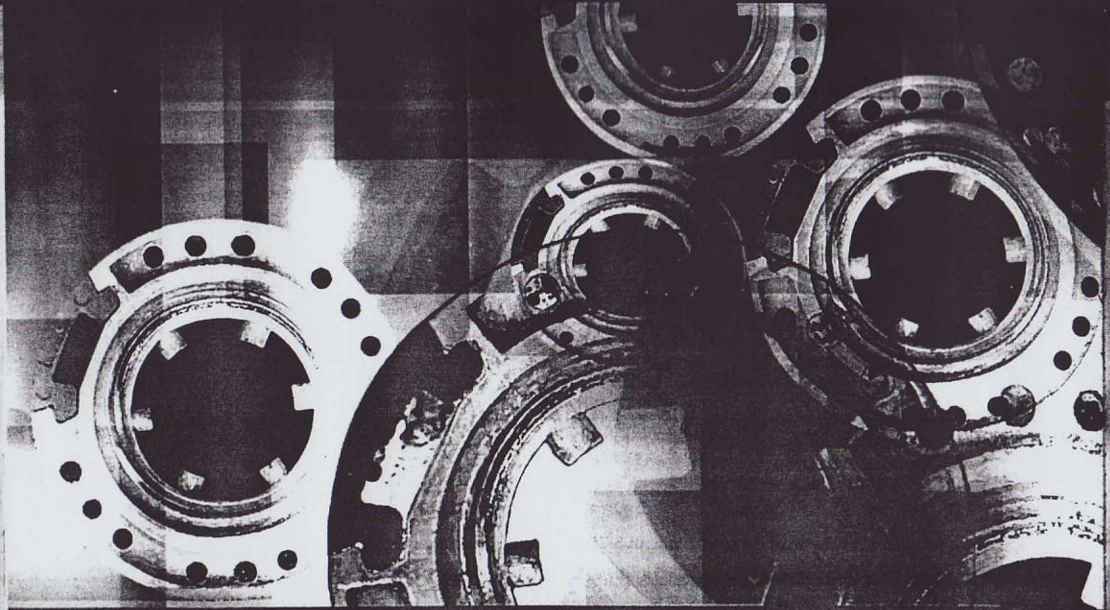

Utilisation of Buffer Management to Build Focused Productive Maintenance

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ABSTRACT

In today's time based competition, high equipment productivity in a manufacturing line is necessary in ensuring a competitive company. Focused Productive Maintenance emphasises the importance of achieving profitability through equipment effectiveness. This paper demonstrates the logic of Buffer Management and Focused Productive Maintenance to shape competitive advantage in utilising resources. Some ideas for future research are given.

Introduction

Total Productive Maintenance is a significant activity in creating an immutable manufacturing system against unexpected disruptions, which do occur during progressing customer orders (Nakajima, 1988). Breakdowns, fluctuations in set-up and processing time, non-instant availability of a busy resource, rush orders and quality problems are examples of disruptions. In the time competition era, managers should mobilise the available resources to minimise these inevitable disruptions (Patterson et al., 1995). Due to resource limitations, they have to focus their efforts to reap optimum results in contributing to the global goal, that is to make more profit now and in the future (Goldratt and Fox, 1992). These real results depend on how the managers arrange materials, jobs, and production resources into a robust schedule without jeopardising the profit.

Drum-Buffer-Rope (DBR) is a scheduling technique that attempts to accommodate the reality in shop floor such as statistical fluctuations, finite capacity variances, and dependent events (Goldratt and Cox, 1992). The schedule can be steered in execution by using Buffer Management. Buffer Management serves as a diagnostic tool in dealing with unexpected disruptions (Schragenheim and Ronen, 1991). The managers can trace the causes of any disruptions that may endanger on the profit and then special attention can be made to improve the system. This mechanism helps productive maintenance to concentrate on the continuous improvement efforts in assuring the reliability of the operating system as a whole.

This paper demonstrates the importance of Buffer Management in helping the managers in building Focused Preventive Maintenance (FPM). The review of the DBR scheduling technique is presented in the following section. The next section reveals how Buffer Management works to direct continuous improvement efforts. Then FPM can be formulated in order to gain real advantages from those ongoing improvement efforts. Avenues for future research are provided to highlight the research agenda on Buffer Management and FPM. Eventually, the last section describes some concluding remarks to provide issues in practice.

