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Modeling and Simulation of Manufacturing Line Improvement

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ABSTRACT
In the paper an example of manufacturing line form automotive industry is analyzed. The line consists of five presses, that can be operated by humans or industrial robots. Since human factors affect destabilization of the production processes, robots are preferred to apply. The problem is how to determine the real difference in the work efficiency between human and robot. Because of problem complexity, Discrete Events Simulation (DES) method have been used. Three models have been developed including manufacturing line before and after robotization and taking into account stochastic parameters of availability and reliability of the machines, operators and robots. Analysis of the production efficiency of the press shop lines operated by human operators or industrial robots are presented. We apply OEE (Overall Equipment Effectiveness) indicator to present how the availability and reliability parameters influence over the performance of the workstations, in particular in the short and long time period.

Keywords: *DES (Discrete Event Simulation), human factors, industrial robots, OEE – overall equipment efficiency, machine reliability*

I. Introduction

Nowadays, one can notice increasing use of automation and robotization, which replace human labor. Industrial robots are used especially for repetitive, high precision tasks (e.g. welding), monotonous activities and actions demanding physical exertion. Industrial robots have mobility similar to human arm, and can perform various complex actions like a human. In addition, they do not get tired and bored. It is estimated that using robotization, many companies obtained the reduction of the production cost by 50%, the increase of productivity by 30% and the increase of utilization by more than 85% [4]. However, the introduction of robotization is related with high costs, thus is profitable only in certain circumstances, including, a high level of production, work with repetitive and precision tasks with ensuring the safety and health at work [12]. Such conditions occur in the automotive industry [10]. The problem is how to determine a real difference in work efficiency between human and robot. The aim of the study is to develop a methodology, which allows to clearly define the throughput growth associated with the replacement of human labor by industrial robots. In order to assess the effectiveness of the robot application, we compare production uptime of humans and robots with the use of the OEE indicator (Overall Equipment Effectiveness) to calculate work efficiency and we use Discrete Event Simulation (DES) for verification. Production systems can be very complex and difficult for analysis. Therefore, the DES method is widely used for design of manufacturing systems [15], for solving scheduling problems [9] and for efficiency [8] and stability analysis [3] of production systems. There are some DES software tools dedicated for production processes simulation, including ARENA, Enterprise Dynamics, FlexSim, Plant Simulation and others [5, 11, 13].

II. Manufacturing line example

Analyzed example of manufacturing line consists of five presses and is used for production of car body parts. Presses are often used in various production processes e.g. pressing, sheet metal forming etc. The schema of press line is presented in Figure 1. The line consist of five serially linked machines, input and output stations and operators or robots for machine tending.

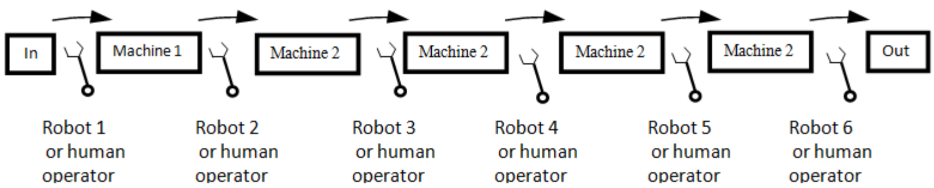

Figure 1. Schema of the manufacturing line

Usually, operator is required for loading and unloading a machine and for transferring a product from one machine to a next production stage. Robots can make that work faster and more regular then human operators, but what will be the difference in production throughput?
The reliability of each component play important role, because failure of one element causes production stopping on the whole line. The machine failures are mostly random and are difficult to predict; therefore, we have used computer simulation for the research. We have developed models including human resources and industrial robots. Because elaborated model is a simplified image of the real system, the next problem is which system parameters are important for the simulation.

