A SIMULATION TOOL FOR MODELLING AND OPTIMIZATION OF A JOB-SHOP PRODUCTION SYSTEM

Eleonora BOTTANI[(a)], Marta RINALDI [(b)], Roberto MONTANARI [(c)], Massimo BERTOLINI [(d)], Francesco ZAMMORI [(e)]

[(a),(b),(c)]Department of Engineering and Architecture, University of Parma, viale delle Scienze 181/A, 43124 Parma (Italy)

[(a)]eleonora.bottani@unipr.it, [(b)]marta.rinaldi@unipr.it, [(c)]roberto.montanari@unipr.it; [(d)]massimo.bertolini@unipr.it; [(e)]francesco.zammori@unipr.it

ABSTRACT

This study carries out an analysis of the machinery department of a main Italian company, which operates as a manufacturer of plants for the food industry. The analysis targets expressively the improvement of the total shop floor time of the jobs in the department and is supported by a simulation model developed under SIMUL8™. Thanks to the model, the dispatching rule currently used by the company to schedule the jobs to be manufactured in the department was compared to additional 6 scheduling strategies, to evaluate potential improvements.

The results obtained have shown that the most remaining operations (MROP) rule returns the most interesting results in terms of total shop floor time for the jobs examined. The outcomes of this paper could be useful to the targeted company to evaluate the implementation of alternative dispatching rules to schedule the jobs.

Keywords: job shop; dispatching rule; simulation model; food machinery industry.

1. INTRODUCTION

"Job shop" production is a manufacturing process where products are designed and produced as per the specification of customers, within prefixed time and cost. The distinguishing features of this kind of production system are low volumes and high variety of products. Also, from an operational point of view, a job shop system comprises of general purpose machines arranged into different departments. Each job demands unique technological requirements and need being processed on machines in a specific sequence. In general, jobs are manufactured following a sequence of orders from the customers, with fixed routes for each job through the plant (Anil Kumar and Suresh, 2008).

Among others, job shop systems can be found among industries described as make-to-order (MTO) production units, engineer-to-order (ETO) production units, high-variety production units or order-driven production units (Velaga, 2016).

As known, to remain competitive on the market, companies should increase the throughput rate, reduce the costs and improve the customer satisfaction. At the production management level, a production manager has to improve the performance of the manufacturing system, by, e.g., reducing the process time, mean set-up time, mean time between failures, mean time to repair and demand variability (Renna, 2017). Due to the complexity and the number of processes typical of job shop systems, production optimisation is a challenging tasks and, frequently, job shop systems relies on experienced workers (e.g. when manufacturing a special product) and production managers in the production planning and management (Supsomboon and Vajasuvimon, 2016).

In this regard, a particularly crucial issue is the scheduling problem that, if not properly faced, may lead to relevant idle times (i.e. a non-value added time when a machine is not being used despite the fact that it is available to be used) and delays. Unfortunately, in many cases, scheduling is a non-deterministic polynomial-time (NP) hard problem, and cannot be optimally solved in a suitable computational time. This is the reason why, managers often require specific tools to manage it., which, in many cases,

Among these tools, simulation-based optimization methods, is generally used as a robust way to find an effective solution within fairly shorter time for larger sized problems (Xie and Allen, 2015). More in general, simulation is one out of several tools that can be used to investigate a real system, its dynamics and logic, as well as its evolution in time or as a function of the input set (Carley, 2003). Also, discrete-event simulation is one of the most powerful methods that allows to recreate the dynamics of a real system in a controlled environment, thus enabling to analyse the interdependencies between its elements, to monitor its main control parameters and evaluate its performance. Nowadays, simulation is widely used in industrial factories, as it allows to vary some parameters or factors to investigate their impact on the system's performance, without affecting the whole system and before implementing any solution in the real situation.

This paper describes the development of a simulation model reproducing a real job shop system and the use of

this model to analyse and improve the performance of the system, with a particular attention to scheduling improvement. . The context where this study was carried out is the mechanical department of a milling plant of a manufacturing company, located in northern Italy.
The remainder of the paper is organized as follows. Section 2 lists the steps followed in the research. Sections 3-5 provide the details of the steps previously listed. Section 6 summarizes the results obtained in the analysis, describes the implications and limitations of the study and outlines future research directions.

