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# Estimation of overall equipment effectiveness using simulation programme

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**Abstract.** A queuing system of the M/M/1/N type with cyclic failure-free and repair times and cyclic defective production is used as a model of a single machine production system. Production tasks arrive according to an exponential process and are served with normally disturbed processing time. Successive working (failure-free) times, repair times and defect-free production have exponential distributions. Defective products can be recirculated and back to the production line according to a Bernoulli distributions. The objective is to evaluate effectiveness of the production system using Overall Equipment Effectiveness before and after introducing improvement initiatives.

## 1. Introduction

According to the words of Dave Logozzo: "If you're sensitive to the flow, you will easily notice wastes" companies aim to achieve a production without downtime in their cells or production lines [1]. Manufacturers aim to eliminate wastes, i.e. anything that does not add a value to a product [1]. Manufacturers try to establish close cooperation with a client and to produce products of a high quality and reasonable prices. The following methodologies are applied for reducing a cycle-time: six-sigma for value-added operations and lean for non-value-added operations. Six losses are distinguished: downtime losses (breakdown losses, set-up and adjustment losses), speed losses (idling and minor stoppage losses, speed losses) and quality losses (quality defects, rework and reduced yield during start-up) according to [2]. Overall Equipment Effectiveness (OEE) is proposed to measure improvement initiatives.

Production in manufacturing cells is realized in a tact time in order to overcome overproduction. The production capacity is adjusted by decreasing or increasing the tact time up to the maximal utilisation of given resources. Companies add overtime for existing workers or increase a number of production cells to meet the capacity constraints. In the paper, the OEE is proposed to evaluate problems with availability (breakdown or equipment failure, set-up and adjustment), performance efficiency (idling and minor stoppage, reduced speed) and product quality (defects and reworks, reduced yield). The OEE is used to maximize performance of existing capacity. A. Ron and J. Rooda [3] compare the OEE to equipment effectiveness E in order to indicate the influence of downtime and rework. P. Muchiri and L. Pintelon [2] investigate how the OEE indicator has evolved with time depending on individual needs of industries, indicating: overall factory effectiveness OFE, overall



plant effectiveness OPE, overall throughput effectiveness OTE, production equipment effectiveness PEE, overall asset effectiveness OAE and total equipment effectiveness performance TEEP. They underlined that the OEE identifies losses reducing a measure of effectiveness of equipment over a period of time. For other performance measurements see [4, 5, 6].

In the paper we deal with the M/M/1/N-type queuing system, in which the arrival stream of jobs is described by exponential process with intensity  $\lambda$ , and jobs are being served individually by a single machine, with the service speed normally distributed with  $\mu$  and  $\alpha$  and setup time  $\beta$ . The total system capacity equals N i.e. we have N-1 places in the magazine and one place in service. If the arriving job finds all places occupied, it is lost. Arriving production tasks form a single waiting line and are served in the order of their arrivals. At time  $t = 0$  the first working (failure-free) period begins that ends with a machine failure after an exponentially distributed time with mean  $\gamma$ . Successively, the repair time with mean  $\eta$  begins immediately at the end of failure-free time. Time to defective product occurrence is described by Bernoulli distribution with mean  $\varpi$ . Defective number of products can be recirculated and back to the production line according to a Bernoulli distribution with mean  $\rho$ . The production line is modeled in the Enterprise Dynamics System (ED). Wastes due to unplanned events in the machine's work on the OEE are summed up running experiments in the ED.

