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Exploring Loss Hidden in Digital Scheduling Data

-A Case of Chemical Production System-

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Abstract

In the era of supply chain digitization, the automation of production scheduling is expected in earnest. However, several constraints of supply chain are included in the production planning structure to be automated, and huge losses may remain latent in this structure. The purpose of this study is to clarify the kinds of temporal loss included in this structure and contribute to a more dynamic supply chain innovation.

Keywords: Digital Production Scheduling; Chemical Industry; Lean Management; Supply Chain

1. Introduction

After taking the orders from customers, production department starts the planning with taking into account various conditions from raw material suppliers and the operation status of production system (Min 2002, Li 2008, Puche 2016). The attention of manufacturing industries has been focused on the automation of this operation with the recent demands for creating society and organizations using information technology such as Industry 4.0 and Society 5.0 (Longo, 2017, Ivanov 2019), however this operation can be attributed to craftsman-like methods and/or personal adjustment skills. In this improvement process, in order to make a computer calculate optimal production plan, it is required to manually organize production conditions, and to develop a database to accumulate the numerical data of them. A great deal of man-hours will be spent, but the standard logic of production planning obtained from this result will make subsequent operations dramatically more efficient.
In order to support this trend, this study investigates the constraints that are the preconditions for planning production. Through the reproduction of the production planning process in the chemical plant of collaborative company, the study understand what constraints exist, organize them. It also quantifies the influence of constraints in the production schedule.
What can be obtained from the above efforts is the management materials for understanding how much time resources have been lost before starting production, and this paper also aims to prepare more dynamic production improvement through the results. In this paper, the following two research questions will be clarified.
Firstly, in digital production scheduling, what kinds of constraints are required from the players in a supply chain, such as material suppliers, production managers, and customers of finished products? Secondly, how much temporal loss is structurally included in digital production scheduling?

2. Research Procedure

The research is advanced by the following four steps with the cooperation of the joint research company.

- Step 1: Understanding the procedure of production scheduling

After receiving explanations from production managers and staffs about production planning, this step organizes the conditions in making a production schedule with understanding the target products, the production process of each product, and the operation time of each process and so on.

- Step 2: Reproducing a production schedule

In this step, the two sub-steps aim to reproduce the production schedule for which a production has already been implemented by hand-made simulation. Firstly, the state of products are chronologically investigated in the actual implementation of this production. This is done by expressing the process where the product is located every determined intervals on the imitation paper depicting in described production flow, and taking a picture of the situation of each interval. Secondly, the time chart of a production for each process is created using by the result. In the time chart, the interval that the photo was taken is considered as one mesh.

- Step 3: Systematizing the constraints of production scheduling

Each constrain of production schedule obtained from Steps 1 and 2 is categorized from the three viewpoints of IPO model as follows:
Input related to the orders from customers and the raw materials from suppliers
Process related to the production system of chemical plant
Output related to a final product and a logistics operation to customers

- Step 4: Measuring the temporal losses with removing constraints in the reproduced schedule

This step consists of two sub-steps. The former considers the countermeasure to eliminate each constrain of production schedule classified in Step 2. The latter verifies how much production time can be raised by installing the countermeasures to the constraints of production schedule in the time chart created in Step 2. In the simulation, the case where any one type of constraint is removed and the case where any two types of constraint are removed simultaneously are performed.

3. Research Results

Each sub-section describes the result of each step of the research procedure illustrated in Section 2.

3.1. Understanding the procedure of production scheduling (Step 1)

The outline of conditions of investigated production system related to a production scheduling is as follows.
<Conditions of target production system>
The number of processes: 4 processes, The outline of each process: Table 1
The types of a product: 6 varieties of 4 series

Table 1. The outline of each process of investigated production system.