Drum-Buffer-Rope

Every manufacturing company is subject to different capacities of resources. Managers have to ensure that the materials can flow fluently through these resources to fulfil demand. The least capacity of resource that is equal to or less than the required capacity of demand is termed a bottleneck (Goldratt and Cox, 1992). Resources that are likely to disrupt the planned flow of product through the production line if they are not properly scheduled and managed are called capacity constraint resources (CCRs), or simply constraint resources. Constraint resources are critical in the production line since they reflect the weakest link that determines the overall output (Dettmer, 1995). If they are not managed properly, they may prevent the system from maximising throughput and hence profit. Here, throughput is defined as the amount of money that can be generated by the manufacturing company through sales over a specified period of time (Goldratt and Cox 1992).

Besides throughput, there are two other ways to measure the performance of bottom line or operational level (Goldratt and Cox, 1992). The second measure is inventory that measures the quantity of money invested in materials that the manufacturing company intends to sell. The third bottom line performance measure is operating expense. Operating expense is the quantity of money spent by the manufacturing company to convert inventory into throughput over a specified period of time. To be competitive, a manufacturing company has to maximise throughput and at the same time minimise inventory and operating expense. In doing so, the global goal of a company, that is to make more profit now and in the future, can be attained.

The profitability of one company can be ensured simply by arranging the way in which materials, jobs, and resources are scheduled. The schedule has to accommodate the complexity of production line and to meet the bottom line performance. In this respect, the Drum-Buffer-Rope (DBR) scheduling technique appears to resolve the problem of complexity and variety in production line as shown in Planning Stage in Figure 1.

DBR's solution begins with considering the finite capacity of the available resources. As mentioned before, the least capacity resource is termed the constraint resource. This constraint resource must first be identified. A way of identifying the constraint resource is simply by observing work centers where inventory accumulates. Since the constraint resource has the slowest rate in production line, it dictates the overall pace, and hence is termed a "drum". The drum represents the schedule of a constraint resource (Spencer and Cox, 1995). Once the customer orders are accepted, due dates are promised based on the availability of time on the constraint resource.

The constraint resource must be exploited to be reliable all the time, for losing one hour in this resource causes losing one hour for the whole system. For this reason, the constraint resource should be protected from statistical fluctuations and disruptions that may occur at the prior non-constraint resources. Therefore, a "buffer" is set in front of the constraint resource to protect throughput from these disturbances. This buffer is termed protective buffer and expressed in time units. The time buffer allows the constraint resource to process the parts during disruptions without starving. Buffers are also planned in the other critical areas, such as assembly and shipping, to guarantee the quoted delivery time. An assembly buffer assures the timely output of different arrival parts before they are processed together. The shipping buffer is useful to accommodate disruptions at the prior resources and demand fluctuations.

A planned protective buffer is estimated subjectively by considering the size and frequency of the delays that can occur because of statistical fluctuations and disruptions at the prior resources and the excess or protective capacity of those prior resources. For the constraint buffer, this length also involves a balancing of the holding costs of work-in process inventory and the consequences of starving the resource constraint. In the same way, the consideration of the initial shipping buffer length also includes a trade-off between the holding costs of finished goods inventories and the risk of missing due dates. However, experience is needed to obtain the optimal buffer time from an initial plan. Practically, the initial buffer length is determined proportionally to the lead-time, usually approximately one-half of the firm's current manufacturing lead time (Umble and Srikanth, 1990). Then the buffer length is adjusted accordingly.

The parts are expected to arrive at the protective buffer before they are scheduled to be processed in the constraint resource. If disturbances occur, the prior non-constraint resources will be able to expedite the late parts' arrival at the protective buffer by using extra capacity. This extra capacity is called protective capacity since it implies a means of protecting throughput from any disruptions. On the other hand, if there are no disturbances, the non-constraint resources tend to utilise their protective capacities and consequently work-in process inventories will exceed the established level. To minimise this unplanned inventory, a "rope" is tied from the drum to the first resource as a gateway point to regulate the releasing of parts in the correct quantities due to the consumption rate of the drum. Hence the non-constraint resources are utilised at a level that is just adequate for the system's ability to attain throughput. The rest of the resources after the constraint resource follow the drum in a forward schedule.

