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Option 1：

Research on Risk Quantification of PC Components Production Scheduling Based on DBR

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Abstract: In order to improve the production and supply level of PC components and reduce the impact of risk accidents on production, this article hopes to solve the risk accident problems faced in industrial construction production by introducing mature constraint theories applied in the manufacturing industry. Firstly, this article introduces the widely used constraint theory and DBR method in traditional manufacturing industry; Secondly, based on the constraint theory DBR method, a pull production mechanism is established for the constraint buffering and material delivery of PC components, and risk accidents are defined and estimated; Then calculate and set buffer zones to reduce their risks and ensure the full utilization of bottleneck resources; The ultimate goal is to reduce production scheduling risks and improve production supply levels.
Key words: TOC Theory; Production of prefabricated components; Risk quantification study

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1 Introduction

Nowadays, the general trend of construction industrialization makes China put forward higher quality and quantity requirements for prefabricated buildings, and then put forward higher production scheduling requirements for PC component production enterprises. In fact, there are relatively few studies on the production scheduling of PC components, and there are some problems in their applicability and feasibility. For example, the occurrence of equipment failure, workers leave, water and power cut, processing errors, negative work and other risks will affect the continuous production of PC components, reduce the supply level of PC components.

Therefore, this paper intends to introduce the mature TOC theory and DBR method in the traditional manufacturing industry, establish the constraint buffer control model, by solve the number of buffer settings, to reduce the risk and harm in the production of PC components, promote the further development of PC components production enterprises, and improve the supply level of PC components.

2 TOC Theory and DBR

Constraint theory originates from the best production technology (OPT) and discrete production mode. It is a management philosophy that pays attention to the identification and removal of bottleneck constraints and then continuously improves the system constraints. The core idea is to maximize the production bottleneck capacity, and improve production rate and profit, through clear resource constraints, according to the existing production capacity scheduling, then through the analysis of the production to find the bottleneck constraint process, before, after the process, between, along, push way arrangement and optimization, and define the "buffer", "rope" concept, all the bottleneck process, repeat the bottleneck steps after contact the bottleneck constraints.[1]

With the gradual application and development of constraint theory, the DBR (Drum-Buffer-Rope) production system control method, namely drum-buffer-rope, technical diagram as shown in figure 2.1, raw materials (Material) into finished product (Finishes) by ABCDE five processes, C with constraint resource (Bottleneck) as drum (Drum), front link has time buffer (Buffer), the first link and constraint rope (Robert) to guarantee the consistency between other links and constraint link.[2]

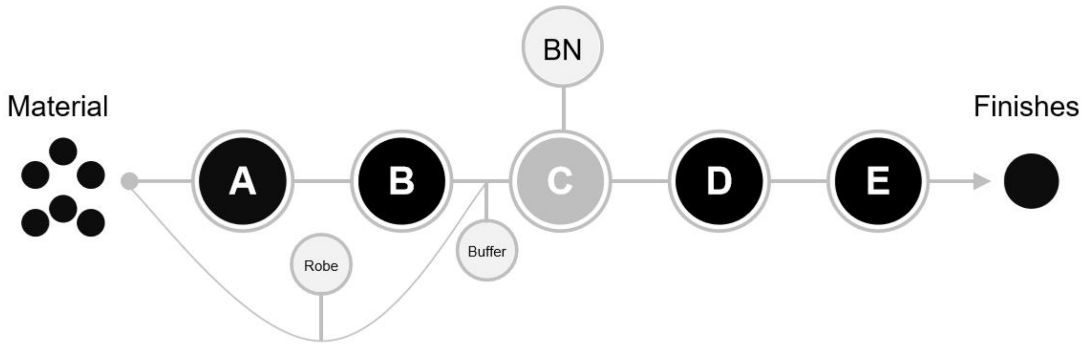

Figure 2.3 Schematic diagram of DBR Technology

Photo source: the author of self-painting

Specifically, the drum means the system constraint after identification, which is the core of the production process, which restricts the production schedule and the system production speed, and determines the production rhythm and effective output.[3] Through the drum control and delivery plan, it reflects the utilization efficiency of the system to the drum. Generally, there are many system constraints with different strength and strength in the system. If there is no obvious system constraint, the logistics bifurcation point is often used as the constraint.

