

# How to manage your assets effectively? Understand the dynamics that govern companies' asset management system

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## **1 Abstract**

The importance of physical assets has been increasingly recognized in recent decades. The significant returns on small improvements in Overall Equipment Effectiveness which is a main measure of companies' operation and production effectiveness and has a significant role in preserving safety and environmental integrity of companies, justify investment in the management of physical assets. On the other hand, there exists wide variation of OEE across firms which raises a question: why do these differences persist despite a high return on investments to maximize OEE? To address this question we need to better understand the dynamic processes that control the evolution of OEE through time.

Building on insights from system dynamics and strategy literature, we seek to answer the above question by mapping the reinforcing loops governing the maintenance function and its interactions with various elements in a firm. These elements can be cultural, economical, human psychology, and organizations' limited resources. We draw on previous literature, extensive case studies and consulting projects to provide such mapping using the qualitative mapping tools from System Dynamics.

Our research outlines several reinforcing loops; once active, any of them could lead a firm towards a problematic mode of operation where reactive maintenance, poor moral, ad hoc processes, financial pressure, and a culture of fire-fighting dominate. The activation of these loops is often triggered by actions with the best of intentions. However these actions which are taken to fix problems in the short-run often activate vicious cycles, erode the capability of the organization over the long run, and lead to a lower OEE.

Knowing the factors affecting the asset management function of a plant increases the plant's safety and limits its environmental hazards in addition to significant costs savings and higher return on shareholders' investment. The strategic importance of OEE and its effect on companies' market capitalization is an important aspect of this research that has been ignored in almost all available literature in this field.

## **2 Importance of maintenance function**

The importance of physical asset management to a firm's success has increased over recent decades. Automation is one reason for this trend, as it has forced industries to delegate more tasks to machines, thus making maintenance more crucial. The *perceived* significance of maintenance by management spans a wide variety of perspectives. Some see it as merely repairing broken equipment in a plant; others take a broader view and see it as critical to a firm's profitability (Tsang, Jardine & Kolodny 1999). Three perspectives can be identified in this regard:

- Cost Centre View
- Production Capacity Assurance View
- Strategic View

The strategic view is increasingly important; however, the others have not disappeared completely and can be found in industrial plants around the world.

### **2.1 Cost centre view**

In the past, maintenance was seen as an unavoidable expense that had to be minimized. With automation, maintenance costs increased and gradually attracted the attention of management. In a benchmarking exercise, Wireman (Wireman 1990) found that the maintenance cost for industrial firms in the USA has grown by 10-15% per year since 1979. However, maintenance costs as a percentage of

companies' operation expenses vary from industry to industry. Retail industries, for example, use fewer and simpler machineries and pay less for maintenance. But mining, oil, gas, and petrochemical industries are asset intensive, and their maintenance costs are a significant portion (30%-40%) of operating costs. Maintenance costs as a percentage of operational costs depend on the design of the plant and the quality and type of machinery, but overall the maintenance departments have more influence on the top management where maintenance costs are a larger portion of operating costs.

## **2.2 Production capacity assurance view**

Starting in the 1980's, and after the introduction of Total Productive Maintenance (TPM), the maintenance function gained recognition as a main contributor to companies' Overall Equipment Effectiveness (OEE). As the main measure of a company's effectiveness, OEE is widely used in TPM and lean manufacturing. OEE is a quantification of how efficiently and effectively a company performs compared to its designed capacity, during its scheduled run time. An advantage of OEE is that it can be broken down into three measures that can be tracked rather easily. OEE is the product of Availability, Performance, and Quality. Availability is defined as the portion of scheduled time that the equipment is ready for production; performance measures the speed with which the equipment is operated during its scheduled production time compared to its nominal capacity; and Quality measures the percentage of products that meet the minimum quality requirements. While OEE standards are a function of industry and equipment types, approximate world class benchmarks for each of these measures are (from [www.oee.com](http://www.oee.com)): Availability: 90.0% Performance: 95.0%; Quality: 99.9%. Therefore world class OEE ranges around:  $90\% \times 95\% \times 99.9\% = 85\%$

Maintenance function affects all OEE constituting measures. For example, Availability is heavily affected by maintenance. All planned shutdown and maintenance activities reduce equipment availability and, hence, affect the company's OEE. Performance is also affected. Any unplanned shutdown and breakdown reduces performance. After each stoppage, a certain amount of time is wasted to bring the production rate back to its normal speed, again decreasing performance. Finally, with respect to Quality, faulty equipment and breakdowns create deficiencies in the final product. They also cause work-in-process to be wasted, especially in process industries, again leading to reduced quality of the product.

Knowing the direct and significant effect of maintenance on OEE, management now realizes the importance of maintenance, no longer seeing it as a cost item that needs to be minimized. Now maintenance expenditures are seen as investments which have major returns, especially if the company is capacity constrained. In commodity industries, being able to increase OEE by a even small margin can create a significant competitive advantage since it reduces the production cost per product volume, yielding a higher profit margin and/or providing more flexibility in potential price wars.

