Learning Maintenance Management through System Dynamics

A Continuous Improvement Process

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Abstract

Maintenance management has become a field of important development according to the operating needs of production planning systems and the impact of new technologies in the industry. The processes of production flow creation and inventory control in the modern factories lead to a more sophisticated maintenance system to ensure low failure rates and reduce accordingly failures consequences, which is a must in these kind of environments to meet the production schedules.

In this paper a maintenance system is modelled to study the effects of different policies that can be applied to reach the above mentioned targets. Moreover the conditions required to create a continuous improvement mechanism for the system are analyzed. Model validation and simulation results are obtained and presented for a real problem in the Spanish industry.

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MAINTENANCE EVOLUTION

During the 80's many industrial companies have been obliged to improve their productivity to maintain their position in the market. This, so called "shock of productivity", has caused benefits in many organizational and technical aspects related to normal companies operations (Furlanetto & Miani & Salvetti & Santini, 1990).

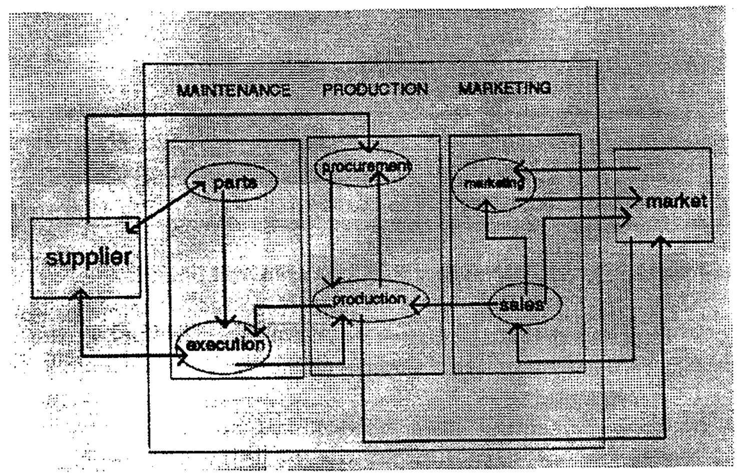

Figure 1. *A system perspective of a company*

The consideration of a company as a "social & technical open system" (Figure 1) has become probably the more important approach to improve the performance of the organizations. For the 90's, new technologies will surely condition the success of many companies. That means that managers will have to update continuously all products development using both, creativity and technology.

The "system approach" instead of the traditional "functional approach" is changing the roles of the previous "maintenance departments". Most of the resources belonging to those departments are now following a process of integration mainly in the production departments according to TPM philosophy (Nakajima, 1989), and only a few remain in a maintenance engineering department. This department has an important responsibility in the "maintenance continuous improvement process".

The above mentioned process is very similar to the quality continuous improvement process (Deming, 82) and uses a very similar approach based on the involvement of all company employees to solve the problem of "machine breakdowns" (Figure 2) which play now the role of the "products defects" in TQC (Suzaki, 87).

	TOTAL PRODUCTIVE MAINTENANCE	TOTAL QUALITY CONTROL
Problem:	Machine Breakdown	Products Defects
Traditional Solution	Breakdown/Replacement of Broken machine Parts	End of Line Inspection/ Sorting and rework
Improved Solution	Condition-Based maintenance/Preventive Maintenance/ Maintenance Prevention	Poka-Yoke (foolproof mechanism)/ Design for Quality
Information for Monitoring	Machine Trouble Record/MTBF (Mean Time Between Failures)	Statistical process control/ Control Chart
Basic Approaches	Education Employee Involvement Maintenance is free"	Education/ Employee Involvement/ "Quality is Free"

MAINTENANCE PROBLEM AND INDUSTRIAL DYNAMICS

Conceptually, the maintenance problem consist in operating the plant at the minimum cost to guarantee the required equipment availability and its adequate operating conditions.

