DOI: 10.2507/31st.daaam.proceedings.061

SIMULATION MODELLING OF ENVIRONMENTAL AND ECONOMIC ASPECTS IN MANUFACTURING SYSTEMS

Robert Ojstersek, Iztok Palcic & Borut Buchmeister

This Publication has to be referred as: Ojstersek, R[obert]; Palcic, I[ztok] & Buchmeister, B[orut] (2020). Simulation Modelling of Environmental and Economic Aspects in Manufacturing Systems, Proceedings of the 31st DAAAM International Symposium, pp.0436-0443, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-29-7, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/31st.daaam.proceedings.061

Abstract

The presented manuscript deals with the new simulation modelling approach for the environmental and economic aspects evaluation in a sustainably justified manufacturing system. First, the research problem of simulation modelling methods for the evaluation of environmental and economic aspects of manufacturing systems is presented and defined. Then a new data-driven simulation modelling approach for environmental and economic aspects of manufacturing systems is presented. The newly proposed block diagram is used from a theoretical and applied point of view. Two major environmental and economic aspects are optimized in terms of machine scrap rate and electrical energy consumption. Promising theoretical results from the proposed block diagram are transferred into a practical application. The numerical and graphical simulation results obtained prove the high relevance of the optimization approaches used. The obtained optimization results of the simulation modelling show a reduction of the electrical energy consumption by an average of 11.6% compared to the initial manufacturing system stage. The importance of proper optimization of the machine scrap rate was demonstrated, using the proposed simulation modelling approach. The optimization results show a high degree suitability of the simulation model approach in the order of the evaluation environmental, economic and other social aspects of sustainable manufacturing systems.

Keywords: Simulation modelling; Data driven modelling; Simio; Sustainable manufacturing; Manufacturing optimization.

1. Introduction

The global manufacturing trend is based on providing personalised products to customers needs. A high degree of personalization can be observed not only in high-mix, low-volume manufacturing systems, but also in mass production systems [1]. The high degree of manufacturing flexibility to meet customer requirements and needs introduces the component of flexibility in manufacturing systems, and the importance of optimizing it for the environmental and economic aspect justification of manufacturing systems [2]. The influence of manufacturing flexibility on their environmental and economic aspects viability has not yet been thoroughly investigated [3]. It is safe to say that this is an important optimization parameter that needs to be well described and evaluated to ensure sustainable manufacturing [4].

Individual research papers deal separately with the area of optimizing high-mix, low-volume manufacturing systems and its impact on environmental and economic aspect eligibility. The optimization problem of manufacturing planning and scheduling is mathematically defined as a NP-hard multi-objective optimization problem [5] and therefore difficult to solve [6]. The researchers present different optimization approaches that use different methods of evolution computation to determine the optimal optimization goal in terms of short flow times, high machine utilisation, efficient costs, etc. [7]. No comprehensive optimization approach could be found in the literature that would present, evaluate and solve the optimization problem of the high-mix low-volume impact on its environmental and economic justification by a comprehensive optimization approach [8]. The limitations relate to the complexity of the mathematical modelling of manufacturing flexibility and the associated data that adequately assess the environmental and economic aspects.

Manufacturing flexibility can be fundamentally structured by using a four-level architecture model that allows for a comprehensive consideration of optimization parameters ranging from transport, production capacity, product type and properties to order batch diversity [9]. It can be argued with certainty that when it comes to scheduling manufacturing orders, their influence on the environmental and economic justification of the manufacturing system electricity consumption, material use, natural resources, the social aspects of the employees and the company and the profitability of the production system is important [10]. In the research work, we present a new approach to simulation studies that comprehensively addresses the problem of planning for high-mix, low-volume manufacturing, where a high degree of flexibility is essential for assessing the environmental and economic viability of the manufacturing system [11]. Based on a four-level architectural model, mathematical model of high-mix low-volume, Flexible Job Shop Scheduling Problem (FJSSP) and the parameters that influence environmental and economic aspect viability are used.

A simulation study carried out in the Simio simulation environment and the IHKA evolution computation method allow for optimal allocation of work orders justifying environmental and economic aspects of manufacturing [12]. The used mathematical and simulation modelling method is evaluated with two FJSSP benchmark data sets [13] and one data set from a real manufacturing system, on the basis of which a comparison between optimized and non-optimized manufacturing systems is performed [14]. In the simulation study, the simulation model is examined according to the newly proposed block structure, which allows a holistic optimization approach and thus the assessment of the environmental and economic sustainability of the manufacturing system. The influence of parameters such as electrical power consumption and products scrape rate in relation to the age of the machines allows a comprehensive consideration of the research question presented.

