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Physical Internet-enabled synchronized optimization for Milk-run transportation and Cross-docking warehouse in industrial park

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Abstract: *For the complex system of the industrial park consisting of the three stages of manufacturing, transportation, and warehouse, the increasingly lean and intelligent manufacturing system can gradually meet the increasing customized demand. However, if the transportation and warehousing stages with a low degree of intelligence cannot effectively match the manufacturing process in real-time, it will cause not only an increase in overall operating costs but also a decline in customer service levels. This paper focuses on the finished product warehousing process in an industrial park under a highly dynamic production environment, and studies the synchronized decision-making problem of transportation fleet and finished product warehouse under the Physical Internet (PI) environment. A PI-based synchronization information framework is proposed to solve the challenge of state perception. To solve the challenge of decision level, Collaborative Optimization (CO) is used to systematically coordinate and optimize the "transportation-warehousing" units with independent decision-making and synchronized operations. Finally, simulation and comparative analysis of the proposed synchronization solutions were carried out based on the actual production data of the cooperative enterprises. The results showed that the proposed method can improve the utilization rate of system resources and reduce the operation cost.*

Keywords: *Physical Internet; synchronization; milk-run; cross-docking; collaborative optimization*

1 Introduction

To meet the optimal response to customized demand, manufacturers are gradually adopting flexible production models, while wholesalers/retailers expect to achieve small-batch deliveries in a short time window. Having very little inventory is an important feature of customized production. Many works of literature believe that there is no finished product inventory under customized production mode (Carr et al. 2000 & He et al. 2002). In fact, customer orders include multiple varieties and small batches of products produced by different manufacturers, which requires a certain space to temporarily store and integrate products of the same order.

However, due to the low and peak seasons of market demand, to avoid investment in capital, manpower, and resources, many manufacturers tend to look for third-party public logistics services instead of building their warehousing systems. The Supply Hub in Industrial Park (SHIP) is a public warehouse that effectively integrates transportation and storage resources. It can provide raw material/finished product logistics services for multiple manufacturers to achieve Just-in-Time (JIT) operations (Qiu et al. 2012). Gradually, transportation companies have shifted their strategy from a large-volume, large-scale transportation mode to Milk-run (MR) to achieve small-volume, high-frequency transportation demand. Warehousing operations will also shift from long-period storage to short-period Cross-docking (CD), realizing the temporary storage of finished products and the integration of different products in the same order (Luo et al. 2019).

Under customized demand, the dynamics of orders, resources, and processes will cause the operation process to be disconnected, resulting in a waste of resources and delays in delivery. For this reason, SHIP has to consider: (1) How to realize batch dynamic transportation, which can improve transportation cost efficiency while ensuring the completeness of the products in the order; (2) How to achieve unitized dynamic storage, which can reduce the storage time of orders while increasing the utilization rate of the warehouse, and shorten the delivery lead time as much as possible; (3) More attention should be paid to the fact that if the transportation only pursues the scale of transportation, it is easy to increase the overall transit time of the product; if the warehouse only pursues the turnover efficiency, it is easy to cause waste of transportation resources. Therefore, how to adjust the two plans to keep the time parameters consistent, to achieve the lowest overall operating cost on the premise of meeting the product delivery time and customer demand, which became the research problem of this paper.

Production logistics synchronization (PLS) is to establish an association between two or three subsystems of independently distributed production, transportation, or warehouse models, so that they can achieve synergy in resource allocation, execution plan, control parameters, etc. (Qu et al. 2016). This paper takes the finished product warehousing process in the industrial park as the research object and defines the synchronization problem between MR transportation and CD warehouse as MR-CD Synchronization. At present, a variety of cutting-edge (e.g., Physical Internet) can be used to solve MR-CD Synchronization in industrial parks. The concept of Physical Internet (PI) is developed based on the Internet of things (IoT) and cloud computing technology (Kong et al. 2012). Although there is a lot of research in this area, there are still some limitations. These research gaps will be transformed into the following research questions: (1) At the perception level, construct a synchronization information framework to realize the real-time perception of the status of the manufacturing, transportation, and warehouse stages and feedback to the decision-making layer for decision-making; (2) At the decision-making level, synchronization control mechanism and method are established to coordinate the inconsistency between transportation and warehouse targets, and the control instructions are issued to the frontline to achieve closed-loop control.

The remaining of this paper is organized as follows. Section 2 analyzes the problem of the finished product warehousing process in the industrial park. Section 3 proposes a solution for synchronized decision-making. Section 4 carries on the case analysis. The last section summarizes the paper and identifies potential future works.

