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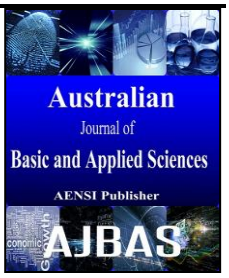

Overall Equipment Effectiveness Forecasting using Markov Chains

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ABSTRACT

Nowadays, consumers expect manufacturers to provide excellent quality, reliable delivery and competitive pricing. This demands that the manufacturer's machines and processes are highly reliable. In order to possess highly reliable machines to make sure smooth manufacturing process, many organizations have implemented Total Productive Maintenance (TPM) as the enabling tool to maximize the effectiveness of equipment. Measurement is an important requirement of continuous improvement process. It is necessary to establish appropriate metrics for measurement purposes. From generic perspective, TPM can be defined in terms of Overall Equipment Effectiveness (OEE) which in turn can be considered a combination of the operation maintenance, equipment management and available resources. The goal of TPM is to maximize equipment effectiveness, and the OEE is used as a measure. In short, OEE is used as a measure when evaluating the result of TPM. This paper intended to find out OEE performance in a manufacturing company. Besides that, it also has figured out the trend of OEE in future by using Markov Chains to calculate. The forecast of OEE is performed by a software name Risk Simulator. Markov Chains used in this software has forecasted that there is high probability of OEE to stay at its current state. By knowing the state of OEE in future, an organization is able to make sufficient preparation to face future situation.

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INTRODUCTION

According to Tsarouhas (2007), many manufacturing systems operate at a lower capacity with a consequence of a higher cost of the producing products. Low productivity is the result of the worst function of the production lines. This can be a result of imperfect maintenance of the machines or workstations. Measurement is an important requirement of continuous improvement process. It is necessary to establish appropriate metrics for measurement purposes. From generic perspective, TPM can be defined in terms of Overall Equipment Effectiveness (OEE) which in turn can be considered a combination of the operation maintenance, equipment management and available resources (Chan *et al*., 2005). The goal of TPM is to maximize equipment effectiveness, and the OEE is used as a measure.

The Markov Process is useful for studying the evolution of systems over multiple and repeated trials in successive time periods. Since the system's state at a particular time is unknown, hence making people interested in knowing the probability that a particular state exists. Besides being used to compute the probability that a particular machine or equipment will continue to function in the next time period, for instance, Markov Chains is also used in predicting a consumer purchasing Product A will continue to purchase Product A in the next period or switch to a competitive brand B. These brands or products are termed states of nature. By entering the probability of a person currently in State 1 will remain in State 1 after one period, and the probability that if the person currently in State 2 will remain in State 2 in the next period, Markov Chains methodology can be used to determine the future probabilities or states of nature and the long-term steady state. Using Markov Chains model, OEE can be predicted over a certain period so that precautions and initiatives can be taken to maintain if good state is shown or to improve if unfavorable state is shown.

This study is intended to find out current OEE performance of a manufacturing company named Company X. Upon obtaining the current OEE, it is used to forecast the future trend of OEE using

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Markov Chains by calculating the probability of one state to stay at current state in future. By predicting the future condition of OEE, organization able to capture an idea on how is the performance of machines in manufacturing site will be. This is crucial as it helps an organization in adopting appropriate strategy to face upcoming challenges. The scope of this study is focused in automotive industry. Besides that, the scope will focus on Overall Equipment Effectiveness (OEE) in order to find out the performance of OEE in the automotive industry. OEE will be calculated and forecasted in order to see the future trend of OEE in automotive industry.

Literature Review:

2.1. Overall Equipment Effectiveness (OEE):

Tracking OEE provides a relative monitor of equipment productivity and the impact of improvement efforts. Understanding efficiency losses drives the improvement effort (DiIorio and Pomorski, 2003). Overall Equipment Effectiveness (OEE) is the TPM metric for measuring equipment effectiveness or productivity. Variations for calculating OEE are in use, however, most are consistent in identifying three major elements of OEE.

- Availability – the effectiveness of the operation to make equipment available to perform production activity.
- Performance – the effectiveness of the operation to execute production activity during the period of time that equipment is Available and able to perform those activities.
- Quality – the effectiveness of the operation to produce units that meet production quality specifications during the period of time that equipment is performing production activity.

