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A Priority Rule Based Production Scheduling Module on Faborg-Sim Simulation Tool

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ABSTRACT

This paper presents the development of a priority, rule-based, a production scheduling module for the Faborg-Sim simulation tool with ten priority rules. Faborg-Sim consists of three modules, i.e., modelling, simulation, and performance evaluation. In this study, a detailed conceptual framework was defined and a case study was modelled and evaluated for a machine parts manufacturing system by using Faborg-Sim. The simulations were run using only six selected priority rules for the information on customers' orders in order to integrate the scheduling module in Faborg-Sim. Simulation models were run separately for each priority rule of scheduling to obtain the best performance of the production schedule. After repeating the simulations, performance measurement parameters were obtained and evaluated on a relative basis.

Keywords: *Production scheduling, Priority rules, Dispatching rules, Simulation, Faborg-sim.*

1. INTRODUCTION

The changing demand of capacity and its management are affected by many different factors. Responding to customers' demands and due dates are very important when changing manufacturing systems and the types of products [1]. Sustainable competition in the market and entering new markets require strong management and control of production parameters and capacity.

On-time delivery, short processing times, low personnel and processing costs, good service, and quality products provide competitive power in the market and satisfy customers' expectations. These conditions are possible only when production is properly managed. Managing production, especially choosing appropriate scheduling approaches, can be quite difficult due to the occurrence of unexpected tasks and events. The system loses its effectiveness due to the uncertainty caused by these complex conditions [2]. At this point, production scheduling, which is a very important function for a production system, comes into question, and it is affected by many factors, such as production levels, lot-size limits, due dates, job precedence, and priority rules [3]. Scheduling is a kind of assignment problem that is related to assigning tasks over a period under constraints [4]. Generally, there are two types of constraints in scheduling problems, i.e., resource capacity and technological constraints [5]. Different methods are used to deal with scheduling problems that become a focus in the development, application, and evaluation of the systems. The use of these methods changes the structure of the system and its objective function. In the literature, heuristics and operations research models, such as integer programming, dynamic programming and branch and bound techniques, have been used extensively to solve

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the production scheduling problems. These methods require that assumptions be made to ease the problem and obtain optimal solutions. However, it is not always possible to develop effective assumptions, so the simulation method becomes an effective method for analysing problems and evaluating different convincing results and for practical purposes [6-8].

Job shop scheduling problems are described as NP hard problems. Because of the difficulty of determining the optimal solution in practice, it is acceptable to identify and use near-optimal solutions [9]. Job-shop scheduling problems are categorized in two groups, i.e., static job-shop problems and dynamic job-shop problems. In static job-shop problems, there are jobs to be sequenced on various machines and job arrivals are static, whereas, in dynamic job-shop problems, jobs arrive randomly and continuously during a period [10]. The simulation method is used mostly for dynamic job-shop problems. Performance assessment parameters, such as resource utilization rate, capacity utilization rate, and definition of bottlenecks, can be obtained. Reduction of lead times and comparison of alternative scenarios are the possible results of simulation [11].

In this study, we developed a priority rule-based, production-scheduling module using the simulation software Faborg-Sim with priority rules. Faborg-Sim was developed in the Industrial Engineering Department at Suleyman Demirel University in 2009, and it has three modules, i.e., modelling, simulation, and performance evaluation [12]. For the best performance value of production schedule, the simulation runs are repeated for each priority rule for scheduling. After the repetitions, the performance measurement parameters are obtained and can be evaluated in a case study by using Faborg-Sim simulation tool to perform modelling and evaluation of a manufacturing system for machine parts.

2. BACKGROUND

In a job-shop scheduling system, for production problems as interruption of machines, re-work and work-in-process present expert systems by the simulation method or by developing a structure to minimize total completion time, taking into account due dates, precedence or priority rules, and maintenance control processes [13-16].

Priority rules have been used for decades as a scheduling procedure in industry. It is known that implementation of priority rules is easy to do in practice. A study of production scheduling by implementing priority rules was used with discrete event simulation and comparison of performances of the rules [17]. A dynamic stochastic job-shop scheduling problem was presented with coordination of priority rules and the analysis of performance by using simulation [18]. In job-shop scheduling problems, two new dispatching rules were presented with process-time and work content and, the experimental study was investigated by the SPT and WINQ rules [19]. In addition, rate-modifying-activity and also sequence dependent machine scheduling models were developed as the rule based approaches for scheduling problems [20, 21]. In fact, the main purposes of scheduling rules are to minimize the total completion time and to meet the due dates. But a simulation tool which is called as Faborg-Sim was developed by multi products, multi parallel machines with customer orders under the performance criteria.

