# Simulation Based Plant Maintenance Planning with Multiple Maintenance Policy and Evaluation of Production Process Dependability

Evgeny Malamura, Tomohiro Murata

**Abstract - In this paper we propose a simulation model combining two processes of different origin (the production process and the information flow of maintenance work-orders) in one model in order to investigate how the interaction between the processes affect the performance of the production system, as well as to define the optimization opportunities.**

**The proposed approach aims to extend the capabilities of the conventional reliability analysis techniques by focusing on dynamic aspects of the production system and to present a method for representation of technical, operational, maintenance, organizational and economic aspects by simulation modeling concepts.**

**Index Terms – Plant Maintenance, Simulation, Production process dependability**

## I. INTRODUCTION

Maintenance can be defined as the combination of all technical and associated administrative actions performed to prevent failure-mode occurrences or to repair failed components. It's a fundamental aspect of industrial system efficiency. Maintenance systems can have a large impact on the profit of a plant and selecting appropriate maintenance policies is vital for each manufacturing company.

Modern manufactures are equipped with complex production lines, which have complex composition of reliability requirements, safety levels, and failure effects. An evaluation of the performance of such manufacturing systems and effectiveness of the applied policies of maintenance also become a complex task that requires appropriate analysis methods and tools. Such methods and tools which allow comparing an impact of maintenance on the production process both in a qualitative and quantitative manner and support determination of efficient maintenance program and plant performance improvement options.

In practice the impact of foreseen maintenance actions is often hard to estimate prior to introduction as well as the plant operation and dynamic characteristics strongly affect components and plant dependability. Thereby production system performance improvement becomes a non-trivial optimization problem.

There is a variety of methods of system analysis to tackle this problem in practice of reliability and safety engineering. These methods are widely used and approved as standards for analyzing hazardous technical systems in the industry (e.g. *Fault Tree Analysis, Event Tree Analysis, Failure Mode and Effect Analysis, Hazard and Operability Study*), as well as many of them are included into more general engineering frameworks (e.g. Reliability Centered Maintenance). However, most of these classical safety analysis methods are limited to static or scenario-oriented

views, and tend to stand isolated in determining individual dependability attributes.

Therefore, an approach *to extend the capabilities of the conventional analysis techniques* including multiple maintenance policies is taken by *focusing on dynamic aspects of the production system* and representation of technical, operational, maintenance, organizational and economic aspects by *simulation modeling concepts.*

## II. PRODUCTION PERFORMANCE AND MAINTENANCE EFFECTIVENESS ANALYSIS SIMULATIONS

Simulation is one of the most widely used Operations Research and management-science techniques. It allows for any arbitrary model complexity and circumvents analytically intractable models. Application of performance analysis and simulation can save money in a production company (not only of the process industry), avoiding potentially costly "trial-and-error" experiments with the real plant.

There are various classical simulation modeling concepts of assessment system performance suitable for evaluation and optimization of maintenance process; such as *discrete Markov chain model, stochastic Petri nets and Monte Carlo simulations* which offer a powerful modeling tools for system dependability studies that allows the description of:

- random phenomena, such as failure occurrence;
- deterministic phenomena, such as maintenance action realization;
- discrete phenomena, such as event occurrence;
- continuous phenomena, such as degradation mechanism evolution

However, lately there are also plenty of software computer packages for discrete event systems simulations which allow creating a visual model of the system under investigation easily, taking into account real life constraints, capacities, failure rates, shift patterns, and other factors affecting the total performance and efficiency of production. Through this kind of model it is possible to test real scenarios in a virtual environment, simulate planned function and load of the system, change parameters affecting system performance, carry out extreme-load tests, verify by experiments the proposed solutions and select the optimal solution. As well as the visual simulation model is usually much more illustrative even for those who has no background knowledge about other classical concepts rest upon mathematical modeling symbolism.

According to the purpose of a simulation model, the differentiations between instances of process in a production system have to be studied by looking at various aspects, either the interrelations between the instances must be investigated. The objects of the production system simulation modeling include:

- Physical topology of the plant (type of component arrangements, plant parameters as throughput rates and resulting bottle-neck locations, etc.);
- Component types and parameters (throughput capacity, working conditions);
- Component and plant failure behavior (intensity of component degradation over time, wear and failure mechanisms, etc.);
- Maintenance strategy and parameters (e.g. intervals of periodic actions, time between major line revisions, availability of resources);
- Organizational aspects of production, supporting services and information work-flow;
- Financial aspects of operation and downtimes;
- Aspects of ecological, social and legislative environment

Due to the nature of these instances of the process may be different (e.g. the physical topology of the production line and the information flow of maintenance orders considered in this research), there may be several groups of output indicators collected in order to evaluate the effectiveness of the system from different point of views.