Buffering is the inventory or time set between the constraint link and the front link to prevent the use of insufficient workload in the constraint link. When the constraint link is operating at full capacity, the pre-loading link does not need to reach full capacity operation and production, so it

will leave a buffer inventory or buffer time to ensure the normal operation of the bottleneck link and reduce the adverse effects of system fluctuations.
The rope represents the communication device between the first link and the constraint link, which can be understood as the "kanban" of coordinated control information, and reflects the condition of the bottleneck link to the upstream operation to prevent too much or too little production, that is, the inventory of the whole system is the most economic under the full load operation of the bottleneck link.[4]
Can be found that DBR production system control method has both the advantages of pull type, with the "weakest" in the system, control the core, the front link according to the demand of the bottleneck link on time, namely the pull production, the subsequent link according to the output of the bottleneck link push system production, namely the push production.[5] By identifying and removing BN and setting the buffer and pulling rope, the system inventory is minimized and the effective output is maximized to improve the overall benefit of the system.

3 Constraint Buffer Control Model Building

3.1 Principles of the constraint buffer control mathematical model
PC components in each stage of the production process will be a "weakest" constraint link limits the whole production system efficiency, so making the current production system at full capacity premise is make the weak link at full capacity, and want to further improve the efficiency of production system is the release, remove the constraints of the link. In addition, there are many negative risks in the production process to reduce the production efficiency of some links, but through the constraint theory can know, not all links of production efficiency will bring the risk of —— nonconstraint link may affect the system production efficiency, constraint link to affect the production efficiency of the system. However, the risk of the non-constraint link has a negative impact until the system is a buffer, which is fully controlled to ensure the full load operation of the constraint link is an effective control of the production efficiency of the system, which can be developed by the DBR method in the constraint theory. [6]
According to the constraint theory, the buffer can be divided into three types in the constraint buffer control stage, namely, time buffer, inventory buffer and not yet mentioned capacity buffer. Time buffer refers to the corresponding material for a period of protection time before the actual required time, To ensure the full load operation of the constraint link; Inventory buffer refers to the safety inventory set up to reduce the negative impact of the non-constrained link risk, Can ensure that part of the processing can be completed after having a negative impact, That is, the constraint link can still continue to maintain the production, Inventory buffer setting is too large is easy to lead to the cost increase is too small is difficult to deal with the risk; Capacity buffer refers to the buffer space set by the actual production operation efficiency and the full load operation, For non-constrained links can be set appropriately, But the protection mechanism of blindly setting the capacity buffer will only significantly reduce the production efficiency of the system, It's not an economic practice.
It can be found that in the constraint theory, the corresponding buffer is set to ensure the continuous full load production of the constraint link, and the logistics balance of the production system is smooth to weaken the influence of the risk. The size of the buffer directly affects the implementation of the production plan —— The buffer is too small to deal with the negative impact of risk, waste, and excessive inventory, which not only increases the production cost, but also increases the difficulty of management, and easily causes the illusion of high production efficiency and affects the judgment of production decision. In actual production, the variability of real-time production leads to the dynamic change of buffer. The adaptation of different order requirements to the same production line will inevitably affect the setting of buffer. For example, under normal circumstances, the increase and decrease of orders will directly bring the increase and decrease of buffer.[7] Therefore, the setting of buffer including position and size is the focus of the mid-term buffer control model, which is also the core problem solved in this section.
3.2 Establishment of the mathematical model of constraint buffer control
According to the constraint theory, in order to ensure the balance and stability of production line logistics, there are two strategic ideas for material delivery:

① A material delivery time strategy, according to the constraint theory DBR method, by setting the constraint warning buffer (TBSmin) to determine the material delivery time node to ensure the full load operation of the constraint link;
② A material delivery sequence strategy, according to the constraint theory constraint bottleneck transfer phenomenon, that is, the non-constraint link will be transformed into a new system constraint link under some production conditions, so it needs to be determined according to the current situation of resource processing. Only by clarifying the current remaining order tasks and the remaining working hours, and selecting the appropriate delivery order can the constraint link and the cost constraint link balance, and prevent the transfer of the constraint bottleneck after the input materials enter the formal production.
The delivery time node is determined according to the actual constraint buffer TBS (t) and the set bottleneck buffer TBSmin, namely when the following inequality is met:

$$TBS(t) \le TBS_{\min} \quad (3.1)$$

The bottleneck buffer is affected by many factors, among which the main influence is the complexity of the production process and process and the order position of the constraint link in the production line. Because the more on the previous process, the product and production line more clear and stable, so when the constraint link closer from the first process, the bottleneck of the smaller the buffer, otherwise the larger, in addition to the process of production equipment failure is also the main factors affecting the buffer, can according to the analysis of the fault to set a suitable buffer size.
The probability and the impact of the risk of the non-constraint link are related to the coping capacity of the production enterprise. This paper considers the risk of the risk of the constraint link and finally solves the recovery, such as equipment failure. The buffer setting shall meet exactly the normal supply during the risk to the recovery period and shall be reproduced to the set buffer amount to prevent the next risk. The defined parameters are shown in Table 4.1.

