Article

Sustainable Production Scheduling in Open Innovation Perspective under the Fourth Industrial Revolution

Sang-Oh Shim [1] , KyungBae Park [2],* and SungYong Choi [3]

[1] Department of Business Administration and Accounting, Hanbat National University, 125 Dongseo-daero, Yuseong-gu, Daejeon 34158, Korea; soshim@hanbat.ac.kr

[2] Department of Business Administration, Sangji University, 83 Sangjidae-gil, Wonju, Gangwon-do 26339, Korea

[3] Division of Business Administration, Yonsei University, 1 Yonseidae-gil, Wonju, Gangwon-do 26493, Korea; sungyong.choi@yonsei.ac.kr

* Correspondence: kbpark@sangji.ac.kr; Tel.: +82-10-2896-0745

check for updates

Abstract: This research addresses a specific issue in the field of operation scheduling. Even though there are lots of researches on the field of planning and scheduling, a specific scheduling problem is introduced here. We focus on the operation scheduling requirements that the Fourth Industrial Revolution has brought currently. From the point of view of open innovation, operation scheduling is known as the one that is using the Internet of Things, Cloud Computing, Big Data, and Mobile technology. To build proper operation systems under the Fourth Industrial Revolution, it is very essential to devise effective and efficient scheduling methodology to improve product quality, customer delivery, manufacturing flexibility, cost saving, and market competence. A scheduling problem on designated parallel equipments, where some equipments are grouped according to the recipe of lots, is considered. This implies that a lot associated with a specific recipe is preferred to be processed on an equipment among predetermined (designated) ones regardless of parallel ones. A setup operation occurs between different recipes of lots. In order to minimize completion time of the last lot, a scheduling algorithm is proposed. We conducted a simulation study with randomly generated problems, and the proposed algorithm has shown desirable and better performance that can be applied in real-time scheduling.

Keywords: open innovation; sustainability; Fourth Industrial Revolution; scheduling; simulation; setup time; automation; manufacturing system; operation; smart factory

1. Introduction

Currently, the need for sustainability and open innovation is getting bigger worldwide [1–8]. In traditional scheduling of a manufacturing environment, planning for lots, i.e., production units, is developed as following. According to the information of customers' order quantity, forecasting quantity of demand and work-in-process (WIP), and the daily quantity of release and move-out for each product during a several-month planning horizon are determined. This is usually called production planning. Then, lots are released for manufacturing and production is started.

In this paper, we address some scheduling issues as manufacturing lines become bigger, product types are various, and recipes of products are more complex. Even though lots of problems on planning and scheduling exist, this paper deals with scheduling lots with the special property. Since open innovation is a key success factor in the Fourth Industrial Revolution, innovative scheduling might be stated as scheduling used by using cloud computing, Big Data, the Internet of Things (IOT), and mobile

technology. With these infrastructures, it is required to manage the manufacturing system and develop scheduling algorithms for improving quality, deliverability, and flexibility, and saving costs.

Here, scheduling on designated parallel equipment, in which a specific recipe of lots should be processed on only predetermined equipment, is considered. A setup operation occurs between different types of lots. To minimize maximum time of the last completed lots, a scheduling algorithm is devised. A simulation test is done and the suggested one gives better solutions in real time.

Usually, in a real manufacturing system, there is designated parallel equipment that can process only predetermined types of lots, which have a specific recipe, due to the quality of the product or managerial convenience. That is, many operators in fieldwork prefer to process lots on equipment in which better yield or better quality can be found. Consequently, they group equipment in such a way that lots with specific recipes can be processed on predetermined (designated) ones. There are also setup operations between processing consecutive lots with different types (recipes) of lots. Since the setup time in this shop is usually longer than that of processing, it is required to schedule lots with the same recipe on designated parallel equipment consecutively to minimize the makespan of the lot. Here, the makespan is the maximum completion time of a lot among all lots. Therefore, we consider scheduling lots on designated parallel equipment with a setup operation to minimize the makespan of lots.

Even though there is much scheduling research on parallel shops, scheduling on designated parallel equipment is relatively little. In the case of parallel equipment without the designated property, it is known that the algorithm by longest processing time (LPT) rule is the best on parallel shops to minimize makespan [9] and how scheduling on parallel shops with a setup operation is done [10]. On the other hand, heuristic algorithms used by dispatching rules on a semiconductor-manufacturing fabrication are proposed [11]. In addition, several heuristics are developed in parallel shops with the property of a sequence-independent setup [12] and scheduling problems for different setup times on manufacturing systems are addressed [13,14]. In the case of 3-designated parallel equipment, to minimize makespan, near-optimal methodology is devised [15], and, with the property of constraint, Kellerer and Strusevich address the same one [16].

As described above, we consider the scheduling problem that can be found in most state-of-the-art technology industries. There are shops with parallel equipment and setup operations that are needed between different types of lots. The time for setup operations is usually longer than that of processing. Due to the quality of products and managerial convenience, operators want lots to be processed on the designated equipment. The objective of this research considered here was to find a near-optimal schedule that shows the minimum makespan of lots.

