Production Planning in Virtual Factory with Material-Inventory Adjustment by Means of Transportations

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Abstract. Rapid production process realization and enterprise integration have been identified among the major imperatives for enabling the next generation manufacturing paradigm, such as INDUSTORY4.0. Virtual factories and enterprises move beyond existing operational limitations by providing concrete tools and approaches for leveraging the information exchange between factories. Factory process optimization will be enabled by the integration of runtime factory selection, forecasting, monitoring, and on-the-fly collaboration. To realize such virtual factories, that each factory enough amount of material-parts inventories to make products according to the production plan is one of the basic conditions to complete the whole production plan. In this paper, at first we construct a mathematical model for optimal production planning in virtual factory with material-inventory adjustment by means of transportations. Material/part inventories are adjustment by transportation from a factory which holds surplus of the material/part inventories to another factory which is short of the inventories. The objective of the model is minimizing the whole production cost and total transportation cost. Next, we evaluate the effectiveness of the mathematical model by random generated data sets. Finally, we discuss the validity of the optimization model proposed in this paper.

Keywords: Virtual Factory, Production Planning, Inventory Adjustment, Transportation

1. INTRODUCTION

In recent years, the requirements of customer have been increased. The people need the better products. They require more convenient life in order to be better. For responds this customer's desire, most companies have to make their own factories. But the factories have many problems. For example, the problems of production planning, quality control, and inventory control. Moreover, the companies have almost one objective, that is "How to product their product without waste and earn more profit?" In actual situation, many problems can occur at the same time, which brought the waste, high production cost, and lost profit. As the transportation problems, it also becomes the cost of transportation between each factories and the distribution to clients.

In this study, we consider the problems of inventory and transportation in factory. We assume the virtual factory situation, which some kind of factories did not have the inventory enough for production. How can we transport other materials from one factory into another factory? We found out about the adjustment of material-inventory by means of transportation.

As the research question above, this study assumes some factories produce the different types of products. The products are making from the same main materials. All factories produce the same product but the amount of order is different. The problem is critical situation when the factory has order; sometimes they cannot produce the item immediately. Because they unable to have enough materials for manufacturing. So the transportation plan have been made, it have to send the lacking materials to the deficient factories. So, all factories have the same conditions, which is all factories can transport materials all the time when they have not enough materials, as shown in Figure 1.

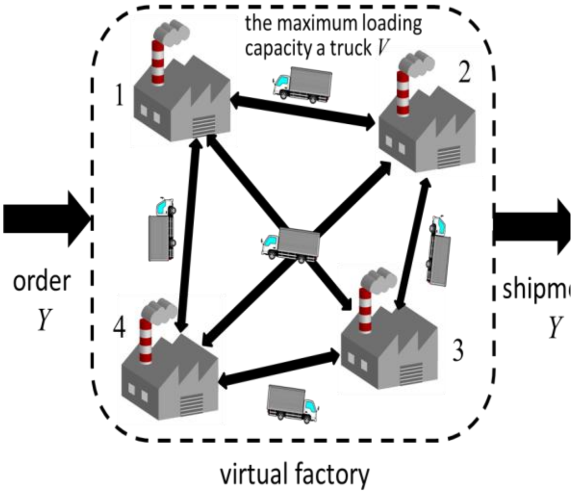

Figure1: Production planning in virtual factory with material adjustment by transportation.

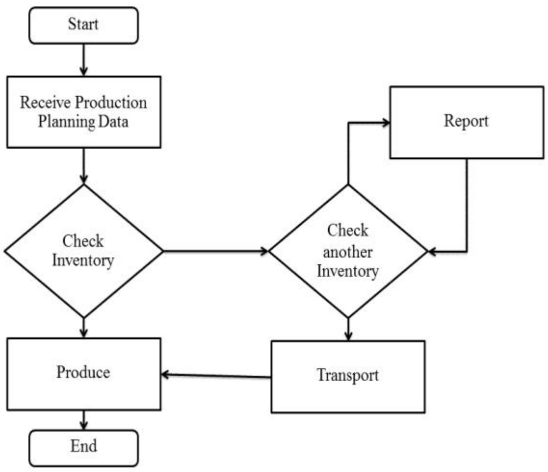

Figure2: Flow chart for inventory checking process.