Table 3.1 Parameter Definition table of the interim constraint buffer control algorithm

Parameter meaning	Parameter symbol
Planning duration	L
Constraint link	B
The front link of the constraint link	A
Buffer between the constraint link and the front link	Tab
fault rate	α
recovery rate	β
Risk time distribution function of A	N(t)
Resolution recovery time distribution function of A	M(t)
The unit production capacity of B	Cb
The unit production capacity of A	Ca

Set A must occur at least one risk, and the recovery can be completed within L. When the system is in normal operation, such risk is random and follows exponential distribution.
The N (t) and M (t) expressions are obtained:

$$N(t) = 1 - e^{-\alpha t} \quad (3.4)$$

$$M(t) = 1 - e^{-\beta t} \quad (3.5)$$

A Average resolution recovery time after risk:

$$Rcv = \int_0^L t dM(t) = \int_0^L t d(1 - e^{-\beta t}) = \frac{1}{\beta}(1 - e^{-\beta L}) - Le^{-\beta L} \quad (3.6)$$

A Average spacing time for two consecutive risks:

$$Int = \int_0^L t dN(t) = \frac{1}{\alpha}(1 - e^{-\alpha L}) - Le^{-\alpha L} \quad (3.7)$$

A After the risk and before decisive recovery, the relationship between buffer and average resolution recovery time satisfies the inequality:

$$Rcv \le T_{ab} \quad (3.8)$$

A After risk and recovery, inventory shall be replenished in time and the inequality shall be met:

$$Tab - Rcv + (Ca - Cb) \times Int \ge Rcv \quad (3.9)$$

So the constraint link B is still running at full load, that is, both formula 3.8 and 3.9:

$$T_{ab} = \max\{Rcv, 2 \times Rcv - (Ca - Cb) \times Int\} \quad (3.10)$$

Equations 9 and 10 with Equation 13 follows Equation 3.11:

$$T_{ab} = \max\{\frac{1}{\beta}(1 - e^{-\beta L}) - Le^{-\beta L}, 2 \times [\frac{1}{\beta}(1 - e^{-\beta L}) - Le^{-\beta L}] - (Ca - Cb) \times \frac{1}{\alpha} \times (1 - e^{-\alpha L}) - Le^{-\alpha L}\}$$

4.3 Constraint buffer control model and algorithm summary

The DBR method of constraint theory is often used in the management of production enterprises. Through the determination and control of buffer, it can guarantee the effective output, and then improve the efficiency of order and the market competitiveness of enterprises. The core of the intermediate constraint buffer control stage is the DBR method based on the constraint theory —— first, arrange the production plan according to the identified "drum"; then, the "buffer" of the constraint link is set to ensure that the front link avoids the risk impact on the production plan; then, the "pull rope" ensures that all processes are processed according to the rhythm of the constraint link. In this section, the definition of buffer disassembly, model building, solution instructions are explained in detail, and the occurrence of risk as the research point, to solve the size of the buffer setting and the corresponding sequence of material delivery, and finally ensure that the constraint link can operate at full load under the risk, that is, to ensure the production efficiency of the production system.

4. Empirical Case Analysis

This paper analyzes a typical example in Chengdu, Sichuan province, China through on-the-spot study, online and offline interviews, combing the whole scheduling process of original production data, selected the standard layer order demand to complete the PC component production buffer control model establishment and solution, to verify the effectiveness and practicability of the model.

First, the buffer size was determined based on the constraint theory DBR method, and 8 + 4 hours daily i. e., 720min were studied as an example. According to the survey findings, Normal 8 hours a day by transport transmission 20 times die platform calculation, For the production link of risks, For example, equipment failure, workers leave, water and power outage, processing errors, sabotage and other events will basically occur, And after two calculations, It is estimated that the probability of risk occurrence in the front link of the post-processing constraint link of the wall board and floor board 2 is $\alpha = 0.1$; Since it is a new production line, The company invests more management resources in it, Rapid recovery works after the risk occurs, Based on the estimates of the recovery rate in the manufacturing sector, Set to the recovery rate of $\beta = 0.85$; According to the total processing time of constraint link b is 30min and the processing time is 25min, The minimum processing time of 20min for all links, Estimates of Ca = (720 / 25) / (720 / 20) =0.8, Cb=(720/30)/(720/20)=0.67.