The remaining parts of this study are organized as following. Section 2 describes the problem here in detail, and some algorithms are presented in Section 3. In Section 4, with randomly generated problem instances, a series of computational experiments was done and performance evaluation is given in a simulation study section. At the conclusion, we conclude this study with the some suggestions.

2. Mathematical Programming

In this problem, parallel-designated equipment and sequence-independent setups, in which setup time is not dependent on the order of processing lots, are considered. The objective is to minimize the makespan. Lots with the same recipe are grouped and these are processed on the designated equipment. Note that the processing time of lots in same group is the same. The time duration of setup operations is also larger than that of processing. Finally, other factors to be considered here are given as following:

(i)   All of the lots to be scheduled should have arrived before scheduling.
(ii)   Production by splitting lots is not prohibited.
(iii)   Equipment can not process more than two lots simultaneously.

Notation used here is suggested before showing mixed integer programming.

E_g　　a set of designated equipment that can process lots in group g according the recipe.
L_g　　a set of lots that are in group g according to recipe.
s_g　　setup time of a lot in L_g.
p_g　　processing time of a lot in L_g.
x_{gle}　decision variable that is 1 if lot l in group L_g is scheduled on equipment e in E_g.
t_{ge}　decision variable that is 1 if lot in group L_g is scheduled on equipment e in E_g.

To describe the problem considered in this research, mathematical programming is given below. Objective function

Minimize makespan　　　　　　　　　　　　　　　　　　　　　　　　　　　　　(1)

Constraints

$$x_{gle} \leq t_{ge} \qquad\qquad\qquad \forall g,\ \forall l \in L_g,\ \forall e \in E_g \qquad\qquad (2)$$

$$\sum_g s_g \cdot t_{ge} + \sum_g \sum_{l \in Lg} x_{gle} \cdot p_g \leq makespan \qquad \forall e \in E_g \qquad\qquad (3)$$

$$\sum_{e \in Eg} x_{gle} = 1 \qquad\qquad\qquad \forall g,\ \forall l \in L_g \qquad\qquad\qquad (4)$$

Objective function (1) shows that minimizing the makespan is the objective of our problem and Constraint (2) implies that one piece of equipment is able to handle only one lot. Constraint (3) also implies the makespan that occurs by the setup and processing requirements. Finally, Constraint (4) represents that only one piece of equipment can process a lot. Here, all decision variables have one or zero (binary values).

3. Heuristics

In this section, we develop heuristic algorithms by using dispatching rules since it takes too much computation time to solve the problem optimally with the mathematical programming suggested earlier. Usually, a methodology used by dispatching rules can give a reasonable solution in real time so that it can easily be used in real systems.

When the status of equipment changes to idle, a lot to be processed next on the designated equipment is selected by computing the value of priority with dispatching rules. Every time equipment becomes idle, by assigning a lot, we conduct the schedule of lots. We modify the existing rules introduced in Lee and Kim [17] and Shim and Choi [18] and suggest five rules of selection of lots. All the rules compute the value of priority of lots to be scheduled, and then according to it, a lot is selected. The first-selection rule is based on the summation of processing and setup times and the lot with the largest value is chosen for processing. Here, it is denoted as the largest processing and setup time (LPST) rule. Second, on the contrary, a lot with the smallest value of summation of processing and setup times is selected (SPST). The next rule is to select an arbitrary lot in the group with the total remaining processing time of the lots, named as the total remaining processing time (TRPT) rule. At the fourth rule, the maximum number of remaining lots (MNRL) rule selects an arbitrary lot in the group with the most remaining lots that are not scheduled. Finally, we used the ratio of TRPT over MNRL as the fifth rule, that is, a lot with the maximum of remaining processing time per lot is chosen for scheduling (TRPT/MNRL). With those developed rules, a constructive heuristic algorithm is suggested.

Step 1　For the current schedule, find equipment in which processing can be started first, that is, select equipment with the smallest load.
Step 2　Select a lot with the highest priority computed by the five rules developed above. Note that five different schedules can be obtained.
Step 3　Assign the selected lot, and then update all the information.
Step 4　Repeat this procedure until there is no lot to be scheduled.

4. Simulation Study

For the evaluation of the devised algorithm, a simulation study on randomly generated problems was performed. To apply a real situation to the field of manufacturing systems, we generated 800 problems, 100 problems for a total of 8 combinations, i.e., number of lots (40 and 80), number of recipe groups (6 and 12), and amount of equipment (5 and 10). We generated processing times of lots from the uniform distribution with range (20–40) and set to uniform distribution with range (2–5) for the number of recipe group. Finally, the setup times of lots were generated from the uniform distribution with range (30–60).

The developed five rules were tested by comparing each rule, and we used the number of the best performance by counting the schedule with minimum makespan by each rule as the performance measure. The simulation program was made with the C++ programming language, and the simulation study was conducted on a desktop computer operating with a speed of 3.2 GHz under an Intel i7-8700 CPU and 32GB memory.

Simulation study results are shown in Table 1. The SPST rule shows the best performance, as seen in the table. In addition, the LPST and TRPT/MNRL rules show better performance than MNRL and TRPT. The computation times for all instances were less than 0.01 s. This implies that this algorithm is very practical in real-time scheduling.