2 Analysis of synchronization problems

2.1 Operation process

The storage process of finished products in the industrial park mainly involves two types of enterprises, manufacturers, and SHIP. As shown in Figure 1, SHIP includes SHIP Fleet and SHIP Warehouse.

Business process: The manufacturer relies on the transportation and warehousing services provided by SHIP to realize the transfer and storage of finished products to reduce the capital investment in logistics and warehouse construction. SHIP integrates the demand of manufacturers to formulate cargo collection and warehousing plans reasonably allocates pickup vehicles and storage locations and ensures that the delivery time of products meets customer demand.

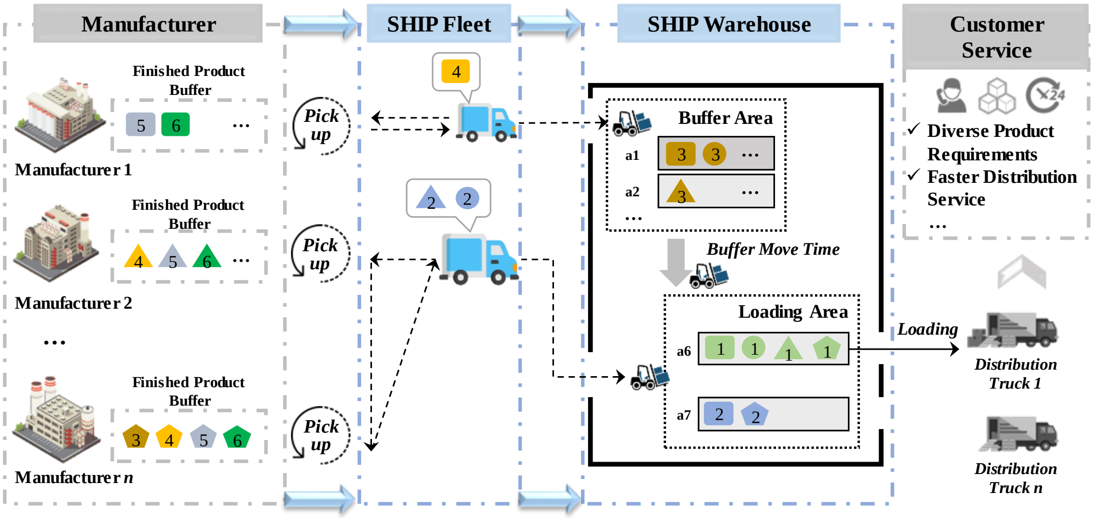

Figure 1: Finished product warehousing process in the industrial park

2.2 Problem analysis

2.2.1 Difficulties in local decision making

- For the transportation stage

What SHIP Fleet considers is the Milk-run transportation decision problem, which has the following characteristics: (1) Generally, the combination of product types in customer orders is complicated. Manufacturers make their production plans based on product demand, resource constraints, etc. Therefore, the product's off-line time will be different; (2) Manufacturers are located in different locations in the industrial park. For some large industrial parks, they may be further apart; (3) To meet the transportation demand of various batches, SHIP Fleet has different types of vehicles with different rated capacities.

Therefore, in the face of factors such as unsynchronized completion time, complex driving paths, and diverse transportation resources, how to plan the types and driving path of the pickup vehicle with the lowest transportation cost has become a difficult point in transportation decision-making.

- For the warehouse stage

What SHIP Warehouse needs to consider is the storage location assignment problem, which has the following characteristics: (1) Since the product stays in the SHIP warehouse for a relatively short time, to increase the circulation speed, the pallets are usually directly stored in the aisle on the ground. (2) SHIP warehouse is divided into two areas: the buffer area and the loading area. The aisle in the loading area is directly connected to the loading platform, and the aisle can be easily loaded onto the distribution trucks. If there is no available aisle in the loading area, the pallets have to be stored in the buffer area first.

Therefore, in the face of the limited storage capacity of the warehouse (especially in the peak sales season), how to plan the warehousing time of orders and allocate suitable aisle with the lowest storage cost has become a difficult point for warehouse decision-making.

