Modelling Modern Maintenance – A System Dynamics Model Analyzing the Dynamic Implications of Implementing Total Productive Maintenance

Jörn-Henrik Thun

Industrieseminar, Mannheim University
D – 68131 Mannheim, Germany
+ 49 621 181 15 84 / + 49 621 181 15 79
thun@is.bwl.uni-mannheim.de

Abstract *In recent years maintenance has become an important factor for operations management. Total Productive Maintenance as approach for improving maintenance has therefore evolved as one of the most popular manufacturing concepts. But often the concept cannot unfold its full potential. In this paper reasons for the failure of Total Productive Maintenance will be presented with respect to dynamic implications. The analysis focuses on the changes for the maintenance department and the machine operators due to the implementation of Total Productive Maintenance. Based on the ongoing changes a dynamic analysis is performed to identify important implications for a successful implementation of Total Productive Maintenance.*

Keywords Total Productive Maintenance, improvement paradox, dynamic implications

THE RELEVANCE OF MAINTENANCE FOR COMPETITIVENESS

Total Productive Maintenance has commonly been accepted as main concept for improving maintenance in the context of operations management. In the last decades the importance of Total Productive Maintenance has risen because of a dynamic competitive environment. To succeed in a demanding market arena manufacturing companies have to fulfil several requirements. One crucial aspect is a reliable manufacturing process.

In the past, maintenance has become a major issue of operations management, because of the need for high machine reliability in a demanding environment. A paradigm shift has evolved concerning the importance of several success factors. Nowadays, cost, quality, and time must be seen as main competitive success factors, which have to be considered simultaneously. As a consequence, manufacturing companies must strive for a superior cost position on the one hand. High process efficiency realized by high production volume and capacity utilization are crucial aspects for cost reduction. As a result the importance of maintenance has risen because of its potential to guarantee a failure-free functioning of the machines in use to enable high process efficiency. On the other hand, quality aspects like product variety, reliability, and longevity are important as well. Accordingly, the production on a high quality level is necessary to meet quality specifications. To guarantee a high process capability maintenance performance must be enhanced as one consequence. Only machines with a high maintenance standard are able to produce with less or no failures. Furthermore, besides cost and quality the aspect of time is crucial. In the context of time based competition [Stalk and Hout, 1990], fast and on-time deliveries are of great relevance to corporate success. This leads to the necessity of a cycle time reduction of the manufacturing process with the consequential need for a high maintenance standard to ensure fast throughput.

Altogether, it can be stated, that manufacturing companies are faced with the need for a dependable production system. Thereby, the most critical difficulty of the described situation can be based on the fact, that the requirements are not mutually exclusive but mainly cumulative [Ferdows, De Meyer, 1990]: Manufacturers have to offer a great variety of products in the least amount of time on a high quality level for an acceptable price. As one crucial consequence, machine maintenance has become increasingly important for manufacturing companies to accomplish these requirements, because a high-level maintenance standard is the key for supporting challenging quality standards, achieving high efficiency, and reaching time competence. In the light of the mentioned requirements for operations management, Total Productive Maintenance has become one of the most expedient approaches to guarantee high machine dependability.

THE DEVELOPMENT OF MAINTENANCE

In terms of maintenance four development stages can be distinguished. The basis, i.e. the first stage of maintenance development, is breakdown maintenance that was the business standard till the 1950ies. The main characteristic of this stage is the way to cope with machine breakdowns. Actions for maintaining equipment are not undertaken before a machine breaks down [Nakajima, 1988]. This reactive "fire fighting strategy" is no longer appropriate in a changing environment.

So the second stage starts with the introduction of Preventive Maintenance since the beginning of the 1950ies – following the development at General Electric. This approach is different from the first one in the way that the aim is to strive for a reduction of down time in advance due to a better planning of maintenance activities. Another aspect of this stage is corrective maintenance developed in 1957, i.e. measurements improving the equipment in terms of dependability due to maintenance activities.

