A SYSTEM THINKING APPROACH ON MAINTENANCE, PRODUCTION AND QUALITY

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The concepts of system thinking and its applicability in maintenance management was analysed in this article. The author analysed various maintenance policies, which have inclination to the concept of system thinking. The maintenance policies revisited include the Integration of Maintenance (IM), Total Quality Maintenance (TQMain), Failure Mode and Effect Analysis (FMEA), and Total Productive Maintenance (TPM). All these strategies are aimed at utilising effectively the maintenance personnel by giving some of the responsibilities of maintenance to production personnel. It was found that, although the founder of these techniques did not mention the concepts of system thinking in their methods, however, to be able to implement effectively those techniques, one must have a holistic approach to the planning of quality, maintenance and production.

Keywords: *System thinking, System dynamics, Maintenance Strategies, Total Quality Maintenance (TQMain), Total Productive Maintenance (TPM)*

INTRODUCTION

System thinking refers to a systematic method for helping people to view real organisations in a broad perspective that include structures, patterns and events, rather than just events themselves. There are basic principles of system thinking that guide one to see this broad view. System thinking is the basis for the approach to develop learning organisation (Stumpf *et al.*, 1994).

To greatly oversimplify systems thinking as a management method, it may be defined as the ability to create models in motion that display the behaviour of a set of complex factors at work in an organization and its environment. These models in motion may take the form of verbal pictures such as paper-and-pencil exercises (for example, causal loop diagrams and stock-and-flow diagrams) and computer modeling (for example, micro-worlds and management flight simulators). Although the pictures created may not be "correct," they are clear enough portrayals to be challenged, to form the basis for dialogue and shared exploration of the issue at hand (Ryba, 1996).

The origin of system thinking goes back to the mid 50s through the research in the area of system dynamics pioneered by Professor Forrester (Sterman, 2001). Professor Forrester recognised that, there is a need to find better ways of testing social systems in the same way we can test ideas in Engineering. System thinking increases the capacity of human being to understand social system explicitly, in the same way that people use the Engineering principles to understand mechanical systems. Therefore system thinking is a tool for decision making, which if used correctly will increase the organisation performance.

Traditionally, people studied the system using mechanistic analysis whereby the whole system was broken down into its constituent components. System theorists grant that such kind of analysis gives out the knowledge of how the parts of the system functions, however, the system theorist quest is for knowledge of how the system operates as a whole, including its role or function in the wider environment or a more encompassing system (Spruill *et al.*, 2001).

In Industrial systems, we face problems and decisions that require operational understanding of the whole system, but our understanding is limited by the way we approach thinking. Our thinking process appears to let us down with issues that need systematic approach, such as TQM or TPM. A system thinking tools helps to break through functional walls between operations and maintenance by providing interconnection between functions. It is imperative to understand the origin of system thinking, and how it can be used to various types of organisational changes, such as Re-engineering, system integration, process redesign, Total Quality Management, Total Productive Maintenance, Integration of Maintenance, and Teamwork concept.

Traditionally, maintenance was thought in isolation of the production system as an independent part. Therefore, the troubleshooting techniques concentrated in identifying the cause of malfunctioning that required "fixing"; this is parts thinking, that is it not a holistic thinking. System thinking broadens this perspective so that people have a better understanding and appreciation for the balance of the interrelated and interdependent parts of a system and understanding of the fragile dynamics of successful change (Pierce, 2002). Therefore in this article, the author will review the system thinking approach concepts and see how those concepts could be applied to the management of maintenance systems.

SYSTEM THINKING CONCEPTS

The approach of system thinking is absolutely different from that of the traditional approach of analysis. The system thinking focuses on the feedback relationship between the thing being studied and the other part of the system, instead of focusing on only one part of the system in isolation. Therefore, the system thinking has a broader view of approach instead of isolating smaller and smaller part of the system. On the other hand, the traditional scientific approach and causal thinking aim at studying the interplay of complex variables through reduction to a small number of elementary variables that can be investigated in isolation. The system thinking is developed as an approach to:

- View the whole instead of looking into parts;
- Understand the interactions and interrelationships of the parts within a system, with other systems and with the surrounding environments; and
- Deal with increasing number of variables and complexity of the system.