III. Work efficiency and OEE

Work efficiency and the use of the production means can be expressed by using the OEE metric that depend on three factors: availability, performance and quality [6].

$$OEE=(Availability)x(Performance)x(Quality) \qquad (1)$$

Availability is the ratio of the time spent on the realization of a task to the scheduled time. Availability is reduced by disruptions at work and machine failures.

$$Availability = \frac{available\ time - failure\ time}{scheduled\ time} \qquad (2)$$

Performance is the ratio of the time to complete a task under ideal conditions compared to the realization in real conditions or the ratio of the products obtained in reality to the number of possible products to obtain under ideal conditions. Performance is reduced (loss of working speed) by the occurrence of any disturbances e.g. human errors.

$$Performance = \frac{ideal\ cycle\ time}{real\ cycle\ time} \qquad (3)$$

Quality is expressed by the ratio of the number of good products and the total number of products.

$$Quality = \frac{good\ products}{overall\ products} \qquad (4)$$

The number of good quality products is a random variable, which can be described by a normal distribution with standard deviation sigma. Quality levels are determined for ranges of the standard deviation sigma. In traditional production systems, the level of 3 sigmas is considered to be sufficient. However, in the modern automated and robotic systems the level of 5-6 sigmas is possible to achieve [2].
In order to make these models more realistic we decided to include availability, performance and quality parameters into account.

3.1. Availability and failures

The term of availability contains planned work time and unplanned events e.g. the disturbances at work and random machine failures. Any unplanned event causes that machines are unavailable and work efficiency decreases. The reliability of objects such as machines or robots is defined as the probability that they will work correctly for a given time under defined conditions of work. The most popular method for estimating reliability parameters uses theory of probability to forecast a value of failure-free time and repair time parameters, under the condition that a trend based on historical value of the parameter is possible to notice. The examples of using normal, exponential, triangular distributions to describe both failure and repair times are described in [4]. In practice, for description of reliability, in most cases the parameter MTTF (mean time to failure) is used, which is the expected value of exponentially distributed random variable with failure rate λ [14].

$$MTTF = \int_0^\infty t\, f(t)\, dt = \int_0^\infty t\, \lambda\, e^{-\lambda x}\, dx = \frac{1}{\lambda} \qquad (5)$$

In the case of repairable objects the parameters MTBF (mean time between failures), and the MTTR (mean time to repair) are used.

$$MTBF = MTTF + MTTR \qquad (6)$$

For complex systems, consisting of *n* serially linked objects, the resultant failure rate λ_s of the system is the sum of the failure rates of each element λ_i:

$$\lambda_s = \sum_{i=1}^{n} \lambda_i \qquad (7)$$

Alternatively, the system $MTBF_s$ is the sum of the $MTBF_i$ inverse:

$$\frac{1}{MTBF_s} = \sum_{i=1}^{n} \frac{1}{MTBF_i} \qquad (8)$$

For the example of robotic line, presented in figure 1, we can use formula 8 with different failure parameters for machines $MTBF_{mi}$ and for robots $MTBF_{ri}$:

$$\frac{1}{MTBF_s} = \sum_{i=1}^{n} \frac{1}{MTBF_{mi}} + \sum_{i=1}^{n+1} \frac{1}{MTBF_{ri}} \qquad (9)$$

Machinery failures affect the availability of means of production and may cause severe disturbances in production processes. The average availability can be calculated with formula 10.

$$Availability = \frac{MTBF}{MTBF + MTTR} \qquad (10)$$

3.2. Human factors

Humans are one of the most unreliable parts of manufacturing systems. In the case of a manually operated systems, a number of human factors (human errors) can lead to destabilization of the manufacturing process [7]. Workers also require a break for rest. They are unpredictable and can make errors and accidents at work can occur. Sick and absent workers can cause the failure of a production plans.

In the computer software, used for production processes simulation, the human factor is not sufficiently modelled. People are treated as quasi-technical elements of production system and they should operate in the same way as a machine. In practice, the human behaviour is unpredictable, thus it might help to explain why simulation models do not respond to the reality as it would be expected [1].