DBR emphasises the difference between constraint resource and non-constraint resources. Any activity in the constraint resource directly impacts on throughput, whereas the non-constraint resources necessarily use their capacity to protect throughput. The constraint resource determines the productive capacity of the company. Instead of having protective capacity to overcome disruptions and non-instant availability, the non-constraint resources often have excess capacity than can be sold to produce other products. This excess capacity is an extra capacity above protective capacity.

In summary, DBR helps the flow of the parts through the resources to produce throughput and to maintain market responsiveness. A drum dictates the overall schedule of other resources to meet orders. Throughput is protected from disruptions by employing a protective buffer and protective capacity. A rope represents the release point control that includes a time buffer and total processing time of the non-constraint resources before a part consumed by the constraint resource. The parts prepared at the release point according to the drum beat flow smoothly through the resources by allowing transfer and process batches. The priority to push the parts to the resources follows First-Come-First-Served (FCFS) dispatching rule. This typical DBR scheduling mechanism can be implemented to achieve low work-in-process inventories, fast flow times, and improved productivity.

Buffer Management

Buffer Management attempts to improve scheduling progress based on appropriate data captured during implementing DBR (Schragenheim and Ronen, 1991). These data reveal the disparity between the actual versus the planned schedule. Substantial improvement efforts can be defined to eliminate the causes of disparities. In this sense, Buffer Management involves three stages: planning, monitoring, and improving as shown in Figure 1.

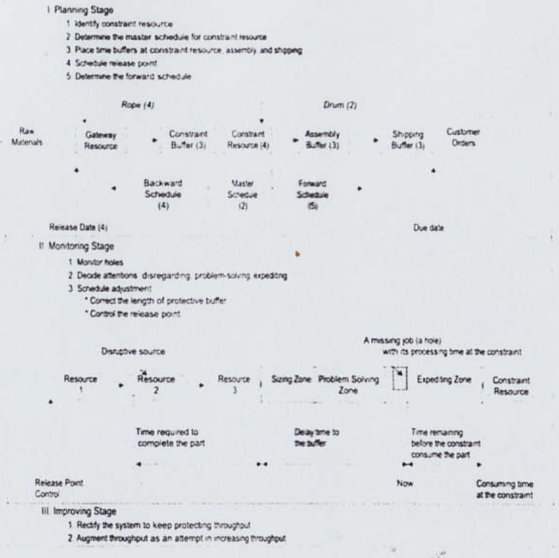

Figure 1. Planning, monitoring, and improving stages of Buffer Management

The DBR scheduling constitutes the planning stage in Buffer Management. It provides an excellent due date performance while at the same time minimising work-in-process inventories. In this stage, five steps must be followed: identify the constraint resource, determine the master schedule for the constraint resource, place time buffers in critical locations to protect throughput, schedule release points in the form of a backward schedule, and determine the forward schedule for the rest of the resources after the constraint resource.

Monitoring the buffer status in front of the resource constraint is the second stage. This stage is critical to know how far the actual buffer differs from the planned buffer and to adjust the schedule. The planned buffer time usually contains several parts or jobs that wait to be processed over a certain period of time. The sequence of these jobs, including the required processing time at the constraint resource over a period of time, is termed buffer content.

The profile of the protective buffer can be analysed by comparing the actual and planned buffer content. Because of the impact of inevitable disruptions, the actual buffer content always differs from the planned buffer content. The comparison between the actual and planned buffer content shows the missing parts that should arrive at the protective buffer, but are not there. This profile provides clues about the health of the system. The problems of the prior resources or at the release point can be anticipated by monitoring missing parts or holes in the protective buffer zone (See the illustration of Monitoring Stage in Figure 1). Each hole indicates: delay time of missing part at the protective buffer (L); missing part's processing time required at the constraint resource (Z); time remaining before the constraint resource consumes that missing part (R); and actual time required for the prior resources to recover from disruptions and to complete the missing part (P). The combinations of these variables can be used to identify the effect of disruptions on the protective buffer and also bases to make adjustment. For instance, Schragenheim and Ronen (1991) use delay time at the protective buffer (L) as an indicator to expedite a part. If this delay time has passed a checking-point at half the time buffer, then expediting should be taken.

Umble and Srikanth (1990) define individual disruption factor for each part as delay time (L) multiplied by processing time at the constraint (Z) which indicates the relative amount of damage done to the protective buffer. The most significant sources of disruption in the production line can be determined by calculating a cumulative disruption factor for each resource. Managers may use this information to prioritise concerns of improvement.