The Japanese Institute of Plant Maintenance (JIPM) definition for Overall Equipment Effectiveness (OEE) is the classic definition of OEE and has been used throughout many industries. TPM has the standards of 90 per cent availability, 95 per cent performance efficiency and 99 per cent rate of quality (Levitt, 1996). An overall 85 per cent benchmark OEE is considered as world-class performance (Blanchard, 1997; McKone *et al*., 1999).

2.2. Markov Chains:

In the early 20th century, a Russian mathematician, Andrei Andreyevich Markov firstly developed stochastic processes which are representations of dynamic systems based on probabilities. His statistical study of language has led to the Markovian hypothesis, which can be summarized as follows: "Future evolution of a system only depends on its present state". This is a very vital assumption because this hypothesis implies that current state of a system contains all information provided by its past. In practice, this condition is rarely satisfied. However, approximation by Markovian models could provide good modeling results (P Vrignat *et al*., 2011).

In a Markov model, an item's condition is modeled in one of a few states, and the probability of an item deteriorating into another state is only dependent on the two states involved. This means that the process is memoryless as the future development of the item is regardless of what has happened in the past (Rausand and Høyland, 2004). The Markov Process is useful for studying the evolution of systems over multiple and repeated trials in successive time periods. Since the system's state at a particular time is unknown, hence making people interested in knowing the probability that a particular state exists. Markov Chains methodology can be used to determine the future probabilities or states of nature and the long-term steady state.

2.3. Total Productive Maintenance (TPM):

TPM is a methodology and philosophy of strategic equipment management focused on the goal of building product quality by maximizing equipment effectiveness. It embraces the concept of continuous improvement and total participation by all employees and by all departments (Society of Manufacturing Engineers 1995 p. ix).

2.4. Markov Chains in TPM:

According to Garg and Deshmukh (2006), there are two classifications for models to approximate maintenance frequency. They can be classified as qualitative which includes techniques like Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM); and quantitative which incorporates various deterministic/stochastic models like Markov Decision models and Bayesian models. They further classified TPM as one of the maintenance techniques and Markov Chains as one of the maintenance optimization models. Due to qualitative models are often criticized as being subjective and, therefore, quantitative models are sometimes proposed to reduce the level of subjectivity (Endrenyi *et al*., 1998; IEEE taskforce, 2001).

There exist a number of quantitative models that describe the impact of preventive maintenance on the lifecycle cost of equipment. Markov state models are frequently used for modeling deterioration processes in which three to four deterioration stages are normally introduced (Chen and Trivedi, 2005). A preventive maintenance decision is either made to do nothing, perform a minor maintenance, or perform an overhaul for each stage (that is sometimes revealed by periodic inspection). Another modeling approach used where all possible markings that are reachable from the initial marking are converted to a continuous-time Markov chain which is, in turn, solved numerically is Petri Nets (PN) (Hosseini *et al*., 2000).

According to Gosavi (2006), Total Productive Maintenance (TPM) is a management initiative that has been widely embraced in the industry. Such implementations have brought a positive strategic outcome, which is the reduced occurrence of unexpected machine breakdowns that disrupt production and ultimately lead to losses which can exceed millions of dollars annually. Stochastic model is an important tool of a TPM program used to determine the optimal time for Preventive Maintenance (PM) (Askin & Goldberg, 2002). PM can help reduce the frequency of unexpected repairs when the failure rate is of an increasing nature (Das & Sarkar, 1999). Hence, Markov Decision Processes (MDPs) (Bertsekas, 1995) are frequently used as the underlying stochastic models in a TPM program.

2.5. Past research:

Wang and Hwang (2004) have used Markov Chain Decisions Analysis to predict maintenance time cycle so that optimum time to perform maintenance can be obtained in order to prevent over-performed maintenance cost. They also used Markov Chains to evaluate maintenance policies, obtain maintenance performance from the structure of optimal policies, and also to help in determining effective and efficient schedules and plans. Among all the issues that they have studied, they did not use Markov Chains to predict the future state of OEE. OEE is the indicator of how good and how frequent maintenance is performed based on the machines' performance. High OEE result shows that machines are working with low breakdown rate. OEE result should be forecasted in order to help in scheduling maintenance planning or cycle time. Hence, it is necessary to use Markov Chains to forecast the OEE result in future.