When the material is not enough to produce, the staff must follow the processes, as shown in Figure 2., which set to check the inventory in each factory. First process is receiving the data of production planning from the planning division. Then, the checking of inventory is happened for determine the amount of deficient materials. If it is not enough, the next process is the checking of inventory in another factories and report to the planning division. The staff will command the transportation, which is transport the needed materials from the over factory into the lacking inventory. But if it is enough, the production will be continuous processes.

This paper is organized as follows. Section 2 is the related works. Section 3 is the proposed mathematical model. Section 4 is the approach to evaluate the effectiveness of the mathematical model by random generated data sets. Finally, section 5 is the conclusion about the validity of the proposed optimization model.

2. RELATED WORKS

2.1 INDUSTORY 4.0

INDUSTORY4.0, or the fourth industrial revolution, is the current trend of automation and data exchange in manufacturing technologies. It includes cyber-physical systems, the internet of things (IoT) and cloud computing. INDUSTRY 4.0 has been called a "smart factory" because factory can work in progress products, components, inventory control and production planning data will collect and share data in real time without human control.(Shrouf F. *et. al* 2014) This control system is very easy to check result in each section. But if something wrong happened, the production line based on concept of the smart factory can show in computer system immediately, what is the problems begin and where is the problematic location.

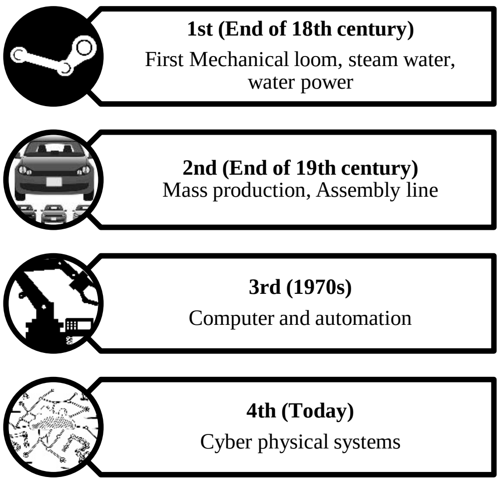

Figure 3: Evaluation of industrial development

Base on this concept, the smart factory can control the production line everywhere and every time because smart factory using the IoT or cloud computing. Then if something happened or need to manage a new line production, you also can do it immediately by using the internet networks, do not need to come to the factory and command by yourself. So, smart factory is suitable solution for factory that has many processes and has many production lines. All information can exchange and sharing for all factory. Because if we know all information in each factory, we can planning to transport the materials. Also we know what kind of material or factories need the transportation.

The cloud computing is one of main concept of the INDUSTRY 4.0. It is the recent technology for shearing data in each factories, which this study interest.

2.2 Cloud computing

Cloud computing has several attractive benefits for business and end users. The main benefits of cloud computing is the rapid data sharing or exchange.

The NIST define the cloud computing is "*A model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.*" (Mell and Grance, 2011)

The cloud computing have three types of services, including: 1) Private cloud services or enterprise cloud are delivered from a business data or hosted data center to internal users. Private cloud is all management, maintenance and updating of data center is the responsibility of the company this service is maintained on a private network. This service is the greatest level of security. 2) Public cloud services, these service is the greatest level of efficiency in shared resources, easily and inexpensive set-up because costs are covered by the provider. For this service the provider is responsible for the management or maintenance of the data canter. 3) Hybrid cloud service includes a variety of public and private cloud service with multiple providers.

As mention above, the benefits of Cloud computing is exchanging and sharing of information. In the same time, the cloud computing can use everywhere and every times whatever the users need. But if the mistake happens, the users can control or stop the problem just in time.

2.3 Definition of virtual factory

In this research, we assume some of factories have produce the same product but have different productivities. As stated in Figure 1, the problem is, when total order come to the virtual factory, some factories cannot produce immediately the assigned amount of products due to lacks of materials. So the factories must check another's factories' whether or not the factories have surplus inventories. As explained in Figure 2, if a factory has surplus of the materials, the factory provide the other factory, which is short of the material, with enough amount of the material by transportation using a track.

Figure 4 illustrates the definition of the virtual factory assumed in this research. The lacks and surpluses of materials are observed by sensors embedded in the factories. The sensors send inventory information to the central control center through cloud computing environment. The central control center draws up production plans of every factories and transportation plans in the virtual factory.