For the purposes of this research we employ two groups of metrics. One is for the assessment of the production line performance. Such metrics usually include measures of

**reliability** and **availability** of a production line, **throughput yield, loading** and **efficiency**. These measures are often combined in the **Overall equipment effectiveness** (OEE) and **Total Effective Equipment Performance** (TEEP) metrics which are commonly used as a key performance indicator of how effectively a manufacturing operation is utilized:

(1) $OEE = Availability * Performance\ Efficiency * Throughput\ Yield$

(2) $TEEP = OEE * Loading$

The other group of indicators belongs to the evaluation of maintenance efforts and includes:

**Maintenance effectiveness -** a measure of the amount of maintenance downtime required to keep equipment (or plant) operating:

(3) $Maint. Effectiveness = \frac{Operating\ Time}{Operating\ Time + DownTime}$

**Maintenance efficiency -** a measure of the maintenance effort required to deliver required performance levels from equipment (or plant):

(4) $Maintenance\ Efficiency = \frac{Maintenance\ days}{Operating\ Time}$

**Ratio of preventive maintenance work to repair -** a measure of planning and scheduling process effectiveness and its influence on breakdown maintenance:

(5) $Ratio\ of\ Prev. to\ Repair = \frac{Prevent .Work}{Breakdown\ Work}$

The **trade-off relationships** which can be investigated in respect of assessment of the effectiveness of an applied maintenance program ultimately implies a trade-off between the cost of performing preventive maintenance and the cost to run the equipment to failure.

### III. SIMULATION DESIGN CONCEPT

The general idea of the simulation approach is to combine two processes of different origin (the continuous production process and the information flow of maintenance work-orders) in one model to investigate how the interaction between the processes affect the performance of the production system, as well as to define the optimization opportunities. Thus a production system that contains numerous components is simulated as an integrated model of two interacting modules.
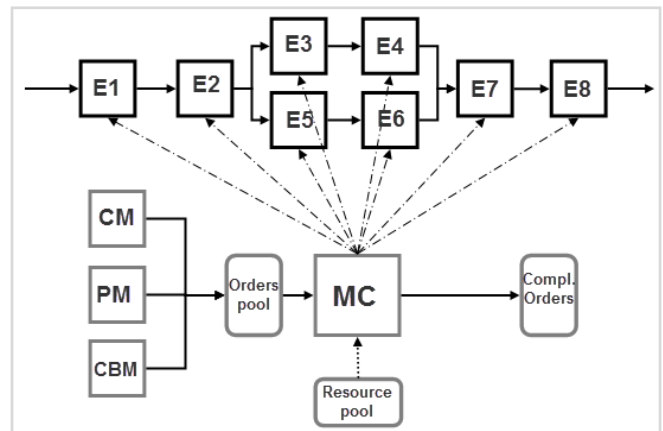


Fig. 1 Simulation design concept

**Maintenance process flow simulation**, if designed carefully, may replicate the flow of maintenance work orders in an information system of a company. The module represents the application of maintenance policies and composed of the following components:

**Corrective Maintenance** (CM) orders issued to the system are requests for equipment repair. When such a work order is issued, the respective machine is already stopped due to an unexpected failure and awaiting for repair activities. These orders are executed as soon as possible by the maintenance coordination workcenter, to bring the failed equipment back to operation.

**Preventive Maintenance** (PM) orders entry point contains a predefined plan (schedule) of maintenance actions for different machines and issues orders in fixed times as per the schedule. The orders are also executed by the maintenance workcenter, which stop the respective machine and change its condition parameters back to initial values after a specific period of time defined in the order.

**Condition-Based Maintenance** (CBM) orders entry point represents a relatively new concept of maintenance policy, when issuing an order depends on a condition of a machine. That links the rule of CBM entry point to degradation patterns of machines.

**Maintenance Coordinator** (MC) workcentre halts respective machines (if not halted yet due to a breakdown) when pick up raised work orders and process the orders in accordance to maintenance parameters described in them. The MC work center is linked to the **Resource Pool**; therefore a maintenance action is postponed when there is a lack of resources.

Complete Orders point collect the output data about the performed maintenance work including types of executed work orders, times of repair etc, which allows calculating Maintenance KPI and evaluation of maintenance effectiveness.

Production Line module represents the arrangement and topology of the system components, the process of production within declared capacities, behavior of the components degradation and failure phenomena.

Each **machine** in the production line has its own function, production capacity, degradation pattern and a rate of a potential failure.

**Failure rate** is the frequency with which an engineered system or component fails, expressed for example in failures per hour. The failure rate of a system usually depends on time, with the rate varying over the life cycle of the machine. Equipment failure pattern is defined by the rate of a potential failure.