## **2.3 Strategic view**

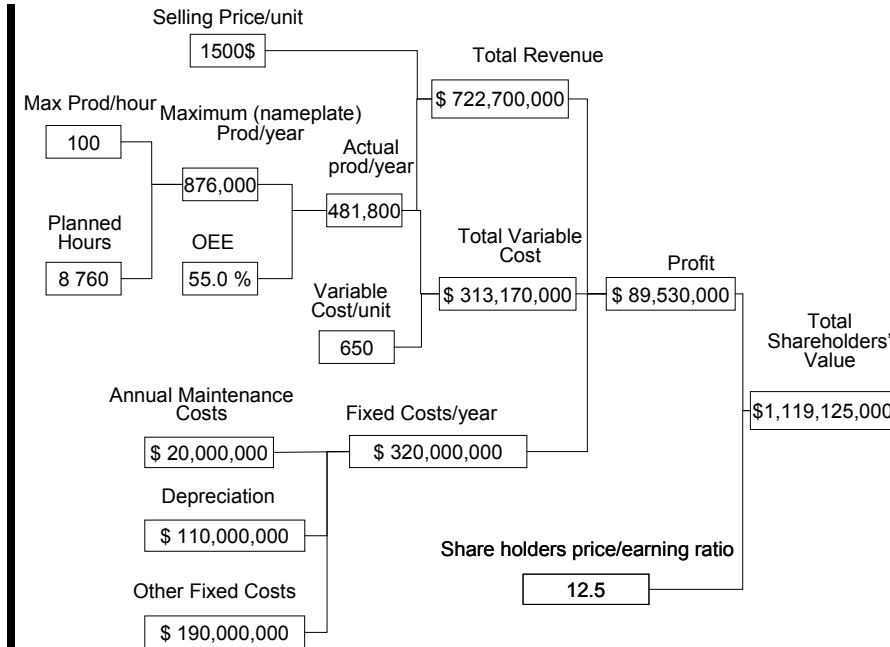
Most environmental and safety related accidents can be connected to asset management practices, and companies now pay more attention to safety and environmental aspects of their operation due to growing public awareness and stricter government regulations. Companies who cannot fulfill their safety and environmental obligations face severe financial punishment in the form of lawsuits and government fines, sometimes leading to bankruptcy. This trend has accelerated because of several recent events, including (Mather 2004):

- Space shuttle Colombia disaster in 2003 which resulted in the loss of all seven crew members.
- August 2003 blackout in northeastern United States and southeastern Canada which lasted 24 hours and cost the economy billions of dollars. It was the most widespread electrical blackout in history, affecting 35 million people in Canada and the USA.
- Hatfield rail crash in United Kingdom on 17 October 2000 which resulted in charging the people responsible for maintaining and managing the railway, including the ex-CEO, with manslaughter.
- New Canadian legislation imposes criminal liability on individuals and companies in the event of workforce accidents.

Thus the importance of asset management has increased, making it a strategic function.

Moreover, the effect of maintenance on OEE and the crucial role of OEE on a company's competitive advantage have been revealed in recent studies. Moderate changes in OEE can result in significant changes in return on investment. For example, Oliverson (Oliverson 2006) shows that a 10-unit increase in a company's OEE can almost double that company's returns.

In fact, this view can be taken further, as returns on assets directly impact a company's share price. The following graph describes a company with OEE of 55%. Under current conditions, the company's profit is estimated to be around 90 million dollars. Its total asset value is \$1,190,000,000 which results in a return on assets of 7.52%. If the shareholders are willing to receive 8% on their investment (equivalent to price/earning ratio of 12.5), the current total value of a company share or its market capitalization (or total shareholders' value) is  $89,530,000/0.08 = \$1,119,125,000$ .



**Figure 1: Return on asset for a company with OEE of 55%**

Keeping everything else constant, if the company improves its OEE measure by 10 units, its financial status becomes:

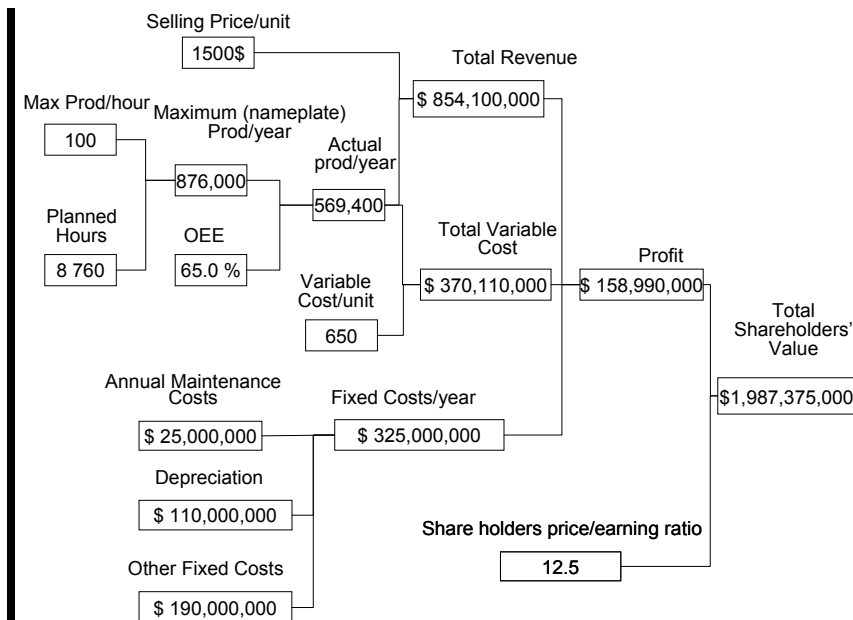


Figure 2: Return on asset for a company with OEE of 65%

If the same return on investment is considered, then the company's total share value is \$1,987,375,000. This shows that with a 10% increase in the company's OEE, shareholders earn \$1,987,375,000 - \$1,119,125,000 = **\$868,250,000**, a huge gain. Clearly, factors influencing OEE are critical strategic success factors for any firm.

#### 2.4 Understanding OEE variability

Given the critical role of OEE in a firm's success, the next question is whether one can change OEE. If OEE remains largely constant or outside management control across an industry, it has little strategic value. However, data suggest otherwise: OEE measures vary widely, as Wireman (Wireman 2004) observes – between 20% and 85+% -giving it great strategic leverage. It seems that certain mechanisms keep firms' OEE measures across industry from converging to the same values; thus, there are leverage points at management's disposal which, if correctly applied, can significantly change a firm's competitiveness. To gain insight into the strategic value of asset management, we study the causal mechanisms that can explain variability in OEE across otherwise similar firms.