2. THE RESEARCH METHODOLOGY

The research methodology adopted in this study is detailed in the steps listed below.

1. *Analysis of the machinery department*. The first step of the study was the analysis of the machinery department and of the related criticalities, with the aim to identify the potential for improvement, as detailed in section 3;
2. *Data collection*. The main figures of the system (e.g. set-up times, processing times, jobs routings, jobs families, etc.) were collected, either from the company's information system or by direct observation. These data were used as input in the simulation model, as detailed in section 4;
3. *Model development and validation*. A simulation model was built to reproduce the mechanical department. The simulation model reproduces the targeted department and provides, as output, some key performance indicators (KPIs). Details related to the development of the simulation model, its validation and the performance level measured for the current scenario are given in section 5;
4. *Analysis and performance improvement*. Starting from the simulation outcomes, new operating policies were proposed, focusing expressively at the scheduling problem. In this regard, seven common dispatching rules were tested and their performance were compared to that of the current scheduling policy. Results of this step are proposed in section 6.

3. ANALYSIS OF THE MACHINERY DEPARTMENT

The company considered in this study (referred to as "Company A" for confidentiality) is an Italian manufacturer of plants for the milling industry. Company A exports its products to several countries worldwide. The company operates on an Engineer-To-Order (ETO) basis, meaning that any new product starts with the design of the plant and includes assembly, installation, civil works, test of the equipment at the customer's site and staff training. In Italy, Company A is leader in its market segment while, on a global basis, it ranks second among the top producers of milling plants.
The department where the research has been carried out (i.e. the mechanical department) covers an area of approximately 2,400 square meters and includes 18 machines. The production process starts from the raw materials (e.g. bars and rods in steel, cast iron, aluminium, brass or other alloy metal alloys), which are processed using mechanical machineries, to realize specific components according to the 2-D or 3-D drawing prepared by the technical division. The mechanical processes performed in the targeted department consists mainly in chip removal operations, to obtain a final component of desired shape. Such processes are carried out by means of turning, grinding and milling machines. These machines are organised according to a job-shop layout, where machines are aggregated into specialized departments. Jobs are scheduled on the different machines using an Earliest Due Date (EDD) rule, i.e. the first job to be processed is the one with the closest delivery date.
Each employee of the department typically controls two machines, with only one exception of an employee who controls three machines. The manufacturing activities are organized in two work shifts of 7 hour each; only one machine works on one work shift of 8 hours.
The main criticalities can be summarised as follows:

- the fact that each employee should control more than one machine simultaneously could lead to some inefficiencies. For instance, the employee could be forced to stop the processing of one production lot to introduce a more urgent one;
- because an employee could supervise two or three machines, it often happens that if he/she is operating on a machine (for instance, for set-up or manual operations), the second machine cannot work until the employee has finished working on the first one. This causes delays in the overall processing time of the department;
- as a consequence of the situations described above, the jobs processed are often sent to the next production department late. The delay is typically caused by a series of inefficiencies and waste, which are often not known to the company;
- the company's top management is aware that the set-up times recorded in the company's information system do not reflect the real values. Indeed, from an administrative point of view, the set-up time is used only to derive an estimate of the manpower cost in the targeted department. All set-up activities that do not strictly require the presence of an employee have a zero-set-up time by default. Therefore, the real efficiency of the machines of the targeted department is not known.

The analysis carried out in this paper aims at solving some of the criticalities above, and in particular at developing a simulation model that evaluates the shop floor throughput time and tries to minimize it.

4. DATA COLLECTION

The correct management of a work cycle in the department depends on many factors, including, among others:

1. Number, shape and size of the pieces to be manufactured;

2. The amount of items to be manufactured in a job (batch size);
3. Delivery date of the order;
4. Manufacturing and set-up time.

A data collection phase was carried out in December 2016 and January 2017 to gather data listed above. To be more precise, the delivery date of each job is recorded in the company's database, together with the order date (thus allowing to estimate the total throughput time of a job as recorded by the company). Similarly, the number, shape and size of the pieces to be manufactured, as well as the batch size, were collected from the company's data base, over a time horizon of 2 months (November-December 2016). These data were also confirmed through direct observation of the department's operating conditions.