$P(t) = 1-exp \{ - (t- t'/ \eta) \}$, where $t'$ - the threshold time-to-failure, or guaranteed life; $\eta$ - the characteristic life.

Preventive or breakdown maintenance actions restore the maintained equipment to the initial state of the decreasing or constant failure rate.

## IV. CASE STUDY

The selected tool for designing the simulation model is SIMUL8 software package for discrete event systems simulations. A model using SIMUL8 is developed to simulate the behavior of LNG train with an expected annual production output of 2600000 ton of LNG (2600 units in the model), which is an average rate of one LNG train in the industry. The input flow is set to 300 ton/hour (7.2 units

daily) that will load equipment up to 70 percent of capacity.

The components of a simplified LNG process train and the respective Maintenance process flow are modeled in Simul8 for the purpose of the research as shown on the following figure.
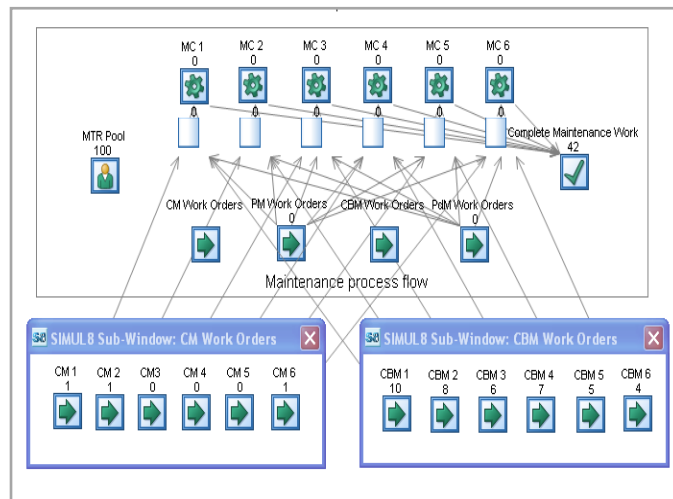


Fig. 2 Visual structure of the simulation in Simul8

The simulation model described above is run four times in order to collect results of various simulation scenarios as follow:

- Scenario#1: Breakdown strategy
- Scenario#2: Preventive strategy
- Scenario#3: Condition-based strategy
- Scenario#4: Combined PM/CBM strategy

The result coefficients are grouped into two categories: Equipment and overall performance indicators (Production output, Overall equipment effectiveness, Total equipment effective performance) and Maintenance performance indicators (Number of production line shutdowns, Downtime, Maintenance efficiency, Maintenance effectiveness
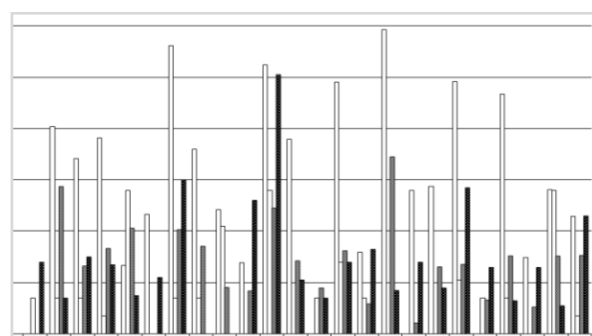


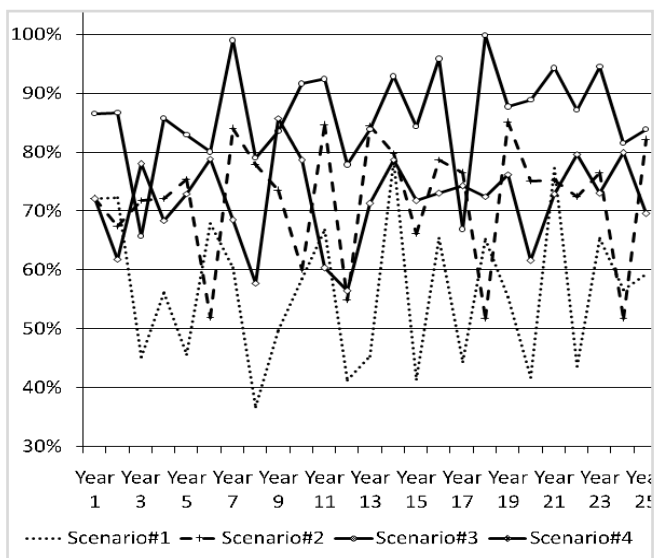Fig. 3 Production line downtime in different simulation scenarios