Reliability engineering has widely studied this problem and several methods have been developed to deal with the reduction of the negative effects of failures (Henley & Humamoto, 92). However, the experience confirms that the solution to the problem is complicated due to the permanent industrial environment change which conditions the cost associated to maintenance determination.

The day-to-day in the plant changes many of the factors that are taken into account to evaluate the cost. For example, changing the mix of products following a market demand trend variation, new critical resources could appear in the plant (Goldratt & Fox, 86) and therefore the cost of opportunity of a breakdown in the new "bottleneck" resource would increase.

Another example can be appreciated when the risk of the operation of an equipment[1] changes, in these situations the evaluation of the cost can, not only change but, be difficult to define.[1]

[1] The RBM (Rosk Based Maintenance) studies, for a moment in time, the design of the maintenance operations to carry out in the equipments according to their level of risk. The methodology pay special attention to the study of the operations to accomplish in those equipment with high risk level (ie high probability of a very bad consequence failure).

Method	Characteristics	Advantages	Disadvantages
Preliminary hazards analysis	Defines de system hazards and identifies elements for FMEA and fault tree analysis. Overlaps with FMA and criticality analysis	A required first step	None
Failure mode and effects analysis	Examines all failure modes of every component. Hardware oriented.	Easily understood. Well accepted, standardized approach; non-controversial, non-mathematical.	Examine non-dangerous failures. Time consuming. Often, Combinations of failures and human effects not considered.
Criticality analysis	Identifies and ranks components for system upgrades.	Well standardized technique. Easy to apply and understand. Nonmathematical	Follows FMEA. Frequently does not take into account human factors, common cause failures, system interactions.
Fault tree analysis	Starts with initiating event and finds the combination of failures which cause it.	Well accepted technique. Very good for finding failure relationships. fault oriented: looking for ways system can fail.	Large fault tree are difficult to understand,bear no resemblance to system flow sheet, and are not mathematically unique. Complex logic is involved.
Event tree analysis	Starts with initiating events and examines alternative event sequences.	Can identify (gross) effect sequences and alternative consequences of failure.	Fails in cause of parallel sequences. Not suitable for detailed analysis.
Hazards and operability studies	An extended FMEA which includes cause and effect of changes in major plant variables.	Suitable for large chemical plants.	Technique is not well standardized or described in the literature.
Cause-consequence analysis.	Starts at a critical event and works forward, using consequence tree; backward using fault tree.	Extremely flexible. Allencompassing. Well documented. Sequential paths clearly shown.	Cause-consequence diagram can become too large very quickly. They have many of the disadvantage of fault trees.

MAINTENANCE MANAGEMENT

Due to all previously mentioned possible environmental variations, the maintenance-production system needs a flexible organization in order to:

- appreciate easier the dynamic behaviour of the factors contributing to the criticality of an equipment (or equipment part).
- introduce the changes in the information system

- plan/put into effect/check the adequate actions

  - maintenance scheduling
  - inspection/predictive/preventive actions
  - corrections actions

- meet less equipment criticality, traduced as:

  - less failure rates
  - less negative (cost evaluated) failures consequences.