Job-shop scheduling problems have been studied by using simulation in the literature. For with the aim of minimizing makespan and evaluating system performance an example of a job-scheduling problem was simulated with Visual SLAM [22]. It was studied for flexible, job-shop scheduling problems with the objectives of minimizing makespan, total workload of machines, and the workload of critical machines using MATLAB simulations [23]. Minimizing tardiness is an objective of some priority rules used in scheduling problems. A priority rule for minimizing mean tardiness in a dynamic job-shop environment was presented and compared by using simulation [24]. Each tardy job causes a tardiness cost. Minimizing tardiness and reducing total tardiness cost were studied, and the performance parameters were compared with simulation [25]. Selecting the right dispatching rules in production scheduling improves machine utilization. Selection of a product mix and the development of a dispatching rule were studied to gain the maximum profit for job-shop scheduling [26]. For dynamic-assembly job shops, scheduling was studied with different degrees of earliness, tardiness, and holding costs for each job. The aim of the study was to present the implementation of priority rules and their costs related with earliness and tardiness [27].

In multi-level assembly job-shops performance was evaluated by using simulation method with priority dispatching rules and jobs weights for flow-time and tardiness [28]. A simulation-based, assembly-scheduling system was presented that aimed to optimize due dates and achieve optimal utilization of personnel and material resources [29]. It is possible to evaluate performance by using simulation. An assembly job-shop problem was presented with priority rules to minimize the flow time and simulation-based evaluation was conducted [30]. The dispatching rules which were FIFO, LIFO, SPT, LPT, MWKR, LWKR and TWORK were used with simulation to performance measurements for dynamic job-shop scheduling [31]. Setup time changes could have an influence on the due dates of jobs [32]. The literature review was classified into three groups, i.e., jobs, class, and job-and-class setup cases. The simulation, integrated-solution method was used by comparing the performance of the priority rules performance in a job-shop scheduling problem with sequence-dependent setup times [33]. About the minimization of the makespan, the use of job-shop scheduling was studied and introduced release dates, deadlines, and sequence-dependent setup times [34]. Simulation can be used as a decision support tool, and a neuro-genetic decision support system integrated with simulation was presented in a study to achieve performance parameters, such as flow time, number of tardy jobs, total tardiness, and machine utilization rates [35]. The simulation method also is used for analysing flexible manufacturing systems. The effects of scheduling rules were examined on the performance of flexible manufacturing systems, including the changes in processing times and breakdown rates [36].

As a result, the aim of this study was to simulate production problems with priority rules for solving the scheduling process to determine performance parameters by using the Faborg-Sim simulation tool.

3. MATERIAL AND METHODS

3.1. Case Study: The Manufacturing of Machine Parts

The system works as one shift of 8 hours per day, and, 4 customers' orders are accepted for production of machine parts in daily. The equipment available in the manufacturing system for processing the production of 4 products daily consists of the following: the M1_TURNING (turning machine) that consists of three parallel units; the M2_MILLING (milling machine) that consists of three parallel units; the M3_DRILLING (drilling machine) that consists of one unit; M4_WELDING (welding machine) that consists of one unit; and M5_MONTAGE (montage station) that consists of one unit. The job-shop manufacturing model is shown in Fig.1.

Each product flows through ten operations for completion. In a report period, which consists of 20 workdays/month, the Faborg-Sim simulation tool runs simulations for 5 days. A case study was performed to model and evaluate the machine production system. The model data is given as Appendix A [12].

3.2. Faborg-Sim Simulation Tool

The simulation tool can be used for various purposes, such as analysing the manufacturing process and making stable decisions for the development and organization of the production systems. For the most part, the simulation results are applied to real systems to be used in design and management [37-41].