A large literature focuses on variability across organizational characteristics. For example, understanding performance heterogeneity is a defining question in the field of strategy (Grant 2002). A key insight from this literature is that reinforcing feedback mechanisms are at the heart of sustained differences across similar metrics in a group of organizations (Arthur 1989). For example learning curves (Argote, Epple 1990) become a source of competitive advantage; as firms gain experience, they drive down their costs and increase their market share, thus increasing their experience and widening their edge over competitors. Network externalities include similar reinforcing mechanisms: as a company's network of customers grows, the utility of its products for new customers increases, leading to an increased market share, more customers, and a more attractive product (consider impact of free in-calling in mobile phone networks) (Katz, Shapiro 1992). Similar dynamics are found in word of mouth sales (Dodson Jr, Muller 1978) and economies of scale and scope (Panzar, Willig 1981), among others. The basic insight common to these examples is that reinforcing feedback mechanisms (e.g. learning → Reduced Cost → More customers → More Learning) amplify small differences among different organizations in a success-to-successful process that leads to large, sustained differences (Frank, Cook 1995).

We build on this insight by analyzing the reinforcing mechanisms that can dominate in the evolution of OEE in an organization. By doing so, we highlight the critical mechanisms that distinguish

between successful and unsuccessful firms. Such causal maps can help managers diagnose the dynamics that keep their facility behind in the competition; they can devise appropriate remedies and learn to maximize OEE.

### **3. Dynamic mapping of the maintenance function**

To look into feedback mechanisms controlling OEE, we use dynamic mapping, which develops a detailed map of causal relationships between factors that affect performance of a system. We adopt causal mapping tools from System Dynamic (SD) (Sterman 2000)(Forrester 1961), which provides a toolbox for studying the behavior of complex dynamic socio-technical systems and proffers techniques for developing causal maps or causal loop diagrams (CLD). These diagrams show how components of a system affect each other, and these causal relationships are at the heart of how organizational performance changes over time. With SD techniques, one can map the dynamics of cause and effect relationships between important components of a system. Important components and relationships are those deemed to determine the behavior and as a result the performance of the system. This approach shares commonalities with strategy mapping proposed by Kaplan but has important differences:

- Strategy mapping focuses on interactions between very significant factors at the corporate level and is not detailed enough to depict the dynamic behavior of support functions such as maintenance.
- The relationships in a strategy map go in one direction: i.e. if X impacts Y, the reverse is typically not considered. However, studies in physics, engineering, and the social sciences have established that *feedback loops* are at the heart of dynamics of change in different kinds of systems. SD focuses on capturing not only one way links, but also feedback causal loops, where causality can go both ways. For example, population increases birth rate which, in turn, increases population; this basic reinforcing feedback loop is at the heart of the exponential growth of world population in the last two centuries. Such reinforcing dynamics are counter-intuitive, because they move systems towards extremes of growth or decline. Reinforcing loops amplify a small change in the system and can eventually lead to large changes. They are called vicious loops if they make a situation worse, and virtuous loops if they improve it. A plethora of studies at the organizational level show how reinforcing loops are behind many functional and dysfunctional organizational behaviors, such as corporate growth (Sterman 2000), delays and cost over-runs in projects(Lyneis, Ford 2007), product development failures (Repenning 2001), and process improvement abandonment (Repenning, Sterman 2002). As discussed above, reinforcing loops are commonly the mechanisms which distinguish between successful and unsuccessful firms.

In fact, there is precedence in applying SD to maintenance problems. One of the first applications of SD in modeling the behavior of a maintenance organization is a case study by Winston Ledet (Sterman 2000, LEDET 1999). Ledet, then a manager at DuPont, was part of a benchmarking study which showed that in spite of spending more money on maintenance, DuPont had lower uptime compared to its rivals. This counter-intuitive finding caused management to investigate. They found that the underperformance was related to several vicious reinforcing loops. Pressure to have more production results lead to less time for preventive maintenance activities, which results in more costly and time consuming reactive maintenance, ending eventually in less uptime. Less uptime will increase pressure on production, and the cycle will continue. We build on this study in the current paper.

Jambekar (Jambekar 2000) used SD to show how different improvement programs such as TPM and TQM are not usually as successful as they should be. He claims that the temporary decline in performance immediately after implementation of such programs, due to the learning period, can curtail the programs prematurely. The literature of explaining dynamic behaviors related to maintenance function is limited however; most studies deal with maintenance briefly, merely to show how it affects the behavior of the organization in general.

In the remainder of this paper, we use SD to build a comprehensive model of causal relationships that govern the performance of maintenance organizations as they relate to OEE, seeking a nuanced understanding of drivers of OEE heterogeneity across firms. In sections 3.1 to 3.7 we introduce causal loops that our fieldwork, previous research, and literature review have found to be significant to maintenance operations. We focus on reinforcing causal loops because, as discussed in section 2, they are central to understanding variations in OEE across organizations. Each loop is a self-contained unit

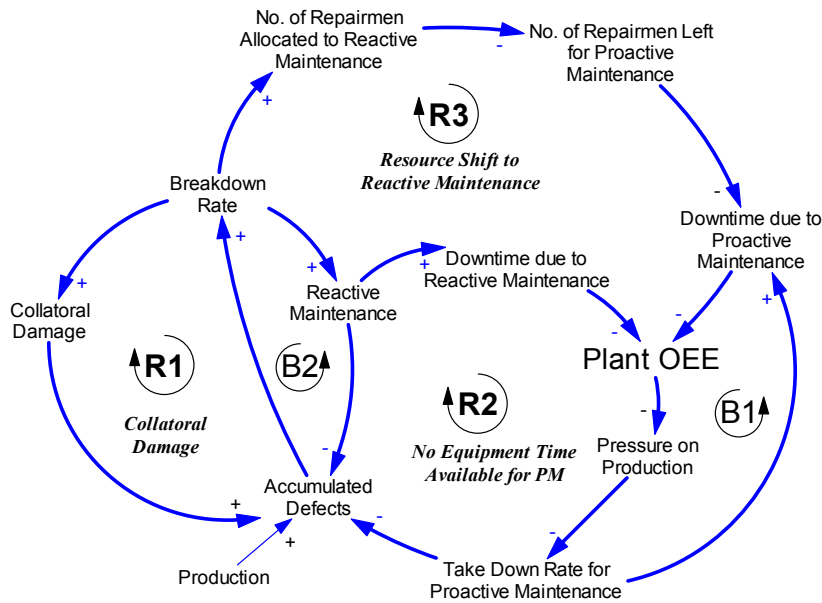
that we have observed at least in one organization; not all loops are active in all organizations. The results are built on a review of the literature, the experience of the authors who visited and audited more than 50 plants, formal interviews, and hours of discussions with maintenance managers and consultants in the industry.