2.2.2 Difficulties in synchronized decision-making

The decision-making results of SHIP Fleet and SHIP Warehouse are independent and mutually influencing. Under dynamic interference, there are the following operational problems:

- The mismatch between planning and execution: The tasks in each stage of the industrial park need to be executed according to the pre-made operation plan. However, due to the large number of random dynamics brought by customization demand, it is easy for the system to fail to complete the execution tasks according to the static decision results made under the ideal static state, or even deviate far.
- Poor synchronization of the execution process: (1) The backlog of finished products at the off-line point will cause the increase of factory operation costs;(2) Different decisions such as vehicle type, departure time, and the driving route will result in different SHIP Fleet transportation costs and finished product storage time;(3) The difference in the decision-making of the finished product's warehousing time and storage location will cause the SHIP warehouse storage cost and the finished product's storage time to be different. Because different companies (even different departments within the company) usually use different management information systems (e.g., ERP, TMS, WMS) for decision-making, performance accounting, etc. This is likely to cause the decision-making process of each stage to be a serial static local optimization process, lacking decision-making for global collaborative optimization with other stages.

2.3 Challenge analysis

As described above, the warehousing process of finished products in the industrial park involves multi-stage participation and multi-parameter interaction. In the dynamic customization production environment, the dynamics generated by any stage may cause inconsistent rhythm in the entire operation process. PLS requires that each decision-making stage be able to carry out autonomous and relevant dynamic coordination based on real-time information under dynamic interference, to eliminate or reduce the impact of random interference on the production system. Therefore, the following two challenges need to be solved.

- Condition monitoring: Under the customized production mode, the finished product warehousing process will inevitably be affected by various dynamic factors (e.g., order changes, resource failure, etc.). Therefore, an information acquisition method is needed to realize the real-time and accurate perception of information in a dynamic operating environment, which is an important foundation for implementing synchronized decision-making applications in the decision-making layer.
- Process control: Traditional experience-based management mechanisms and integrated decision-making methods are difficult to apply to highly dynamic production environments with complex resource relationships. Therefore, to maintain the global optimal operation of the system, it is necessary to introduce appropriate control mechanisms and coordinate optimization methods for guidance, and conduct real-time collaborative control according to the dynamics that occur in each correlation stage.

3 PI enabled MR-CD synchronization solutions

3.1 MR-CD synchronization information framework

The synchronization information framework of this paper is based on the AUTOM information framework solution proposed by Huang et al. (2012). The AUTOM framework is an extensible Manufacturing Internet of Things (MIoT) information framework that complies with the ISA-95 international standard. It provides a theoretical basis and a feasible way for the establishment of the IoT environment in industrial parks.

As shown in Figure 2, the information framework is composed of a smart object layer, gateway layer, service layer, and application layer. First of all, the smart object layer serves the frontline operation of the industrial park. Secondly, the gateway layer and the service layer are the basic equipment for realizing information transmission in the industrial park. Finally, the application layer provides decision support for manufacturers, SHIP, and other enterprises in the industrial park.

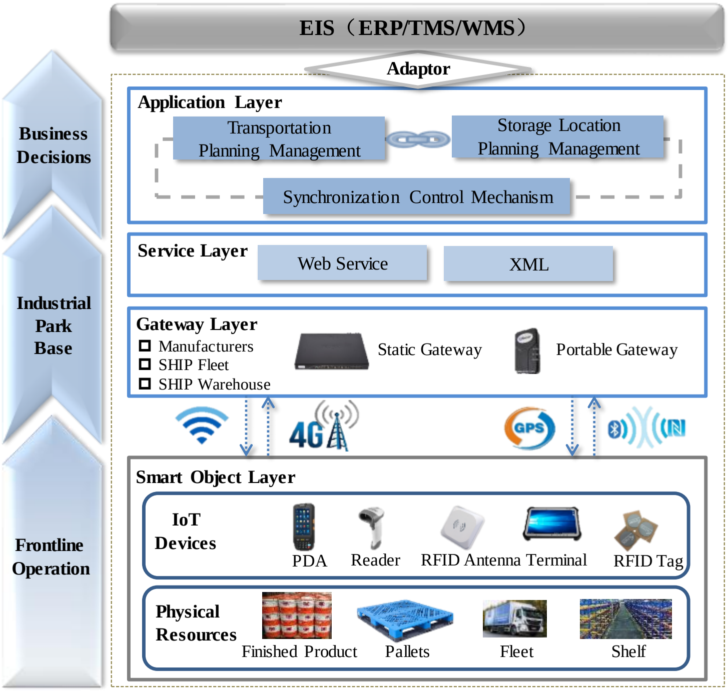

Figure 2: MR-CD synchronization information framework

3.2 MR-CD synchronization control mechanism

Based on the synchronization concept proposed by our research team (Qu et al. 2016; Zhang et al. 2020), considering the various dynamic impact ranges in the finished product warehousing process of industrial parks. This section proposes the MR-CD synchronization control mechanism from the qualitative perspective. The synchronization stage of this mechanism is divided into the plan-making phase and plan-correction phase, as shown in Figure 3.