The data extracted from the company's database showed that overall, the company has manufactured 1002 jobs in the targeted department, and 213 during the observation period.

As far as the type of equipment and tools used are concerned, jobs can be processed by more than one machine of the targeted department; the analysis of the data retrieved from the company' database showed that approximately 73% of the jobs manufactured are processed by only one machine, while approximately 24% should be processed by two machines; the remaining jobs need to be processed by either three (2.75%) or four (0.52%) machines.

The manufacturing and set-up time are both recorded in the company's database. More precisely, the processing time is recorded in the company's database for 968 out of the 1002 jobs manufactured, while the set-up time is available for 853 jobs. However, as already mentioned, the company's top management was aware that the set-up time recorded could differ from the real values in a significant way. Therefore, the activity of the targeted department was directly observed, approximatively, for a month (2 weeks in December 2016 and 2 weeks in January 2017) to collect both set-up times and the processing times of the jobs manufactured by the company. The batch size was also recorded in the observation period.

Some of the results are shown in Figure 1, which clearly shows that most of the products manufactured (94.3% approximately) exhibit a processing time of less than 294 min. More specifically, the processing time ranges from 0 to 6 minutes for 19.1% of these jobs and from 6 to 12 minutes for 14.89% of these jobs.

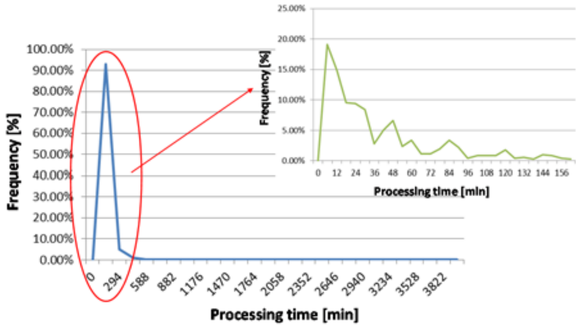

Figure 1: Processing time (company's data)

A similar analysis was carried out for the set-up times; this was made with respect to 756 jobs out of the 1002 manufactured by the company. Table 1 provides an extract of obtained results, which have been organized into classes of 15 minutes for visualization purpose.

From Table 1 it is easy to see that more than 85.4% of the jobs have a total set-up time of less than 60 minutes, corresponding to the sum of the set-up time on the different machines of the department under examination. For approximately 8.8% of the jobs, the total set-up time ranges from 60 to 90 minutes.

The data recorded in the company's database were compared to those obtained from the direct observation. To this aim, the ratio "time recorded in the company's database" over "time observed" was computed. The corresponding results are proposed in Table 2. From Table 2 it can be seen that for only 16.13% of the jobs observed the ratio between the time recorded in the company's database and that observed is in the range 0.8-1, which shows correspondence between these data. Instead, for the remaining jobs the correspondence is significantly weaker. Also, for approximately 41% of the jobs observed, the ratio is less than 1, indicating that the time recorded in the company's database is lower than the real value.

The same analysis, carried out on the set-up time, leads to the results proposed in Table 3. Results are similar. Only for less than 10% of the jobs examined, the observed set-up time corresponds to that recorded in the company's database; also, for more than 78% of the jobs, the set-up time recorded in the company's database is lower than that observed in the real functioning of the department.

The dissimilarities between the data recorded and that observed are one out of several possible causes of jobs' tardiness at the departmental level. Overall, in the light of the observed dissimilarities, subsequent analyses were carried out using the real data of manufacturing and set-up time, instead of those recorded in the company's database.

Table 1: set-up time (company's data)

Class	Set-up time (min)	Absolute frequency	Relative frequency	
1	0	93	12.3%	
2	15	217	28.7%	
3	30	200	26.5%	
4	45	46	6.1%	
5	60	90	11.9%	85.4%
6	75	20	2.6%	
7	90	37	4.9%	
8	105	9	1.2%	
9	120	8	1.1%	
10	135	0	0.0%	
11	150	7	0.9%	
12	165	1	0.1%	
13	180	12	1.6%	
14	195	3	0.4%	
15	210	2	0.3%	
16	225	0	0.0%	
17	240	1	0.1%	
18	255	1	0.1%	
19	270	1	0.1%	
21	300	3	0.4%	
22	315	0	0.0%	
23	330	0	0.0%	
24	345	0	0.0%	
25	360	0	0.0%	
26	375	4	0.5%	
27	405	1	0.1%	