2. Problem description

Environmental and economic justification aspect are a part of the multidisciplinary research field of sustainable manufacturing as a broad field in the era of Industry 4.0 (Fig. 1), as there is an urgent need to reduce the environmental impact of industrial production. Issues of sustainable manufacturing are being studied in detail for manufacturing types ranging from high-mix, small batch to mass production. This involves the development of durable products with comprehensive life cycle considerations and the implementation of sustainable manufacturing processes and systems capable of minimising negative environmental impacts and minimising the consumption of natural materials, energy and other resources. All shareholders involved must be economically sound and socially beneficial. Sustainability is the engine for innovation and creative thinking. Innovation and creative thinking promote accelerated growth in manufacturing and the design of new products. Social well-being and economic growth at a reasonable cost-time investment depends strongly on the level and quality of optimized manufacturing systems [15].

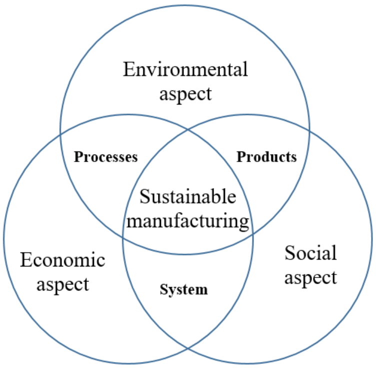

Fig. 1. Sustainable manufacturing three-dimensional aspects

The multi-objective optimization parameters of manufacturing systems must include energy savings (machine operation and idle energy consumption) and natural resources (management of natural material waste), reprocessing and improvement of manufacturing parts scrap rate during manufacturing and assembly processes. The main objective of sustainable manufacturing is the introduction of a new integrated product cycle with presence and the optimization of the manufacturing systems life cycle, regarding products and services.

This manuscript answers two main research questions of sustainable manufacturing related to:

- manufacturing system optimization based on three main objectives (minimising energy consumption, material and product waste, optimizing manufacturing processes and techniques related to manufacturing methods, production utilisation, manufacturing flexibility, reducing production and labour costs and the high efficiency of timely manufacturing systems);
- increasing the energy efficiency of operations and downtime; lower, cleaner and renewable energy use, with the optimization of transport and materials handling; manufacturing processes with low pollution, waste and emission production; industrial symbioses using new optimization techniques for sustainable natural cycles in manufacturing systems, based on mathematical and simulation modelling techniques using simulation scenarios to ensure sustainable manufacturing systems [16].

3. Simulation modelling

The environmental and economic viability of a manufacturing system is the key to an effective investment in terms of cost and time. The simulation modelling of environmental and economic suitability includes a comprehensive treatment of the manufacturing system, the product and all participants involved in the manufacturing of the product. The presented research work focuses on the evaluation of the impact of environmental and economic aspects on the manufacturing system and the importance of appropriate optimization with respect to the sustainability of the enterprise. Fig. 2 presents proposed block diagram of the sustainable manufacturing system. The key to optimizing sustainable viability is a holistic view of the existing optimized system. In the initial phase, sustainably justified manufacturing deals with the design of the product or the customer order that the production will manufacture, the technological process, the consumption of energy, natural materials, the provision of high quality and in the feedback with the product, which guarantees a renewable life cycle with the possibility of introducing continuous manufacturing process improvements.

It is evident that an optimized, planned and scheduled production system is crucial, which, with its high efficiency, allows for sustainable production justified energy consumption, waste production reduction, natural materials and waste optimization, high quality of products and wider enterprise social responsibility. Presented work is based on determining the correlation between the percentage of machine scrap in relation to the age of the machines and the amount of downtime of the individual machines in the high-mix low-volume manufacturing system. The second optimization parameter is related to determining the energy consumption during operation and the downtime of the machine to perform the operation in relation to economic aspect. The optimization of these parameters was carried out with the evolutionary computation IHKA method. IHKA algorithm optimally allocates work orders and individual operations according to the available machines and their parameters, trying to meet the given parameters.