In the 1960ies the approach of Maintenance Prevention was introduced. Development aspects are included in maintenance activities. The effort for necessary maintenance should be decreased by a better design and planning in the development and purchasing of machines. The third development stage deals with Productive Maintenance as an integrative approach for the different maintenance activities that the maintenance department still has the responsibility for. The fact that the maintenance department was more and more overloaded with maintenance tasks simple maintenance tasks were assigned to the machine operators. This was the basis for the fourth stage, the development towards Total Productive Maintenance [Nakajima, 1988; Nakajima, 1989].

The overall goal of Total Productive Maintenance is to raise the overall equipment effectiveness [Shirose, 1989]. The overall equipment effectiveness is calculated by multiplying the availability of the equipment, the performance efficiency of the process and the rate of quality products [Dal, Tugwell, and Greatbanks, 2000; Ljungberg, 1998]. This measure can be used as an indicator for the dependability of the production system.

Nowadays, five pillars have evolved as a standard of Total Productive Maintenance; they will be described briefly in the following: The first pillar acts on the "six big losses" [Shirose and Goto, 1989]. Primary malfunctions are identified and eliminated in an initial setup project. This is done by project teams consisting of maintenance staff, machine operators, and engineers. The core of the second pillar is a scheduled maintenance program. Maintenance activities should be done on a regular basis following a given time schedule to realize the approach of preventive maintenance [Ainosuke, 1989]. The third pillar deals with the development of an autonomous maintenance program [Goto, 1989a]. Autonomous maintenance may be the most ambitioned part for implementing Total Productive Maintenance because it depends on shop-floor operators' commitment. Following the approach of autonomous maintenance workers perform simple maintenance tasks like cleaning and lubricating. The fourth pillar of Total Productive Maintenance is training, because maintenance activities formerly done by the maintenance personnel are assigned to the machine operators. Therefore, operators need to have a better understanding of the machines and build up knowledge about maintenance activities [Aso, 1989]. Maintenance prevention, the fifth pillar of Total Productive Maintenance, strives for making maintenance activities unnecessary or easier by developing and purchasing "maintenance-free" machines. The aim is to raise equipment dependability, maintainability, and the ease of operation (Gotō, 1989b). The basis of Total Productive Maintenance is the 5S-Programm. The 5S-program supports the pillars of Total Productive Maintenance, because a tidy and clean working environment fosters the "Parlor Factory" [Nakajima, 1988].

DYNAMIC IMPLICATIONS OF TOTAL PRODUCTIVE MAINTENANCE

Implications for the Maintenance Department

The discussion of the history of maintenance has shown that a fire-fighting maintenance strategy in terms of reactive maintenance leads to unexpected machine breakdowns. Furthermore, the maintenance department is busy most of the time repairing machines. It does not have the time to do maintenance tasks on a regular basis nor does it have the time to improve the maintenance system within the production process. This leads to the fact that preventive maintenance tasks are neglected resulting in more machine breakdowns. Machine breakdowns eat up the maintenance department's capacity to maintain or improve the production system on a regular basis. In the long run, the vicious circle "Repairs eat up Prevention" results in a situation with many unexpected machine breakdowns and an overloaded maintenance department. This is the crucial behaviour of a production system without maintenance free machines and an overloaded maintenance department.