The appearance of holes in this buffer zone helps managers to define actions: whether to disregard, solve the problem, or expedite. If holes appear in the red zone near the scheduled constraint resource, expediting should begin immediately on those parts. Otherwise, the missing parts will threaten the throughput. Expediting is a process of recovering the system from perturbation by implementing resource allocation strategies. In the middle zone, the missing parts should be traced to find when and where the problems and to decide on-going improvement efforts. Hence, the middle zone is termed the problem-solving zone. Any hole in the last-third zone will be disregarded since it is still far away from consumption of the constraint resource and the prior resources can replenish that hole by using their protective capacities. Since most of holes appear in this region, it is termed the sizing zone.

Moreover, managers also use information from monitoring holes to correct the length of the planned protective buffer. If more than ten per cent of the parts in the red zone are expedited, it indicates the length of buffer is too small (Umble and Srikanth, 1990). The planned buffer needs to be immediately increased until the red or expediting zone is completely full. If the problem-solving zone is almost full, the planned buffer length is too large and needs to be cut to the level only if the expediting zone is totally full. If some parts have already arrived before the planned schedule at the sizing zone, it indicates that these parts are produced too early at the prior resources. The materials for these parts are launched prematurely at the release point. Managers need to promote discipline to control the input of materials at the release point.

Monitoring the protective buffer provides an opportunity to increase the competitive edge in delivering finished goods on time. This opportunity does not only depend on the awareness of holes to decide attention and to control the release point, but also on the ability of defining ongoing improvement efforts. This is the last stage of buffer management (see Improving Stage in Figure 1).

The monitoring stage serves as the alarm of concern and the decision making of attention, whereas the improving stage is needed to rectify the system and to augment throughput. To rectify the system means to focus improvement efforts at the source of disruptions on the two lines of predetermined actions: problem-solving and expediting. This first step can use the tools of total quality management and just in time in order to obtain zero defects and zero wastes respectively. An augmenting throughput attempts to increase the throughput. The last step is realised by guiding productive maintenance to provide a reliable system.

In summary, Buffer Management promotes ongoing improvement by providing a signal system to eliminate potential problems that threaten to disturb the plan and to cause real damage. The improvement activities on the bottom line can be concentrated on problems at hand. Buffer Management is also a means for controlling resources activities and production lead-time. Besides that, Buffer Management also breaks the limit of improvement by involving maintenance to increase throughput.

Focused Productive Maintenance

A major trend in new manufacturing is increased investment in expensive equipment such as robotics, numerical control machines, and inspection tools. This obviously requires careful management and maintenance to evaluate and control the investment and effectiveness of equipment. Managers need to put a proper perspective on this maintenance function in providing fast time response. Maintenance function is not only devoted to support production system but also to driving continuous improvement to increase throughput. The real progress in increasing throughput is an operational target of focused productive maintenance that can be realised only by involving

entire workers (Patterson *et al.* 1995).

Focused Productive Maintenance is needed to ensure real progress in striving for profitability both in short and long terms. Buffer Management is used to direct TPM in creating FPM by focusing on a few critical resources and subordinating other non-critical resources to support the maximal contribution of the critical resources. FPM is based on four principles. Firstly, knowledge of operations in the production line, such as production process, equipment, scheduling, is utterly important to start preventive maintenance program. This helps to concentrate on key success factors and activity such as identifying a problem's cause and not only its effects. Moreover, knowledge of operations enables a company to develop its proprietary technology about the machinery. Other issues are the assurance of product quality through uniformity and reliability of equipment.

The second principle is the total participation of workers. FPM must be implemented on a company-wide basis. Workers involved undertake maintenance activity on their equipment. They share the preventive maintenance efforts, provide assistance to mechanics with repairs when equipment fails, and work in cooperation to improve process and equipment performance. Management support is the third principle to fully exhibit a commitment to productive maintenance such as training, recognition of success, infrastructure, and transfer of knowledge (Hipkin and Lockett, 1994). Managers need to set a training program for licensing their workers in basic maintenance. Finally, maintenance is dedicated to accelerating an increase in throughput, hence securing profits (Chakravorty and Atwater, 1994).