## 2. Problem formulation

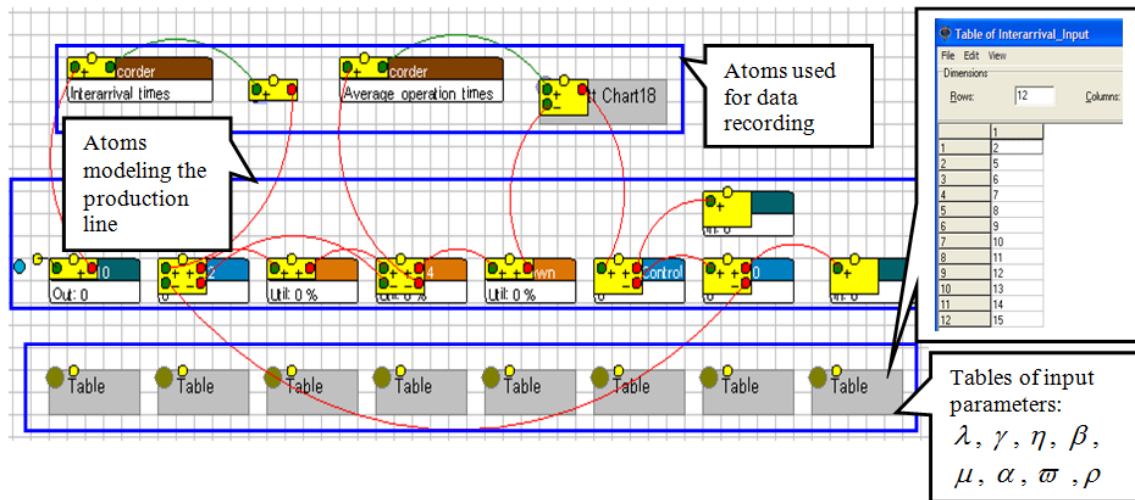
The assumption of the TPM method is to maintain machines in the state of productivity. The responsibility of each maintenance employee is to identify, monitor and remove causes of waste: breakdowns, little downtimes, work below a nominal performance, retooling of a machine and inadequate quality. Breaks for technical service are included in the production schedule. Each unplanned disturbance causes an increase in waste. The objective is to assess waste due to unplanned events over the OEE indicator, such as: (1) unplanned downtimes because of equipment failure occurring after failure-free time with mean  $\gamma$  and with repair time with mean  $\eta$ , (2) set-up and adjustment losses  $\beta$  during changing over from requirement of one item to another, (3) reduced speed losses with mean  $\mu$  and deviation  $\alpha$  due to differences between equipment designed speed and actual operating speed, (4) quality defects with mean  $\varpi$  due to malfunctioning production equipment, (5) reworks with mean  $\rho$  due to malfunctioning production equipment, (6) reduced yield during start-up that is losses that occur from machine start-up to stabilization.

The OEE indicator compares the real usage of the machine to the ideal usage, according to plan. The available time is the time duration of a shift. The schedule includes predicted downtimes: machine failures, changing of workers' shift, retooling, etc. A time of efficient production is the time of a product production. Components of the OEE: Availability (A), Performance (P) and Quality (Q) represent an impact of a waste in the production systems efficiency [2]. It is good when the OEE indicator reaches around 80% to make full use of machines and equipment. Below we study in details the influence of key system parameters  $\lambda$ ,  $\gamma$ ,  $\eta$ ,  $\beta$ ,  $\mu$ ,  $\alpha$ ,  $\varpi$  and  $\rho$  on the OEE and his components A, P and Q in different scenarios of system operation.

## 3. Simulation model creation

The model is created using a graphical user interface by selecting the component objects of simulation model from the available predefined atoms. Following atoms are used to model the manufacturing line: production process, source, buffer, machine for setup time, critical machine, machine for close down time, control stand (starting from the left hand side in the figure 1). Good quality products are sent to the upper sink. If a bad quality product can be reworked is sent back to the production line, if the product cannot be reworked is sent to waste (bottom sink). In the system P1 manufacturing process is executed. Atoms used in the model are subjected to the parameterization process. Possible alternative input parameters  $\lambda$ ,  $\gamma$ ,  $\eta$ ,  $\beta$ ,  $\mu$ ,  $\alpha$ ,  $\varpi$  and  $\rho$  for the process are presented in Sections describing the experiments and results. The input parameters are modeled in eight tables, the example

of table for interarrival times is in figure 1. Two data recorder atoms are used to collect information about  $\lambda$  and  $\mu$ , and atoms: Gantt Initialize and Gantt Chart are used to generate Gantt charts after a simulation.



**Figure 1.** Atoms of the simulation model.

#### 4. Simulation Experiment

Simulation experiments for the variable parameters of the production system ( $\lambda, \gamma, \eta, \beta, \mu, \alpha, \omega, \rho$ ) are made with the application of the Experimental Wizard Module. The experimental module allows to perform various experiments in an automatic way for many simulations without the interaction of an analyst. The option: Separate runs was selected as the method of Simulation. Number of independent simulations (of observations) is 10. Duration time of observation is 4800 mins in each simulation. In each simulation input parameter values are read from tables. In order to read automatically a value of  $\lambda$  in each simulation following codes are written in 4DScript: On start of simulation run: *if(Interarrival\_Input(1,1)>11,set Interarrival\_Input (1,1,2))* and On end of simulation run: *set Interarrival\_Input (1,1, Interarrival\_Input (1,1)+1)*. After each run of simulation a value of is read from a vector indicated in the cell (1,1) of *Interarrival\_Input Table*. Each time of simulation value of a counter from the cell (1,1) is increased by 1. The counter receives the value of 2 if the value of counter is more than 11. In the Source atom, parameters: inter-arrival time and time till first product arrives are described by: *mins(Interarrival\_Input(Interarrival\_Input (1,1),1))*.