IV. Modelling of manufacturing line

In order to analyze the presented problem the mechanical press line from automotive enterprise, has been taken into account. We used the Enterprise Dynamics software, which allows computer-modeling and simulation of discrete production processes with the use of human resources as well as robots. Parameters of typical manufacturing process were taken into account including constant machine cycle time 5s, constant robot speed 180°/s, stochastic parameters of operator time, which was described by normal distribution with 10s mean time and 2s standard deviation. Availability parameters include planned setup time 15 minutes per shift, and break for rest for workers 15 minutes per shift. Failure parameters were taken into account including short time human errors rate and long time machine and robot MTBF. Typical reliability parameters include MTBFm=500 hours and MTTRm=4 hours for machines and MTBFr=1000 hours and MTTRr=4 hours for robots. Also normal quality distribution of good and bad product has been included into the model.

The first model presented in the Figure 1, is a simply reference model. It consist of five machines, input and output station. It represents production in ideal conditions and can be used for calculation of maximal production limit.

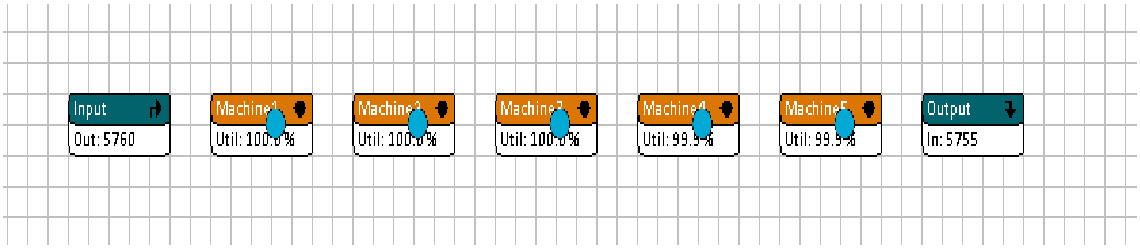

Figure 2. Reference model of manufacturing line

The second model shown in the Figure 3, includes five human operators, six buffers, and output for good and bad quality products. Work time schedule is used for defining planned work pauses and additional MTBF objects are used for simulation of random failures.

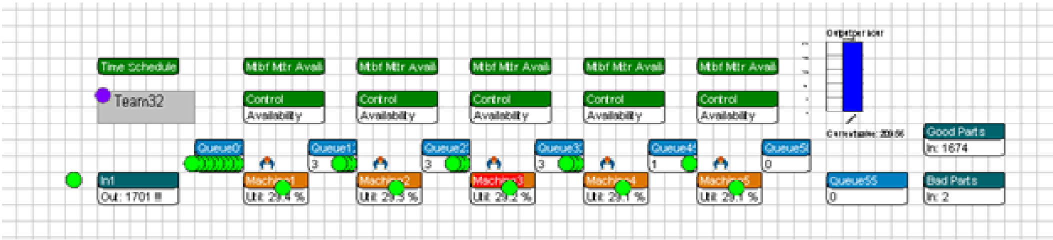

Figure 3. Model of manually operated line after 8 hours of simulation

Irregular work of operators and human errors cause disturbances in the production process. Assuming human unreliability on the basis of HEART (Human Error Assessment and Reduction Technique) for “routine and highly practiced rapid tasks involving relatively low level of skill”, the nominal value of human error equals to 0.01 [16]. Therefore, human errors rate can be described by parameters: MTBFh=8 hours and MTTRh=5 minutes.

We assume that other employee can replace sick and absent worker, but it is impossible to replace broken machines and robots, and they require repairing.

The third model presented in the Figure 4, includes industrial robots. Because of the constant speed and very regular work of robots, buffers are not needed.