### **3.1 Production pressure and maintenance performance**

The first diagram (Figure 3) depicts factors affecting plant OEE and their interrelationships. Arrows denote the relationships between components, and the sign on the arrow indicates the nature of the relationship. A positive sign means that any increase in the first variable will result in an increase in the dependent variable. A negative sign means any increase in the first component will result in a decrease in the dependent variable. Plant OEE is the main determinant of plant performance; any shortfall in OEE increases the “pressure on production” to reach the production targets, hence the negative sign for the link from plant OEE to pressure on production. Maintenance impacts plant availability and thus OEE through both proactive and reactive maintenance. Activities such as fixing broken items or preventing future failures by performing proactive maintenance reduce availability and have a negative link to OEE. However, there is an inherent tradeoff between proactive and reactive maintenance as they both use the same pool of resources (people and equipment). They also achieve a similar goal (keeping the system running) albeit through different channels: if the production staff releases equipment staff for routine preventive tasks, maintenance personnel can detect failures in their early stages, well before they become critical and lead to failures requiring reactive maintenance. Appropriate corrective or repair actions can be taken in a scheduled manner, minimizing equipment downtime. In addition, required staff, spare parts, and tools can be scheduled in advance, avoiding the need for expensive expedited orders or workforce overtime wages. If maintenance follows this path, breakdowns will be under control over time, resulting in higher OEE, despite regular downtime.

However, the real situation in an operation and maintenance environment is typically far from ideal. Operation is regularly under pressure from top management to meet output goals. This pressure can become extreme if there is a spike in demand or if an unintended long shut-down has reduced output for some time. In these situations, there is a temptation for operation to increase OEE by postponing certain proactive and preventive activities. Figure 3 demonstrates this tendency through the negative link from pressure on production to the “take down rate for proactive maintenance” (Balancing loop B1).

As shown in Figure 3, pressure on production prevents production from allowing the maintenance crew to access equipment for Proactive Maintenance (PM) activities (we assume proactive to include preventive actions as well). While this helps meet production targets in the short run, latent defects increasingly accumulate in the equipment. This process of wear and tear continues, and potential failures not found and fixed by PM eventually cause the equipment to break down.



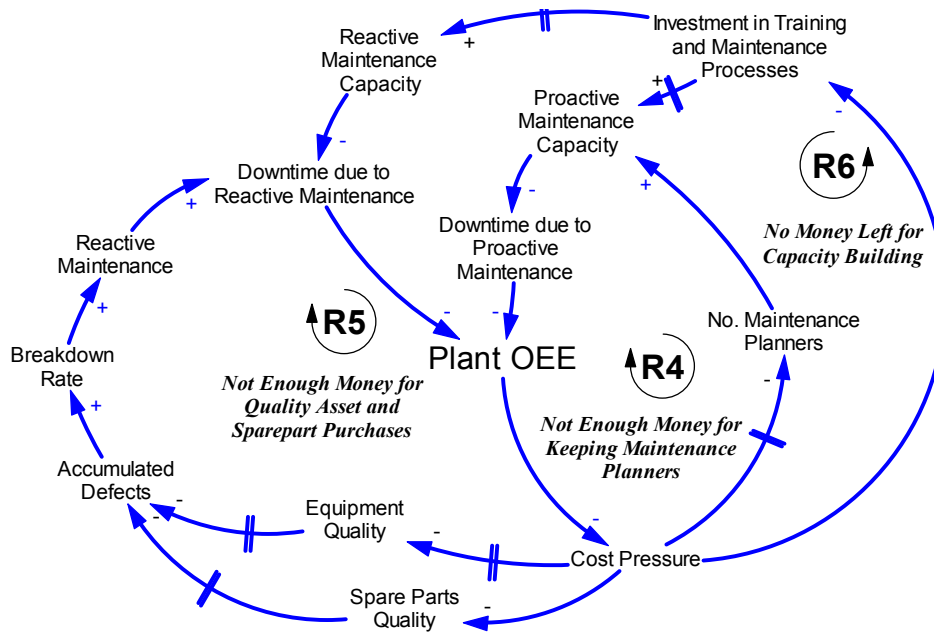
**Figure 3: Proactive maintenance loses ground to reactive maintenance**

Breakdowns usually have secondary effects we call collateral damage. That is, due to breakdown, other parts of the system, not previously damaged, are strained or become defective. For example, a seized bearing can bend the shaft or damage the electrical motor by putting more pressure on it. These damages increase the accumulated defects and add to future breakdown. This last link completes the first reinforcing loop, R1, which we name “Collateral Damage” to capture the crux of the dynamic: breakdowns lead to collateral damage, increasing the accumulated defects and further pushing up the breakdown rate. Breakdowns also need emergency reactive maintenance that removes some accumulated defects (B2 loop) but leads to downtime. These downtimes, in turn, result in production losses, which increase pressure on production, and the cycle continues as proactive maintenance is ignored (R2: No Equipment Time Available for PM). In many cases, emergency maintenance requires over-time work, the ordering of emergency spare parts, and switching resources from tasks with lower urgency to fixing breakdowns. Proactive tasks are low-urgency, and as resources (staffing, tools, spares) are taken away from PM activities, they are executed more slowly and with lower quality, ultimately resulting in more downtime than in the original estimates. This puts more pressure on production, closing another reinforcing loop (R3).