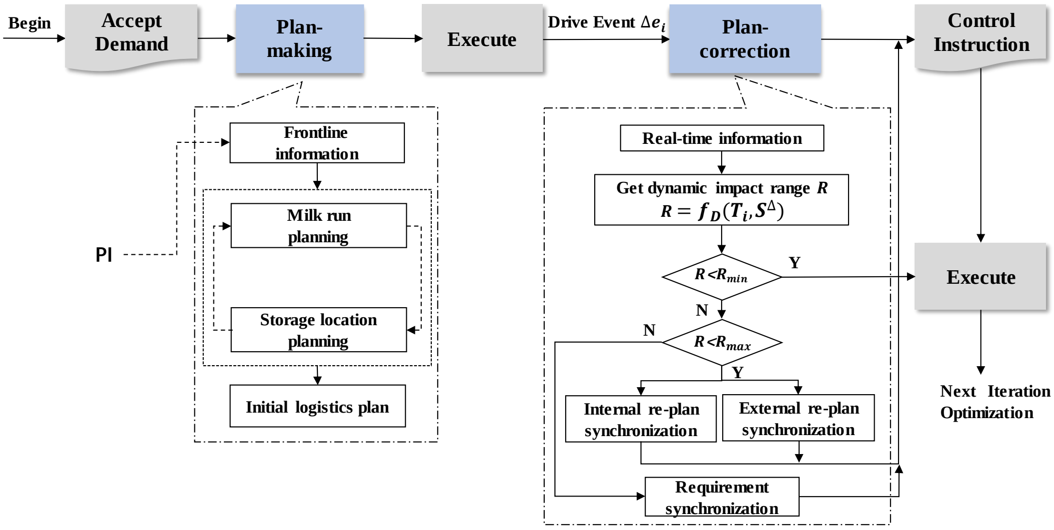

Figure 3: The synchronization control mechanism

- Plan-making phase

After receiving the manufacturer's delivery demand, basic data such as vehicles, order delivery dates, and cargo lane capacity are obtained through the smart object layer. At the same time, SHIP makes collaborative decisions on the transportation plan and the warehousing plan until the initial logistics plan with the lowest overall operation cost is produced.

- Plan-correction phase

During the operation of the production system, the occurrence of various dynamic events may lead to deviations between actual execution and planned data. First, the synchronization control mechanism judges the dynamics of the execution layer. Then, the corresponding synchronization mode is triggered according to the dynamic range of influence. Finally, after formulating a revised plan, it is issued to the executive layer in the form of control instructions.

3.3 Collaborative optimization

MR-CD synchronization is an optimization problem involving the two disciplines of transportation and warehouse. It has the characteristics of distributed and coupled. This is mainly reflected in the fact that all decision-making bodies are at the same level and interdependent. Collaborative Optimization (CO) is one of the multidisciplinary optimization methods to solve large-scale complex coupling problems, which has been introduced into the optimization of production systems by many scholars (Qu et al. 2017; Lin et al. 2020). The CO algorithm has a typical two-level optimization structure, so it is suitable for solving the MR-CD synchronization problem in this paper.