Table 2: comparison between the processing time observed and that recorded in the company' database

Class	Ratio	Absolute frequency	Relative frequency	
1	0	0	0.00%	
2	0.2	3	2.42%	
3	0.4	16	12.90%	
4	0.6	15	12.10%	
5	0.8	17	13.71%	41.13%
6	1	20	16.13%	16.13%
7	1.2	12	9.68%	
8	1.4	11	8.87%	
9	1.6	8	6.45%	
10	1.8	5	4.03%	
11	2	3	2.42%	
12	2.2	4	3.23%	
13	2.4	3	2.42%	
14	2.6	2	1.61%	
15	2.8	0	0.00%	
16	3	5	4.03%	42.74%

Table 3: comparison between the set-up time observed and that recorded in the company' database

Class	Ratio	Absolute frequency	Relative frequency	
1	0	0	0.00%	
2	0.2	18	19.78%	
3	0.4	24	26.37%	
4	0.6	17	18.68%	
5	0.8	12	13.19%	78.02%
6	1	9	9.89%	9.89%
7	1.2	2	2.20%	
8	1.4	2	2.20%	
9	1.6	3	3.30%	
10	1.8	0	0.00%	
11	2	0	0.00%	
12	2.2	2	2.20%	
13	2.4	1	1.10%	
14	2.6	0	0.00%	
15	2.8	0	0.00%	
16	3	0	0.00%	
17	3.2	1	1.10%	
18	3.4	0	0.00%	
19	3.6	0	0.00%	
20	3.8	0	0.00%	12.09%

5. MODEL DEVELOPMENT AND VALIDATION

A simulation model of the machinery department was built using the commercial software SIMUL8^{TM} for Windows. SIMUL8^{TM} uses dynamic discrete simulation and is commonly exploited to simulate systems that involve processing of discrete entities at discrete times. Examples of those systems are production, manufacturing, logistic or service provision systems. As output, it generates statistics of performance parameters and metrics of the production system examined (Concannon et al., 2007). Also, the software embodies statistical tools, able to process the input data and output of the model, set the number of replicates, and elaborate the output. In real situations, there are many other factors that can involve the criticalities in this department.

The scheme of the simulation model, as it has been developed in SIMUL8^{TM} is proposed in Figure 2. From Figure 2 it can be seen that the model structure reflects the layout of the machinery department. Each machine is reproduced using a set of 4-5 work centres and a buffer (or queue). Each work centre represents one of the activities required to process a job. These include, for each job: set-up time; processing time; job material handling and waiting time of the job, once processed. Specific rules have been set, so as to allow these activities to be executed in the correct order, avoiding overlapping. Also, each machine has a defined availability, which was estimated starting from the direct observation of the machinery department.

The buffer is used to represent the physical area available in front of each machine, where jobs can be temporarily stored.
As input, the model uses data collected in the Data collection step; these data include, among others, the number, shape and size of the pieces to be manufactured; the sequence of machinery operations to process each job; the manufacturing and set-up time.

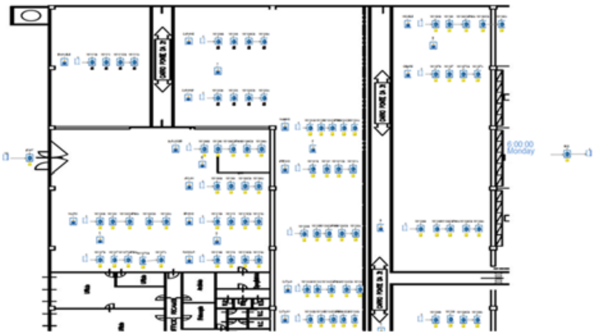
Figure 2: Scheme of the simulation model.

The model was run with the data collected and validated by comparing the number of jobs manufactured per day with real data. Comparing the simulated and real data is one of the possible ways to validate a simulation model (Kleijnen, 1995). To this end, the number of replicates was set at 10, which should ensure sufficient reliability of the results obtained, and the simulation duration was set at one week. The comparison showed a good correspondence between the simulated data and the real one, in terms of the number of jobs processed per day and over the whole week.