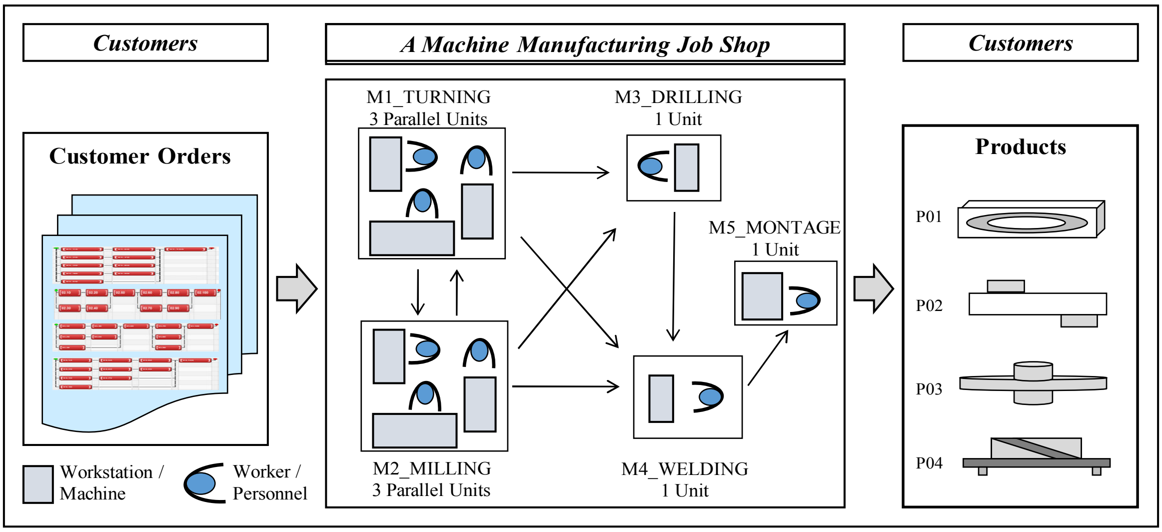

Figure 1. Model of manufacturing system

The Faborg-Sim simulation tool is used to evaluate production systems through modelling and simulating them. It was developed in a research project entitled "Development of Simulation Software for Facility Organizing, Production System Structuring, and Performance Measuring." The project was conducted in the Industrial Engineering Department at Suleyman Demirel University in Isparta, Turkey, using Microsoft Visual C# 3.0 object-oriented programming language with database [12]. The Faborg-Sim software consists of three modules, i.e., a modelling module, a simulation module, and a performance-evaluation module.

Faborg-Sim is provided to design and simulate very complex production systems that may have complex workflow plans (product), product trees, and additional parallel workstations and personnel types at the same time. It includes extensive modelling data that were gathered from the work environment. Thus, the production systems can be evaluated with higher reality and flexibility for simulation.

The Faborg-Sim simulation tool provides different parameters of system performance, including utilization rate of personnel and the workplace, cycle/lead time of products, work-in-process for customers' orders, delivery rate, and the sum of the logistics for a production system. The performance indicators are given as Table 1 [12, 46].

The degree of achievement of a specific goal can range from 0% to 100%, and this concept allows the calculation of the overall achievement of the goal by combining the individual values through an additive or a lexicographic preference function [42].

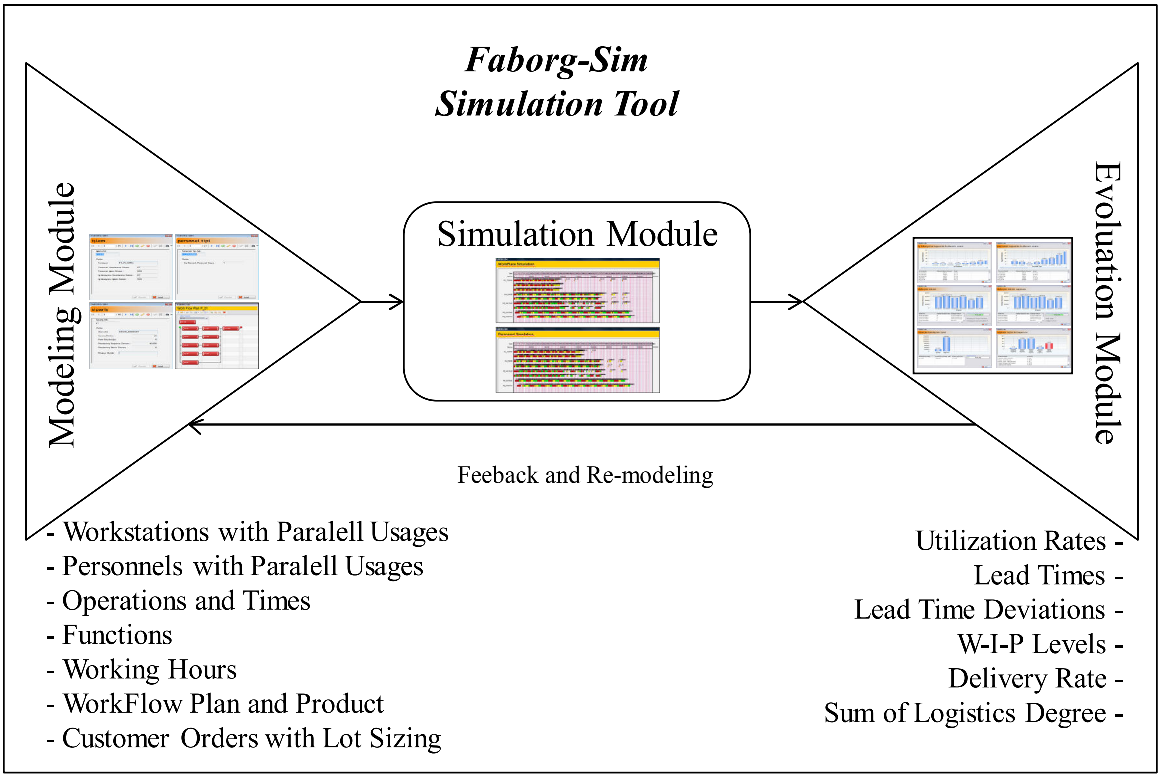

Figure 2. Faborg-Sim simulation tool

Table 1. The goal achievement degrees in Faborg-Sim Performance Evaluation Module [12, 46]

