late delivery, diminishing of the ambient pollution due to less defective products, sparing the company's reputation and finally the improvement of the quality concept among the personnel.

4. CONCLUSIONS

The maintenance department should be included as a strategic unit to achieve the company's aims, as an early detection and consecutive solving of failures in maintenance will improve overall efficiency in an important way. The proposed methodology is a step to achieve this.

Among advantages of the methodology the following can be mentioned:

- Changes the old paradigm that an equipment, when functioning, is necessarily working well
- Introduces the product as the main indicator of good health of the equipment and foments the register of corresponding data
- Stimulates the systematic analysis of the production equipment and their failures
- The initial investment for implementation is relatively low while the benefits are important
- The improvements are achieved on a short term

Disadvantages are:

- Its implementation is time consuming and depends on the general state of the production equipment
- It requires qualified personnel with basic knowledge in statistics, besides their technical capacities

The achievements obtained by the prevention of sporadic failures are less evident as for the detection and elimination of sporadic failures. However, this is exactly the aim of the maintenance department: its main objective should not be to repair defect equipment, but prevent its ware out and loss of functionality by detecting in a timely way chronic failures in the equipment.

REFERENCES

Cuatrecasas L., 2000. *TMP: Hacia la competitividad a través de la eficiencia de los equipos de producción*. Gestión 2000, Barcelona, España.

Wadsworth H. and Stephens, K., 2005, *Métodos de control de calidad.* Compañía editorial continental, México.

BIOGRAPHICAL NOTES

Ann Wellens is a chemical engineer with postgraduate studies in Industrial Administration (KUL, Belgium) and a master degree in Environmental Engineering (UNAM, Mexico). At the moment she is a full-time lecturer in the Systems Department of the Industrial and Mechanical Engineering Division of the National University of Mexico (UNAM). She has been working in air pollution issues for the last 15 years, dictating courses, collaborating in research projects and participating in conferences related with mathematical modeling of air pollution dispersion and statistics.

Joel Esquivel obtained his bachelor degree in Mechanical Electrical Engineering (UNAM, México) and his master degree in Industrial Engineering in the same university. He has been working as a maintenance engineer in different facilities and productive branches.