Improved operating time can be achieved by maximizing overall equipment effectiveness that works to eliminate the six big losses categorised into three aspects (Nakajima, 1988), these are: down time: (1) equipment failure, (2) set-up and adjustment; speed losses: (3) idling and minor stoppages, (4) reduced speed and defects: (5) process defects, (6) reduced yield. The overall equipment effectiveness is calculated as follows. Overall equipment effectiveness = machine availability x performance efficiency x rate of quality, or

$$\text{Overall equipment effectiveness} = \frac{\text{Planned time} - \text{Down time}}{\text{Planned time}} \times \frac{\text{Net operating time} - \text{Lost time}}{\text{Net operating time}} \times \frac{\text{Good parts}}{\text{Parts produced}}$$

Equipment effectiveness is a key measure which indicates the true effectiveness of equipment when it is running (Nakajima, 1988). This measure determines the actual outcome of a company in terms of the productive capacity of the constraint resource. A high equipment effectiveness (Nakajima suggests more than ninety percent) reflects the capability of a company to utilise its resources in response to the customers' demand in the market. Buffer Management helps the managers to focus on the critical resources that need high equipment effectiveness. In this case, the equipment effectiveness preferred for every constraint resource is one hundred percent to fully protect organizational performance. Thus the local measurement of equipment effectiveness of the constraint resource can be aligned with global organizational performance. Furthermore, the competitive edge of a company can be restored, since Buffer Management can provide a simple explanation of material flows, a proactive tool to detect potential disruptions, a way to control lead time, and a tool to guide ongoing improvement efforts. Meanwhile FPM ensures the constraint resource can work continuously and supports the overall manufacturing line through solving problems related to reliability and maintainability of equipment. Figure 2 illustrates the logic of how Buffer Management and FPM shapes the competitive advantage of a company.

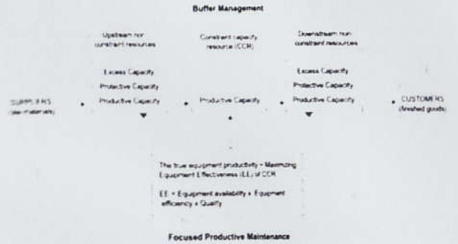

Figure 2. Restoring competitive advantage based on Focused Productive Maintenance

From the system's perspective towards company's goal, managers apply FPM through adopting the Five-Step Focusing Process. The Five-Step Focusing process of the Theory of Constraints (TOC) can be significantly helpful in guiding FPM to increase throughput at the system level (e.g. Goldratt and Cox, 1992; Chakravorty and Atwater, 1994). The Five-step Focusing Process enables the managers to determine the locations where FPM will meaningfully improve the system ability to increase profit in the shortest time. This Five-Step Focusing Process includes:

1. Identify the system constraint(s).

   Identifying the constraint resource is critical since it can inhibit growth in profit. There is at least one constraint resource in every production line. A constraint may be a physical resource such as raw material, money and capacity. Accumulated work-in-process inventories and frequently delayed due dates are signal examples of the finite capacity in a particular machine. Another type of constraint is policy or regulation.

2. Decide how to exploit the constraint(s).

   The constraint resource must be effective as possible to maximise the return per constraint unit. Managers devise a plan to maximise the flow of parts through that constraint. Before exploiting the constraint(s), the maintenance function must ensure that the constraint resource rarely or never breaks down. If the constraint is in the form of policy, exploitation attempts to replace this policy to enable the company reaching higher performance towards its goal.

3. Subordinate all other actions to exploiting the constraint(s).

   After the plan is organised to exploit the constraint resource, the other resources required to complete the manufacturing process should be aligned with the use of the constraint resource. DBR assists the managers to subordinate all other actions to exploiting the constraint resource, such as scheduling and controlling the material input and effectively utilising the non-constraint resources to ensure the flow of materials. The improvement efforts are based on the buffer information system at the factory level and supported by total participation in preventive maintenance at the equipment level. Actions can be conducted to solve problems at disruptive sources, and to expedite the delayed parts that potentially jeopardise throughput. Alarm at problem-solving zone calls for tracking the source of disruptions, eliminating disruptions by applying corrective maintenance to minimise repair time and costs, and avoiding repetitive set-up time during downtime. Expediting may include tracking the missing parts, recovering the breakdown resource through using corrective maintenance, and catching up the schedule by prioritising delayed parts to be processed at the non-constraint resources. Preventive maintenance at equipment level, problem solving, and expediting are required to attain equipment effectiveness. Achieving equipment effectiveness leads to a decrease in processing variability and upgraded safety. Minimising variability and unplanned failures results in an increased protective capacity, a reduced buffer length, and a more steady input control (the rope). Throughput will increase, delivery time will be shorter, and thereby a company will enhance its competitiveness.