Goal Achievement Degree	***Formulas***[1]
Lead Time (GADLT)	$T_{D,aq} = t_{dS,aq} + t_{zwS,aq} + t_{zuS,aq}$ $T_{zwS,aq} = t_{ztS,aq} + t_{SAN,aq} + t_{SAV,aq}$ $t_{zuS,aq} = \left(\sum t_{SS}\right)_{aq} + \left(\sum t_{SZ}\right)_{aq}$ $DLM_q = \max_{w \in W}\{LWD_{wq}\}$ $LWD_{wq} = \sum_{a=1}^{AAV_{wq}} \left(T_{awq} + t_{zt,awq}\right)$ $DLG_q = \frac{DLM_q}{DLS_q}$ $GADLT = \frac{1}{AAA} \cdot \sum_{q=1}^{AAA} DLG_q$
Lead Time Deviation (GADLTD)	$PDT_q = DLS_q - \frac{DLM_q}{GADLT}$ $NPTD_q = \frac{DLS - \frac{DLM_q}{GADLT}}{\frac{DLM_q}{GADLT}} = \frac{DLS_q}{DLM_q} . GADLT - 1$ $DPTD_q = \frac{1}{1 + \lvert NPTD_q \rvert}$ $GADLTD = \frac{1}{AAA} . \sum_{q=1}^{AAA} \frac{1}{1 + \left\lvert \frac{DLS_q}{DLM_q} . GADLT - 1 \right\rvert}$
Capacity Utilization Rate (GADCUR)	$GADCUR = \frac{NCT}{TC}$ $NCT = \sum_{q=1}^{ABA} \sum_{a=1}^{CCF_q} \left(t_{dS,a,q} + t_{zuS,a,q}\right)$ $TCS = \sum_{r=1}^{NDR} TCS_r$

[1] Nomenclature is given in Appendix B.

Work In Process (GADWIP)	$MOQ=\frac{1}{RPTZ}\sum_{q=1}^{ABA}\sum_{a=q}^{CCF_q}\left(t_{dS,aq}+t_{zuS,aq}\right)^2$ $WOQ=\frac{1}{RPTZ}.\sum_{q=1}^{ABA}\sum_{i=1}^{CCF_q}WTB_{a,q}.\left(t_{dS,aq}+t_{zuS,aq}\right)$ $GADWIP=\frac{MOQ}{MOQ+WOQ}$
Sum of Logistics (GADSOL)	$GADSOL=\frac{g_1.GADLT+g_2.GADLTD+g_3.GADCUR+g_4.GADWIP}{\sum_{i=1}^{4}g_i}$
Completed Customer Orders Rate (GADCOR)	$CCO=\frac{FCO}{TCO}*100$

3.3. Priority Rules

Priority rules, which are used in simulation-based implementations for decision making, first assess the jobs to be processed by a machine in a given period of time. Simulation-based scheduling methods with priority rules do not provide optimal results, but they depict the comparison of the rules [43]. Performance of the usage of the priority rules has been investigated for the last 30 years with different methods that involve simulation [44-46].

Priority rules are generally used for sequencing tasks in job-shop scheduling. Customers' orders are queued before initiating production. This paper presents the 10 priority rules that are commonly used and that are integrated into the Faborg-Sim simulation tool (Fig. 3). A brief definition of each of the 10 rules is given in the following. It allows selecting the priority rule and running the simulation, so it provides the opportunity to compare results and choose the best rule.

- *First-Come, First-Served Rule (FCFS):* The job that arrives first at the machine will be the next job that is processed by the machine.
- *Last-Come, First-Served Rule (LCFS):* The job that arrives last at the machine will be the next job processed by the machine.
- *Shortest Processing Time (SPT):* The job with the shortest processing time among waiting jobs will be processed next by the machine to minimize total flow time.
- *Longest Processing Time (LPT):* The job with longest processing time among waiting jobs will be processed next by the machine to minimize the total completion time.
- *Earliest Due Date (EDD):* The job with the earliest due date will be processed next by the machine. The aim of this rule is to improve customer satisfaction.
- *Lowest Remaining Number of Operations (LRNOP):* The job that has the lowest remaining number of operations will be processed next by the machine. The aim of the rule is to maximize the number of orders delivered to customers.
- *Greatest Remaining Number of Operations (GRNOP):* The job that has the greatest remaining number of operations will be processed next by the machine. The aim of this rule is to maximize the utilization rate of capacity.
- *Shortest Remaining Processing Time (SRPT):* The job that has the shortest remaining processing time will be processed next by the machine. This aim of this rule is to minimize the total completion time and minimize the latest job delivery time.
- *Longest Remaining Processing Time (LRPT):* The job that has the longest remaining processing time will be processed next by the machine. The aim of this rule is to maximize the utilization rate of capacity.
- *Service in Random Order (SIRO):* The job that is selected randomly from the waiting jobs will be processed next by the machine.