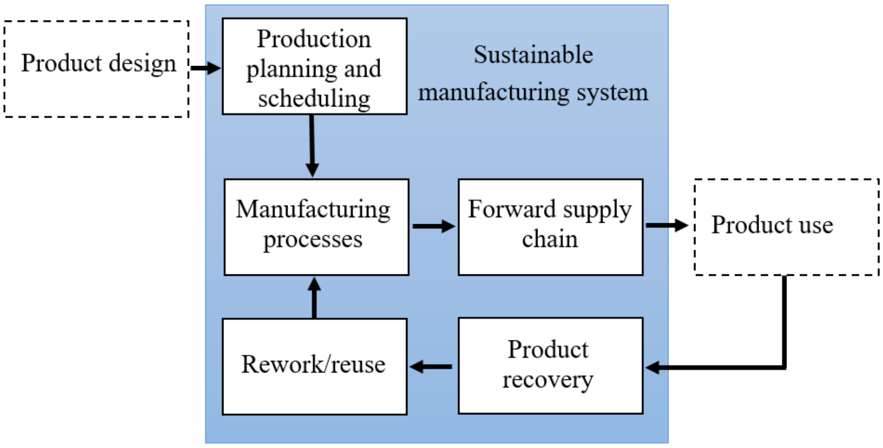

Fig. 2. Sustainable manufacturing block diagram

3.1 Environmental Aspects Modelling

Modelling of the individual machine scrap percentage was carried out by classifying the machines into four groups according to their age (Sg_1, Sg_2, Sg_3 and Sg_4). The Table 1 shows that the mathematical model predicts a depreciation period of the machine of eight years. With the eight-year depreciation period, the linear function and a four-stage classification, it is possible to determine the individual values of the scrap percentages used by the optimization algorithm in the optimal determination of the operations in relation to the available machines. Fig. 3 shows a graphical representation of the functional relationship between the scrap percentage and the age of the machine. With the proposed approach, we can define the machine scrap values individually. The advantage of the presented method is the possibility to use a data driven simulation model to which a specific (realistic) functional relationship between the scrap rate and the age of the machine can be assigned.

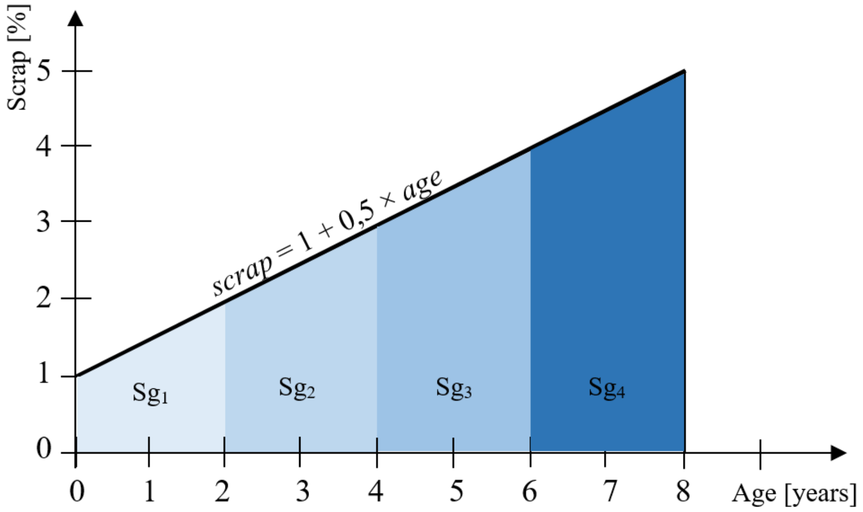

Fig. 3. Scrap percentage modelling regarding machine group classification

Following the pattern of using the values from the Table 1 to determine the scrap percentages, the values of the energy consumed by each machine were determined by the values of the power consumption during the operating (E_{Mo}) and idle periods (E_{Mi}). The constant value of the factor between power consumption during operation and downtime was 0.15, which was used according to the literature [18]. Abbreviations in Table 1 presents machine age (M_a), machine scrap rate percentage (M_s) and machine scrap group classification (M_{sg}).