Besides that, Hugues *et al*. (2002) used Markov Chains to predict aircraft operational reliability. A generic Markov process model is defined to predict the aircraft operational reliability inferred by given equipment. This generic model is then used for each equipment with its own parameter values (mean time between failures, mean time for failure analysis, mean time to repair, and etcetera). The aim is to calculate the probability of being in one of the two states which does not enable to take-off at the end of a stopover during a given mission. A finite succession of stopovers and flights is the mission. From this case, Markov Chains is used to predict the operational reliability of aircraft. This means that Markov Chains is used to see whether aircraft able to operate properly or not, according to the probability obtained. Thus, this tool can be applied in knowing OEE performance too. Markov Chains can be utilized to see whether OEE result will change or not over the time. If change does occur, how will it change to be: either from good to bad or from bad to good. This prediction is useful in providing management a future sign so that necessary actions can be taken to maintain good OEE reading.

A condition-based replacement and spare provisioning policy is proposed by Wang *et al*. (2008) for a deteriorating system with a number of identical units. The deterioration processes of these units are modeled as discrete-time Markov Chains. Markov Chains is the most widely used tool for modeling unit deterioration and analyzing maintenance activities. A typical discrete-time Markov Chains is utilized for modeling deterioration of units under the proposed condition-based replacement and spare provisioning policy. Again, Markov Chains is used to calculate the deterioration of units so that maintenance can be performed in time to prevent any failure or breakdown. However, it is not used in calculating the future state of OEE although OEE is included in maintenance. Thus, there is a need to apply Markov Chains in calculating the future state of OEE so that performance of machines can be known in advance. Necessary steps can be taken to boost up OEE readings if the Markov Chains shows an undesirable trend. Thus, issues that once beyond control can now be controlled. As a result, loss due to breakdowns can be reduced.

Research Methodology:

3.1. Research design:

The research design used in this paper is causal research. In causal research, the emphasis is on specific hypotheses about the effects of changes of one variable on another variable.

3.2. Research strategy:

The strategy used in this research is experimental. Experimental design is a set of procedures for devising an experiment such that a change in a dependent variable may be attributed solely to the change in an independent variable. The independent variable in this experiment is current OEE while the dependent variable is forecasted OEE.

3.3. Measurement of OEE:

OEE can be calculated using the formulas shown below (OEE, 2002):-

OEE = Availability (A) × Performance Efficiency (P) × Rate of Quality (Q) (3.1)

where:

Availability (A) = Operating Time / Planned Production Time (3.2)

Operating Time = Planned Production Time – Down Time

Planned Production Time = Shift Length – Breaks (3.4)

Performance Efficiency (P) = Ideal Cycle Time / (Operating Time/Total Pieces) (3.5)

Ideal Cycle Time = Shift Length / Scheduled Number of Products (3.6)

Quality Rate (Q) = Good Pieces / Total Pieces (3.7)
Good Pieces = Total Pieces – Reject Pieces (3.8)

3.4. Population and sampling:

The population in this study is the Manufacturing Operation and Engineering Department of Company X. Due to this is an experiment, so non-probability sampling is used in collecting data as the data that is going to be collected is just from one organization – Company X only. Non-probability sampling is one in which each element of the population does not have an equal probability of selection. When choosing type of non-probability sampling, purposive or judgmental sampling is chosen as the method of choosing samples. The reason of choosing purposive sampling is the subject to be studied is fixed, which are the machines in the production line. The research sample in this study is the machines available in Manufacturing Operation and Engineering Department. The instrument that is going to be used in this study is observation. Observation is carried out by observing closely the activities of machines and data is recorded. Data recorded will become the input of OEE calculation.

3.5. Data analysis technique :

Company X uses Microsoft Excel in analyzing data and when calculating OEE. Upon obtaining the current OEE, these OEE readings will be used as input to forecast OEE performance in future. When forecasting future OEE trend, a software name Risk Simulator is used. By using this software, forecasting activity becomes easier, faster and more accurate.

RESULTS AND DISCUSSION

4.1. The analysis and findings on Overall Equipment Effectiveness (OEE):

Table 4.1: OEE result for 4 SMT lines.

SMT	A	P	Q	OEE
1	93%	100%	97%	90.21%
2	94%	100%	99%	93.06%
3	93%	97%	96%	86.60%
4	93%	99%	98%	90.23%

Referring to the table above, OEE result for four Single Mounted Technology (SMT) lines was presented. SMT was just a name which Company X given to its production lines. Among these four lines, SMT 2 possessed the best performance while SMT 3 had the lowest percentage of OEE although all of them have passed world-class benchmark. In order to see what will those lines perform in future; forecasting was done and would be presented in following part.