The rationale for using system thinking is based on the fact that, system thinking provides us with methods for describing, analysing, and planning complex system using a structured way of building models. The method offers a way of understand complex real world problems; simplify them using structured models and communicating this understanding and the simplification to others (Holmberg, 2000).

The general approach is to describe the components of the system (i.e. rules, policies, phenomena, machines, people, etc.), and then decide which components should be included in the system and the definition of their interrelationship. Within the system thinking, qualitative data and metaphors can be used to depict what the components look like, and how they are related. For practical reason, it is not necessary and in fact not reasonable to include all components of the system, therefore, only those closely related component and those that are relevant to the issue at hand will be included in the system analysis (Holmberg, 2000).

Senge (1990) calls system thinking a discipline for seeing wholes, for shifting away from narrowing the focus to one particular part and instead expanding it to many parts that have impact upon one another. System thinking views an organisation and its respective environment as a complex whole of interrelating, and interdependent parts. It stresses the relationship and the process that make up the organisational context, rather than the separate entities or the sum of the parts. Some of the best-known strategies used to implement system thinking include systems modeling, simulations, causal loops, archetypes, and scenario planning (Gardener and Demello, 1993).

Senge (1990) describes several archetypes, typical structures that recur both in our organisations and in our personal life. The explained structures depict different ways people react to reduce pressure in a short term only to create big problems in the long run. This situation occurs because we are not aware that the same action can produce negative results in the long run, and also because negative consequences of our decisions are reflected in other part of the organisation. Therefore, system thinking will help us to avoid being seduced by short-term solutions, which might result into catastrophic effects in the long run. Therefore, He (ibid.) cautions us that making separate changes at once temporarily improves performance in few areas, but creates more confusions and slows down system-wide performance.

There are many schools of systems thinking, some emphasize qualitative methods, others stress formal modeling. For sources of method and metaphor, they draw on fields as diverse as anthropology, biology, engineering, linguistics, psychology, physics, and Taoism, and seek applications in fields still more diverse. All agree, however, that a systems view of the world is still rare. In some text the terminology system theory is widely used and other texts use the terminology system dynamics. System dynamics is a method to enhance learning in complex systems. Just as an airline uses flight simulators to help pilots learn, system dynamics is, partly, a method for developing management flight simulators (often based on formal mathematical models and computer simulations) to help us learn about dynamic complexity. System dynamics modelling stresses the importance of and methods to operationalize and quantify such so-called soft variables (variables for which no numerical data may be available). Omitting such concepts assumes their impact is zero, one of the few assumptions we know to be wrong (Sterman, 2001).

However, successful intervention in complex dynamic systems requires more than technical tools and mathematical models. System dynamics is fundamentally interdisciplinary. Because we are concerned with the behaviour of complex systems, system dynamics is grounded in the theory of non-linear dynamics and feedback control developed in mathematics, physics, and engineering. Because we apply these tools to the behaviour of human as well as technical systems, system dynamics draws on cognitive and social psychology, organization theory, economics, and other social sciences (Sterman, 2001). System dynamics has the following major characteristic (Dutta, 2001):

- It uses stock and flows to model organisational processes (Stock represent accumulations in the system);
- Flows connect pairs of stocks and cause changes in stock level;
- Connectors convey information only, and information flows are not conserved;
- Converters are used to hold inputs, outputs, intermediate values, and to perform computations; and
- Feedback effect, which is used in determination of dynamic behaviour.

System dynamics is strongly related to systems thinking (Senge, 1990), which states that structure determines behaviour. So changing the business system's structure means changing the behaviour of the system and thus changing the future of a company. By simulating scenarios for organizational change, their effects can be observed immediately, and a strategy can be developed that shapes the future of the company according to its vision.

System theory offers the ability to explain concepts such as feedback, self-regulating and interdependence of variables, which preserved the complexity of the whole system. The system thinking approach is suitable for complex problems involving various interrelating components, or those that depend on the actions of others, or those that have dependence on the past performance. Each system has a purpose to accomplish, and it requires that all parts must be fit to accomplish the purpose. System thinkers realise that no part can accomplish the system purpose alone. Any imbalance in the system components diminishes the ability of the system to effectively accomplish its purpose. Therefore, the purpose can only be effectively accomplished if there is a balance within all systems components (Scholtes, 1998).