4. Determine if it is necessary to elevate the constraint.

   Step four attempts to increase overall performance by concentrating continual improvement efforts on the constraint resource such as implementing additional preventive maintenance to increase its capacity and purchasing additional capacity. Other ways taken by management to expand constraint capacity are simplifying the operation process or shifting the burden of the constraint resource to other non-constraint resources. This obviously involves a capital investment in more equipment and some waiting periods before the new investment can put into operation. Hence this step is better not taken until the three-first steps have been accomplished. If the capacity problem is completely eliminated, the resource constraint is broken.

5. If a constraint is broken in the previous steps, then return to the first step and repeat the process for the next constraint, but do not allow inertia to cause a new constraint.

   This step is to anticipate the deterioration of current improvement efforts by identifying an erroneous operation policy before dealing with new improvement efforts. So if the current improvement efforts successfully stop the constraint resource being a constraint, and the company still cannot sell the products to the market, that means the constraint has already shifted to another resource. Go to step 1 to keep maximising throughput by adapting the new improvement efforts to the new constraint. However, managers should be aware of the market place as the next constraint.

The five-step focusing process also helps managers to realise synergistic effects of combining focused productive maintenance with total quality management and just in time simultaneously on the same problems. Managers face the pressure of competition without bothering to lose the competitive edge in applying FPM to gain more throughput, a lower work-in-process inventories, and a lower maintenance cost. Periodic evaluation directly spots the source of the problems. In doing so, equipment effectiveness can be restored in short time and at the same time continual improvement is suggested to eliminate six big losses. Consequently, focused productive maintenance upgrades the consistency and reliability of manufacturing performance, thereby decreasing the production variability.

Avenues for Future Research

Buffer Management provides some significant research agenda. In the planning stage, some researchers have advocated an iterative process to determine the initial buffer length based on the proportion of current manufacturing lead-time. More precise heuristics to estimate the buffer length are needed to improve the performance of the shop floor in delivering the customers' demand. For example, Goldratt (1990) refers to dynamic buffering to eliminate the waiting time of parts in the shop and Hurley (1996) outlines a concept of buffer heuristic method to expedite the potential late orders.

In the monitoring stage, an effective report system is needed to inform the status of disruptions on the upstream resources. The future research can be addressed to develop an information system to exhibit the performance of the non-constraint resources. The data can be used to initiate continuous improvement. This reporting system should be conducive to the principles of FPM, especially if real time production control is of interest. The relationship between protective capacities of non-constraint resources and the lead-time based on buffer status is also interesting to examine. Moreover, research on identifying the difference among productive capacity, protective capacity, and excess capacity can create a more flexible manufacturing company in terms of product mix and resource utilisation.

The knowledge of Buffer Management can be transferred throughout other divisions within the company. Research on training material is needed to enhance workers' knowledge in mastering the logic of FPM, for example the link between Buffer Management and FPM to increase the performance of the overall company. The understanding of various trade-offs in managing resources helps workers to choose reasonable trajectories of operations policies on the shop floor, thereby empowering them to conduct continuous improvement.

Concluding remarks

Focused Productive Maintenance is not only to support the reliability of manufacturing line but also directly to improve bottom-line performance. Five-step focusing process helps focused productive maintenance in figuring out the priority of maintenance and improvement efforts to eliminate unplanned equipment downtime. On the shop floor, Buffer Management is a proactive approach to fully protect throughput. Therefore, profitability would result from more reliable and effective equipment.

FPM is a people-oriented concept, which aims to promote a culture in which workers take responsibility for the care and routine maintenance of their equipment and workspace. To quicken the improvement process, Buffer Management provides workers with an alarm system to concentrate on problems, diagnostic and equipment improvement efforts. Obviously, FPM improves the overall effectiveness of equipment, with the active involvement of workers.

Implementing FPM will allow people to take part creatively by mastering knowledge of process, resources, tools, and performance measurement. The true power of focused productive maintenance is tapping the knowledge and experience of all workers to generate ideas and contribute to the goal of the company, which is to make profit now and in the future. Moreover, management support is indispensable in harnessing the advantages of FPM in the long run. FPM is akin to a root enabling a manufacturing company to grow up in quality and finally to reap benefits of the profitable maintenance process.

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