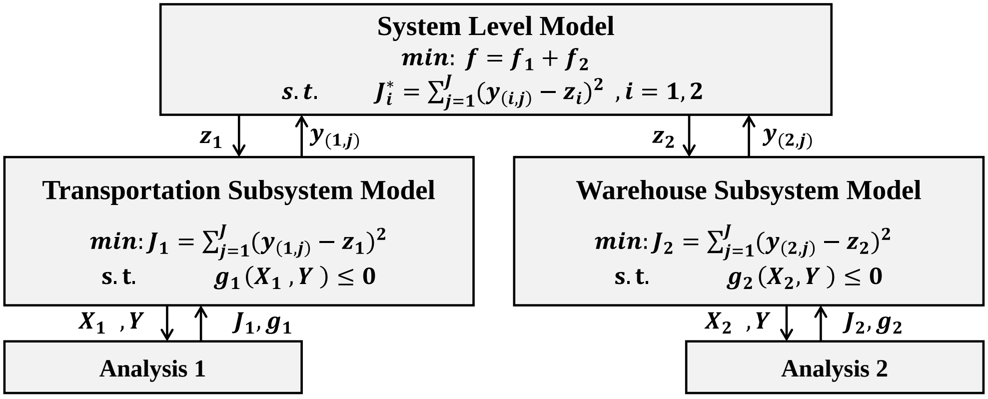

Figure 4: CO framework

Figure 4 shows the collaborative optimization framework of CO. The top layer of the framework is the optimization of logistics system-level disciplines, and the bottom layer is the optimization of two subsystems, transportation, and warehouse. The entire synchronized decision-making problem is decomposed into two-level nonlinear programming problems: (1) The system level allocates design variables $z_i = \{X_i, Y\}$ to the transportation and warehouse subsystems respectively;(2) Under the condition of satisfying their respective constraints, the transportation and warehouse independently solve the optimal solution $y_{(i,j)}$ with the smallest possible deviation from z;(3) The system level coordinates the coupling variable Y between transportation and warehouse through consistency constraints;(4) After multiple iterations of optimization, a solution that satisfies the consistency constraints and has the lowest logistics cost is obtained.

4 Case study

Based on the actual production data of a large chemical group in China that our research team cooperates with, this section verifies the synchronization solution proposed in this paper through data simulation.

4.1 Business process and basic data

The group has a total of four factories in its industrial park, producing wood paint, interior wall paint, exterior wall paint, and latex paint. The finished product warehousing process is similar to Figure 1. After the group customer service receives the customer's order, it will be assigned to the corresponding factory for production in the form of a production order according to the product type. Table 1 shows the production data of the group on a certain day after the desensitization treatment. In this paper, 10 am is set as 0 times. The completion time and the latest pickup time constitute the pickup service time window. Table 2 is the basic information of SHIP Fleet vehicles, and Table 3 is the basic information of SHIP Warehouse aisle.

Table 1: Customer order information

No	Customer Order	Manufacturer	Completion Quantity	Completion Time	The Latest Pickup Time	Delivery Time
1	1	1	6	168	190	260
2	1	2	8	129	161	260
3	1	3	10	210	239	260
4	1	4	10	114	143	260
5	2	1	5	147	179	350
6	2	2	6	144	177	350
7	2	3	12	300	333	350
8	2	4	8	156	181	350
9	3	1	8	345	379	470
10	3	2	10	292	309	470
11	3	3	6	333	366	470
12	3	4	13	243	277	470
13	4	1	6	96	134	200
14	4	2	8	72	102	200
15	4	3	8	168	196	200
16	4	4	10	96	127	200
17	5	1	8	249	284	380
18	5	2	10	244	269	380
19	5	3	5	315	346	380
20	5	4	15	218	249	380

Table 2: Basic data of vehicle

Vehicle Type	Loading Weight (pallets)	Number	Running Speed (km/h)
1	30	6	15
2	40	4	15

Table 3: Basic data of aisle

Aisle Type	Aisle Number	Area	Capacity(pallets)	Buffer Move Time(min)
1	a1-a5	Buffer area	20	30
2	a6-a7	Loading area	60	0

4.2 Mathematical models

According to the MR-CD Synchronization studied in this paper, this section proposes a CO-based synchronization optimization mathematical model from a quantitative perspective. To simplify the problem without loss of generality, the problem assumptions and parameter descriptions are shown in Tables 4 and 5. Among them, the units of the order quantity and the vehicle capacity mentioned in Table 4 and Table 5 are pallets.

Table 4: Problem assumption

No	Assumption	No	Assumption
1	There are several manufacturers in the industrial park, and each manufacturer is responsible for producing one type of product	2	A customer order contains multiple types of products, and different products are produced by the corresponding manufacturer
3	One category product in one order is a production order	4	The capacity of the finished product buffer is sufficient
5	Vehicle overload is not allowed	6	Movement time is fixed
7	The vehicle departs from SHIP and returns to SHIP after pickup	8	Ignore unloading and loading time of warehouse
9	Movement from the buffer area to the loading area is one-way	10	Production orders are not allowed to split for transportation
11	The number of pallets stored in the aisle cannot exceed its capacity	12	All products in the order will be delivered after entering the warehouse