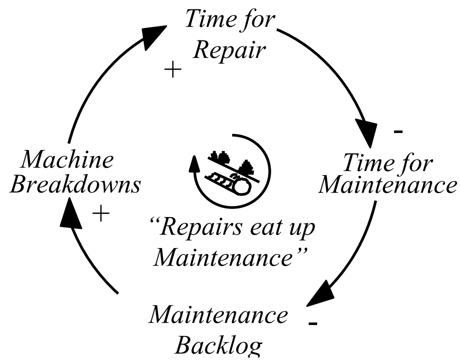

Figure 1: The "critical" Feedback Loop of "Breakdown Maintenance"

The implementation of Total Productive Maintenance implies several changes concerning maintenance. One aspect is a change in responsibilities. As stated before, due to the implementation of autonomous maintenance simple maintenance tasks are assigned to machine operators. This leads to the fact that the maintenance department is relieved, because simple maintenance tasks are done by machine operators. Thereby the vicious circle will be broken through. A main consequence is that the maintenance department is not overloaded with fire-fighting activities but can act on preventive maintenance and necessary improvement. Furthermore, improvement by maintenance prevention and training of machine operators can be gained.

The New Role of Workers by the Implementation of Total Productive Maintenance

As a consequence of the change of responsibilities machine operators must be trained to be able to fulfil the new maintenance requirements. Due to the fact that the maintenance department is relieved, simple maintenance tasks like lubrication must be done by the machine operator himself. Although the maintenance tasks transferred should be easy, there will be still a lack of knowledge concerning the know how to fulfil these tasks. So the machine operators must be trained. The training must be carried out by the maintenance department to guarantee a sufficient maintenance level of the machine operators.

The transference of the simple maintenance tasks has two implications regarding the machine operators. As stated before machine operators must be trained in order to learn managing the assigned maintenance tasks on the one hand. Thereby, it has to be considered that learning processes can not be done overnight. They are time consuming, thus the existing lack of knowledge will be reduced gradually and not immediately. But, in the long run, the learning process leads to the fact that operators achieve a higher understanding of the functioning of the machine. Accordingly, they can give insights about their day to day work for the improvement of maintenance activities, i.e. contributing to a better design with respect to maintainability.

On the other hand, machine operators might get a feeling of being overstrained. First of all, the maintenance tasks hinder them from fulfilling their day to day work load, because the sum of the additional workload and the normal workload are too much. Furthermore, production pressure initiated by the management is problematic. The problem works analogously to the "production pressure chokes off PM" cycle described by Maier [Maier, 2000]. The willingness of the machine operators to perform maintenance tasks will decrease. Secondly, machine operators might be swamped with the new maintenance tasks with the consequence that they refuse to do the necessary maintenance activities. Both aspects lead to the fact that maintenance will not be done properly. As a consequence the machine operators must be trained to be able to fulfil the simple maintenance tasks faster and more accurate [Aso, 1989]. Training and patience must be seen as the remedy against refusal and overstrain.

Implications for Maintainability

The implementation of Total Productive Maintenance goes along with several other implications. One important point is that the maintenance department has more capacity to fulfil preventive maintenance tasks, thus the maintenance schedule is done properly. By assigning simple maintenance tasks to machine operators the vicious circle will be broken through as stated before. If the maintenance department has the time to do preventive maintenance activities on a regular basis, machine breakdowns will decline. This sets free time capacity of the maintenance department. Accordingly, the maintenance department can work together with engineers elaborating valuable results with regard to maintainability. In the long run, an improvement of machine maintainability will decrease the need for simple maintenance tasks. Additionally, maintenance prevention will make maintenance tasks easier, thus more maintenance tasks can be assigned to the worker. Furthermore, machine operators will develop a better understanding of machines fulfilling simple maintenance tasks in the long run. This understanding can lead to valuable hints for improving machine maintainability as well. Figure 2 depicts a causal loop diagram of the maintenance system.