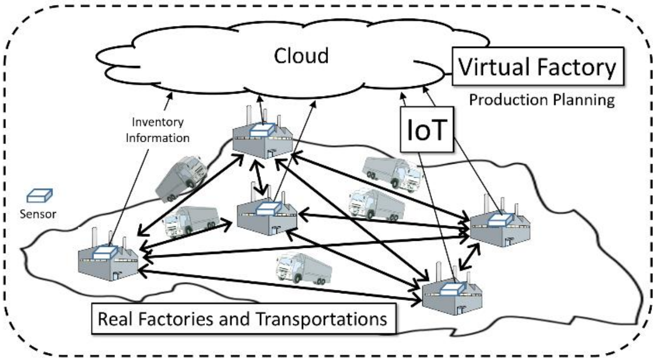

Figure 4: Illustration of virtual factory

2.4 Inventory transportation

Global business has many logistic problems in their business and still cannot find the best way to solve logistic problem. Transportation topics still have the problems, which need to solve and improve. This study desired to be a part of the decreasing cost of transportation.

In this research inventory transportation is occurs whenever the condition, which is illustrated in Figure 5, is satisfied. When the total amount of materials are over the capacity of a track, the materials are transported by enough number of tracks.

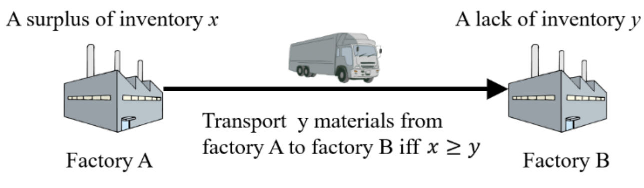

Figure 5: Illustration of inventory transportation.

3. CONSTRUCTING MATHEMATICAL MODEL

The basic mathematical model of Production Planning in Virtual Factory with Material-Inventory Adjustment by Means of Transportations (PPVF).

PPVF

< Preliminaries >

Y : order to / shipment from the virtual factory

y_i : a divided amount of the order Y assigned to factory i

$$Y = \sum_{i \in I} y_i$$

i : a factory i

SI: a set of factories

pc_i : cost to make a product at factory i

PC : the total production cost

$$PC = \sum_{i \in I} c_i \cdot y_i$$

l_k : a necessary amount of material k to make a product (k =1, 2, 3, …., m)

m : the number of kinds of materials

L_{ik} : an inventory of material k at a factory i

q_{jik} : the amount of material k transported from factory j to factory i

tc : a unit transportation cost

t : a truck t

r : the maximum number available trucks

T : a set of trucks

TC : the total transportation cost

V : the maximum loading capacity of a truck

D : the shipment due

pt_i : time to make a product at factory i

s : speed of a truck

SM : set of material

SL :

$$\delta_{ij} = \begin{cases} 1 & \text{if some materials are transported from factory } i \text{ to factory } j \\ 0 & \text{otherwise} \end{cases}$$

$\boldsymbol{\Delta}$: matrix[δ_{ij}]

<Assumptions>

1. The order to each factory is constant.
2. The inventory of each factory is constant.
3. All trucks have same specifications.
4. A transportation cost does not change according to the weight of materials.

<Mathematical Model>

Objective

Minimize $PC + TC$

$$PC = \sum_{i \in I} pc_i \cdot y_i \tag{1}$$

Constraints

Feasibility condition for Total Material-Inventory

$$\sum_{i \in I} L_{ik} \geq Y \cdot l_k \Big|^{\forall} k \tag{2}$$

Occurrence condition of Material Transportation

$$\text{If } l_k \cdot y_k \leq L_{ik} \Big|^{\forall} i, k \quad \text{then } \boldsymbol{\Delta} = [\mathbf{0}] \tag{3}$$

(Ordinal Production Planning)

$$\text{Else if } l_k \cdot y_k > L_{ik} \Big|^{\exists} i, k \quad \text{then } \boldsymbol{\Delta} = [\mathbf{0}] \tag{4}$$

(Material Transportations occur)