The discrete-event simulation run for analyzing the behavior of the model. Results of production system work are generated in reports. In tabel 1 the example of the report generated for the input data described in the Section " Effect of speed of processing on the OEE" is presented.

#### 5. Effect of speed of processing on the OEE

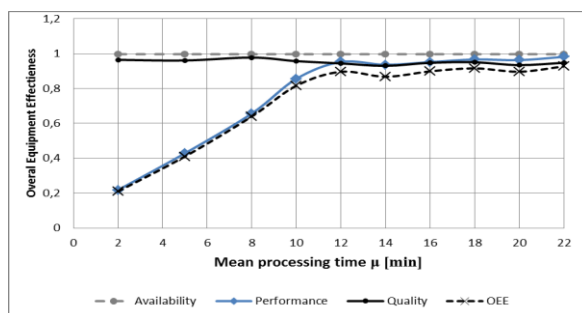
Let us observe the OEE after  $T=4800[\text{min}]$ , taking interarrival time, mean values for operating speed, setup time, failure-free and repair times, defects-free times and rework occurrence times equal to 9, 8, 5, 340 and 16[min], 95 and 50 [number] respectively. A production task is stored in a finite-capacity buffer if it arrives and the machine is busy or setup activities are done. The level of buffer saturation  $n=6$ . The machine needs a setup time before providing the service of the first task after the idle time.

Let us analyze now the impact of the processing rate on the OEE. Observe the mean A, P and Q for the system described above and for 10 values of mean processing rate  $\mu$  of jobs, namely 2, 5, 8, 10, 12, 14, 16, 18, 20, 22, 24 [min] and standard deviation equals to 2[seconds]. The results of the simulation are presented in the table 1 and geometrically in the figure 2. For low processing speed (2-9) the OEE is below 80% which is unacceptable. For processing speed (2-9) differences between

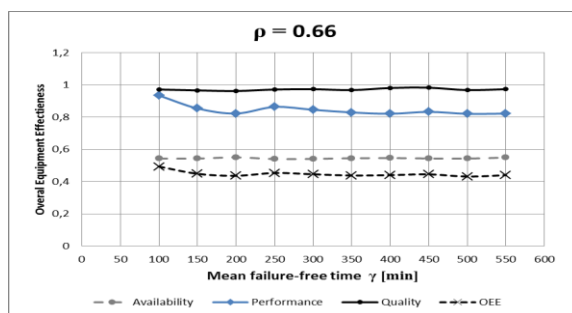
results obtained for the OEE are significant. As the service speed increases, the differences are getting smaller. The explanation of this phenomenon is in that, at a very high processing rate, the production capacity of the production system is not used since the intensity of arrivals equals 9. Improvements in equipment effectiveness over a period of time is economically reasonable only if the interarrival time of a new task decreases as well.

**Table 1.** Raw data and mean OEE computing as a function of processing rate after simulation time  $T=288000$ [seconds].

Raw Data									
Server	Average staytime (Ideal Cycle Time) [in seconds]								
121,807	240,09	361,62	481,589	602,088	722,241	842,855	963,312	1083,585	1204,003
Server14	Departures								
556	544	554	545	476	397	340	298	265	238
Server	Utilization(%)								
Idle	0,764	0,543	0,304	0,086	0,002	0,002	0,002	0,002	0,002
Busy	0,231	0,453	0,692	0,909	0,993	0,993	0,993	0,993	0,993
Down	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003
Sink	Good Units								
514	512	521	510	454	372	324	288	255	234
Source	Units Started								
533	533	533	533	481	400	342	303	273	247
Availability (A) = Availability Time / ( Simulation Time /60)									
Availability Time = (Simulation Time - (Busy x Simulation Time))/60									
4784	4784	4784	4784	4784	4784	4784	4784	4784	4784
(A)	0,996	0,99	0,9967	0,9967	0,9967	0,9967	0,996	0,996	0,996
Performance = (Good Units* Average staytime ) / Available Time									
0,218	0,428	0,656	0,855	0,952	0,936	0,951	0,966	0,962	0,981
Quality = Good Units / Units Started x 100									
0,964	0,960	0,977	0,956	0,943	0,93	0,947	0,95	0,934	0,947
OEE = Availability (A) x Performance x Quality									
0,209	0,41	0,639	0,816	0,895	0,867	0,898	0,915	0,896	0,926