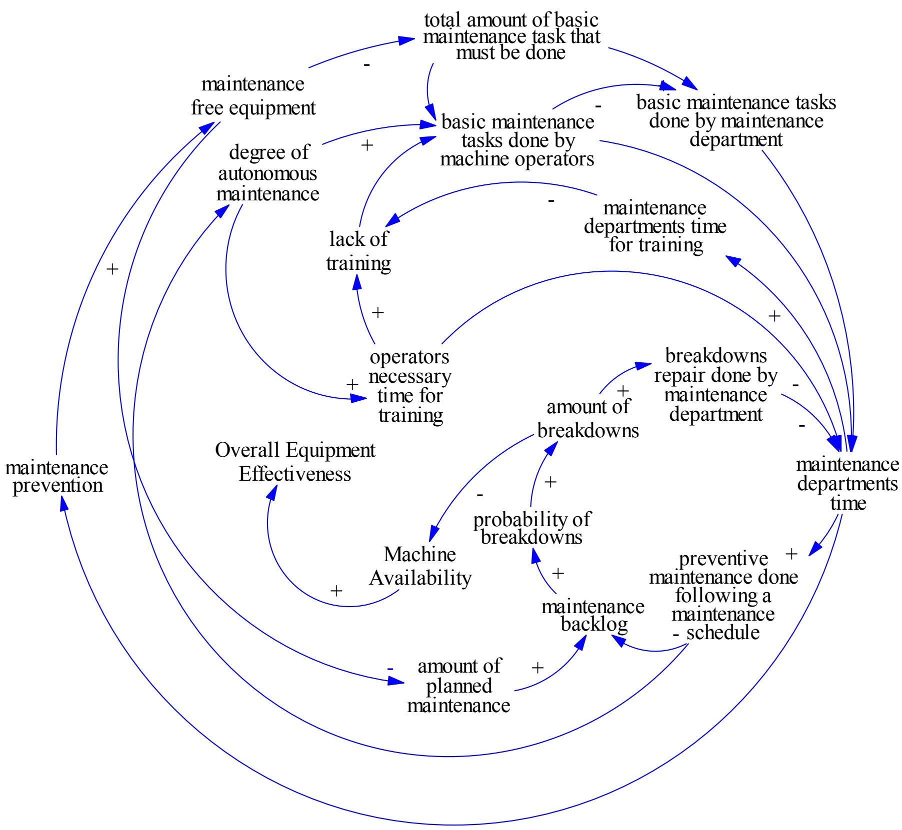

Figure 2: Causal Loops of Total Productive Maintenance

The described changes due to the implementation of Total Productive Maintenance result in a counterintuitive behaviour of the underlying system. This dynamic behaviour can lead to a misunderstanding of the system, thus wrong decisions in terms of maintenance might be the consequence. Despite the great potential of improvement programs, e.g. Total Productive Maintenance, for operations management, most attempts to use them have ended in failure which is described by the "improvement paradox" [Keating, Oliva, Repenning, 1999; Sterman, Kofman, and Repenning, 1997]. Therefore, a system dynamic model will be useful showing the dynamic behaviour of maintenance.

ANALYZING THE DYNAMICS OF MAINTENANCE

In the following a system dynamic model will be introduced to analyze the dynamics of maintenance [Forrester, 1961; Forrester, 1971; Sterman, 2000]. In a first step the initial model will be described. This model is the basis for the analysis of the consequences of the implementation of Total Productive Maintenance. A major assumption is that machines are maintenance free in terms of simple maintenance tasks, i.e. maintenance tasks are not necessary to keep machines running. Machines just have to be maintained on a regular basis. The necessary amount of regular maintenance can be done by the maintenance department. In this situation there are no machine breakdowns because machine maintenance is done properly. This leads to a model in an equilibrium state. Figure 3 depicts the basic structure of the maintenance model [Sterman, 2000].