Here, we deal with the case of $l_k \cdot y_k > L_{ik} \Big|^{\exists} i, k$ when $l_k \cdot y_i > L_{ik} \Big|^{\exists} i, k$. The amount of the material k in the factory i is not enough to make y_i products. According to the feasibility condition for the total material-inventory, at least one factory has surplus inventory of the material k, i.e., for a material k,

$$\{l_k \cdot y_i > L_{ik}\} \wedge \{l_k \cdot y_j < L_{jk}\} \Big|^{\exists} i, j, \ i \neq j \ .$$

When $l_k \cdot y_i > L_{ik} \Big|^{\exists} i, k$, let SF_k be a set of factories in which each factory j satisfies

$$\{l_k \cdot y_i > L_{ik}\} \wedge \{l_k \cdot y_j < L_{jk}\} \Big| \ i \neq j$$

For the material k, and let SM_i be a set of materials that are short in the factory i.

Let SI_k be a set of factories in which each factory i satisfies $l_k \cdot y_i > L_{ik}$. For the material k, and let

$$SI_{ALL} = \bigcup_{k=1}^{m} SI_k$$

A constraint for the maximum number of trucks.

$$\sum_{i \in SI_{ALL}} \left\{ \text{Ceil}\left(\sum_{k \in SM_i} q_{jik} \Big| j \in SL_k, i \neq j \right) \Big/ V \right\} \leq r \tag{5}$$

A constraint for the necessary amount of material k

transported to factory

$$L_{ik} + \left\{ \sum_{j \in SL_k} q_{jik} \middle| k \in SM_i, i \neq j \right\} \geq l_k \cdot y_i \middle| i \in SI_k \tag{6}$$

The total transportation cost

$$TC = \sum_{i \in I} \left\{ \sum_{k \in SM_i} \sum_{j \in SL_k} \left\{ \mathrm{Ceil}\left(\sum_{k \in SM_i} q_{jik} \middle| j \in SL_k, i \neq j \right) \middle/ V \right\} \cdot tc \right\} \tag{7}$$

4. PROPOSED NUMERICAL EXPERIMENTS

The product of wheel is used as the example product. It uses for study the material-inventory adjustment by means of transportations. The wheel is using for chairs, tables or car body. The production of wheel needs 9 sub-materials for make the components. The details shown in Table 1 and Figure 6.

Table 1: A description of the product sample

No.	Name of material	Description
1	Wheel Housing	On one process need 3 pieces
2	Side Piece	On one process need 2 pieces
3	Top piece	On one process need 1 piece
4	Wheel,with tyre,100mm	On one process need 1 piece
5	MSBolt,M10x70,Galv	On one process need 1 piece
6	M10.washer,Galv	On one process need 2 pieces
7	M10,Nut,Galv	On one process need 3 pieces
8	MS Bolt,M10x30	On one process need 1 piece
9	M10 Square nut	On one process need 1 piece

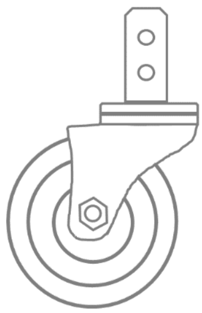

Figure 6: Picture of the product.

The loading capacity of a truck is defined from the box size, assuming is 32cm*40cm*18cm and can contain product 20 pieces for a box. Because of the truck size is 1.5m*3.4m*1.8m. So the loading capacity of a truck is 398 boxes.

The available truck for transportation have 10 trucks for using all factories but do not need to use all trucks, we use only when have to transport necessary material.

As the equation (5) above, the maximum amount of truck is 7 trucks. Because a factory has enough inventories to product but some factories have not enough. Regarding on the example of input data in Table 2, it lead to the total number of lacking inventory within 3 factories, which is 20,681 pieces. A unit cost of transportation is assumed 10USD.

Before the adjustment, the maximum number of truck for transport the material is 7 trucks. The transport cost of Wheel housing is 70 USD. After the adjustment, however, the process will transport all material to another factory at the same time, we can use 3 trucks for contain all material and the cost of transportation will be decrease to 30 USD.

5. CONCLUSION

As the title of this study: the production planning in virtual factory with material-inventory adjustment by means of transportations, we proposed the way to solve this problem by using the concept of Industrial4.0 and cloud computing. The adjustment of inventory has created together with the checking of materials that have enough for production or not? This study tries to arrange the material into the factories that have the problem by transportation. It helps to know the amount of materials and trucks. In this process, we hope to save the production time and cost. However, it cannot control the quantity of production because the order is not control in each factory. Due to the lack of understanding of the highest amount of orders from customers, so this proposed mathematical model can answer this problem.