6. ANALYSIS AND PERFORMANCE IMPROVEMENT

Some key performance indicators (KPIs) were quantified using the output of the model, in order to evaluate the effectiveness of the targeted department; these KPIs include:

- The total shop floor time of the department, i.e. the time required to complete the set of activities required to process the full set of jobs scheduled to be manufactured in a week in the targeted department;
- the machine effectiveness, i.e. its effective use in the day (excluding, e.g., stops, waiting, loading/unloading operations).

A modified scenario was then designed and tested by means of the simulation model, to evaluate possible improvements in the above KPIs. To be more precise, the new scenario makes use of different dispatching rules, i.e. of specific rules to assign the jobs to the different machined of the department (Sculli and Tsang, 1990). A total of 6 common and easy to use rules was derived from the literature and tested on the set of jobs processed, and the relating results were compared to that returned by the scheduling rule currently used by the company (i.e. the EDD). The rules chosen for testing are:

- Total Work (TWORK): the selected job owns the lowest total processing time (this latter obtained as the sum of the working time of the operations already performed and those still to be performed);
- Minimum set-up time (MSUT): The selected job involves the minimum setup time on the machine being considered;
- Operational Expiration Date (OPNDD): the chosen job has the shorter "expiration date". This latter is obtained as the ratio of the difference between the delivery date and the starting time of the job and the number of operations to be carried out on the job;
- Few remaining operations (FROP): the chosen job owns the lowest number of remaining operations to complete;
- Most remaining operations (MROP): the chosen job has the greatest number of remaining operations to be performed;
- First in the system first served (FISFS): The allocated job is the one that entered in the system first.

The simulation model was used to reproduce 104 (random) weeks of functioning of the department, to test the rules listed above and compare the results with those of the current scheduling policy, obtaining (6 + 1) x 104 = 728 scenarios in total. The simulation was stopped once all the jobs have been processed; hence, the simulation duration reflects the total shop floor time of the department.
A summary of the performance of the dispatching rules, in terms of the total shop floor time, is proposed in Table 3. The table shows that the best rule to prioritize the jobs in the targeted system is the MROP, which returned a lower total shop floor time compared to the current scenario. More precisely, this rule returns the lowest shop floor time for the system considered in 22.3% of the scenarios simulated. Further rules that provided interesting findings are OPNDD and FISFS. The rule currently used by the company to prioritize the jobs, i.e. the EDD, returned optimal results in terms of total cycle time only in 11.18% of the scenarios simulated.

Table 3: comparison between the shop floor time observed and that recorded in the company' database

Scheduling rule	Number of optimal scenarios	Percentage of optimal scenarios
TWORK	16	10.53%
MSUT	17	11.18%
MROP	34	22.37%
FROP	20	13.16%
OPNDD	25	16.45%
EDD	17	11.18%
FISFS	23	15.13%

In the light of the fact that MROP returned the most effective results, the performance of this rule was investigated in further details. To this end, the total processing time of the MROP was compared to that of the EDD, to quantify the savings achievable when using the new rule. It was found that the average difference in the total shop floor time (across the whole sample of 104 weeks simulated) accounts for 400 minutes, corresponding to the average saving achievable using the MROP rule; a peak of 2877 minutes saved was also observed (Table 4).

Table 4: savings in the processing time (EDD vs. MROP)

Class	Absolute frequency	Relative frequency
0	0	0.00%
411	42	84.00%
822	5	10.00%
1233	2	4.00%
1644	0	0.00%
2055	0	0.00%
2466	0	0.00%
2877	1	2.00%

As a further analysis, the simulation model was used to reproduce the operating conditions of the machinery department over 3 (real) weeks observed between December 2016 and January 2017, with the use of the MROP rule. This analysis aims at evaluating the possible savings in the total shop floor time the company could have achieved if it had applied of the MROP rule in the observation period. For all weeks simulated, the MROP rule returned better performance than the EDD one in terms of the total shop floor time. Also, the efficiency of the machines was found to improve considerably when using the MROP rule. Results, for a sample week (week no.2) are proposed in Figure 3 and 4).