Systems can be classified in several ways such as organisational systems, political systems, industrial systems, etc. These systems are referred to as soft systems and they are described by language rather than mathematical relationships. All operating systems have goals, objectives and some sort of connectivity, since system implies interrelatedness. To be able to fulfil system objectives, there must be a set of resources to be used by the system. Organisational systems must also have means of measuring performance and make decision, but these processes have control mechanisms, which act within certain boundaries. Then there are also human activities, which are also part of the system hierarchy. Therefore all these form sub systems within large systems or larger systems incorporating smaller systems. In order to comprehend the theoretical underpinnings for the system thinking it is necessary to provide methodologies and tools that are reformative to change how we think.

System thinking has its own language and processes. Important tools of system thinking include the following (Ron, 2001):

- **Feedback** – any reciprocal flow of influences. Feedback is both cause and effect.
- **Causal Loop Diagram** – linear or circular diagrams that show the relationships between the elements of a system and emphasize feedback diagram.
- **Archetypes** – common patterns or themes among large system causal loop diagrams, which are named for the effects they create. Among them include: Limit to Growth, shifting the Burden, Drifting Goals, Fixes and Fail, and Escalation.
- **Mental Models** – pictures in our head, which show how the world (or the organisation) works.
- **Leverage Points** – one of the system thinking laws says that small changes can produce big results, and that the area of highest leverage is usually non-obvious. Finding those obscure points of influence requires careful observation, data gathering and computer modeling.

Using Causal loop diagrams system thinking can be used to explain non-obvious interdependence between such factors as: different groups in the organisation; corresponding actions taken by organisation or its customers; quantitative and qualitative variable (e.g. revenue growth and motivation respectively); as well as short term and long term consequences of managerial decisions. Therefore, system thinking can help managers to meet the four important challenges in the managerial tasks: motivating people to change; generating collaboration among the groups that are blaming one another on the current situation; focusing limited change resources; and ensuring continuous learning once the decision for change has been made (Stroh, 2000).

Kaplan and Norton (1992) use linear cause-and-effect relationship in their model whereas Senge (1990) uses a different technique in which he turns the linear cause-and-effect relationships into circular loops. The technique of closing the loop plays an important role as it challenges people's desire to oversimplify relationships (Holmberg, 2000).

Many of the initial applications of systems theory focused on the change, management and the decision-making processes in an organisation. Examples of the areas where system thinking approach has produced better results include the following:

- Complex problem that involve helping many actors to see the "big picture" and not just their part.
- Recurring of problems or those that have been made worse by past attempts to fix them.
- Issues where an action affects (or is affected by) their surroundings, either the natural environment or the competitive environment, as well as
- Problems whose solutions are not obvious.

How do we then apply the system thinking? The starting point is to identify the level of thinking from which we are attempting to solve the problem. There are basic three levels: events level; patterns levels, and system level. At the event level one notes the symptoms of the problems. The symptoms should not be viewed in isolation but a broader perspective should be involved to find the relationships among various symptoms. At the pattern level one looks at the trends that have been happening over time or over several departments. At this level, it is important to ask such questions: How long has this problem or trend been occurring? Are other departments experiencing the same kind of problem? Are there other events that seem to have triggered the problem? The last level is the system level: once you have identified what is wrong and the trends associated with the problem, the next step is to ask yourself "Why?" (Dolny and Mahon, 2000).

OBJECTIVE

The main objective in this article is to analyse the concept of system thinking and analyse its applicability in the maintenance management. The concept of system thinking will be revisited and its benefits in a productive organisation will be analysed. Likewise, various maintenance policies, which have an inclination to the concept of system thinking will be analysed. This will enable the author to find how the concept of system thinking could be used to improve maintenance management.

SYSTEM THINKING AND MAINTENANCE MANAGEMENT

At this juncture, let us look into the interdependence between productivity and maintenance. The concept of productive from the volume of production viewpoint can be considered as a product of system capacity and the availability of the equipment. The system capacity is an inherent characteristic of the system, which depends on the design, facility layout and installation of the production equipment. The equipment availability depends on the effectiveness of the maintenance system.

In addition, the interdependence of maintenance and production can be viewed from their central functions. The departments of maintenance and production are highly interconnected in their functioning through the utilisation of the same resource equipment. The production department needs the equipment for production of goods while the maintenance department require the equipment for the maintenance function. Therefore, it would have been an ideal situation to carry out the production and maintenance strategic planning concurrently to avoid the conflicts of priorities. In this situation, the system thinking concept could be used to show how the two interrelated departments could be unified as one whole system.