	Machine									
	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
E_{Mo} [kWh]	10	4	4	25	25	25	4	10	4	10
E_{Mi} [kWh]	1.5	0.6	0.6	3.75	3.75	3.75	0.6	1.5	0.6	1.5
M_a [years]	2	1	6	7	8	1	2	5	6	1
M_s [%]	2	1.5	4	4.5	5	1.5	2	3.5	4	1.5
M_{sg}	Sg_2	Sg_1	Sg_3	Sg_4	Sg_4	Sg_1	Sg_2	Sg_2	Sg_3	Sg_1

Table 1. Scrap and electrical energy consumption modelling data

3.2 Economic Aspects Modelling

The research work is focused on the high-mix low-volume manufacturing type of FJSSP, where flexibility exists at the manufacturing level. The simulation study was performed on the two commonly used benchmark data sets (Kacem and Brandimarte) to which some additional data have be added in terms of costs, product mix, product volume, machine workstation dimensions and set-up times. The additional data presented has been generated mathematically with suitable interdependency functions. When using a data set from the real world, some constant values from the manufacturing system were used to ensure the completeness of the simulation results. The classification of the machines into three groups according to their characteristics allows a detailed optimization with respect to the most important optimization parameters in terms of manufacturing flexibility and the environmental and economic justification of the manufacturing system. The method of mathematical modelling determines the dependencies between machine groups and optimization parameters. The mathematical modelling of the corresponding values is based on the method of functional dependencies discrete modelling [17]. The Table 2 shows three groups of machines divided by the operating (O_c) and idle (I_c) running costs of the machines calculated by the factor of discrete modelling. The correlation factor between running and idle costs classifies machines as group G_1, represented by small machines, group G_2, medium machines, and group G_3, large machines. According to the machine classification, the operating costs are between 30 and 60 EUR/h. The individual machine classification of manufacturing systems can be made according to the proposed approach of discrete factor calculation. The values shown in the Table 2 are based on the fixed costs of the individual groups and the recalculated idle running costs of the machines.

Group (M_{cg})	O_c [EUR/h]	F_c [%]	I_c [EUR/h]	Factor
G_1	40-50	40	22-26	$x = 2/5$
G_2	51-60	50	30-41	$x = 1/2$
G_3	61-70	60	40-53	$x = 3/5$

Table 2. Machine cost group classification

The recommendations in [18] have defined the fixed costs (F_c) as 40% in the case of a small machine, 50% in the case of a medium-sized machine and 60% of the fixed costs in the case of a large machine. The production capabilities of the manufacturing company can be divided into three groups, according to which the optimization of flexibility and the sustainable justification of the manufacturing system can be carried out. The number of groups, the range and the interdependencies can be adapted according to the specific optimization problem.

When defining the performance and characteristics of individual machines, it is necessary to adequately link the interdependence of the individual parameters, especially when adding parameters by mathematical modelling of randomly distributed values. The determination of the group size depends on the calculation of the operating and idle running costs. The values of the idle running costs were modelled mathematically using the method of determining discrete values according to the correlation factor given in the Table 2. The cost value of operation and idle time is defined in the Table 3 by the setup time (t_{set}) of the operation, which enables the determination of the cost-time function of the production system. The constant values of the layout position of the machines in the production system are determined according to the two-axis x, y coordinate system (x_{loc} and y_{loc}).

	Machine									
	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}
M_{cg}	G_2	G_1	G_1	G_3	G_3	G_3	G_1	G_2	G_1	G_2
O_c [EUR/h]	43	35	39	53	52	59	36	45	38	45
I_c [EUR/h]	21.5	14	15.6	31.8	31.2	35.4	14.4	22.5	15.2	22.5
x_{loc} [m]	0	0	5	5	10	10	15	15	20	20
y_{loc} [m]	0	5	0	5	0	5	0	5	0	5
t_{set} [min]	16	15	50	24	35	38	16	22	18	39

Table 3. Machine cost modelling data

The values 4 shown in the table describe individual variables according to the three-group classification. The data show the values used in the simulation study and the basis on which the IHKA method [10] optimized the manufacturing system. The parameters were determined from the costs, energy consumption, the condition of the production system and other related data. For the calculation of the data in the Table 4, some assumptions have to be made, such as: the production system works in two shifts; financing of the purchase of machines (50% own resources, 50% loan with 8% interest); electricity value constant 8 EUR/100 kWh; 4% maintenance costs; annual plant costs 100 EUR/m^2 and 4% additional operating costs.