Set-up time | Processing time | Machine stops | Employee's stops | No jobs to process

MACCHINE	SETUP	WORKING	CARSCAR	FERMO CAUSA MACCHINA	FERMO CAUSA OPERATORE	FREE
M01003	5.70%	37.59%	22.14%	11.47%	1.37%	21.73%
M01006	1.88%	50.71%	6.20%	15.31%	6.34%	19.57%
M01012	2.10%	47.27%	10.40%	15.86%	0.00%	24.38%
M01015	11.18%	42.29%	4.68%	8.03%	1.54%	32.28%
M01018	1.86%	12.39%	1.57%	5.57%	2.11%	76.51%
M01021	16.35%	45.16%	6.61%	5.53%	5.32%	21.02%
M01024	8.05%	56.79%	3.73%	5.64%	0.45%	25.34%
M01027	0.78%	75.75%	9.50%	6.14%	0.43%	7.40%
M01030	2.90%	16.04%	1.99%	5.59%	0.84%	72.64%
M01033	0.11%	58.75%	14.11%	5.13%	0.52%	21.37%
M01036	0.09%	52.18%	4.25%	6.09%	1.20%	36.18%
M01039	0.19%	45.53%	3.00%	5.00%	7.77%	38.49%
M01042	14.84%	41.66%	7.33%	4.49%	2.15%	29.52%
M01045	8.41%	77.23%	0.78%	5.05%	1.92%	6.60%
M01057	3.88%	17.29%	3.21%	4.75%	0.54%	70.33%
M01060	7.01%	18.45%	5.53%	5.36%	2.22%	61.42%
M01063	8.55%	48.60%	5.32%	5.62%	5.44%	26.46%
M01066	3.47%	33.54%	14.38%	5.32%	4.51%	38.79%

Figure 3: machine's efficiency in week no.2 – MROP rule.

Set-up time | Processing time | Machine stops | Employee's stops | No jobs to process

MACCHINE	SETUP	WORKING	CARSCAR	FERMO CAUSA MACCHINA	FERMO CAUSA OPERATORE	FREE
M01003	5.70%	37.59%	22.14%	11.47%	1.37%	21.73%
M01006	1.88%	50.71%	6.20%	15.31%	6.34%	19.57%
M01012	2.10%	47.27%	10.40%	15.86%	0.00%	24.38%
M01015	10.73%	42.11%	4.66%	7.99%	0.40%	34.11%
M01018	1.85%	12.32%	1.56%	5.54%	0.91%	77.81%
M01021	17.39%	44.96%	6.58%	5.50%	5.56%	20.00%
M01024	8.05%	56.80%	3.73%	5.64%	1.34%	24.43%
M01027	0.82%	75.93%	9.26%	6.15%	0.41%	7.43%
M01030	2.90%	16.03%	1.99%	5.59%	0.65%	72.85%
M01033	0.11%	58.75%	14.11%	5.13%	0.52%	21.37%
M01036	0.09%	52.18%	4.25%	6.09%	1.20%	36.18%
M01039	0.19%	45.15%	2.98%	4.96%	6.70%	40.02%
M01042	14.41%	41.74%	7.34%	4.50%	2.50%	29.52%
M01045	8.41%	77.24%	0.78%	5.05%	1.91%	6.60%
M01057	3.88%	17.27%	3.21%	4.74%	0.33%	70.57%
M01060	7.00%	18.45%	5.53%	5.36%	2.58%	61.08%
M01063	8.62%	49.01%	5.36%	5.67%	5.86%	25.48%
M01066	3.47%	33.56%	14.39%	5.32%	4.40%	38.85%

Figure 4: machine's efficiency in week no.2 – EDD rule.

7. CONCLUSIONS

This study has proposed the analysis of the machinery department of a main Italian company manufacturing plants for the food industry. The analysis, supported by a simulation model developed under SIMUL8™, has targeted in particular the revision of the dispatching rule currently used by the company to schedule the jobs to be manufactured in the department. A total of 6 alternative rules was tested using simulation and the relating results were compared in terms of the total shop floor time generated by each rule. The choice of this specific KPI was motivated by the fact that one of the main criticalities of the department analysed refers to the delay experienced by the jobs processed.