A critical insight is that all these reinforcing loops can also act in a virtuous direction: finding time for preventive maintenance can reduce accumulated defects, reducing breakdowns and improving uptime and OEE, thus releasing much-needed resources for further preventive maintenance. We introduce the dynamics in the vicious direction mainly because these painful stories more clearly connect with the day-to-day experiences of managers.

### 3.2 Effect of cost on delaying investment with long term returns

The previous scenario reflects what happens in the short term with excessive pressure on production and sacrifice of proactive maintenance. Next, we discuss dynamics that unfold in longer time horizons and relate to the financial impacts of maintenance activities. For presentation clarity, we remove previous loop labels and arrows/variables not used in the new dynamics.



**Figure 4: Long term investments are ignored over short term financial performance**

A downturn in OEE leads to partial loss of revenue and thus, increased cost pressure. Moreover, having many unforeseen breakdowns creates a fire-fighting situation in which the availability of resources is unpredictable. Resource limitations and uncertainty make planning and scheduling efforts less effective which, in turn, cast doubt on the value of planners whose jobs do not directly contribute to the bottom-line. Cost pressures act as a catalyst, and the company starts to relocate planners to other jobs or to lay them off. This reduces quality and quantity of PM activities, further reducing future plant OEE (R4). The significant delays involved in causal links are highlighted by two parallel lines on the arrow.

Cost pressures can also cause companies to purchase lower quality spare parts and equipment. Low quality spare parts become defective more quickly, leading to more accumulated defects in equipment. The same trend appears when equipment of lower quality is substituted for the higher quality equipment purchased when the company was not under financial pressure. Increased defects lead to further breakdowns and lower OEE (R5). This loop includes important delays and therefore is not as salient when managers are making hard tradeoffs for allocating limited funds.

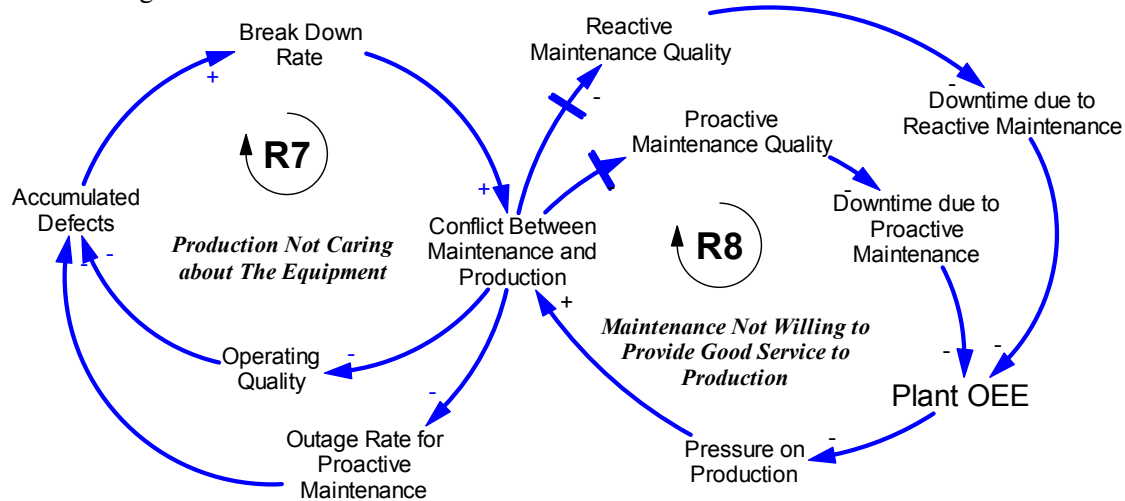
Management which is under financial pressure also regularly cuts investments in employee training and maintenance process improvement. This dynamic is not limited to maintenance department, as training and process improvement activities are among the first to be sacrificed company-wide in hard times. Its impact is, however, often more severe in the maintenance department because benefits of trainings and improved systems are ignored more often in support functions such as maintenance. Less investment in training and maintenance processes reduces maintenance capacity. This, in turn, leads to longer repair time, lower quality repairs, and less efficient use of resources – resulting in more financial pressure through reduced OEE (R6).

### 3.3 Conflicts between maintenance and production

In this section, we focus on the interaction of maintenance and production. Many production and maintenance employees have experienced the conflict that arises between the two functions when a serious breakdown happens while production is under pressure to meet targets. In fact, the relationship between production and maintenance is often governed by a culture of mutual blame. Production blames maintenance for unexpected breakdowns, being slow in repairing the broken equipment, doing poor quality repairs, not coordinating time of PM activities with production well in advance, among others. Meanwhile, maintenance blames production for not operating the equipment properly, not reporting an impending failure, not letting maintenance do its PM tasks to prevent breakdowns from happening, and



so on. A simplified version of these conflicts, which include other reinforcing loops influencing OEE, is shown in Figure 5.



**Figure 5: Conflicts between maintenance and operation causes more downtime**

Output pressures and high breakdown rates are potent ingredients for conflict between maintenance and production, and continued conflict further reduces collaborative tendencies. For example, operators become less concerned about the equipment's handling. They see the maintenance crew as their competitors or even enemies. Thus, they become reluctant to spend much energy to maintain the equipment, a job perceived to belong to maintenance staff. They gradually become less concerned about incipient failures and the proper operating of equipment which ultimately results in more accumulated defects and breakdowns, adding to the current conflict between production and maintenance. They may even stop cooperating with maintenance in releasing equipment for PM tasks, as operators argue, "What is the point of having PM when we experience so many breakdowns?" This behavior results in more breakdowns, less OEE, and more conflicts (R7).

Lack of care and responsibility can also originate from the maintenance side. Maintenance personnel under constant operators' nagging may be less willing to provide timely service to production. This reduces repair quality, slows the repairing of broken items and PM tasks, and reduces willingness to give production shutdown notices in a timely manner, among others. These behaviors results in longer down times, creating more conflict and closing another reinforcing loop (R8).