Table 5: Parameter description

Notation	Description	Notation	Description
i	Manufacturer Number, $i = 1,2,\dots,n$	C_{buf}^{i}	Penalty cost of delayed arrival of vehicle v
m	Customer order number, $m = 1,2,\dots,M$	C_{fix}^{v}	Fixed cost of vehicle v
v	Vehicle number, $v = 1,2,\dots,V$	C_{var}^{v}	Unit transportation cost of vehicle v
a	Aisle number, $a = 1,2,\dots,N$	C_{fix}^{a}	Fixed storage cost of aisle a
Q_m	The total quantity of order m	C_{var}^{a}	Unit storage cost of aisle a
p_m^i	Quantity of production order	C_{del}	Delayed delivery time of order m
w_v	Loading weight of vehicle v	$t_{i,m}^{in}$	warehouse entry time of production order
T_0^v	The departure time of vehicle v	t_m^{in}	warehouse entry time of customer order m
t_{ij}	Travel time of vehicle v from i to j	T_{bm}	Buffer move time
at_i^v	The time when vehicle v arrives at i	dt_m^{req}	Delivery time of customer order m
$\left[et_i^k, lt_i^k\right]$	The $k\ th$ time window of i	t_m^{out}	Allowed delivery time of customer order m
$wt_{i,m}^v$	Waiting time of vehicle v at i	$[B_0, E_0]$	Operation time of ship
$g_{i,m}^v$	1, if the production order is transported by vehicle v, and 0 otherwise	x_{ij}^v	1, if the vehicle runs from i to j, and 0 otherwise
s_i	Service time required by i	$\delta_{k,m}$	1, if order m is moved to loading area after k and 0 otherwise
q_i^v	Pick-up weight of i	η_m	1, if buffer area is the place order m located before it is transshipped to the loading area, and 0 otherwise
at_{war}^v	The time when vehicle v arrives at SHIP	$\theta_{m,a}$	1, if order m is located on aisle a, and 0 otherwise
V_a	The capacity of aisle a	$\mu_{m,i,a}$	1, if production order is located on aisle a, and 0 otherwise
C_{wait}^v	The waiting time cost of vehicle v	$u_{t,a}$	1， aisle a is used at time t, and 0 otherwise

4.2.1 System level model

The objective function and consistency constraints of the logistics system level are as follows:

$$min\ f = f_t^2 + f_w^2 \tag{1}$$

$$J_t^* = \left(y_{(1,1)} - z_1\right)^2 \leq \varepsilon \tag{2}$$

$$J_w^* = \left(y_{(2,1)} - z_2\right)^2 \leq \varepsilon \tag{3}$$

Equation (1) represents the system level objective optimization function of the industrial park; Equations (2)-(3) represent consistency constraints, Where at_{war}^{v} is the coupling variable Y of the transportation subsystem model and the warehouse subsystem model.

4.2.2 Transportation Subsystem Model

$$\begin{gathered} min\ \ f_t = \sum_{v=1}^{V}\sum_{j=1}^{n} C_{fix}^{v} \times x_{0j}^{v} + \sum_{v=1}^{V}\sum_{i=1}^{n}\sum_{j=1}^{n} C_{var}^{v} \times t_{ij} \times x_{ij}^{v} + \\ C_{wait}^{v}\sum_{v=1}^{V}\sum_{i=1}^{n} max\left(et_i^k - at_i^v, 0\right) + C_{buf}^{i}\sum_{v=1}^{V}\sum_{i=1}^{n} max\left(at_i^v - lt_i^k, 0\right) \end{gathered} \tag{4}$$

Equation (4) represents the transportation cost returned by the optimization of the transportation subsystem. The first term is the fixed cost of the vehicle, the second term is the running cost of the vehicle, and the third and fourth terms are the penalty cost of the time window.

$$\sum_{i=1}^{n}\left(q_i^v \sum_{j=1}^{n} x_{ij}^v\right) \leq w_v, v \in \{1,2,\dots,V\} \tag{5}$$

$$\sum_{j=1}^{n} x_{0j}^{v} = \sum_{i=1}^{n} x_{i0}^{v} \leq 1, v \in \{1,2,\dots,V\} \tag{6}$$

$$\sum_{v=1}^{V}\sum_{j=1}^{n} x_{ij}^{v} \geq 1\,, i \in \{1,2,\dots,n\} \tag{7}$$

$$\sum_{m=1}^{M} p_m^i = \sum_{v=1}^{V} q_i^v\,, i \in \{1,2,\dots,n\} \tag{8}$$

$$\sum_{v=1}^{V} g_{i,m}^{v} = 1, i \in \{1,2,\dots,n\}, m \in \{1,2,\dots,M\} \tag{9}$$

$$at_i^v + wt_{i,m}^v + s_i + t_{ij} = at_j^v \tag{10}$$

$$T_0^v + \sum_{i=0}^{n}\sum_{j=0}^{n} x_{ij}^v \times \left(wt_{i,m}^v + s_i + t_{ij}\right) = at_{war}^v \leq E_0, v \in \{1,2,\dots,V\} \tag{11}$$

Equation (5) represents the overload constraint; Equation (6) represents that the vehicle departs from the SHIP and finally returns to SHIP; Equations (7)-(8) represents that the offline point allows multiple visits and the manufacturer's demand are met; Equation (9) represents that the production order is not allowed to be split and transported; Equation (10) calculates the time when the vehicle v arrives at the manufacturer j; Equation (11) represents SHIP operating time constraints.