This study had two limitations: the uncontrollable situation of customer requirements and the intermittently time of transportation scheduling. In real situation, the factories cannot be known how many products will produce. Sometimes the unnecessary transportation is happened because of unbalanced strategies between the controllable order and production planning. As mention above, the schedule of transportation are defined often over a period of, but not regular time base on the requirements. So, some factories have been being impacted with delay.

This study plan to improve the problems of schedule of transportation, the distribution, and the ordering in the future works. The scheduling variable will be included into the mathematical model. Then, the result of distribution will be more consider after the calculation. Finally, the ordering sequence will be improved based on the time sequence model.

REFERENCES

Dale H. (1990) *Quality Control*, Prentice-Hall, Englewood Cliff, NJ.

Posada J., Toro C., Barandiaran I., Oyarzun D.,Stricker D., Amicis R., Eduardo B., Eisert P., Döllner J. and Vallarino JR I.(2015) Visual Computing as a KeyEnabling Technology for Industrie 4.0 and industrial Internet, *Proceedings of the IEEE Computer Society Visual Computing challenges*, 26-40

Shrouf F., Ordieres J., and Miragliotta G. (2014) *Smart Factory in Industry 4.0:* A Review of the Concept and of Energy Management Approached in Production Based on the Internet of Things Paradigm. *Proceedings of the 2014 IEEE IEEM*, 697-701.

Stefan H. (2014) *Industry 4.0 upgrading of Germany's industrial capabilities on the horizon. Slomka L.(ed) Deutsche Bank Research,* Spec comparison table for mini truck: *http://www.japancardirect.com/mini-trucks-spec-comparrison-table/*

Xu X. (2011) From Cloud Computing to Cloud Manufacturing, *Proceedings of the Robotics and Computer-Integrated Manufacturing 2011 Journal*, 75-86

Marston S., Li Z., Bandyopadhyay S., Zhang J., Ghalasasi A. (2010) Cloud computing – The business perspective *Proceedings of the Decision Support System University of Florida, FL, United States.*

Mell, P. and Grance, T (2011) *The NIST Definition of Cloud Computing*, Recommendations of the National Institute of Standards and Technology. Reports on Computer Systems Technology, Special Publication 800-145, National Institute of Standards and Technology.

Michaeel C. (1993) The Modern Industrial Revolution, Exit, and the Failure of Internal Control Systems *Proceedings of The Journal of Finance VOL. XLVIII, No.3* 831-88

Table 2: Example of input dataset.

Week	Materials No.	Factory1			Factory2			Factory3		
		Order	INV	INV Lack	Order	INV	INV Lack	Order	INV	INV Lack
1	1	4200	3213	-987	5400	14037	8637	1600	4171	2571
	2	2800	2438	-362	3600	7326	3726	3400	4420	1020
	3	1400	534	-866	1800	6066	4266	1700	1198	-502
	4	1400	7846	6446	1800	1843	43	1700	946	-754
	5	1400	12903	11503	1800	2050	250	1700	2034	334
	6	2800	6944	4144	3600	3492	-108	3400	3473	73
	7	4200	9321	5121	5400	8746	3346	5100	2677	-2423
	8	1400	4647	3247	1800	1057	-743	1700	1421	-279
	9	1400	3256	1856	1800	1599	-201	1700	1226	-474
2	1	3900	1083	-2817	5400	12086	6686	5100	2434	-2666
	2	2600	2857	257	3600	11445	7845	3400	3394	-6
	3	1300	1114	-186	1800	4850	3050	1700	948	-752
	4	1300	15962	14662	1800	405	-1395	1700	1203	-497
	5	1300	10292	8992	1800	1149	-651	1700	1645	-55
	6	2600	4136	1536	3600	3333	-267	3400	2026	-1374
	7	3900	10908	7008	5400	4916	-484	5100	4324	-776
	8	1300	6522	5222	1800	1809	9	1700	1109	-591
	9	1300	4214	2914	1800	2903	1103	1700	1235	-465