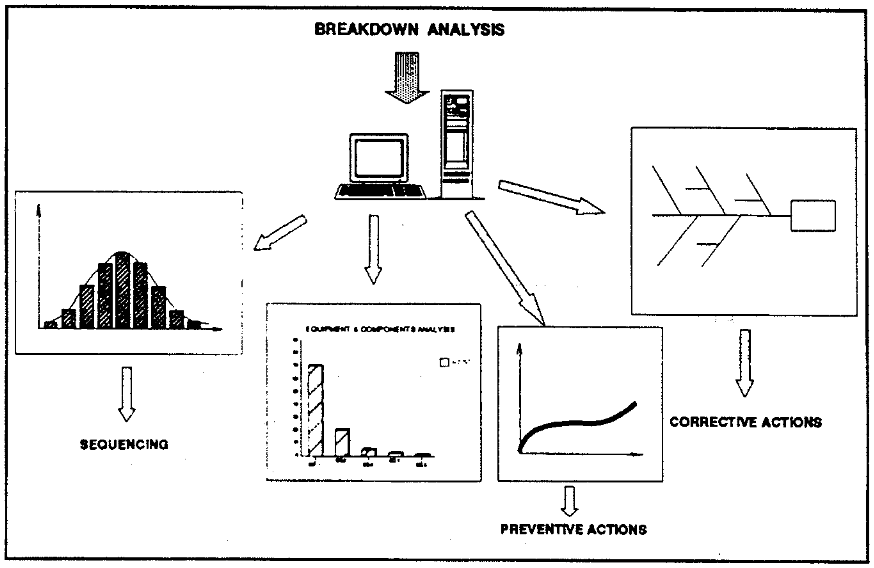

Figure 2. *From analysis to actions.*

When the above points are applied systematically by all employees the company will have a learning maintenance system organization, and can achieve normally the best results.

In most of the leader companies, and making again parallelism between maintenance and quality, the critical points to maintain are obtained following a "quality management approach" according to an evaluation of their "non quality maintenance cost":

MAINTENANCE	QUALITY
COST TO REPAIR	INTERNAL NON QUALITY COST
COST OF OPPORTUNITY	EXTERNAL NON QUALITY COST

and the, normally less significant, "quality maintenance cost" due to:

MAINTENANCE	QUALITY
COST TO INSPECT&PREDICT	INSPECTION COST
COST TO PREVENT	PREVENTION COST

The process of management consists in studying the results obtained through these evaluation and plan actions to avoid the core problem (failure mode of a part) producing the failures. The problem solving basic tools are here used to make this task easier and systematic (Douchy, 86).

SYSTEM DYNAMICS APPROACH

System Dynamics can contribute offering a medium/long-term perspective to evaluate the system response to a maintenance policy in a complex industrial environment. This is very important in a management area where people pay more attention to short term local issues, and cost-cutting pressure is extremely high.

The contribution of System Dynamics to the development of new mental models (Carroll & Sterman, 93?) to assist in the appreciation of the dynamic complexity of the maintenance system can be of main interest.

The model presented can help in the maintenance of decision making process offering the possibility to apply preventive/predictive or corrective maintenance actions facing the decision according to the "quality cost" of the maintenance system, calculated as previously mentioned.

MODEL CHARACTERIZATION

The model uses the idea of having the plant equipment, during its scheduled working time, in three possible situations: in good condition, starting to fail (failing) or out of order.