No. of process	First process	Second process	Third process	Fourth process
Function	Storage of raw materials	Chemical reaction	Storage of products	Shipping of products
The type of equipment	3types (Drum, Tank lorry, Storage)	1 types (Reactor)	2 types (Reactor, Storage)	2types (Drum, Tank lorry)
Conditions	Delivery methods from suppliers are a drum or a tank lorry. In case of the former, raw materials must be stocked until the day before implementing next process. In case of the latter, raw materials are stocked on the day when next process is implemented, and they are also temporarily transferred to a storage receiver.	This process consists of two sub-process such as reaction and clean. The time of reaction is 24 hours. In case that the type of next product is changed just before, the time of clean process is 12 hours. In case that type of next product is not changed just before, the time of clean process is 6 hours.	Cleaning is needed before every storage of a product. In case that the type of next storage product is changed just before, the time of this process is 12 hours. In case that type of next storage product is not changed just before, the time of this time is 6 hours.	Final products should be wait with occupying a reactor or a storage in the previous process until suppliers come for them.

3.2. Reproducing a production schedule (Step 2)

The right of Figure 1 shows the aspect of hand-made simulation. The production flow is described in an imitation paper and the position of a product is put in this paper by a post-it. The example like the light of Figure 1 shows that ‘product A’ puts the beginning of process flow by pink colour post-it. This is recorded as a photo and this simulation is done on during two months such as from January 2018 to February 2018.
After finishing this all hand-made simulation, the time chart is developed like Table 2. It is organized by a date and a process. In the former, one day is divided every 6 hours, and the latter consist of four processes such as the storage process of raw materials, reactor process, the storage process of products, and the shipping process of products. If a product is put in a process, this term is coloured in the time-chart.
The status of this simulation is obtained from the developed time-chart as shown in Table 3. The table includes in six figures as a) operation time, b) start-up time by New Year, c) waiting time, d) cleaning time, e) total time, and f) operation rate. The second process is the main process of total production flow and adds values to raw materials by a reactor. Its operation rate is 31% and this process can afford to more produce.

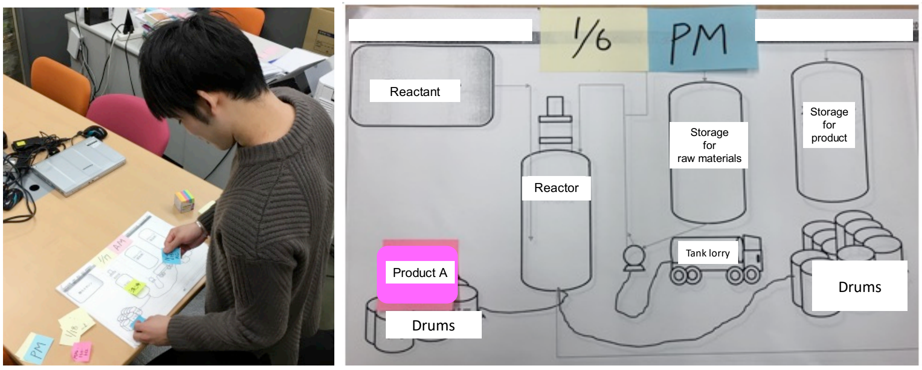


Figure 1. Hand-made simulation and its output.

Table 2. Example of the time chart based on hand-made simulation.

Process / Date		16 (Tue.) 8-14	14-20	20-26	26-8	17 (Wed.) 8-14	14-20	20-26	26-8	18 (Thu.) 8-14	14-20	20-26	26-8	19 (Fri.) 8-14	14-20	20-26	26-8
First process	Drum																
	Tank lorry																
	Storage																
Second process	Reactor																
Third process	Reactor																
	Storage																
Forth process	Drum																
	Tank lorry																

Black: Cleaning process
Others: Storage of raw materials, Reactor process, Storage of products, and Shipping of products

Table 3. Results of hand-made simulation on January, 2019.