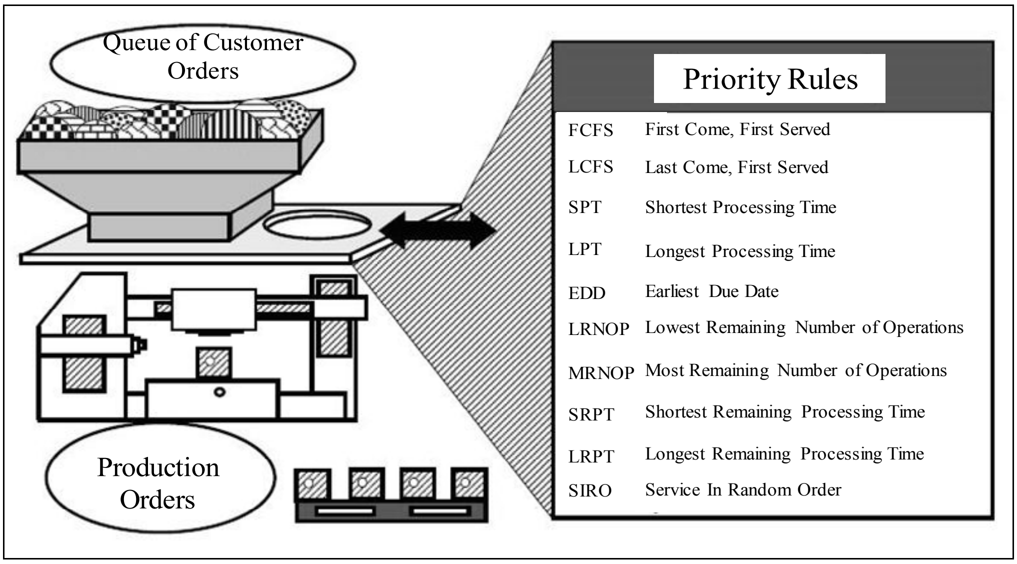

Figure 3. Priority rules for customer orders in Manufacturing Systems [45]

Algorithms of priority rules were developed and were coded on the Microsoft® C# 3.5 platform with an Intel® Core2Duo CPU. PR-Sched Module, which includes the module that contains the 10 priority rules module and was integrated with the Faborg-Sim software. Thus, the production systems can be simulated easily by using the appropriate rules.

3.4. Priority Rule-Based Production Scheduling Module (PR-Sched)

The Faborg-Sim simulation module, a simulation form prepared for the selection of priority rules, appears on the screen, and the user can select the appropriate rule for the type of production that was modelled by the simulation module (Fig 4). Then, the "Simulate" button is activated to initiate the simulation. After the simulation is completed, the performance evaluation parameters execute and Gantt charts are drawn [12].

Figure 5 shows an overview of the PR-Sched module algorithm. After the modelling data are completed, the priority rule is selected from the PR-Sched module. For example, the FCFS rule was selected as the scheduling/dispatching rule. The modelling data are used to calculate the total process number (TPN), and then schedulable process set is obtained as considering first operations of each customer orders from product by workflow plan editor.

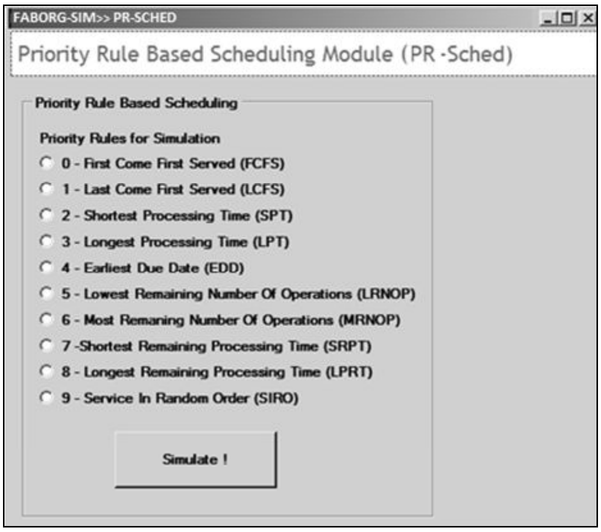

Figure 4. Priority rules in simulation module of Faborg-Sim

The TPN is also the iteration number for scheduling. When the simulation is conducted, the selection of processes is done by choosing the associated priority rule, and the chosen process is deleted from schedulable process set. Thus, the schedulable process set is updated and the control of TPN may or may not be accomplished. In other words, we need to know if there is any operation remaining in the schedulable process set. So, the simulation is completed, and the performance parameters, i.e., utilization rates, lead time, lead time deviations, work-in-process levels, delivery rate, and sum logistics degree, can be used in the evaluation module of the Faborg-Sim tool if the users wish to do so (Fig. 5). In this paper, we used only 6 priority rules, and FCFS, LCFS, LPT, EDD, LRNOP, and LPRT were selected from customers' orders and their information for this case study.