	$\boldsymbol{M_{cg}}$		
Data	G_1	G_2	G_3
Purchase price of the machine [EUR]	20,000	70,000	200,000
Machine power [kW]	4	10	25
Workplace surface [m^2]	10	20	30
Depreciation period [year]	8	8	8
Useful capacity of the machine [h/year]	3,000	3,200	3,400
Energy costs [EUR/kWh]	0.40	1.00	2.50
Tool costs [EUR/h]	2	3	4
Costs of machine [EUR/h]	3.95	8.67	18.27
Worker gross costs [EUR/h]	8	10	12
Additional costs [EUR/h]	0.16	0.35	0.73
Workplace costs [EUR/h]	12.11	19.02	31.00
Variable costs [%]	12.8	24.6	38

Table 4. Machine operation cost calculation data

4. Results and Discussion

The simulation study was carried out with two separate optimization methods. The first part was a simulation study of an optimized production system, which was carried out with the EC method IHKA. The second part of the simulation study was the application of conventional optimization priority rules to determine the optimal production order sequence. After two separate optimization methods, the simulation results showed that the optimization results were significantly different, so that the optimization results obtained with the IHKA EC method were represented as optimized system and the results of conventional technology optimization were called a non-optimized manufacturing system. The simulation study evaluated the effects of high-mix low-volume manufacturing type on the environmental and economic eligibility Simulation experiment was performed Kacem 15×10 [13], Brandimarte Mk10 [14].

The simulation results obtained by the Kacem 15×10 data set represent theoretical FJSSP problem, results from Brandimarte Mk10 data set are describing more realistic manufacturing system data. For the Kacem 15×10 dataset, the optimization algorithm procedure is available to determine the order of execution of a single operation for all machines from the machine set, each operation can be executed on any available machine. However, for the Brandimarte Mk10 data set, the single operation must be performed on a machine that is suitable for that operation, i.e. the welding operation can only be performed at the welding workstation (a real data set primarily intended to evaluate the applicability of the optimization approach).

The Table 5 shows the results of IHKA method and priority rules calculation of the manufacturing system according to the parameter of electrical energy consumption at the time of order (data set data) execution, where M_{oecc} indicates machine operational energy consumption costs and M_{iecc} indicates machine idle energy consumption costs.

	IHKA calculation			**Priority rules calculation**		
Dataset	M_{oecc} [EUR]	M_{iecc} [EUR]	∑ [EUR]	M_{oecc} [EUR]	M_{iecc} [EUR]	∑ [EUR]
Kacem 15×10	92.7	6.1	98.8	106.2	12.5	118.7
Mk10	475.7	80.6	556.3	475.4	118.6	594

Table 5. Machine electrical energy consumption cost results

The numerical results (Fig. 4) show the importance of using advanced evolutionary calculation methods to determine the optimal distribution of work orders in terms of electrical energy consumed during operation and to minimise idle times, leading to environmental consumption of natural resources and energy efficiency, ensuring economic benefits. Using the Kacem 10×15 data set, we can see the importance of optimizing orders schedules based on the allocation of individual operations to a specific machine. The results of an optimized manufacturing system ensure a 16.8% reduction in electrical energy consumption costs for the same order set. In the IHKA case, energy consumption during machine operation was 12.7% lower than with the priority rules optimized system, while significantly longer idle times with the IHKA optimized manufacturing system also resulted in 51.2% less electricity costs during the idle period.

The data sets Mk10 confirm the validity of the simulation model approach, since the power consumption at processing time is identical for both systems. The same power consumption at processing time is attributed to the benchmark data set structure of the Mk10, under the condition that a certain operation only needs to be performed on a certain machine, which is defined in the sequence order production data. The determination of the electrical energy costs consumption while idle for the completion of the operation depends on the ability to optimize the planning of the work task accordingly. The results of the idle energy consumption show that in the Mk10 data set, the total electrical energy consumption costs of the priority rules manufacturing system increased by 32.1% compared to the IHKA optimized manufacturing system. Total reduction in electrical energy consumption cost in Mk10 data set is 6.3%.