### 3.4 Effect of excessive breakdowns on an organization's culture

In this section, we discuss the causal relationships that connect organizational culture with the maintenance function. As time passes, and pressures discussed in previous parts persist, plant employees get used to a reactive environment, and this turns into a new norm. Persistence of this trend creates a generation of employees who have seen only reactive behaviors and cultures. In such a culture, PM is seen as a futile practice, only reducing equipment uptime which otherwise could be used to produce more products. Operators become increasingly unwilling to let maintenance crews access the equipment for PM activities. This, in turn, results in more failures over time, and the cycle continues. The corresponding dynamic (R9) is depicted in Figure 6.

A more subtle process can reinforce these dynamics. High reactive maintenance rates give opportunities for repair staff to demonstrate their capabilities by bringing back broken equipment to production. In this fire-fighting environment, the one who can extinguish a fire faster gets better recognition. This reward process attracts other capable repair staff from less interesting positions, such as PM and planning, to more appreciated positions, such as fixing broken equipment. As a result, the quality of PM activities declines, sealing a self-fulfilling prophecy that maintains that PM does not pay off (R10).

A culture is shaped over a relatively long time (hence the delay signs on the corresponding arrows), and once established, it is very difficult to change – it is hard for plant and maintenance managers to move from a reactive culture to a proactive one.

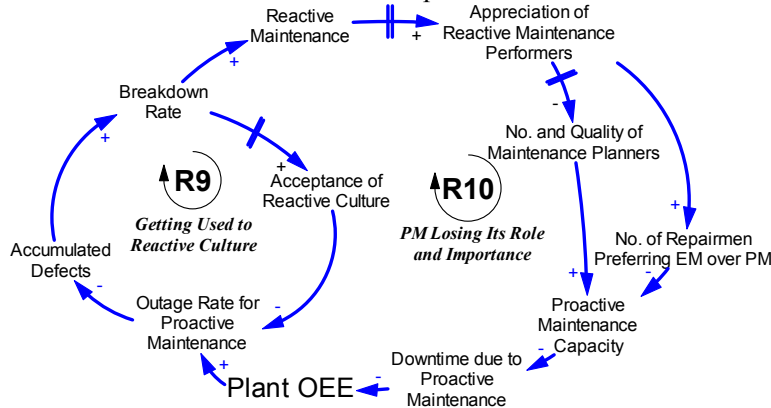


Figure 6: Change of the organization's culture from proactive to reactive

### 3.5 Effect of excessive breakdowns on a company's long term success

The consequences of maintenance activities are not limited to the plant's boundaries. Frequent breakdowns cause unplanned downtimes which hinder delivery of products to customers. Persistent delivery delay gives the company a poor delivery reputation. Customers penalize the company by paying less for the same product, which creates further financial problems for the company. Management will pressure the plant managers to cut costs and increase output which results in fewer resources for PM tasks (R11).

A similar dynamic emerges in product quality. In many industries, breakdowns introduce product defects. Defective products damage a company's reputation, reducing the selling price and the number of customers, resulting in financial pressure and further problems in maintenance organization (R12).

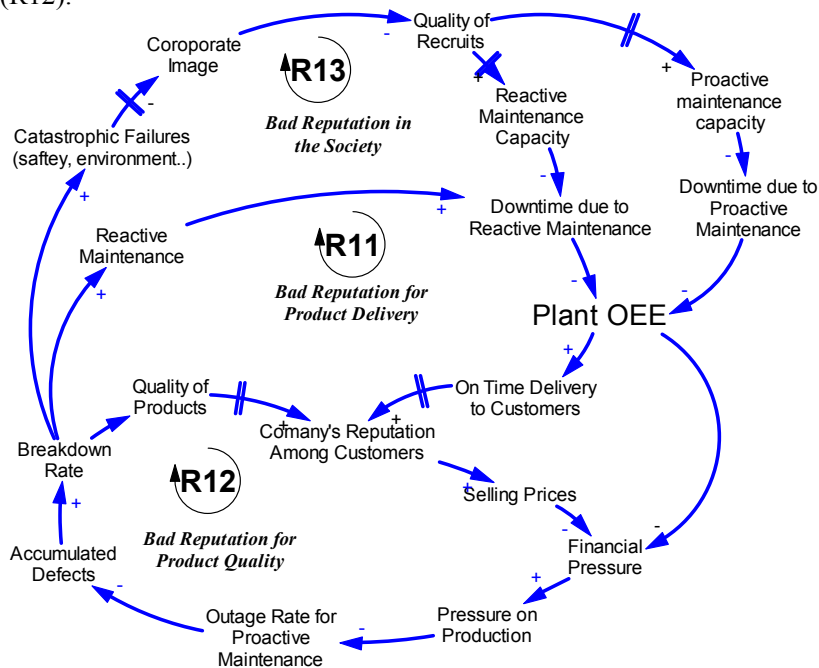


Figure 7: Company's reputation will decrease over the time due to frequent breakdowns

Finally, because of the unpredictable and uncontrollable nature of breakdowns, they are typically the main source of safety and environmental hazards. Expensive fines and lawsuits increase

the financial burden on the company (this creates another loop, not shown here). Companies with low safety and high environmental hazard rates also lose status in society and in the labor market. Highly competent job applicants prefer companies with good reputations or demand higher salaries if they are asked to work for companies with an unfavorable image. Over time, this will reduce the quality of the recruits and add to the company's problems. In loop R13, we show the effect of the quality of recruits on the maintenance activities central to this paper, but similar feedback is found throughout the organization. Low quality recruits will under-perform as planners, maintainers, and repair staff. This reduces a plant's OEE, the company's revenue, and PM activities, and eventually results in more breakdowns.