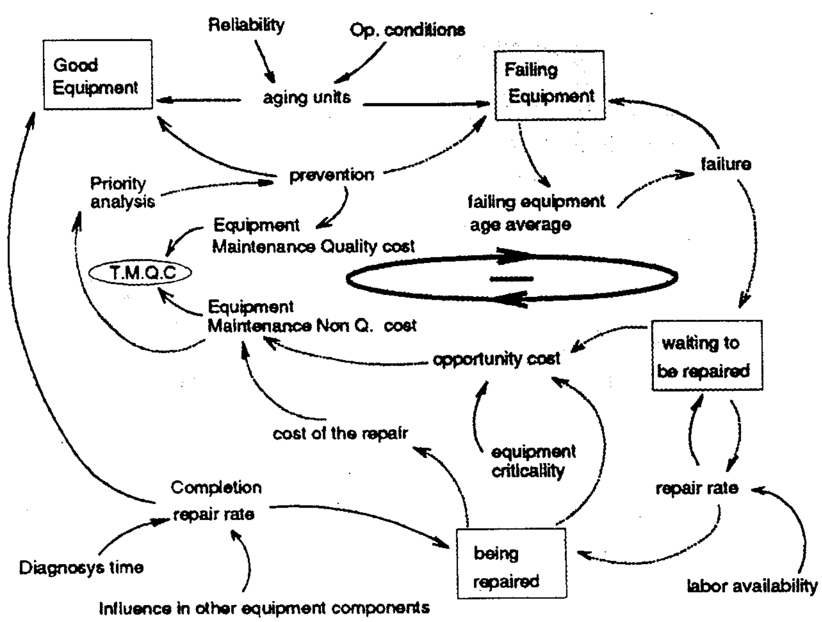

Figure 3. *Influence diagram*

The equipments start failing after a "life time" or reliability period estimated by the manufacturer but which could be modified by the "in situ" operating conditions. When the equipment is arriving to the highest failure probability age, the manager has the possibility to decide whether to prevent the failure or to repair it. This is complicated due to the amount of equipments, the cost of the resources to control, prevent and repair, and many times due to the lack of "real time" estimation about the more critical equipments and their normal mode of failure.

The model tries first to classify critical equipments according to their maintenance total quality cost considered as a level variable, filled in by the records of equipment maintenance operations which are generated every day.

<u>**situation**</u>	<u>**cost rates**</u>
breakdown ---->	opportunity cost in terms of production loss, risk,...
breakdown ---->	cost of the repair (labor & parts & external)
inspection op. -->	cost (labor & parts & external)
preventive op. -->	cost (labor & parts & external)

The model assumes that the time required to release inspections and preventive maintenance does not affect production activity[2], that means that these operations do not generate opportunity cost. This is one of the advantages of the preventive maintenance. A second one is the fact that correcting a failure is, more complicated than preventing it in terms of diagnosis time, also more expensive in terms of parts required to repair and other possible components of the equipment affected by the failure. A third negative aspect to be considered when a failure appears is that labor-manpower availability can affect downtime, lengthen it.

When certain equipment are causing an important maintenance total quality cost, more pressure needs to be addressed to the failure mode analysis and to the inspection and preventive maintenance, always according to mean time between every particular modal failure of the equipment. This is the main negative (goal seeking) feedback loop in the model which regulates the total quality cost of maintenance operations through the investment in quality of the maintenance service.

LEARNING ADQUIRED WITH THE MODEL

In many companies, the maintenance system remains nowadays as a technical close system where the disorder trends to increase[3]. the organization admits a level of disorder, or probably is better to say, is used to coexist with it[4].

Through the experience with the model the company can learn how to improve its performance (investment to accomplish in maintenance quality) with the minimum total quality maintenance cost. The evaluation of the benefits to be obtained when improving reliability for most critical equipments[5] can be, among other possibilities offered by the model, easily released.

The learning adquired with the model also shows the evolution that the system follows to become

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[2] These kind of operations are normally external (ie. do not require to stop the equipment), to the equipment operation or can be carried out in an appropriate interval of time (shingo, 88).

[3] The Thermodynamic 2nd. Principle demonstrates how a closed system can only evolve towards a more entropy status.

[4] For example, many times people repair thing instead of studying the way to increase reliability.

[5] Sometimes simple engineering modifications improve substantially equipments reliability. Most of the manufacturers engineering departments appreciate the feedback given by the companies who are using their products and studying the mode in which the failures appear. This feedback directly address the main product problems in the field and will reduce considerably external non quality cost of the manufacturer. This cooperation can only offer mutual benefits for both companies.

an open system with a continuous improvement process.

For a period evaluated of three years, the improvement in the company's performance concerning maintenance, calculated as the Total Quality Cost of this service, can be estimated around 20% as an average of three different projects.

CONCLUSION

System Dynamics can be used to demonstrate the medium-long term benefits of a continuous improvement process in maintenance. Moreover, the dynamic behaviour of the industrial plants environment can be fully reproduced in the SD models. This fact can very usefull in order to the correct determination of the equipments which need special care according to their critical situation.

The learning of new mental models adquired through System Dynamics and the benefits obtained by the quality maintenance system introduction in several companies has been appreciated for real industrial scenarios.

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