Process		a. Operation time	b. Start-up time by New Year	c. Waiting time	d. Cleaning time	e. Total time	f. Operation rate (a/e)
First process	Drum	96 hr (36 hr) 16 scales	0 hr (0 hr) 0 scales	516 hr (144 hr) 86 scales		612 hr (180 hr) 102 scales	16%
	Tank lorry	24 hr (6 hr) 4 scales	84 hr (36 hr) 14 scales	504 hr (138 hr) 84 scales			4%
	Storage	24 hr (6 hr) 4 scales	90 hr (36 hr) 15 scales	498 hr (138 hr) 83 scales			4%
Second process	Reactor	192 hr (42 hr) 32 scales	24 hr (24 hr) 4 scales	330 hr (114 hr) 83 scales	66 hr (0 hr) 11 scales		31%
Third process	Reactor	180 hr (84 hr) 30 scales	48 hr (36 hr) 8 scales	318 hr (60 hr) 53 scales	66 hr (0 hr) 11 scales		29%
	Storage	96 hr (48 hr) 16 scales	312 hr (84 hr) 52 scales	174 hr (48 hr) 29 scales	30 hr (0 hr) 5 scales		16%
Forth process	Drum	30 hr (0 hr) 5 scales	66 hr (36 hr) 11 scales	516 hr (144 hr) 86 scales			5%
	Tank lorry	12 hr (0 hr) 2 scales	402 hr (132 hr) 67 scales	198 hr (48 hr) 33 scales			2%

Upper: Weekdays+ Holidays, Middle: Holidays, Lower: The number of scales in a time chart

3.3. *Systematizing the constraints of production scheduling (Step 3)*

Figure 2 shows a system of constraints of production schedule. They are the five types of constrains. The two constrains such as C. the number of workdays and E. shipping constrains originate in a customer and a plant respectively. And then, the eight countermeasures of five constrains is considered in the figure. They are utilized in next step.

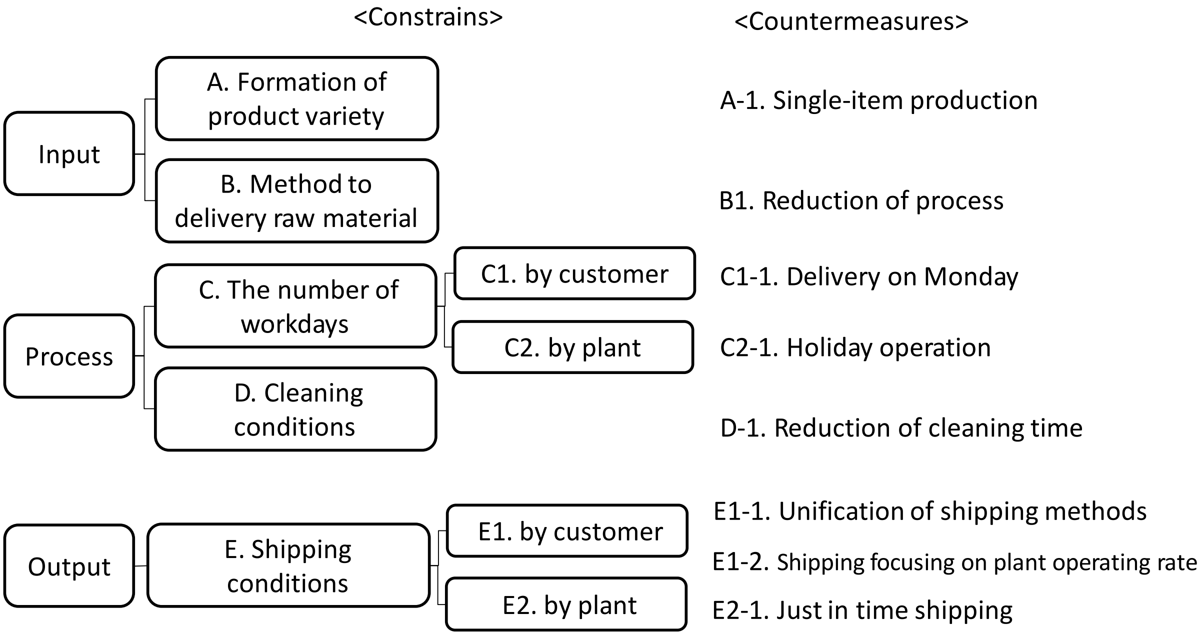


Figure 2. Constrains of production scheduling and their countermeasures.