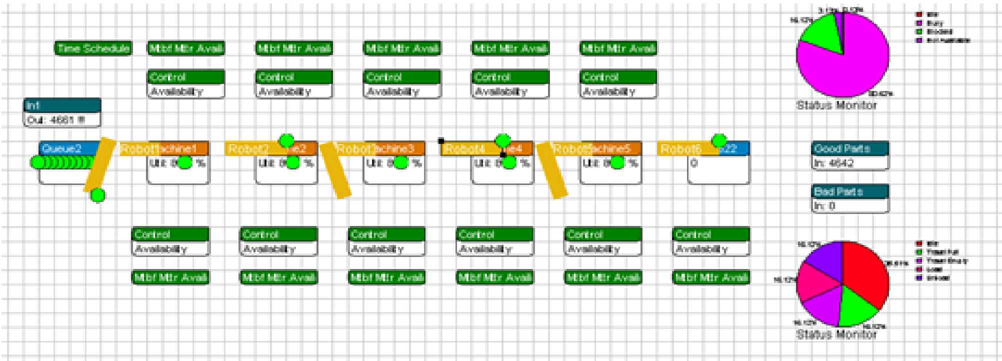

Figure 4. Model of robotized line after 8 hours of simulation

We can see a great improvement of production throughput and machine utilization for robotic line, however each simulation run, can give little different results because of random failures. Therefore, we have made series of experiments, containing different number of simulations runs and simulation time from 8 hours to 6000 hours.

V. Experiment results

The production value P obtained from a single simulation run is a random variable that consists of several parameters. The random nature of failures causes a significant dispersion of obtained values and relatively large standard deviation. The average production value Pavg of simulation experiments are summarized in Table 1. Each experiment consists of fifty samples (simulation runs). The value MaxLimit determines the maximum possible production volume in a given period of time under ideal working conditions and for a machine cycle time (Tm=5 seconds). Since the model was build based on the OEE components, and contain parameters of availability, performance and quality, the production value from simulation can be directly used to calculate the OEE indicator.

$$OEE = \frac{Average\ production}{Maximal\ production\ limit} \quad (11)$$

The standard deviation shows the differences between the average value of production and the value of production achieved in each simulation run. For the robotic tended line, the values of standard deviation are greater because of a much greater production volume and possibility of robots failures. This phenomenon can be explained that sick humans can be replaced but robots not.

Table 1. Simulation results for manually operated and robotic lines (average production value P_{avg} in [PCs.] for 50 runs of simulation, α=0,95, MTBFm=500h, MTBFr=1000h, MTTR=4h)

	Human Operators	Robots	Human Operators	Robots	Human Operators	Robots	Human Operators	Robots
Time	8h		24h		2000h		6000h	
Max Limit [PCs.]	5760		17280		1440000		4320000	
Average Production P_{avg} [PCs]	1681	4404	5111	13300	427179	1094949	1281345	3279888
Standard deviation [PCs]	50.72	619.3	85.28	1432	714.96	19331	1207	27496
OEE	**0,2918**	**0,7646**	**0,2958**	**0,7697**	**0,2967**	**0,7604**	**0,2966**	**0,7592**

Production throughput of the robotic line has increased about 2.6 times comparing to the line before robotization.The OEE related performance of the production line operated by robots has improved by 46% comparing to the manually operated line. The OEE indicator equals to OOEh=29.18÷29,67% for humans and OEEr=75,92÷76,97% for robots, and correspond with the values assigned by the theory presented in Table 2. Values calculated by the theory are: availability of the whole robotic system A=0,912; performance P=0,8333; quality Q=0,99999. That gives OEEr=76,0%.

Table 2. Values of the OEE indicator

Manufacturing line	Human operated line OOEh	Robotic line OEEr
Availability	0,893	0,912
Performance	0,333	0,833
Quality	0,9973	0,99999
OEE	0,297	0,760

This shows that reliability parameters have significant influence on the productivity of the production system and reliability improvement can change the OEE score. Comparing the OEE factors achieved for human operator and robot the greatest improvement is in the performance.