4.2. Forecasting analysis on OEE using Markov Chains:

Forecasting machine performance enabled researcher to see the trend of changing for machines, whether the machines will perform better or reverse. The tool used in forecasting is Risk Simulator software, a software good in forecasting including market share and managing risks. Undoubtedly, Risk Simulator can also be used in forecasting machine performance as been used in this study.

Based on the data collected, the researcher has sorted out the data into two states, which are State 1 and State 2. The categorization of states was according to the current OEE results, by allocating them depends on a set boundary. In this study, the current OEE results ranged from the lowest 85.67% to the highest 94.05%. Hence, in order to predict the long-term steady state of OEE, researcher has separated out the two states by stating State 1 as the OEE results are more or equal to 90% while State 2 as the OEE results are less than 90%. Through this allocation, probability of OEE's state to stay in old state or switch to another state can be known, providing information about OEE performance in future. Below is the conditions mentioned just now written in formula form:-

State 1: OEE $\geq$ 90%
State 2: OEE < 90%

For the initial probability of State 1, it was calculated by dividing number of days that in State 1 with total number of days in a month. The same goes to State 2 probability calculation. Following sections will show the initial probability calculation and forecast result, according to the four SMT lines. Formulas for calculating probabilities are as follow (Easy Calculation, 2011):

$$P(A \cup B) = P(A) + P(B) - P(A \cap B)$$
$$= P(A) + P(B) - [P(A)P(B)]$$
$$P(B \mid A) = \frac{P(B \cap A)}{P(A)}$$

4.2.1. Forecast for SMT 1:

Table 4.2: Probability of states in current period to stay at own states in next period for SMT 1.

	Next Period	
Current Period	State 1	State 2
State 1	76.00%	24.00%
State 2	60.00%	40.00%

Table 4.3: Steady state probability for SMT 1.

	State 1	State 2
OEE:	71.43%	28.57%

As a result from the previous 50 periods forecast, a steady state probability was obtained and it was shown on the table above. From here, it can tell that the probability of State 1 to stay at State 1 was 71.43% but there was a probability of 28.57% for State 1 to change to State 2. This meant that there was high possibility that OEE performance will stay at more than 90%.

4.2.2. Forecast for SMT 2:

Table 4.4: Probability of states in current period to stay at own states in next period for SMT 2.

	Next Period	
Current Period	State 1	State 2
State 1	93.70%	6.30%
State 2	93.20%	6.80%

Table 4.5: Steady state probability for SMT 2.

	State 1	State 2
OEE:	93.67%	6.33%

As a result from the previous 50 periods forecast, a steady state probability was obtained and it was shown on the table above. From here, it can tell that the probability of State 1 to stay at State 1 was 93.67% while the probability of State 1 to switch to State 2 was 6.33%, meaning there was a 6.33% of chance the OEE result in SMT 2 would get worse. The high State 1 probability was because, almost all of the days, SMT 2 has achieved high OEE figures, meaning that the performance of SMT 2 was great.

4.2.3. Forecast for SMT 3:

Table 4.6: Probability of states in current period to stay at own states in next period for SMT 3.

	Next Period	
Current Period	State 1	State 2
State 1	100.00%	0.00%
State 2	100.00%	0.00%

Table 4.7: Steady state probability for SMT 3.

	State 1	State 2
OEE:	100.00%	0.00%

As a result from the previous 50 periods forecast, a steady state probability was obtained and it was shown on the table above. From here, it was clearly seen that probability of State 1 was at 100% while probability of State 2 was at 0%. Meaning it was confident that State 1 will continue to stay at State 1 for long-term, the OEE results for SMT 3 was heading to a more favorable and motivating state.

4.2.4. Forecast for SMT 4:

Table 4.8: Probability of states in current period to stay at own states in next period for SMT 4

	Next Period	
Current Period	State 1	State 2
State 1	77.80%	22.20%
State 2	66.70%	33.30%

Table 4.9: Steady state probability for SMT 4.

	State 1	State 2
OEE:	75.03%	24.97%

As a result from the previous 50 periods forecast, a steady state probability was obtained and it was shown on the table above. From here, it can tell that the probability of State 1 to stay at State 1 was 75.03% while the probability of State 1 to change to State 2 was 24.97%. This meant that there was high probability that OEE performance would stay at more than 90% by showing a desirable improvement.

Conclusions:

In conclusion, this study has achieved the objectives set, from calculating OEE to use calculated OEE to perform forecasting. Accomplishment to the objectives set can be seen through results shown above. OEE for four SMT lines has been presented and future OEE trend can be found in this paper too. By looking at the forecasting, company can respond well to future situation by deciding which strategy or action to take.