4.2.3 Warehouse Subsystem Model

$$\begin{gathered} min\ \ f_w = C_{fix}^{a}\sum_{a=1}^{N} u_{t,a} + \sum_{i=1}^{n}\sum_{m=1}^{M}\left(t_m^{out} - t_{i,m}^{in}\right) \times p_m^i \times C_{var}^{a} + \\ C_{del}\sum_{m=1}^{M} max\left(t_m^{out} - dt_m^{req}, 0\right) \end{gathered} \tag{12}$$

Equation (12) represents the storage cost returned by the optimization of the warehouse subsystem, the first and second terms are the fixed and variable costs of using the aisle, and the third term is the penalty cost of delayed delivery of customer orders.

$$\sum_{m=1}^{M} \mu_{m,i,a} \leq 2, a \in \{1,2,\dots,N\} \tag{13}$$

$$\sum_{i=1}^{n}\sum_{a=1}^{N} \mu_{m,i,a} \leq 1, m \in \{1,2,\dots,M\} \tag{14}$$

$$\sum_{m=1}^{M} \theta_{m,a} \leq 1, a \in \{1,2,\dots,N\} \tag{15}$$

$$\sum_{a=1}^{N} \theta_{m,a} \leq 1, m \in \{1,2,\ldots,M\} \tag{16}$$

$$\sum_{m=1}^{M} \sum_{i=1}^{n} \mu_{m,i,a} \times p_m^i \leq V_a, a \in \{1,2,\ldots,N\} \tag{17}$$

$$\sum_{m=1}^{M} \theta_{m,a} \times Q_m \leq V_a, a \in \{1,2,\ldots,N\} \tag{18}$$

$$t_{i,m}^{in} = at_{war}^{v} \sum_{v=1}^{V} g_{i,m}^{v} \tag{19}$$

$$t_m^{in} = max\left(t_{i,m}^{in} \mid i = 1,2,\ldots,n\right) \tag{20}$$

$$\sum_{m=1}^{M} \theta_{m,a} \times \mu_{m,i,a} = 0 \tag{21}$$

$$t_m^{out} = t_m^{in}, if\ \eta_m = 0 \tag{22}$$

$$t_m^{out} = \sum_{k=1}^{M} \delta_{k,m}\left(t_m^{in} + T_{bm}\right), if\ \eta_m = 1 \tag{23}$$

Equations (13)-(16) express the constraints of order storage in the cargo lane; Equations (17)-(18) express the capacity constraints of cargo lanes; Equations (19)-(20) calculate the arrival time of production orders and customer orders respectively; Equation (21) means that the products of a customer order can only be stored in the same area at the same time; Equations (22)-(23) respectively calculate the time for customer orders to meet the delivery demand.

4.3 Result analysis

Matlab R2016b software was used to program and simulate the above examples. The transportation and warehouse subsystem models are solved by genetic algorithm (GA). The GA parameters are set as follows: population size is 100, the iteration number is 500, crossover probability P_c=0.6, mutation probability P_m=0.06. At the same time, the CO method is used to coordinate the decision-making results of transportation and warehouse.

4.3.1 Plan-making phase

Before the start of production execution, driven by customer demand, static data on the frontline is obtained through the smart object layer. The application layer coordinates and optimizes the transportation decision and warehouse decision under the distributed coordination framework of the CO algorithm, to obtain the initial logistics plan with the minimum total system operation cost.

Table 6 shows the initial scheduling results of the SHIP Fleet. Among them, 0 represents SHIP, 1 in 1(2) represents the manufacturer number, and 2 represents the customer order number produced. Figure 5 shows the time when the pickup vehicle arrives at each manufacturer. It can be seen that the service can be reached within the time window of each manufacturer. Besides, Figure 6 is a Gantt chart for aisle distribution, which shows that customer orders can be shipped on time.