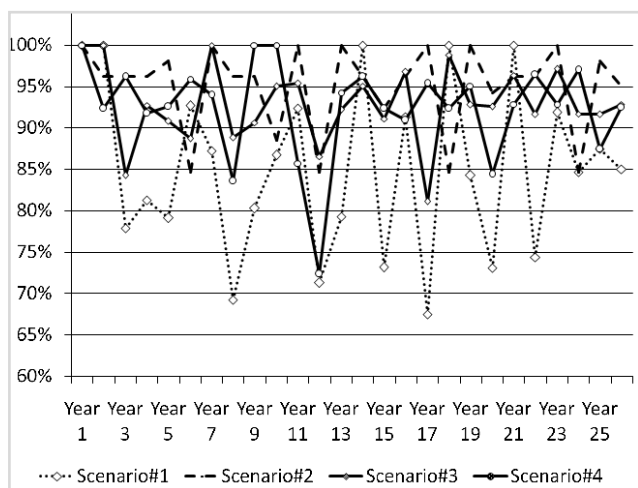Fig. 4 Total equipment effective performance (TEEP)



Fig. 5 Maintenance effectiveness

The scenario#1 is considered as a worst-case simulation. All units are maintained in the Corrective manner, in spite of real requirements demanded by the case. Taking into account its' general cost ineffectiveness and huge negative safety and environmental impact in case of this scenario is implemented in real life, however the collected data will be the basic point of reference for the results comparison.

However the generally accepted manner of performing maintenance activities in the industry is the planned campaigns of annual maintenance shutdowns of the production line. The scenario#2 simulates this strategy applied to the case study. This scenario also takes a possibility of random equipment failures into account, yet

the schedule of shutdowns composed for the purpose of preventing all possible failures at heavy cost of over-maintenance if necessary, therefore there is no corrective work expected to occur.

The scenario#3 simulates the Condition-based maintenance strategy implemented to perform the routine maintenance activities. This strategy is expected to reduce the over-maintenance work, therefore increase production rate and equipment performance indicators.

The Scenario#4 represents a combined strategy of mixed Preventive and Condition-Based maintenance actions. The schedule of preventive tasks is adjusted to avoid over-maintenance in this case, thus the maintenance downtime is reduced and the overall performance of the production line increases

## V. CONCLUSIONS

The proposed approach aims to leverage the conventional techniques of production system analysis to introduce an open and extensible framework of methods for investigating different maintenance strategies and plant modification options.

The results of experiments show that combined strategies customized according to the requirements of the different plant segments devote more attention critical components while avoiding costly over-care where not appropriate.

The research does not aim to answer all the questions of increasing plant performance indicators by better maintenance or deliver a new concept of applicable maintenance strategies and fault monitoring schemes, but it provides a demonstration of a way to enhance conventional analysis methods and generate new models which improve the production system performance analysis.

The designed simulation model describes a behavior of a simplified production system, which can be extended in future to obtain more realistic values of maintenance and system performance indicators as well as append direct cost indicators. The further extension of the model must include details of a supply chain system, and specifications of

maintenance resources, which are highly critical for estimating the real costs of maintenance strategies.

## REFERENCES

[1] J. Ashayeri, A. Teelen: "A Production and Maintenance planning model for the Process Industry", Department of Econometrics Tilburg University, The Netherlands 1996

[2] J.H. Bullock: "Maintenance Planning and Control", National Association of Accountants, New York, NY. 1979

[3] R.E.M. Deenen, C.E. van Daalen, E.G.C. Koene: "Maintenance performance improvement with System Dynamics", Delft University of Technology, Netherlands, 1999

[4] R. Dekker: "Applications of maintenance optimization models: a review and analysis", Erasmus University, Rotterdam, The Netherlands 1996

[5] S. Fabricius: "Modeling and Simulation for Plant Performability Assessment with Application to Maintenance in the Process Industry", Swiss Federal Institute of Technology, 2003

[6] B. R. Haverkort, I. Niemegeers: "Performability modeling tools and techniques", University of Twente, Netherlands 1996

[7] "Reliability Centered Maintenance Guide for Facilities and Collateral Equipment", Aeronautics and Space Administration, Washington, D.C., 2000

[8] N. Rezga; X. Xiea; Y. Matia: "Joint optimization of preventive maintenance and inventory control in a production line using simulation", Université de Metz, France, 2001

[9] J. Shalliker, C. Ricketts: "An Introduction to SIMUL8 Release Nine", School of Mathematics & Statistics, University of Plymouth, 2002

[10] L. Swanson: "Linking maintenance strategies to performance", Department of Management, Southern Illinois University Edwardsville, Edwardsville, 2000

[11] Takafumi: "Advanced maintenance system of LNG receiving terminal for low cost operation and high reliability by RBM and RBQC", 23rd World Gas Conference, Amsterdam 2006