3.4. *Measuring the temporal losses with removing constraints in the reproduced schedule (Step 4)*

Table 4 shows the results of removing the one type of a constraint of production scheduling, and Table 5 shows the results of removing the two types of a constraint of production scheduling. From the result of two tables, the available time of all processes is maximized when E2-1. Just in time shipping is installed. It is found to raise 120 hours in a month by installing E1-2 and E2-1. When comparing Tables 2 and 6, the available time of a reactor increases though early starting the cleaning of a reactor with just-in-time shipping a product.

Table 4. The result of removing the one type of a constraint of production scheduling.

Countermeasures	a. Operation time	d. Cleaning time	e. Total time	f. Operation rate (a/e)	g. Available time of all processes	g. Available time of some processes
Bench Mark	192 hr (42 hr) 32 scales	66 hr (0 hr) 11 scales		31%		
A-1. Single-item production	288 hr (84 hr) 48 scales	66 hr (6 hr) 11 scales		47%		
C2-1. Holiday operation	192 hr (42 hr) 32 scales	42 hr (6 hr) 7 scales	612 hr (180 hr) 102 scales	31%	60 hr (4 hr) 10 scales	24 hr (0 hr) 4 scales
D-1. Reduction of cleaning time	192 hr (42 hr) 32 scales	66 hr (0 hr) 11 scales		31%	12 hr (0 hr) 2 scales	12 hr (0 hr) 2 scales
E1-2. Shipping focusing on plant operating rate	192 hr (42 hr) 32 scales	66 hr (0 hr) 11 scales		31%	18 hr (0 hr) 3 scales	12 hr (0 hr) 2 scales
E2-1. Just in time shipping	192 hr (42 hr) 32 scales	66 hr (0 hr) 11 scales		31%	72 hr (0 hr) 12 scales	42 hr (0 hr) 7 scales

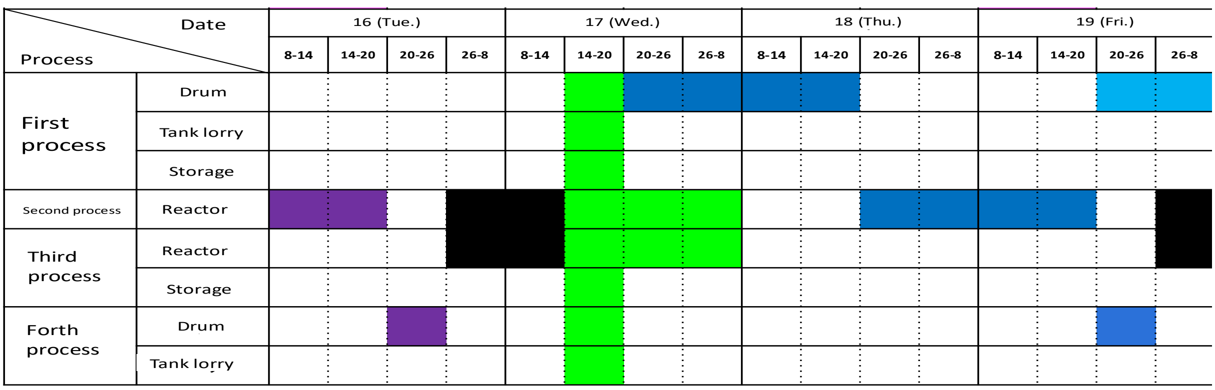
Upper: Weekdays+ Holidays, Middle: Holidays, Lower: The number of scales

Table 5. The result of removing the two types of a constraint of production scheduling.