The functions of maintenance and production departments in modern production systems are so inter-related that it is no longer possible to consider each as a separate, isolated element. Efforts to reduce the cost of either one of these functions may end up increasing costs in the other side to the extent that there is no more savings. It is therefore important that maintenance and production departments are considered and planned on a unified basis with the object of achieving the minimum overall operation costs (Kelly and Harris, 1978).

The automation and concatenation of the modern plant require heavy capital expenditure, which make the downtime to become extremely costly. Ideally the plant should operate without any downtime 24 hours a day, 7 days a week. However, this is not possible under normal condition of operation of the plant. To ensure optimum plant availability regular maintenance should be carried out on the plant. The maintenance should be so planned that it produces minimum downtime on the plant to reduce the losses caused by the stoppage of production. Unplanned maintenance can lead to extremely damage, which could lead to excessive losses caused by the downtime of the production. Therefore, with increasing complexity and sophistication of production equipment the maintenance department becomes an indispensable part of the production system. The profitability of the production department becomes more and more dependent upon the skills and organisation of the maintenance department. This situation calls for system thinking to be able to carry out an extensive analysis of the production and maintenance department as one system. Therefore, the solution lies in viewing organisation as a system of interconnected and interdependent parts, which together yield products and services (Packard *et al.*, 2002). The relationship between maintenance and production department is depicted on Figure 1.

Intense competition in the market has brought with it rapid advancement in technology and it has brought many changes in the pattern and outlook of the industry. New products are continually being developed, new techniques; new processes, systems and methods are applied. These changes, although they concern mostly the production department, but their effects reflect back to maintenance department. As the new production methods and machines are developed and introduced, there must be corresponding changes in the maintenance department. The maintenance department must also become progressive, employing the latest techniques to keep pace with the advancement of production technology. Therefore, the changes that are taking place in the

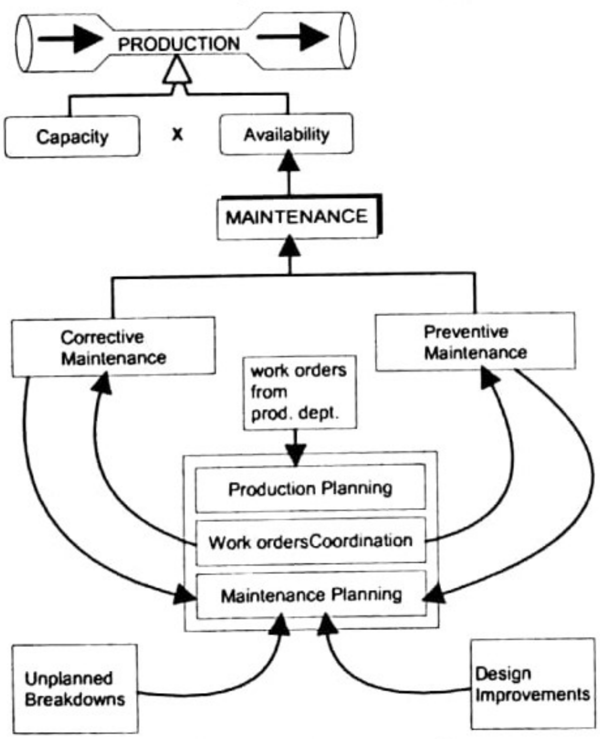

Figure 1: Relationship between Maintenance and Production

production department have effects also in the maintenance management. Indeed the production planning and maintenance planning should be harmonised to avoid confusion and chaos in the end products of the system. This implies that there is a need for a system thinking approach in the planning of production and maintenance.

There are a good number of maintenance management models that have elements of system thinking in them, although the model themselves do not explicitly advocate the system thinking theory in their development and applications. The Integration of Maintenance strategy advocates that production personnel should undertake simple maintenance tasks, and maintenance personnel can also be used in the production work. This strategy refers to the giving over of the maintenance tasks to the production personnel as well as the integration of the maintenance personnel in the production. The integration of the maintenance personnel in the production may be accompanied by the creation of the small maintenance service centres in each production department as a support centre. To be able to implement the integration of maintenance strategy, it is important to have the planning of production and maintenance as a unified whole. Therefore, in this case one needs to have a broad view of maintenance and production as interdependent operation units. It means that one must have system thinking tools to be able to implement the integration of maintenance strategy.