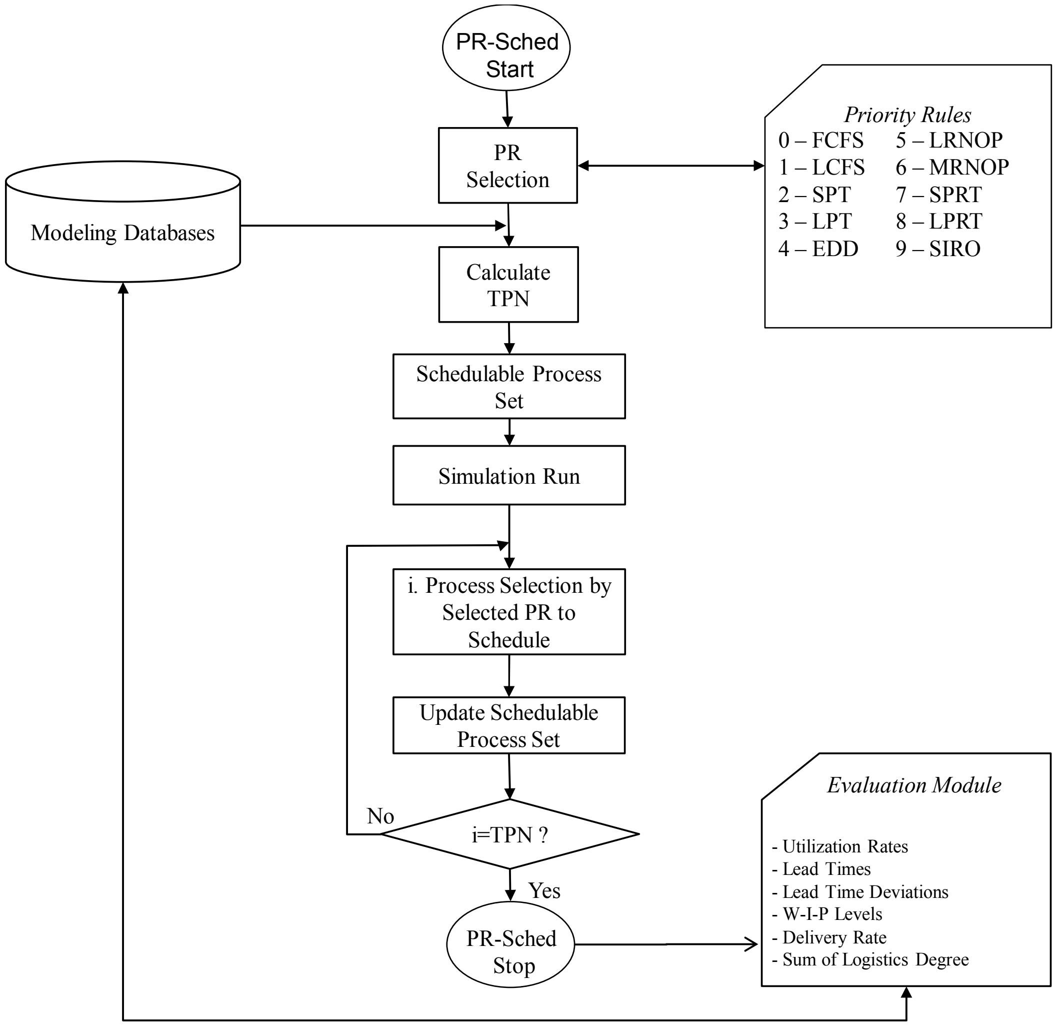

Figure 5. Faborg-Sim PR-Sched Module Algorithm

4. SIMULATION RESULTS

In modelling using the Faborg-Sim tool, its inputs are; personnel, work-times, machines, functions, and job-processing times. Due to these values, the selected priority rules are used, and the evaluation module demonstrates the performance parameters, such as personnel utilization rate, machine utilization rate, the number of delivered jobs, and lead time. The manufacturing of machine parts or products is modelled as network graphs, where each activity is assigned to at least one machine, workplace, or worker, with separate setup and execution times, if required.

The values of the performance parameters of the initial situation and alternative scenarios are given in Figure 6. The goal achievement degrees of the performance parameters are lead time (GADLT), lead-time deviation (GADLTD), capacity utilization rate (GADCUR), work in process (GADWIP), sum of logistics (GADSOL), and completed customers' orders rate (GADCOR). The simulation results of the initial situation and the first alternative, which reduced setup times (A1) by 50%, were compared. It can be seen that the performance parameters (GADLT, GADWIP, and GADSOL) of all priority rules, except FCFS, are about 5-10% greater in A1. Other performance degrees (GADLTD, GADCUR and GADCOR) are about 5-15% lower.

The simulation results of the initial situation and the second alternative, the batch size of which was divided into three parts (A2), were compared, and it can be seen that the performance parameters of all priority rules are lower than they were initially. Due to the reduced batch sizes of orders, an unbalanced capacity occurs for production scheduling. Thus, part of an order must wait for another part to be delivered to the customer and/or each order is divided into three sub-orders. As a result, the degree of delivered orders decreases even though capacity utilization rates are high.

5. CONCLUSIONS

In this research paper, production scheduling was studied by using priority rules and integrating them by using into the Faborg-Sim simulation tool. The simulations were repeated for each scheduling priority rule. After these repetitions, the performance measurement parameters were obtained and evaluated. The effects of different set-up times and lot size on scheduling were investigated for priority rules in manufacturing systems.

Several different criteria and parameters exist for the evaluation of production systems and of the effects on performance parameters in a production environment. By integrating simulation and production-scheduling methods, it is possible to evaluate various performance parameters that have given input values. The system bottlenecks can be identified visually and excessive waiting times can be eliminated. The simulation results give users the information they need and provide an opportunity for decision making.