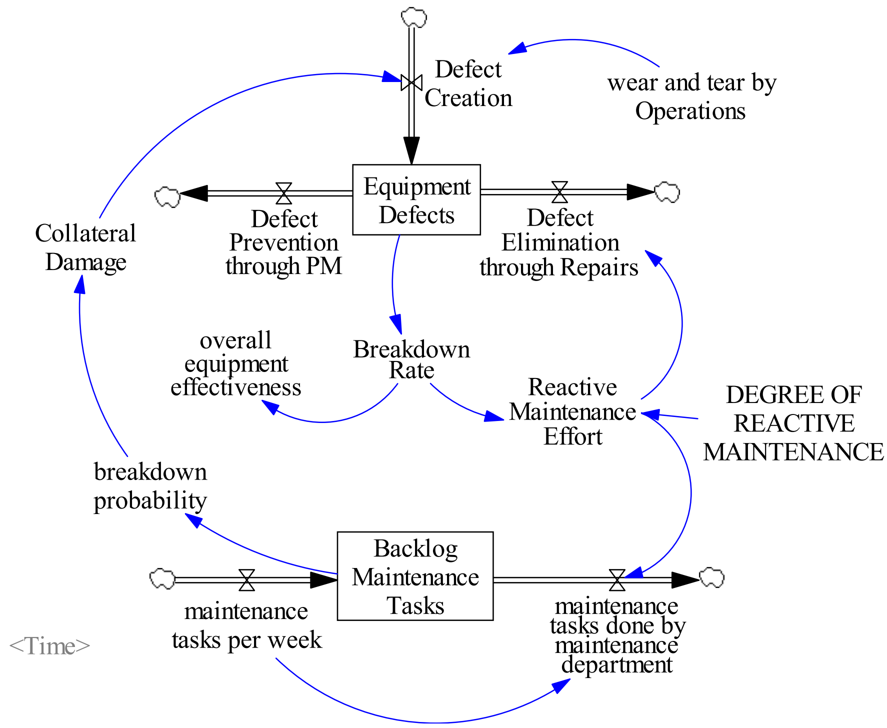

Figure 3: The Basic Maintenance Model

This model will be extended with the ongoing changes initiated by the implementation of Total Productive Maintenance. First, the assumption of maintenance free machines will be given up. As a consequence simple maintenance tasks must be done. This leads to the fact that the maintenance department is overloaded. Secondly, autonomous maintenance is introduced. Simple maintenance tasks are assigned to machine operators. Accordingly, machine operators have to be trained. Finally, the approach of maintenance prevention is embodied into the model, thus the amount of necessary maintenance tasks decreases. Based on the simulation of the maintenance model critical aspects can be identified. The following figure shows the model including the changes by the implementation of Total Productive Maintenance.