Failure mode and effects analysis (FMEA) is essentially a systematic brainstorming session aimed at finding out what could go wrong with a system or process (Clifton, 1990). To be effective it requires expertise and sound prior knowledge of the system under analysis. The essence of the FMEA technique is to list for each system component, all possible modes of failure and the potential effect of each failure on the rest of the system. The concept behind an FMEA is to render the system capable of being analysed by breaking it down into its component parts. However, most systems are so complex that analysts resort to limiting the number of failure modes for a component or restricting the types of risks to be considered (White, 1995). However, in FMEA, the analysis of each component is usually carried out the maintenance department. This situation calls for system thinking to be able to carry out an extensive analysis of the production and maintenance department as one system. Therefore, the solution lies in viewing organisation as a system of interconnected and interdependent parts, which together yield products and services (Packard *et al.*, 2002). The relationship between maintenance and production department is depicted on Figure 1.

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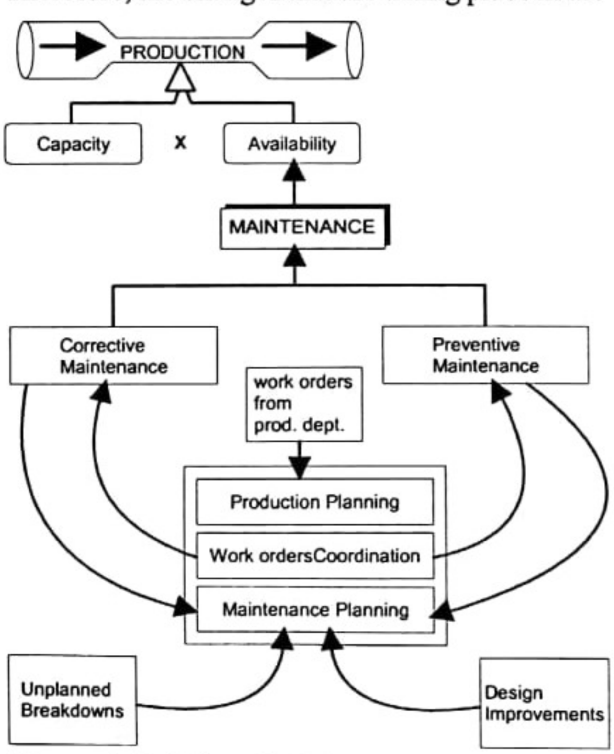

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The Total Quality Maintenance (TQMain) model developed by Al-Najjar (1996) insists that maintenance should be integrated with production and scheduled with it. The TQMain approach propounds that preventive maintenance, whether age or condition based, should be scheduled to avoid busy production periods, but on the other hand production schedules should incorporate time for the maintenance calculated to be essential to sustain quality and minimise total downtime (Sherwin, 2000). It is obvious that the developer of this model wanted maintenance and production to be considered in a holistic way instead of planning each of the two functions in isolation.

Total Productive Maintenance (TPM) is another model, which represents a great number of elements of system thinking in maintenance. Factors affecting the effectiveness of the production equipment can be grouped into "six main sources of losses" (Al-Radhi and Heuer, 1996):

- Breakdown of equipment;
- Time lost during set-up and changing of tools;
- Machine running empty (i.e. without production material);
- Reduction of tact speed of the machine;
- Operational difficulties; and
- Losses caused by poor quality (such as reworking costs, scrap costs, guarantee costs, etc.).

The Overall Equipment Effectiveness (OEE) measure of TPM combines the above six big losses under three headings: availability (which also include preventive downtime, speed (actual production rate / theoretical production rate) and quality (I – proportion defective). Therefore, the OEE consists of three main components: the overall degree of usage of the equipment, the degree of performance of the equipment and the degree of quality of the equipment. Through multiplication of these three components, it is possible to get the following relationship:

$$OEE = \frac{t_{plan} * \left(n_{prod} - AS - AR\right)}{T_B} \qquad (1)$$

Where:

t_{plan} planned operation time

n_{prod} Number of produced work pieces

AS Number of scrap work pieces

AR Number of reworked work pieces

T_B Equipment planned occupation time[1]

From the mentioned relationship one can wonder how then TPM is related to maintenance, since all the six sources of losses are mainly production problems. The first source of loss (i.e. breakdown of equipment), is purely maintenance problem. The second source of loss (i.e. Time lost during set-up and changing of tools), and the third one (i.e. Machine running empty) are purely production related source of loss. However, the fourth source of loss (i.e. Reduction of tact speed of the machine), and the fifth one (i.e. Operational difficulties) are mainly caused by maintenance problems. The last sources of loss is partly attributed to maintenance system and partly attributed to quality management system. It is to be noted that, a pre-condition for the successful implementation of TPM is the existence of Total Quality Management (TQM) system in operation (Sherwin, 2000).