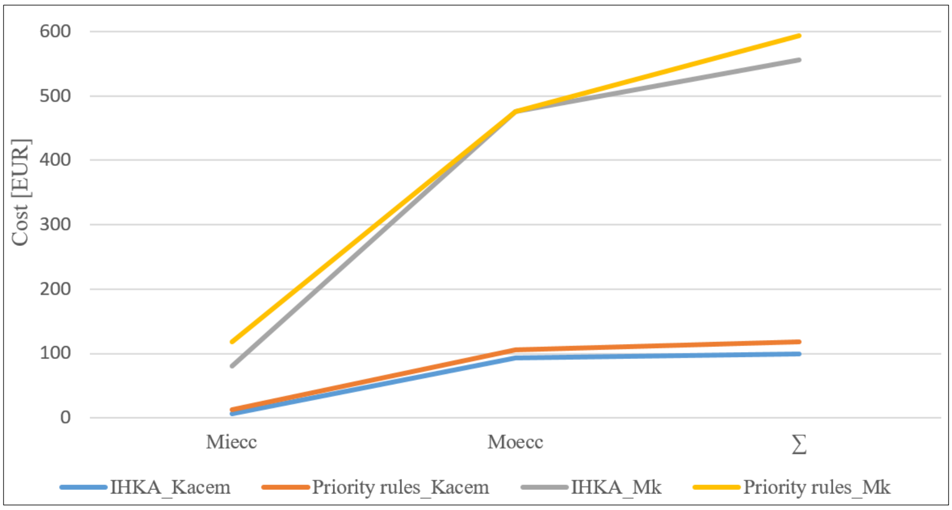

Fig. 4. Numerical results of Kacem 15×10 and Brandimarte Mk10 data sets

5. Conclusion

The initial research question of investigating the impact of environmental and economic aspects on the sustainable orientation of manufacturing system was answered using the simulation modelling method. The research problem of assessing the sustainable orientation was examined under two environmental and economic aspects, and the production system was evaluated using two different data sets that realistically describe the FJSSP. A block diagram was proposed that allows the implementation of a simulation model from the point of view of the parameters mentioned above.

The environmental aspect of manufacturing flexibility was evaluated by modelling the dependence of the products scrap rate percentage in relation to the age of the machine. The data driven simulation model allows the evaluation of test data sets and real production systems data. The presented approach of classifying machines by age and scrap rate is based on mathematical modelling and the interdependence of parameters. The financial aspect is represented by determining the operating costs and the idle costs of individual operation. The calculation of fixed and variable costs depending on the initial investment (size) of the machine is presented. Depending on the financial value of the electricity costs, the electricity consumption of the machine is determined. Using two optimization approaches (IHKA EC method and application of priority rules), a simulation study was carried out on the importance of production optimization in terms of ecological and financial justification is performed. The presented results prove the high importance of the FJSSP production optimization from the environmental and economic point of view.

Following the results of previous studies, which examined the effects of manufacturing flexibility on their cost-time investments, the presented research has enhanced them by examining the sustainable aspects of FJSSP manufacturing system. Given the holistic approach to sustainable manufacturing in research, this paper presented focuses on two aspects that are crucial to achieving positive environmental and economic impacts. Since this paper does not evaluate with the social aspect of sustainable manufacturing, which is crucial for the impact of collaborative workplaces design, we will further extend our research to the field of assessing the social aspect of sustainable manufacturing in production systems. Currently, the work is limited to the evaluation of highly flexible manufacturing systems (FJSSP), further research will also consider other types of manufacturing systems, from batch to mass production. With the methods, approaches and findings presented, the simulation model, extended by parameters describing the social aspect, can be presented, which mainly refers to the worker workplace design evaluation.

The presented research work enables the application of the presented approach both for the evaluation of test data sets (theoretical examples) and for the assessment of real problems in FJSSP manufacturing systems.

6. Acknowledgments

This research was funded by the Slovenian Research Agency (ARRS), Research Core Grant P2-0190.

7. References

[1] Seng, D. W.; Li, J. W.; Fang, X. J.; Zhang, X. F. & Chen, J. (2018). Low-carbon flexible job-shop scheduling based on improved nondominated sorting genetic algorithm-II. International Journal of Simulation Modelling, Vol. 17, No. 4, pp. 712-723, ISSN 1726-4529, doi:10.2507/ijsimm17(4)co18

[2] Ojstersek, R.; Lalic, D. & Buchmeister, B. (2019). A new method for mathematical and simulation modelling interactivity: A case study in flexible job shop scheduling. Advances in Production Engineering & Management, Vol. 14, No. 4, pp. 435-448, ISSN 1854-6250, doi:10.14743/apem2019.4.339

[3] Ojstersek, R.; Acko, B. & Buchmeister, B. (2020). Simulation study of a flexible manufacturing system regarding sustainability. Internarional Journal of Simulation Modelling, Vol. 19, No. 1, pp. 65-76, ISSN 1726-4529, doi:10.2507/ijsimm19-1-502