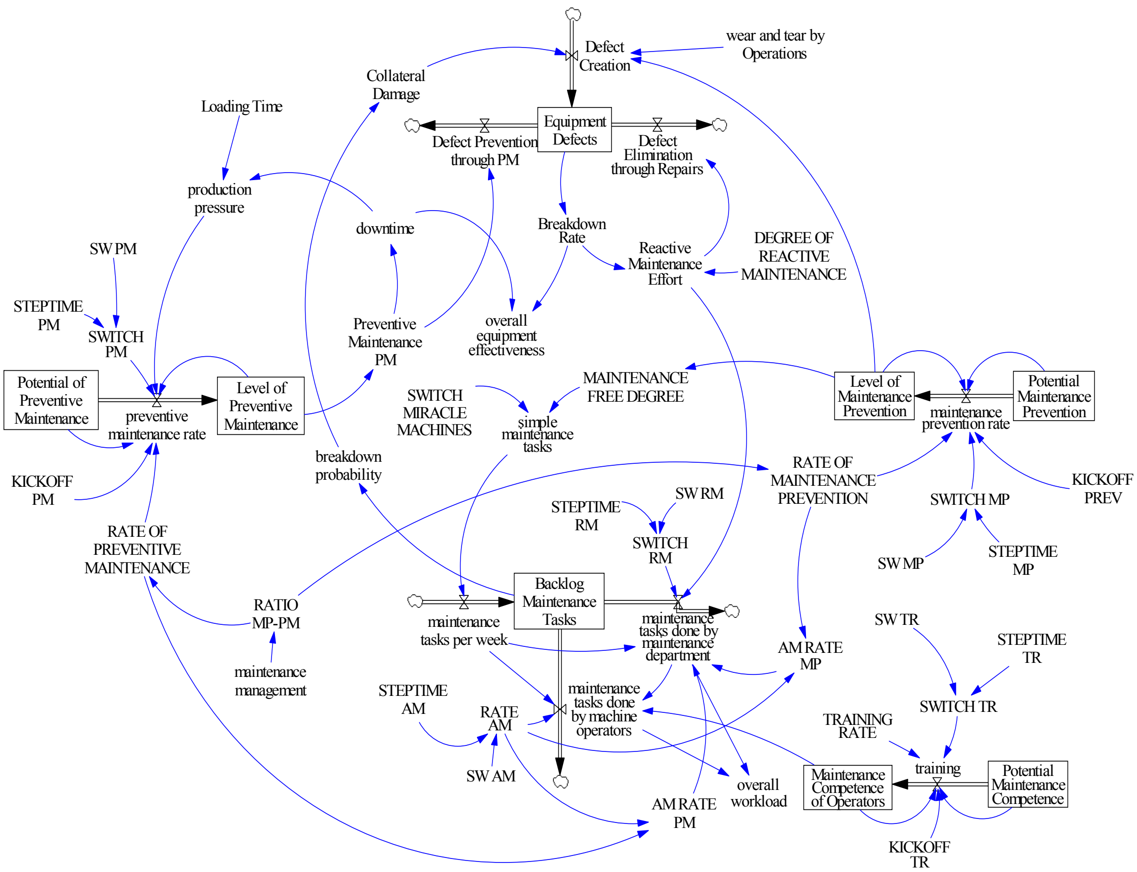

Figure 4: Total Productive Maintenance Model

Several simulation runs show the dynamic behaviour of the model. The following figure depicts the behaviour of the overall equipment effectiveness.