The level of maintenance in a manufacturing company influences the quality of production processes, which in turn influence the quality of products. Likewise, the speed of machine is highly influence by the condition of the equipment at a particular time. If the machine is not in a good

1 (According to VDI 3423 this is a specific planned time during which the machine ought to be occupied by a workpiece). For example the equipment planned occupation time in a month can be obtained through multiplication of the length of the shift in hours x Number of shifts x Number of working days in the concerned month.

order the operators are forced to reduce the production speed. The reduced speed of machine causes backlog of work in progress in the production schedule, which put more stress on the production department to increase the utilisation of the machine. The increased utilisation of the machine by the production department, in this

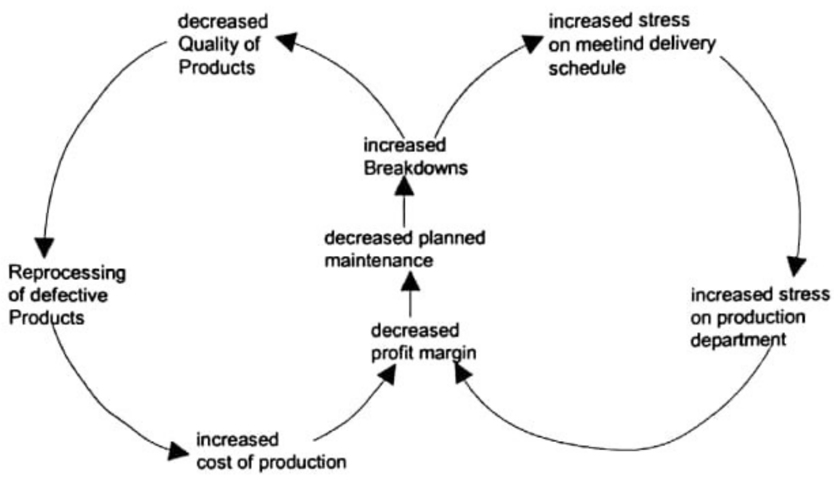

Figure 2: System Perspective of Maintenance, Production and Quality

case, means the increased occupation time of the machine by the production department. The increased occupation time of the machine by the production department is at the expense of the planned maintenance. In this case the planned preventive maintenance schedule will be postponed. The postponement of the planned preventive maintenance will cause the increase in breakdowns. The breakdowns will affect the planned schedule of the production department and will affect also the quality of products, which will increase the number of defective products. This relationship is depicted on Figure 2.

By analysing the information depicted on Figure 2, it is obvious that the leverage is on maintenance. That is, if we improve the level of planned maintenance its effects will be seen in the reduction of breakdowns. The reduction of unplanned breakdown will enable the production department to abide to their scheduled production and on the other side will reduce the number of scraps and rework of defective products. By meeting the production schedule, there will be less stress to the production department, and the production department will have ample time needed for planned maintenance. The end results of the both direction of the loop depicted in figure 2 will be the reduction of the cost of production and an increase in profit to the organisation.

CONCLUSION

In this article, the concept of system thinking was revisited and its applicability on maintenance management was analysed. In addition, the various maintenance management policies such as Integration of Maintenance, Failure Mode and Effects Analysis (FMEA), Total Quality Maintenance (TQMain), and Total Productive Maintenance (TPM) were analysed. It was found that all these policies have elements of system thinking although the founder of those techniques did not explicitly advocate the system thinking in their approaches. The TPM was found to have a holistic approach to maintenance, quality and productivity in its concept to the approach of maintenance management.

NOMENCLATURE

FMEA	Failure Mode and Effects Analysis
OEE	Overall Equipment Effectiveness
TPM	Total Productive Maintenance
TQM	Total Quality Management
TQMain	Total Quality Maintenance

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