**Figure 2.** Mean OEE as a function of processing rate after  $T=288000$ [seconds].

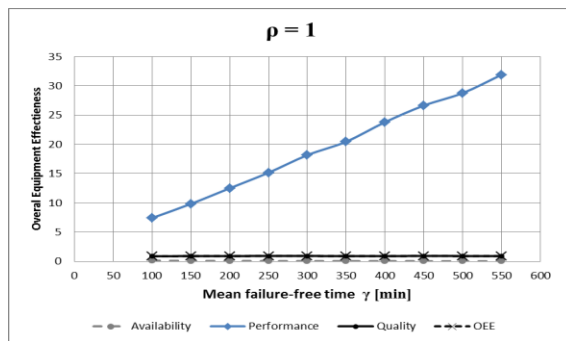


**Figure 3.** Mean OEE as a function of failure-free time and traffic load equal to 0.66.

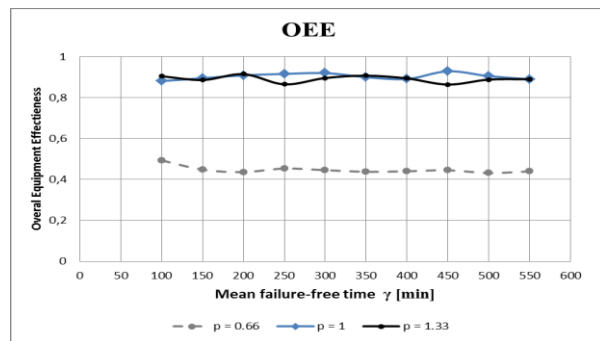
## 6. Impact of the failure-free period duration on the OEE

Let us study now the possible impact of the failure-free period duration  $\gamma$  on the OEE before the fixed time  $T$ . Let us take into consideration the system in which mean service rate equals  $\mu = 9$  [min], the repair time is long with mean  $\eta = 16$  [min] and for 10 mean values of  $\gamma$ : 100, 150... 600 [min].

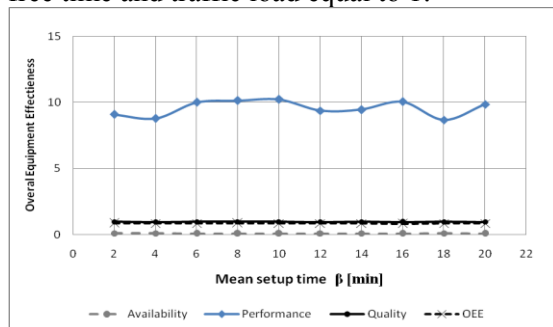
Accepting means of processing times:  $\lambda = 6, 9$  and  $12$  [min], we get the values of the traffic load  $\rho = \lambda / \mu$  equal to  $0.66, 1.0$  (critical loading) and  $1.33$  (overloading), respectively. For the initial condition  $n=6$  we obtain the results given for  $\rho = 0.66$  in the figure 3 and for  $\rho = 1$  in the figure 4. The OEE increases for the increasing  $\rho$  to the critical loading level. A slight decrease of this characteristic is connected with the increasing  $\gamma$ . Comparing the OEE for critical loading and the case of the overloaded system, the OEE for  $\rho = 1.33$  is slightly worst (figure 5), in practice, the only time period during which the machine does not process the jobs is its repair time.



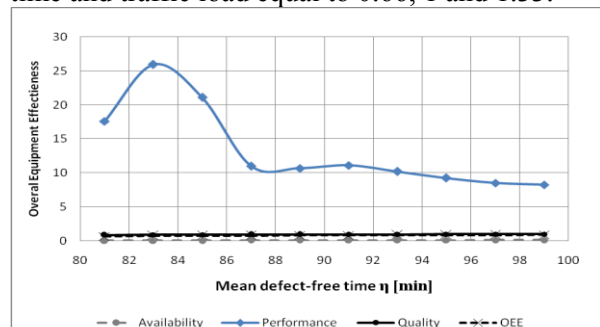
**Figure 4.** Mean OEE as a function of failure-free time and traffic load equal to 1.