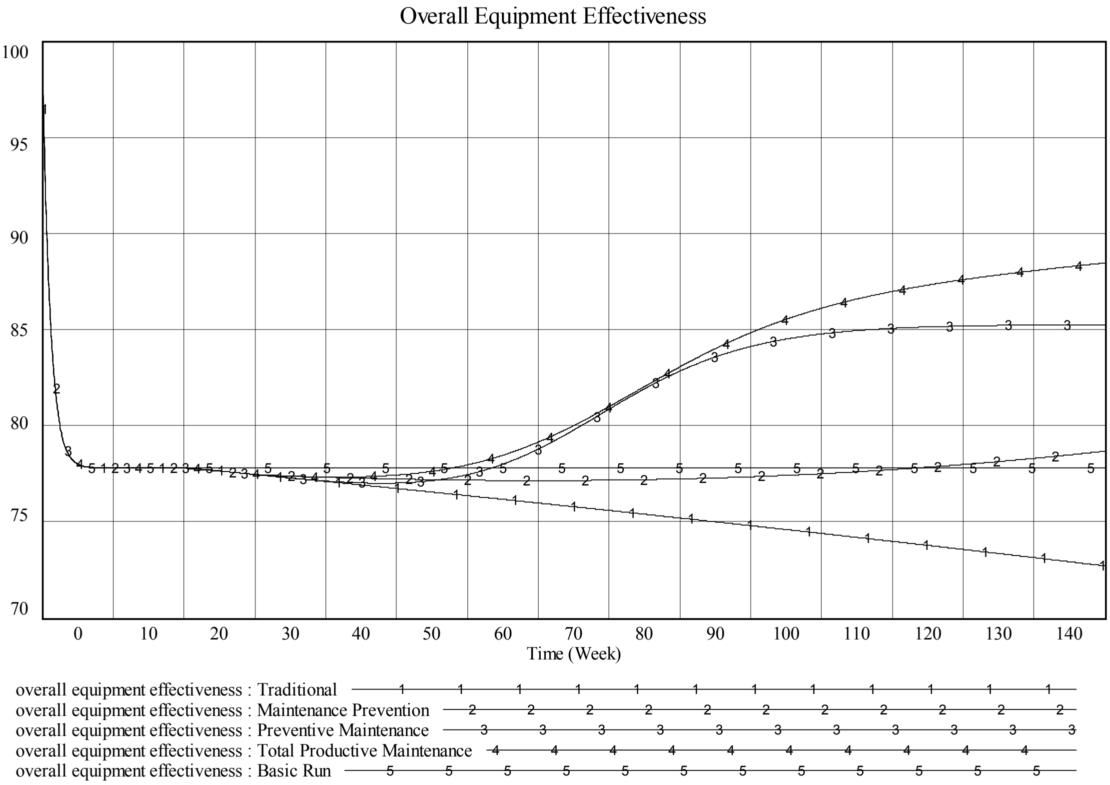

Figure 5: Simulation runs of Total Productive Maintenance

The simulation shows that the particular approaches of Total Productive Maintenance have a different impact on the behaviour of the system (see figure 5). In a test simulation run the system is run with 100% maintenance free machines – there is no necessity for simple maintenance tasks. The overall equipment effectiveness reaches an equilibrium after some periods shown by the simulation run "Basic Run". In a second run the assumption of "miracle machines" is given up. In a system with realistic machines maintenance tasks have to be fulfilled. Because of the limited capacity of the maintenance department maintenance tasks can not be done appropriately. This leads to the effect that machine breakdowns will occur leading to necessary repairs and therefore to the "critical" reinforcing feedback loop of "Breakdown Maintenance" depicted in figure 1. The time used for repairs prevents the maintenance department from doing maintenance tasks resulting in further unexpected machine breakdowns.

Following the idea of preventive maintenance scheduled maintenance tasks are done by the maintenance department. Due to the fact that their capacity is limited machine breakdowns still happen because simple maintenance tasks are not done properly anymore. The vicious circle "repair eats up maintenance" is still running bringing the overall equipment effectiveness down. Accordingly, to implement preventive maintenance effectively simple maintenance tasks have to be assigned to machine operators in order to disburden the maintenance department. To enable the machine operators to fulfil the maintenance tasks they must be trained as well. Otherwise a backlog of simple maintenance tasks will still be accumulated. The resulting simulation run "Preventive Maintenance" shows that the overall equipment effectiveness will first decrease for a short period of time and than stabilize on higher level. This situation can be characterized by a “worse before better”-effect, because before the overall system can be improved machine operators need to be trained.

In a next step maintenance prevention is done exclusively. Preventive Maintenance, autonomous maintenance, and training is not considered. The simulation run “Maintenance Prevention” shows that the overall equipment effectiveness will decrease in the first periods. In the long run the overall equipment effectiveness will increase. A reason for that is that less maintenance tasks have to be done improving the maintenance system in the long run on the one hand, but still repairs must be done because of missing preventive maintenance on the other hand.

Finally, as well preventive maintenance accompanied by autonomous maintenance and training as maintenance prevention is incorporated into the model following the idea of Total Productive Maintenance. The simulation run “Total Productive Maintenance” shows that the system achieves the highest overall equipment effectiveness in the long run. Conclusively, for a successful implementation of Total Productive Maintenance it seems to be necessary to understand the functioning and the interaction of the different facets of Total Productive Maintenance thus the concept can unfold its whole potential.

CONCLUSION AND FURTHER RESEARCH

In the paper dynamics of an implementation of Total Productive Maintenance are discussed within the framework of a system dynamics model. Gradually, the pillars of the concept are built into the model. Simulation runs show that the pillars have a different impact on the systems behaviour. By the implementation of Total Productive Maintenance the performance of the overall system might be worse in the beginning but improve in the long run depending on the management of maintenance.