VI. Conclusion

As it was predicted, the experiments confirm the advantage of the application of robotic operated production lines comparing to manually operated lines. The computer simulation of the simplified model of the production line with machines, operators and robots with stochastic (short-time and long-time) reliability parameters allows for better representation and understanding of a real production process. This is particularly to see in the case of work in three shifts a day for a long period of time. The work organization and robots synchronization play important role and therefore the efficiency of the production line operated by robots has improved the OEE indicator by 46% comparing to a manually operated line. Because of irregular work of human operators, the buffers (queue) are needed for equalization of production flow and therefore loading (unloading) products from buffers result in low performance of human operators. Also breaks for rest result in lower OEE value. This is one of the best examples of robotic improvement in manufacturing. However, in other cases of machine tending, the difference between human operator and robot is not so clearly to see even for long time simulations.
The use of OEE factors allows to compare results from other manufacturing systems. The reality is that most manufacturing companies have OEE scores closer to 60%, but there are many companies with OEE scores lower than 40%, and small number of world-class companies that have OEE scores higher than 80%.
There are some place for improvement of availability, performance and quality. Availability depends on planned and unplanned breaks at work. Performance score depends on machine cycle time and high robot speed. The quality depends on stability of manufacturing process parameters.
Results obtained with presented methodology can be used for detailed designing of a robotic system and for economic analysis, regarding labor costs and costs associated with the investments in robotization.

References

[1] T. Baines, S. Mason, P. O. Siebers, J. Ladbrook. Humans: the missing link in manufacturing simulation? Simulation Modelling Practice and Theory, No 12, 2004, pp. 515–526.
[2] M. Barney, T. McCarty. The new Six Sigma. Prentice Hall Professional, New York, 2001.
[3] A. Burduk. Stability Analysis of the Production System Using Simulation Models", Process Simulation and Optimization in Sustainable Logistics and Manufacturing, Springer, 2014, pp. 69-83.
[4] A Glaser. Industrial robots, Industrial Press, New York, 2009.
[5] G. Gołda, A. Kampa, I. Paprocka. Simulation model of robotic manufacturing line. Position Papers of the 2016 Federated Conference on Computer Science and Information Systems, M. Ganzha, L. Maciaszek, M. Paprzycki (eds). ACSIS, Vol. 9, pages 107–113 (2016), http://dx.doi.org/10.15439/2016F307

[6] R. C. Hansen. Overall Equipment Effectiveness, Industrial Press, 2005.
[7] C. E. Harriott, J. A. Adams. Modeling Human Performance for Human–Robot Systems, Reviews of Human Factors and Ergonomics, No 9, 94, 2013, http://rev.sagepub.com/content/9/1/94
[8] A. Ingemansson, and G.S. Bolmsjo. Improved efficiency with production disturbance reduction in manufacturing systems based on discrete-event simulation', *Journal of Manufacturing Technology Management*, Vol. 15, No. 3. 2004, pp. 267–279.
[9] A. Kampa. Planning and scheduling of work in robotic manufacturing systems with flexible production. Ed. B. Skołud: Hueristic Methods of Project and Production Scheduling. Journal of Machine Engineering, Vol. 12, No. 3, 2012, pp. 34-44.
[10] R. Kulanek. Press Excelence Center COMAU, i.e. robotics press line at the world level", available at www.robotyka.com 2014, (in polish, accessed 15.12.2015).
[11] B. Santhosh Kumar , V. Mahesh, B. Satish Kumar. Modeling and Analysis of Flexible Manufacturing System with FlexSim. International Journal of Computational Engineering Research (IJCER), Volume 05, Issue 10, October – 2015, pp. 1-6.
[12] S. Y. Nof. Handbook of industrial robotics. John Wiley & Sons, New York, 1999.
[13] I. Paprocka, W. Kempa, K. Kalinowski, C. Grabowik: "Estimation of overall equipment effectiveness using simulation programme". Modern technologies in industrial engineering (ModTech2015), 17-20 June 2015, Mamaia, Romania. Materials Science and Engineering ; vol. 95 1757-8981. Institute of Physics Publishing, Bristol, 2015, s. 1-6, doi:10.1088/1757-899X/95/1/012155
[14] D.J. Smith. Reliability, Maintainability and Risk. Practical methods for engineers, Elsevier, Oxford, 2005.
[15] C. Xie, T. T. Allen. Simulation and experimental design methods for job shop scheduling with material handling: a survey. The International Journal of Advanced Manufacturing Technology, 2015, p. 233-243.
[16] D.D. Woods. Modeling and predicting human error", In J. Elkind, S. Card, J. Hochberg, and B. Huey (Eds.), Human performance models for computer-aided engineering Academic Press, 1990, pp. 248-274.