[4] Rosen, M. A. & Kishawy, H. A. (2012). Sustainable manufacturing and design: concepts, practices and needs. Sustainability, Vol. 4, No. 2, pp. 154-174, doi:10.3390/su4020154

[5] Du, Y.; Wang, J. L. & Lei, L. (2019). Multi-objective scheduling of cloud manufacturing resources through the integration of cat swarm optimization and firefly algorithm. Advances in Production Engineering & Management, Vol. 14, No. 3, pp. 333-342, ISSN 1854-6250, doi:10.14743/apem2019.3.331

[6] Ojstersek, R.; Brezocnik, M. & Buchmeister, B. (2020). Multi-objective optimization of production scheduling with evolutionary computation: a review. International Journal of Industrial Engineering Computations, Vol. 11, No. 3, pp. 359-376, ISSN 1923-2934, doi:10.5267/j.ijiec.2020.1.003

[7] Buchmeister, B.; Palcic, I. & Ojstersek, R. (2019). Artificial intelligence in manufacturing companies and broader: an overview. Chapter 07 in DAAAM International Scientific Book 2019, pp. 081-098, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-24-2, ISSN 1726-9687, Vienna, Austria, doi:10.2507/daaam.scibook.2019.07

[8] Joung, C. B.; Carrell, J.; Sarkar, P. & Feng, S. C. (2013). Categorization of indicators for sustainable manufacturing. Ecological Indicators, Vol. 24, pp. 148-157, doi:10.1016/j.ecolind.2012.05.030

[9] Benjaafar, S. & Ramakrishnan, R. (1996). Modelling, measurement and evaluation of sequencing flexibility in manufacturing systems. International Journal of Production Research, Vol. 34, No. 5, pp. 1195-1220, doi:10.1080/00207549608904961

[10] Ojstersek, R. & Buchmeister, B. (2020). The impact of manufacturing flexibility and multi-criteria optimization on the sustainability of manufacturing systems. Symmetry, Vol. 12, No. 1, paper 157, 22 pages, doi:10.3390/sym12010157

[11] Buchmeister, B.; Palcic, I. & Ojstersek, R. (2019). Manufacturing scheduling performance – a case study, Proceedings of the 30th DAAAM International Symposium, pp. 0020-0029, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-22-8, ISSN 1726-9679, Vienna, Austria, doi:10.2507/30th.daaam.proceedings.003

[12] Ojstersek, R. & Buchmeister, B. (2020). Simulation modeling approach for collaborative workplaces' assessment in sustainable manufacturing. Sustainability, Vol. 12, No. 10, paper 4103, 18 pages, doi:doi.org/10.3390/su12104103

[13] Kacem, I.; Hammadi, S. & Borne, P. (2002). Pareto-optimality approach for flexible job-shop scheduling problems: hybridization of evolutionary algorithms and fuzzy logic. Mathematics and Computers in Simulation, Vol. 60, No. 3-5, pp. 245-276, doi:10.1016/S0378-4754(02)00019-8

[14] Mastrolilli, M. & Gambardella, L. M. (2000). Effective neighbourhood functions for the flexible job shop problem. Journal of Scheduling, Vol. 3, No. 1, pp. 3-20, doi:10.1002/(SICI)1099-1425(200001/02)3:1<3::AID-JOS32>3.0.CO;2-Y

[15] Xu, S. Z. (2019). A petri net-based hybrid heuristic scheduling algorithm for flexible manufacturing system. International Journal of Simulation Modelling, Vol. 18, No. 2, pp. 325-334, ISSN 1726-4529, doi:10.2507/ijsimm18(2)co6

[16] Rupnik, B.; Nardin, R. & Kramberger, T. (2019). Discrete event simulation of hospital sterilization logistics. Technical Gazette, Vol. 26, No. 5, pp. 1486-1491, doi:10.17559/TV-20180614102011

[17] Ojstersek, R. & Buchmeister, B. (2017). Use of simulation software environments for the purpose of production optimization, Proceedings of the 28th DAAAM Internatioanl Symposium, pp. 0750-0758, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-11-2, ISSN 1726-9679, Vienna, Austria, doi:10.2507/28th.daaam.proceedings.106

[18] Warnecke, H. J.; Bullinger, H. J.; Hichert, R. & Voegele, A. A. (1996). Kostenrechnung fuer Ingenieure, Carl Hanser Verlag, Munchen, Germany, ISBN 3-446-18696-6