For further research the interplay of maintenance prevention and preventive maintenance should be analyzed concerning their impact on the overall equipment effectiveness. Furthermore, the potential of “maintenance ease”, a facet of maintenance prevention, should be investigated.

REFERENCES

Ainosuke, M. (1989): “Preventive Maintenance”, in: Nakajima, Seiichi (Ed.): TPM Development Program – Implementing Total Productive Maintenance, Cambridge/MA, pp. 85–164.

Aso, M. (1989): “Maintenance Skill Training”, in: Nakajima, Seiichi (Ed.): TPM Development Program – Implementing Total Productive Maintenance, Cambridge/MA, pp. 85–164.

Dal, B., Tugwell, P., and Greatbanks R., (2000): “Overall equipment effectiveness as a measure for operational improvement”, in: International Journal of Operations and Productions Management, Vol. 20, No. 12, pp. 1488–1502.

Ferdows, K. and De Meyer, A., (1990), “Lasting Improvements in Manufacturing Performance: In Search of a New Theory”, Journal of Operations Management, Vol. 9, pp. 168–184.

Forrester, J. W. (1961), Industrial Dynamics, Cambridge/MA.

Forrester, J. W. (1968), Principles of Systems, Cambridge/MA.

Goto, F. (1989a): “Autonomous Maintenance”, in: Nakajima, Seiichi (Ed.): TPM Development Program – Implementing Total Productive Maintenance, Cambridge/MA, pp. 165–218.

Goto, F. (1989b): “Maintenance Prevention”, in: Nakajima, Seiichi (Ed.): TPM Development Program – Implementing Total Productive Maintenance, Cambridge/MA, pp. 85–164.

Keating, E. K., R. Oliva, N. P. Repenning, S. Rockart, and J. D. Sterman (1999): “Overcoming the Improvement Paradox”, in: European Management Journal, Vol. 17., No. 2, pp. 120–134.

Ljungberg, O., (1998): “Measurement of overall equipment effectiveness as a basis for TPM activities”, in: International Journal of Operations and Productions Management, Vol. 18, No. 5, pp. 495–507.

Maier, F. H. (2000): “Feedback Structures Driving Success and Failure of Preventive Maintenance Programs”, in: Van Dierdonck, R. und A. Vereecke (Edit.), Operations Management: Crossing Borders and Boundaries: The Changing Role of Operations – 7th International Conference of the European Operations Management Association, Vlerick Leuven Ghent Management School, Belgium, pp. 376–383.

Nakajima, S. (1989): “An Introduction to TPM”, in: Nakajima, Seeiihi (Ed.): TPM Development Program – Implementing Total Productive Maintenance, Cambridge/MA.

Nakajima, S. (1989): TPM Development Program – Implementing Total Productive Maintenance, Cambridge/MA.

Nakajima, S., (1988): Introduction to Total Productive Maintenance (TPM), Cambridge/MA.

Shirose, K. (1989): “Equipment Effectiveness, Chronic Losses, and Other TPM Improvement Concepts”, in: Nakajima, Seiichi (Ed.): TPM Development Program – Implementing Total Productive Maintenance, Cambridge/MA, pp. 27–84.

Shirose, K. and Goto, F. (1989): “Eliminating the Six Big Losses”, in: Nakajima, Seiichi (Ed.): TPM Development Program – Implementing Total Productive Maintenance, Cambridge/MA, pp. 85–164.

Stalk, G. and T.M. Hout, (1990): Competing Against Time: How Time-based Competition is Reshaping Global Markets, New York.

Sterman, J. D. (2000), Business Dynamics – System Thinking and Modelling in a Complex World, Boston et al.

Sterman, J. D., Kofman, F. and Repenning, N. P. (1997): “Unanticipated Side Effects of Successful Quality Programs: Exploring a Paradox of Organizational Improvement”, in: Management Science, Vol. 43, No. 4, pp. 503–521.

Back to the Top