### **3.6 An organization's loss of faith in itself**

If a company is unable to manage breakdowns and reduce emergency incidents, over time, the employees whose jobs are affected by such an environment seek ways to remedy the situation. In a reactive organization, failures happen unexpectedly, and inventory systems cannot predict and order required spare parts well in advance. Lack of required spare parts results in longer equipment downtimes, and this increases pressure on maintainers. In response, maintainers may keep critical spares handy, just in case, gradually creating unofficial and local spare part inventories. This short term solution reduces the need to deal with the root cause of the problem – a reactive organization with poor work management. Those parallel systems or shortcuts undermine improvement projects in the organization. The following case study from an OEE improvement project undertaken by one of the authors reveals some of these dynamics.

The plant in question had some serious design issues which were revealed shortly after the owner took over from the contractor who built the plant. Because of the design issues, the plant suffered from frequent breakdowns and unscheduled shutdowns. After a few months, the management decided to establish a new group within the maintenance department. Composed of the plant's most skilled maintainers, the group was organized in such a way as to attend to breakdowns promptly and resume production by applying quick-fixes. They then passed the problem on to regular maintainers who later performed a more complete repair job. Over the years, this group had gained respect; they were seen as the ones who had saved the plant on many occasions. High bonuses, respect from management, and freedom from bureaucracy (they did not need to do proper planning and scheduling or fill out work orders, and had their own private spare parts inventory, etc) had made this group seem a utopia in the eyes of other maintenance technicians and engineers.

At the time of our engagement, the plant was 15 years old. After four or five years, the plant had solved most of its technical and design problems, but the group was still operating in the maintenance department. They had gained such prestige that they managed to live in the organization even though they had not been needed for 10 years. The group still had the most skilled maintainers, and the head of the group was the second most powerful person in the maintenance department. Because of this group, the maintenance department was not able to improve the quality of the work management and maintenance systems. Major maintenance activities could not be planned properly, as the group was not used to planning and scheduling; it was responsible only for taking action in times of major breakdowns. Spare parts inventory personnel were not able to predict required spare parts, since this group did not keep accurate records of used spare parts and was not willing to share its local and private inventory of spare parts with the central store. The same was true in other aspects of work management, such as estimates of required manpower to do a specific job. Since a significant part of the maintenance activities was not recorded or managed properly, others in the maintenance department had little incentive to do their job properly. They asked, "Why do data collection, data recording, planning, and scheduling if many major activities don't go through the same process?"

On several occasions, the organization decided to persuade this group of highly skilled trades people to become more systematic in its operations. However, each time the group tried to become more organized, it lost flexibility. Performance decreased as a result of changes in routines, resulting in delays in responding to emergencies. The systematic method was quickly abandoned in favor of the previous practices. This resistance to system improvement led to less capable proactive maintenance practices, longer equipment downtimes and thus lower OEE, more pressure on production, less opportunity for conducting proactive maintenance and therefore more breakdowns. This dynamic had kept the

organization in reactive mode for 15 years, and the longer the company stayed in reactive mode, the more difficult it was to move out of it. The above dynamics are captured in reinforcing loops R14 and R15 in Figure 8.

Another relevant dynamic is what we call loss of faith in data collection. Maintenance is largely about controlling and improving equipment reliability. Reliability cannot be controlled and improved effectively unless it is measured, and this requires a great deal of accurate data. Those data include failure frequencies, PM frequencies, condition monitoring data, quality of spare parts, repair times, spare parts usage, etc. Some of these data are used to measure and predict the reliability of the equipment, such as failure frequencies, and others are needed for planning and scheduling purposes, such as repair times, spare part consumption, etc. If there are parallel systems such as those described above or maintainers are under constant work pressure with frequent disruptions due to emergency incidents, such data are either not collected or are not collected accurately. This results in poor planning, scheduling, and prediction of system reliability and reduces the proactive maintenance capacity of the company, resulting in more breakdowns, and the cycle continues. After a while, the data ceases to have an impact on planning (because of poor quality); employees realize this and have less incentive to collect data. This behavior is shown in loop R16.

Loop 17 depicts a similar dynamic with respect to management's interest in process improvement in maintenance function. If a company invests in systems improvement projects and does not see tangible results because of resistance in the organization and a lack of employee faith, management gradually loses interest in investing in improvement projects. These beliefs, when crystallized, make it difficult for the company to be receptive to future improvement suggestions made by either the company's employees or external consultants, further closing the door to improvement opportunities.

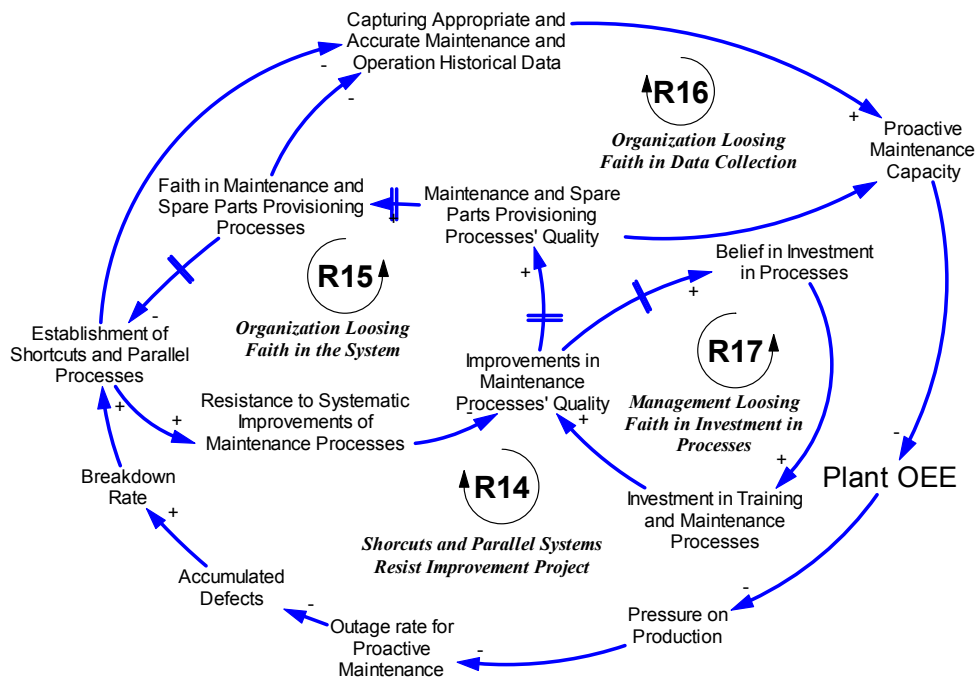


Figure 8: Organization and management loses its faith in systems and investment in system improvements