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CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

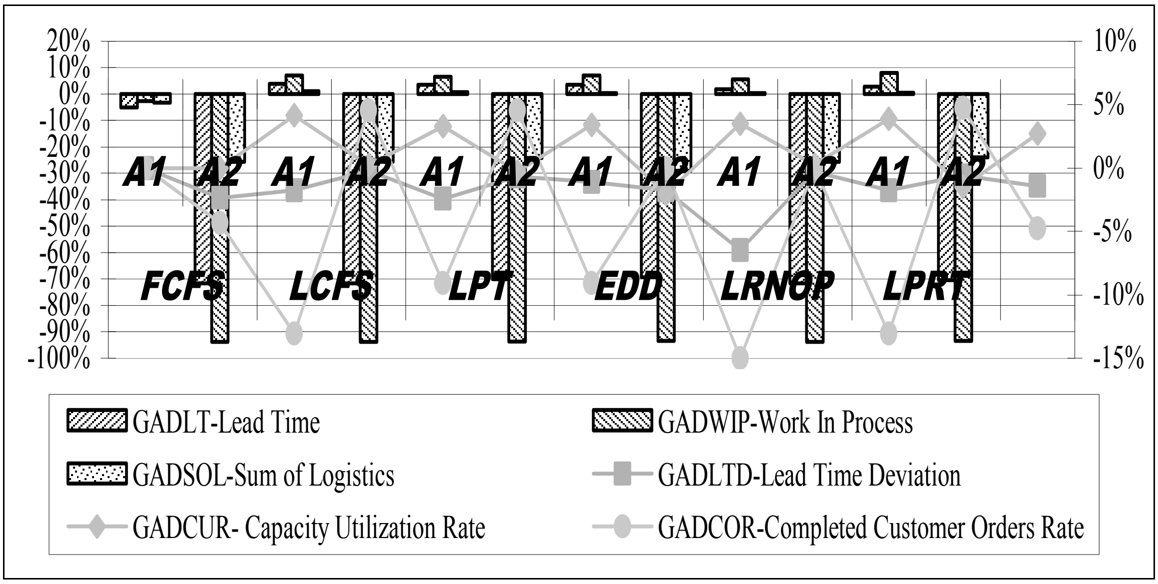

Figure 6. Simulation results

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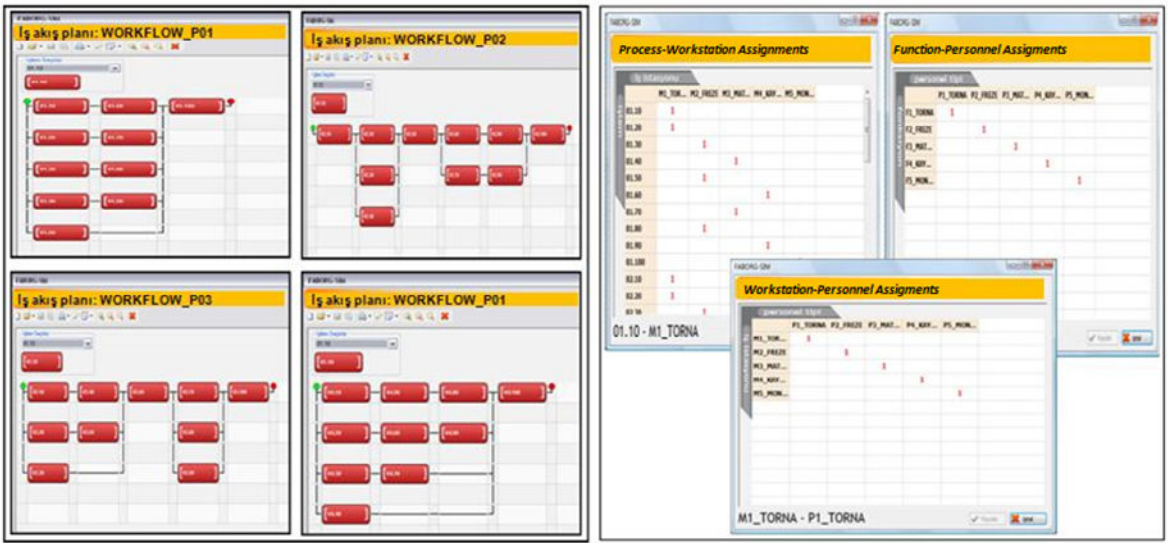
Appendix A. The model data: Workflow plans, assessment matrices and operation times [12]