Into the 3.11 column of:

That is, a time buffer protection of 1.17min should be set before the post-processing constraint

$$\begin{aligned} T_{ab} &= \max\{\frac{1}{\beta}(1 - e^{-\beta L}) - Le^{-\beta L}, 2 \times [\frac{1}{\beta}(1 - e^{-\beta L}) - Le^{-\beta L}] - (Ca - Cb) \times \frac{1}{\alpha} \times (1 - e^{-\alpha L}) - Le^{-\alpha L}\} \\ &= \max\{\frac{1}{0.85}(1 - e^{-0.85*720}) - 720 * e^{-0.85*720}, 2 * [\frac{1}{0.85}(1 - e^{-0.85*720}) - 720 * e^{-0.85*720}] - \\ &(0.8 - 0.67) * \frac{1}{0.1} * (1 - e^{-0.1*720}) - 720 * e^{-0.1*720}\} \\ &= \max\{\frac{20}{17}, \frac{179}{170}\} \end{aligned}$$

link. When the actual buffer time is much less than Tab, the production of the front link should be accelerated so that the actual buffer time is close to Tab. The 1.17min here does not mean that the pre-link of the constraint link needs to be completed 1.17min in advance, but means that the output of 1.17min can be placed in the cache area, so that when the risk is issued in the front link of the constraint link, the continuous production of the constraint link can still be guaranteed until the risk of the front link is removed. For example, PC components processed by a die processing limit is $1.3m^3$, need to set at least $1.3*1.17/25=0.061m^3$ buffer inventory, but in fact all the single PC components in production are more than $0.061m^3$, and all PC components are the whole production parts, so the buffer inventory set to 1 component can realize when the constraint link front link risk, the constraint link can still maintain full production until the front link recovery risk. Although the consolidation approach mathematically brings the suspicion of excess inventory, the buffer inventory setting can be achieved for a single PC component in actual production, such as reserving a separate template buffer next to this link.

And income time buffer smaller reason is that the production line for March 20 years new production line, such as mechanical failure risk possibility is relatively low, and because the company in order to expand market, signed a large number of orders but also invested a large number of skilled workers and management personnel to ensure the smooth operation of the production line, so the recovery rate will be higher. That is to say, with the aging of the production line, mechanical failure risk probability will gradually increase, recovery time increases, recovery rate drops, will eventually lead to increased buffer time to resist the risk of production line stagnation, and the model algorithm as the risk of rising probability and more obvious effect, also can remind managers need to strengthen the risk management.

5 Conclusions

The research results of this article can provide a risk quantification and control approach based on constraint theory for managers of PC component production enterprises in the industry, and also provide a perspective for academic research on building industrialization by introducing manufacturing management theory.

Reference s

[1] Wang Jun Development status and thinking of China's construction industrialization [J].Journal of Civil Engineering, 2016,49(5): 1-8.

[2] Xie Sicong, Chen Xiaobo.Two-stage production scheduling optimization of prefabricated building components based on multi-layer coding genetic algorithm [J].Journal of Engineering Management, 2018,32(01): 18-22.

[3] Goldratt E M.It's Not Luck [M].Aldershot.England: Gower, 1994.

[4] Kong Xiangkui, Lu Weichao.Study on the Sustainable Marketing Ability of Construction Enterprises Based on TOC [J].Value Engineering, 2017, 36 (12): 27-30.

[5] Chen Yirong.Research on the Construction Supply Chain Performance Evaluation System Based on TOC [J].Enterprise Report, 2013 (13): 62-63.

[6] Han Xiaokang.Research on Pre-control of Engineering Cost Based on Neural Network and TOC Theory [D].Xi'an University of Architectural Science and Technology, 2011.

[7] Application Research Group of TOC Theory in Cost Management of Construction Projects.Application Research of TOC Theory in Cost Management of Construction Projects [J].Times Economy and Trade, 2017 (12): 70-73.

[8] Tian Dengdeng, Jiang Lizhao, Hu Yaqin, Zhang Jinhua.Study on Optimization of production