#### 4. Discussion and future directions

There is strong support for a strategic view of the maintenance function given its impact on OEE and its role in preserving safety and limiting the environmental impact of firms in a number of different industries. The significant profit and market capitalization returns which result from small improvements in OEE, and the wide variation of OEE measure across firms, raise a critical question: why do differences persist despite the clear incentive to maximize OEE (to the extent that incremental

benefit of increasing OEE is not outweighed by its incremental costs) ? This question is especially intriguing because the factors influencing OEE are generally understood.

Building on insights derived from system dynamics and strategy literature, we sought to answer this question by mapping the reinforcing loops governing the maintenance function and its interactions in a firm. Our research uncovers several such reinforcing loops; once active, any of them can lead a firm towards a problematic mode of operation in which reactive maintenance, poor moral, ad hoc processes, and a culture of fire-fighting dominate. The activation of these loops is often triggered by actions taken with the best of intentions. For example, re-allocation of maintenance resources to emergency fixes may be done to meet current production targets. However, actions taken to fix problems in the short run often activate vicious cycles, erode the capability of the organization over the long run, and lead to lower OEE overall. Once in this mode of operation, it becomes increasingly difficult for a firm to change course: the ineffective processes take root in organizational routines and culture, financial pressures mount, reducing the opportunities for investment, and organizational reputation erodes. In contrast, firms that benefit from these loops by activating them in a beneficial direction can gradually build the resource buffers needed to stick to best practices of proactive maintenance – even in light of environmental pressures – establish their best practices in organizational culture, and achieve a positive external image that helps them continue to operate in this virtuous mode.

Besides explaining variations in OEE, understanding the dynamics that govern a maintenance organization has other benefits:

- It helps the organization focus on performance drivers and root causes rather than symptoms.
- It causes everyone in the organization to be more patient during improvement processes which require painful changes, as everyone knows that the temporary pain is a necessary part of improvement. This requires extensive communication between employees and management and comprehension of the dynamics involved.
- It promotes long-term, systemic thinking in the organization and makes solutions with only short-term benefits less attractive. It helps prevent actions that in the long term harm the organization.
- It creates a platform for discussions regarding a company's strategic direction and tactics to move in that direction. It provides an alternative mental model to replace decision-making heuristics based on gut feeling and intuition. These heuristics can be hard to criticize, judge, and understand; a framework to organize and communicate maintenance strategy overcomes this challenge.
- It gradually eliminates a culture of mutual blaming because it makes root causes and underlying structural factors more visible to everybody involved.
- It helps people in the organization, especially those with less visible roles, see how their day to day work affects the company's success. This creates incentives and meaning for all stakeholders.
- It facilitates communication between the organization and its stakeholders, especially shareholders. Necessary investment formerly seen as unnecessary expense might be approved if the organization can convince its shareholders that the expense will boost the company's profit in the long term.

Our qualitative modeling can assist a firm's improvement actions. From a strategic perspective, maintenance organizations need to understand which loops are active or may become active in their setting; they need measurement and monitoring systems to alert them should a vicious cycle be taking over; and they should plan interventions so that they can use these loops in a beneficial way. Below, we provide a set of research and consulting opportunities that build on these insights.

First, the causal loops we have discussed here are generic and need to be customized for each organization. We have extracted these loops from our previous research and the literature, and we expect new dynamics to be added to this set as research reveals mechanisms we have not noticed. As the generic loop-set grows, we need to design and implement a method to quickly customize this loop set to focus on the most salient mechanisms in an organization. We are working on the design of an adaptive

online survey method which will narrow the loop set to a core set of processes which organizational stake-holders will find relevant to their particular setting.

Second, we should explore a mapping between the causal mechanisms discussed here and the performance metrics available in typical maintenance organizations. Such mapping would allow us to quickly select a minimum set of performance measures that need to be monitored to provide quick alerts when reinforcing loops are getting out of control, and to monitor dynamic targets showing how these loops should move over time.

Finally, quantification of these qualitative loops in a simulation model following system dynamics or agent-based modeling approaches would add much needed quantitative rigor to policy analysis based on these loops. This is feasible but expensive given the extent of data collection, calibration, and validation required for robust organization-level models. Future research is needed to build a customizable simulation model that can be quickly calibrated to data from a new organization and enable concrete quantitative advice on allocation of resources among its various maintenance activities. This is an ambitious goal which requires extended partnership with industrial clients who are willing to take risks in order to distinguish their maintenance organization through state-of-the-art research.

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**About the Presenter:**

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Over the last few years he has been involved in many projects in different industrial sections such as utility and gas distribution companies, petrochemical, copper mining, aluminum smelter, car manufacturing, alumina process, steel manufacturing, food processing, coal mining, etc.

He is the author of *Expert Knowledge Based Reliability Models* and a frequent global speaker on different subjects in asset management. Ali has been Chair of the International Physical Asset Management Conference for the last 5 years.

Ali is also an RCM II practitioner. His areas of expertise include maintenance performance management, Life Cycle Costing, use of tacit knowledge in asset management, optimization of maintenance tactics, reliability centered maintenance, and managing change in organizations.

In 2008, Ali was selected by Asia Society as one of the world's most dynamic young leaders. The Asia Society was founded in 1956 by John D. Rockefeller III; among its supporters are former UN Secretary-General Kofi Annan, Henry Kissinger, and Rupert Murdoch.