a) Workflow Plans b) Assignment Matrices

		Process Code	10	20	30	40	50	60	70	80	90	100
Product 01	Workplace	Workplace	M1_TURN.	M1_TURN.	M2_MILLING	M3_DRILL.	M2_MILLING	M4_WELD.	M3_DRILL.	M2_MILLING	M4_WELD.	M5_MONT.
		PT (s)	400	400	450	900	450	500	900	450	500	1000
		OT (s)	400	400	450	900	450	500	900	450	500	1000
	Personnel	Personnel	P1_TURN.	P1_TURN.	P2_MILLING	P3_DRILL.	P2_MILLING	P4_WELD.	P3_DRILL.	P2_MILLING	P4_WELD.	P5_MONT.
		PT (s)	400	400	450	900	450	500	900	450	500	1000
		OT (s)	400	400	450	900	450	500	900	450	500	1000
Product 02	Workplace	Workplace	M1_TURN.	M1_TURN.	M2_MILLING	M3_DRILL.	M4_WELD.	M1_TURN.	M2_MILLING	M3_DRILL.	M3_DRILL.	M5_MONT.
		PT (s)	200	200	300	100	250	200	300	100	100	500
		OT (s)	200	200	300	100	250	200	300	100	100	500
	Personnel	Personnel	P1_TURN.	P1_TURN.	P2_MILLING	P3_DRILL.	P4_WELD.	P1_TURN.	P2_MILLING	P3_DRILL.	P3_DRILL.	P5_MONT.
		PT (s)	200	200	300	100	250	200	300	100	100	500
		OT (s)	200	200	300	100	250	200	300	100	100	500
Product 03	Workplace	Workplace	M1_TURN.	M1_TURN.	M2_MILLING	M2_MILLING	M3_DRILL.	M4_WELD.	M1_TURN.	M2_MILLING	M3_DRILL.	M5_MONT.
		PT (s)	400	400	500	500	300	600	400	500	300	800
		OT (s)	400	400	500	500	300	600	400	500	300	800
	Personnel	Personnel	P1_TURN.	P1_TURN.	P2_MILLING	P2_MILLING	P3_DRILL.	P4_WELD.	P1_TORNA	P2_MILLING	P3_DRILL.	P5_MONT.
		PT (s)	400	400	500	500	300	600	400	500	300	800
		OT (s)	400	400	500	500	300	600	400	500	300	800
Product 04	Workplace	Workplace	M1_TURN.	M2_MILLING	M2_MILLING	M3_DRILL.	M2_MILLING	M3_DRILL.	M3_DRILL.	M4_WELD.	M4_WELD.	M5_MONT.
		PT (s)	200	300	300	400	300	400	400	500	500	600
		OT (s)	200	300	300	400	300	400	400	500	500	600
	Personnel	Personnel	P1_TURN.	P2_MILLING	P2_MILLING	P3_DRILL.	P2_MILLING	P3_DRILL.	P3_DRILL.	P4_WELD.	P4_WELD.	P5_MONT.
		PT (s)	200	300	300	400	300	400	400	500	500	600
		OT (s)	200	300	300	400	300	400	400	500	500	600

Appendix B. Nomenclature for formulas of goal achievement degrees

a	: Process or function
q	: Customer order
w	: Path
$T_{DS,aq}$	: Production/cycle/lead time
$t_{dS,aq}$	: Process time
t_{zwS}	: Travel time between operations or time of transition,
t_{zuS}	: Additional time.
$T_{zwS,aq}$	: Travel time between operations or time of transition,
$t_{ztS,aq}$	: Transportation time
$t_{SAV,aq}$	: Waiting time
$t_{SAN,aq}$	: Transfer time
$t_{zuS,aq}$	: Additional time
$t_{SS,aq}$	: System fault sourcing necessary break (waiting) time
$t_{SZ,aq}$	: Additional operation time
DLM_q	: The minimum production time
LWD_{wq}	: Path (w) length
AAV_{wd}	: Count of process,
T_{awq}	: Customer order time
$t_{zt,awq}$	: Necessary waiting time
w, W	: Count of path in an order
DLG_q	: The degree of production time
DLS_q	: The simulated production time
$GADLT$	: Goal achievement degree of lead time,
AAA	: Completed customer orders in reporting time zone,
AEA	: All customer orders in system, AAA ≤ AEA.
PTD_q	: The production/lead deviation for customer order (q).
$NPTD_q$	: The norm- production/lead deviation for customer order (q).
$DPTD_q$	: The degree of production/lead deviation for customer order (q).
$GADLTD$	: The goal achievement degree of production/lead time deviation.
$GADCUR$	: The goal achievement degree of capacity utilization rate,
NCT	: The used capacity (time) in a period report time zone,
TC	: The theoretical capacity.
ABA	: Count of started customer orders in report period, ABA ≤ AEA,
CCF_q	: Count of completed function in work flow plan for customer order (q),
TCS	: The theoretical capacity of system,
NDR	: Count of organizational units,
r	: The indicator of organizational units, $r \in IN$.
MOQ	: The minimum exist order quantity,
$RPTZ$	: The report period of time zone.
WOQ	: The waiting order quantity,
$WTB_{a,q}$	: The waiting time before simulation run for customer order (q) function (a).
$GADSOL$	: The goal achievement degree of Sum of Logistics,
g_i	: The weighted-factor, i=1,2,3,4.
CCO	: The completed customer orders (%),
FCO	: The finished customer orders,
TCO	: The total customer orders