Table 1. Overall results.

Lots [†]	Group [‡]	Equipment [**]	Largest Processing and Setup Time (LPST)	Smallest Processing and Setup Time (SPST)	Total Remaining Processing Time (TRPT)	Maximum Number of Remaining Lots (MNRL)	TRPT/MNRL
40	6	5	36 *	70	2	1	11
		10	6	92	3	3	8
	12	5	22	82	1	2	10
		10	32	66	1	1	9
80	6	5	22	78	3	2	10
		10	14	62	2	3	14
	12	5	12	76	4	2	13
		10	16	66	3	1	18

* Number of best solutions found among 100 instances by using each rule.
† Number of lots.
‡ Number of groups according to the recipe of lots.
** Amount of parallel equipment.

5. Concluding Remarks

Lately, sustainability and open innovation in manufacturing systems are very important for mass customization, which is currently a rising issue. A smart factory is one way for sustainability and it is necessary to develop innovative production scheduling for the success of the Fourth Industrial Revolution.

A scheduling problem on designated parallel equipment was addressed for the objective of minimizing makespan in relation with productivity. A constructive algorithm by using five lot-selection rules is proposed and evaluation for the developed one was done through a simulation study within test problems to apply real manufacturing situations. The methodology devised here showed good performance and it can be very practical in in the field of scheduling in terms of solution quality and speed for solving it.

This research might be extended variously. For instance, an arrival time of lots in which all lots have different ones can be considered. We may also introduce the case in which setup operations are sequence-dependent.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Greco, M.; Grimaldi, M.; Cricelli, L. Hitting the nail on the head: Exploring the relationship between public subsidies and open innovation efficiency. *Technol. Forecast. Soc. Chang.* **2017**, *118*, 213–225. [CrossRef]
2. Barge-Gil, A. Open, semi-open and closed innovators: Towards an explanation of degree of openness. *Ind. Innov.* **2010**, *17*, 577–607. [CrossRef]
3. Dahlander, L.; Gann, D.M. How open is innovation? *Res. Policy* **2010**, *39*, 699–709. [CrossRef]
4. Huizingh, E.K.R.E. Open innovation: State of the art and future perspectives. *Technovation* **2011**, *31*, 2–9. [CrossRef]
5. Gassmann, O.; Enkel, E.; Chesbrough, H.W. The future of open innovation. *R D Manag.* **2010**, *40*, 213–221. [CrossRef]
6. Yun, J.H. How do we conquer the growth limits of capitalism? Schumpeterian Dynamics of Open Innovation. *J. Open Innov. Technol. Mark. Complex.* **2015**, *1*, 17. [CrossRef]
7. Lara, A.P.; Da Costa, E.M.; Furlani, T.Z.; Yigitcanla, T. Smartness that matters: Towards a comprehensive and human-centred characterisation of smart cities. *J. Open Innov. Technol. Mark. Complex.* **2016**, *2*. [CrossRef]
8. Yun, J.H.; Won, D.K.; Park, K.B. Dynamics from open innovation to evolutionary change. *J. Open Innov. Technol. Mark. Complex.* **2016**, *2*. [CrossRef]
9. Graham, R.L. Bounds on multiprocessor timing anomalies. *SIAM J. Appl. Math.* **1969**, *17*, 416–429. [CrossRef]
10. Allahverdi, A.; Gupta, J.N.D.; Aldowaisan, T. A review of scheduling research involving setup considerations. *OMEGA-Int. J. Manag. Sci.* **1999**, *27*, 219–239. [CrossRef]
11. Wu, M.C.; Huang, Y.L.; Chang, Y.C.; Yang, K.F. Dispatching in semiconductor fabs with machine-dedication features. *Int. J. Adv. Manuf. Technol.* **2006**, *28*, 978–984. [CrossRef]
12. Tang, C.S.; Wittrock, R.J. *Parallel Machine Scheduling with Major and Minor Setups*; IBM TJ Watson Research Center: York Town Heights, NY, USA, 1985.
13. So, K.C. Some heuristics for scheduling lots on parallel machines with setups. *Manag. Sci.* **1990**, *36*, 467–475. [CrossRef]
14. Tang, C.S. Scheduling batches on parallel machines with major and minor setups. *Eur. J. Oper. Res.* **1990**, *46*, 28–37. [CrossRef]
15. Goemans, M.X. An approximation algorithm for scheduling on three designated machines. *Discret. Appl. Math.* **1995**, *61*, 49–59. [CrossRef]
16. Kellerer, H.; Strusevich, V.A. Scheduling problems for parallel designated machines under multiple resource constraints. *Discret. Appl. Math.* **2004**, *133*, 45–68. [CrossRef]
17. Lee, D.H.; Kim, Y.D. Scheduling algorithms for flexible manufacturing systems with partially grouped machines. *J. Manuf. Syst.* **1999**, *18*, 301–309. [CrossRef]
18. Shim, S.O.; Choi, S.W. Scheduling Jobs on Dedicated Parallel Machines. *Appl. Mech. Mater.* **2013**, *433–435*, 2363–2366. [CrossRef]