The results obtained have shown that the MROP rule returns the most interesting results in terms of total shop floor time for the jobs examined. From a practical point of view, this outcome could be useful to the targeted company to evaluate the implementation of alternative dispatching rules to schedule the jobs. At the same time, however, it is not expected that these results are optimal in general and, probably, they do not provide a definitive solution to the targeted production department. In this respect, the natural future step of the research will be to implement the alternative scheduling rule in the manufacturing department in a pilot trial, to provide a quantitative evaluation of the resulting benefits.

REFERENCES

Carley, K.M. (2003). Computational organizational science and organizational engineering. Simulation Modelling Practice and Theory, 10, 253–269

Concannon, K., Elder, M., Hindle, K., Tremble, J. and Tse, S. (2007), Simulation Modelling with Simul8™ (ISBN: 0973428503), Visual Thinking International, available at: www.simtech.hu/_data/VFS_6084183539ff1c826da47589a021838c.pdf (accessed 2 August 2014).

Kleijnen, J.P.C. (1995). Verification and validation of simulation models. European Journal of Operational Research, 82, 145-162

Renna, P. (2017). Allocation improvement policies to reduce process time based on workload evaluation in job shop manufacturing systems. International Journal of Industrial Engineering Computations 8, 373-384

Sculli, D. and Tsang, K.K. (1990). Priority dispatching rules in a fabrication/assembly shop. Mathematical and Computer Modelling, 13(3), 73-79

Supsomboon, S., Vajasuvimon, A. (2016). Simulation model for job shop production process improvement in machine parts manufacturing. International Journal of Simulation modelling, 15, 611-622. Retrieved July 2017 from http://www.ijsimm.com/Full_Papers/Fulltext2016/text15-4_611-622.pdf

Xie, C. and Allen, T.T. (2015). Simulation and experimental design methods for job shop scheduling with material handling: a survey. International Journal of Advanced Manufacturing

Technology, 80, 233–243. DOI 10.1007/s00170-015-6981-x

AUTHORS BIOGRAPHY

Marta RINALDI is research fellow at the Department of Engineering and Architecture of the University of Parma. She graduated (with distinction) in Industrial Engineering and Management in 2011 and got a Ph.D. in Industrial Engineering in 2015. From 2011 to 2014 she was scholarship holder at the Interdepartmental Center CIPACK. She currently works on discrete event simulation and its application to industrial plants, manufacturing systems and business processes, and is author of more than 20 papers in this field.

Eleonora BOTTANI is Associate professor in Mechanical Industrial Plants at the Department of Engineering and Architecture of the University of Parma. She graduated (with distinction) in Industrial Engineering and Management in 2002, and got her Ph.D. in Industrial Engineering in 2006, both at the University of Parma. Her research activities concern logistics and supply chain management issues. She is author (or co-author) of more than 130 scientific papers, referee for more than 60 international journals, editorial board member of five scientific journals, Associate Editor for one of those journals, and editor-in-chief of a scientific journal.

Roberto MONTANARI is Full professor of Mechanical Plants at the University of Parma. He graduated (with distinction) in 1999 in Mechanical Engineering at the University of Parma. His research activities mainly concern equipment maintenance, power plants, food plants, logistics, supply chain management, supply chain modelling and simulation, inventory management. He has published his research in approx. 70 papers, which appear in qualified international journals and conferences. He acts as a referee for several scientific journals, is editorial board member of 2 international scientific journals and editor of a scientific journal.

Massimo BERTOLINI graduated in 1999 in Mechanical Engineering at the University of Parma and received his Ph.D. in Production Systems and Industrial Plants from the same university in 2004. Since 2002 he has been a Lecturer in Industrial Plants at the Department of Engineering and Architecture of the University of Parma. He is currently Associate professor of Operations management at the same university. His research activities mainly concern equipment maintenance, reliability, production planning, logistics and food safety. He has published more than 60 papers in international journals and conferences.

Francesco ZAMMORI graduated with distinction in 2004 in Management Engineering and completed his post-graduate studies in 2009, when he received a Ph.D. in Industrial Engineering from the University of Pisa. From 2012 he is Assistant Professor at the University of Parma where he teaches Management Accounting Systems, Project Management, Information Science, Data Bases and Information Systems. His research interests mainly concern: *(i)* Lean Thinking, *(ii)* Hybrid Production Planning and Control Systems, *(iii)* Modeling and Simulation and *(iv)* Project Management. His research activities led to the publication of more than 40 works, most of which accepted on prestigious international journals.