Countermeasures	a. Operation time	d. Cleaning time	e. Total time	f. Operation rate (a/e)	g. Available time of all processes	g. Available time of some processes
Bench Mark	192 hr (42 hr) 32 scales	66 hr (0 hr) 11 scales		31%		
A-1. Single-item production + C2-1. Holiday operation	300 hr (84 hr) 50 scales	72 hr (18 hr) 12 scales		50%		
A-1. Single-item production + D-1. Reduction of cleaning time	204 hr (60 hr) 34 scales	48 hr (6 hr) 8 scales		33%		
C2-1. Holiday operation + D-1. Reduction of cleaning time	192 hr (42 hr) 32 scales	42 hr (6 hr) 7 scales		31%	78 hr (5 hr) 13 scales	30 hr (0 hr) 5 scales
C2-1. Holiday operation + E1-2. Shipping focusing on plant operating rate	192 hr (42 hr) 32 scales	66 hr (0 hr) 11 scales	612 hr (180 hr) 102 scales	31%	66 hr (0 hr) 11 scales	24 hr (0 hr) 4 scales
C2-1. Holiday operation + E2-1. Just in time shipping	192 hr (42 hr) 32 scales	42 hr (0 hr) 7 scales		31%	102 hr (24 hr) 17 scales	24 hr (0 hr) 4 scales
D-1. Reduction of cleaning time + E1-2. Shipping focusing on plant operating rate	192 hr (42 hr) 32 scales	42 hr (0 hr) 7 scales		31%	30 hr (0 hr) 5 scales	24 hr (0 hr) 4 scales
D-1. Reduction of cleaning time + E2-1. Just in time shipping	192 hr (42 hr) 32 scales	48 hr (0 hr) 8 scales		31%	66 hr (0 hr) 11 scales	24 hr (0 hr) 4 scales
E1-2. Shipping focusing on plant operating rate + E2-1. Just in time shipping	192 hr (42 hr) 32 scales	66 hr (0 hr) 11 scales		31%	120 hr (0 hr) 20 scales	36 hr (0 hr) 6 scales

Upper: Weekdays+ Holidays, Middle: Holidays, Lower: The number of scales

Table 6. The part of the time chart after installing countermeasures E1-2 and E2-1.



Black: Cleaning process
Green: Available time by removing constrains
Others: Storage of raw materials, Reactor process, and Storage of products, and Shipping of products

4. Discussion & Conclusions

The five types of supply chain constraints were found in this paper, and they are classified according to the IPO viewpoints of the input related to material supply and customer orders, the process related to production systems, and the output related to the shipment of finished products. In addition, this paper is able to clarify the temporal

loss of each supply chain constraint. Particularly, in the case of this production schedule, it was found that 120 hours of production time could be created in a month for the main equipment by eliminating the constraints on shipping.
This study quantitatively reveals that there are multiple kinds of supply chain constraints inherent in the data set for digital production scheduling that cause temporal losses. This finding contributes to resolving the misunderstanding that the digitalization of production scheduling can perfectly eliminate the physical structure of the supply chain. It also suggests that there are still many supply chain issues that need to be considered and resolved manually. From this point of view, it is no exaggeration to say that the digitization of supply chain highlights the more essential management issues of a supply chain. The effort addressed in this paper is only for one plant of one chemical company. The future study expects that supply chain losses in other areas of the manufacturing industry as well as other companies in the chemicals industry will be clarified, and structural issues in supply chain management be more dynamically addressed.
In general, people begin to draw up their plans before carrying out various activities. However, these plans contain certain restrictions, and when carrying out the plans, they accept them without any doubt. However, tackling those limitations is one of the first and most important efforts to achieve more satisfactory performance, results, and benefits. Planning operations in production activities, which are the core functions of the supply chain, are affected by many types of management resources including human, machine, and materials. The more supply networks are developed globally, the more the constraints related to them increase exponentially. There is no doubt that they will be complicated and difficult, however, by trying to solve them, it will be possible to create a more innovative supply chain landscape that we have never seen before. We hope that this research will support this endeavour.
The concept of temporal loss and its mitigation has mainly been discussed so far in the context of production operation in isolation. In this paper, in response to the requirements arising from the era of digital innovation in supply chains, this issue can be explored as part of the production planning operation, that is, the upstream of production operations. One of the contributions of this paper is that these recommendations have been made systematically and quantitatively to promote more dynamic innovation in supply chain management. In addition, this is useful for more efficient installation of digital production scheduling.

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