Future work should be more focused on broadened area of study. Currently, Markov Chains is used to forecast the future state of OEE so that trend of OEE to be at which state, either good or bad one can be known. It is suggested that in future work, Markov Chains can be used in forecasting states of elements that consist OEE such as availability, performance and quality. This is because these three elements play a vital role in affecting OEE's result. Changes in any one of them may bring significant impact to OEE performance. Hence, there is a need to use Markov Chains to narrow down the forecasting activity into depth as one under-performed element may influence OEE significantly. By forecasting on these elements, conditions of these elements can be known, thus, being taken care of and ultimately improve OEE performance.

REFERENCES

Askin, R., J. Goldberg, 2002. Design and analysis of lean production systems. New York: Wiley.

Bertsekas, D.P., 1995. "Dynamic programming and optimal control." Belmont, MA, USA: Athena Scientific.

Blanchard, B.S., 1997. "An enhanced approach for implementing total productive maintenance in the manufacturing environment", Journal of Quality in Maintenance Engineering, 3(2): 69-80.

Chan, F.T.S., H.C.W. Lau, R.W.L. Ip, H.K. Chan and S. Kong, 2005. "Implementation of total productive maintenance: a case study", International Journal of Production Economic, 95: 71-94.

Chen, D. and K.S. Trivedi, 2005. "Optimization for condition-based maintenance with semi-Markov decision process", Reliability Engineering and System Safety, 90: 25-9.

Das, T.K., S. Sarkar, 1999. Optimal preventive maintenance in a production inventory system. *IIE Transactions*, *31:* 537–551.

DiIorio, S. and T. Pomorski, 2003. SEMI Equipment Performance and Productivity Measurement – Methods, Algorithms, and Standards. Brooks-PRI Automation Asia User Conference 2003, Shanghai.

Easy Calculation, 2011. Multiple Event Probability Formula. Retrieved November 3, 2011, from www.easycalculation.com

Endrenyi, J., G.J. Anders and A.M. Silva, 1998. "Probability evaluation of the effect of maintenance on reliability – an application", IEEE Transactions on Power Systems, 13: 576-83.

Garg, A. and S.G. Deshmukh, 2006. "Maintenance management: literature review and directions", Journal of Quality in Maintenance Engineering, 12: 205-38.

Gosavi, A., 2006. "A risk-sensitive approach to total productive maintenance", Automatica, 42: 1321-1330.

Hosseini, M., R.M. Kerr and R.B. Randall, 2000, "An inspection model with minimal and major repair", IEEE Transactions on Reliability, 49: 88-98.

Hugues, E., E. Charpentier and A. Cabarbaye, 2002. "Application of Markov processes to predict aircraft operational reliability", 3rd European Systems Engineering Conference.

IEEE taskforce, 2001. "The present status of maintenance strategies and the impact of maintenance on reliability", IEEE Transactions on Power Systems, 16(4): 638-46.

Levitt, J., 1996. Managing Factory Maintenance, Industrial Press Inc., New York, NY.

McKone, K.E., R.G. Schroeder and K.O. Cua, 1999. "Total productive maintenance: a contextual view", Journal of Operations Management, 17: 123-44.

OEE, 2002. Calculating Overall Equipment Effectiveness (OEE). Retrieved March 17, 2011, from www.oee.com

Vrignat, P., M. Avila, F. Duculty, S. Aupetit, M. Slimane and F. Kratz, 2011. "Maintenance policy: degradation laws versus hidden Markov model availability indicator", Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability, 1748006X11406335, first published on.

Rausand, M. and A. Høyland, 2004. System Reliability Methods and Applications, 2nd ed., Wiley, Trondheim.

Society of Manufacturing Engineers, 1995. Total Productive Maintenance in America. Dearborn, MI, Society of Manufacturing Engineers.

Tsarouhas, P., 2007. "Implementation of total productive maintenance in food industry: a case study", Journal of Quality in Maintenance Engineering, 13(1): 5-18.

Wang, C.H. and S.L. Hwang, 2004. "A stochastic maintenance management model with recovery factor", Journal of Quality in Maintenance Engineering, 10(2): 154-164.

Wang, L., J. Chu, and W.J. Mao, 2008. "An optimum condition-based replacement and spare provisioning policy based on Markov chains", Journal of Quality in Maintenance Engineering, 14(4): 387-401.