**Figure 5.** Mean OEE as a function of failure-free time and traffic load equal to 0.66, 1 and 1.33.



**Figure 6.** Mean OEE as a function of setup time after  $T=4800$  [min].



**Figure 7** Mean OEE as a function of defect-free time after  $T=4800$  [min].

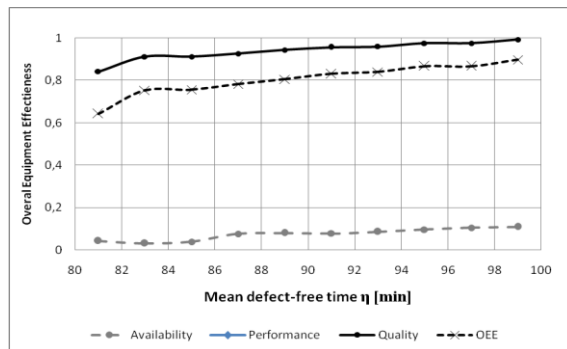
## 7. Impact of the setup time on the OEE

Let us investigate what is the impact of setup time duration  $\alpha$  on the OEE. Observe the system for proportion: repair time/failure free-time:  $8/500$  [min] and for 10 mean values of  $\alpha$ , namely  $2, 4, \dots, 20$  [min]. For  $\lambda = 9$  and  $\mu = 8$  [min], we obtain results visualized in figure 6. As one can observe, the mean  $\alpha$  increases, however, the OEE decreases very little. The explanation of this phenomenon is in that, the intensity of arrivals equals 9 is close to the ideal cycle time thus no setup times activities are done for this data in the most scenarios.

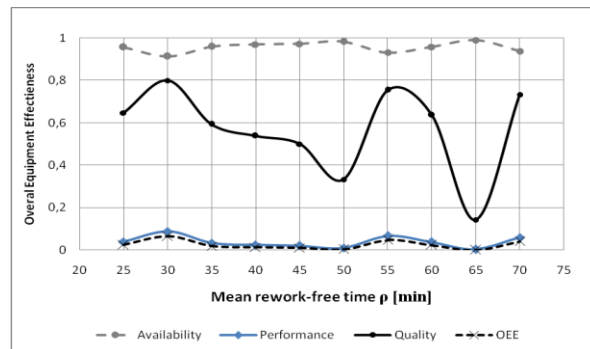
## 8. Impact of the defects-free time on the OEE

Next we investigate what is the impact of defects-free time duration on the OEE. Take  $\alpha = 22$ , and observe the system for 10 mean values of  $\eta$ , namely  $81, 83, \dots, 99$  [min]. We obtain results visualized in the figure 7 and 8. As one can observe, the OEE increases as  $\eta$  increases. For  $81 < \eta < 87$  the performance value of the system changes very rapid.





**Figure 8.** Mean OEE as a function of defect-free time with the range 0 to 1 for Y axis.



**Figure 9.** Mean OEE as a function of rework-free time after  $T=4800$  [min].

### 9. Impact of the rework-free time on the OEE

Finally, investigate what is the impact of rework-free time duration on the OEE. Observe the system for  $\eta = 89$  and for 10 different mean values of  $\rho$ , namely 25, 30... 70[min]. We obtain results visualized in figure 9. As one can observe, the impact of rework-free time on the OEE is the highest. We can see the burstiness of the OEE as  $\rho$  increases.

### 10. Conclusions

In the paper the effectiveness of production system of the M/M/1/N type with cyclic failure-free, repair times and cyclic defective production is evaluated. In the production system defective products can be recirculated and back to the production line. The Overall Equipment Effectiveness is used to evaluate improvement initiatives. Differences between results obtained for the OEE are significant for processing speed from 2 to 9. Increasing the processing speed over 9 is economically unreasonable since the intensity of arrivals equals 9. Increasing the traffic load to the critical loading level increases the OEE as well. The setup time has no effect on the OEE. The OEE increases with the defects-free time increasing. Increasing rework-free time a high burstiness of the OEE has been noticed.

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