Table 6: The result of the initial route planning

No	Route	Vehicle Type	Loading Rate	Warehouse Entry Time
1	0-2(2)-1(2)-4(2)-3(4)-0	1	90%	172
2	0-1(1)-3(1)-4(5)-0	2	77.5%	222
3	0-2(5)-4(3)-3(3)-1(3)-0	2	92.5%	350
4	0-1(4)-4(1)-2(1)-0	1	80%	133
5	0-1(5)-3(2)-2(3)-3(5)-0	2	87.5%	320
6	0-2(4)-4(4)-0	1	60%	100

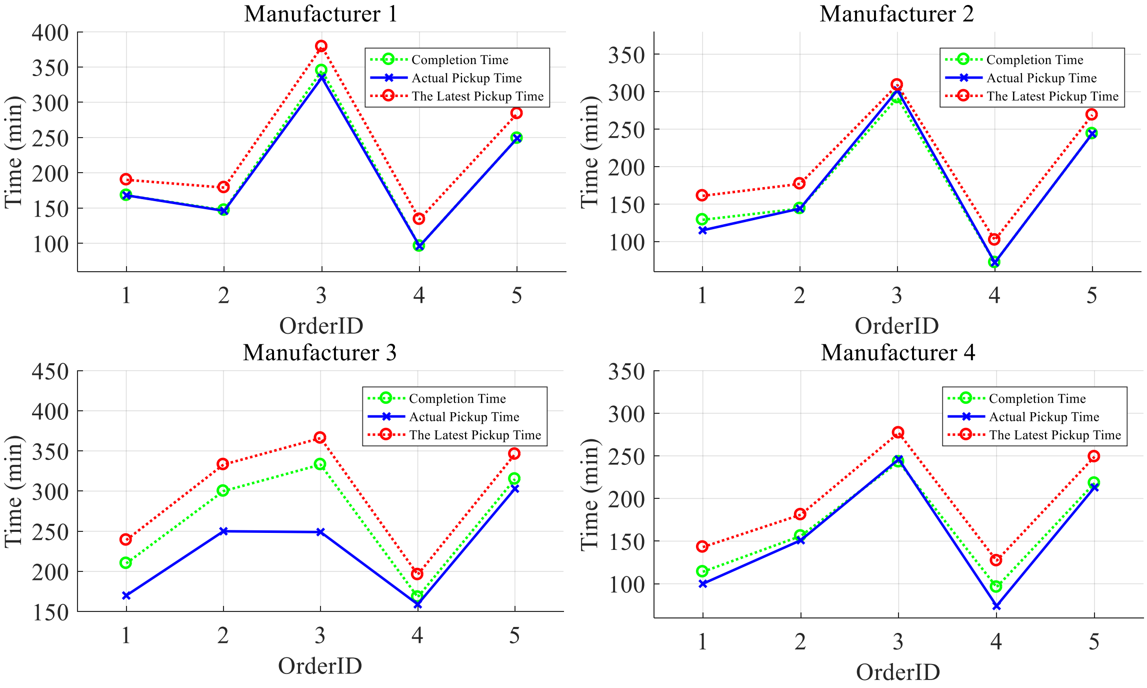

Figure 5: Initial planning of vehicle arrival time

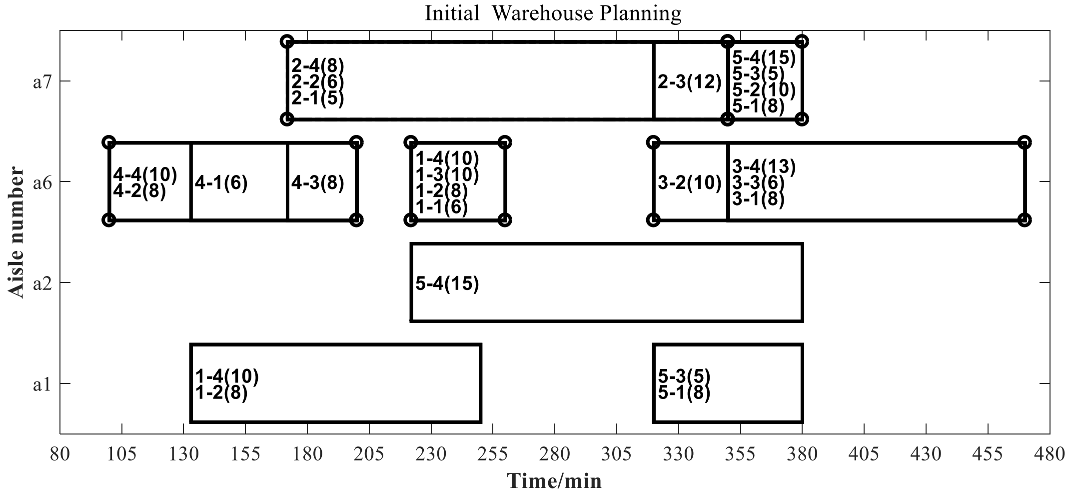

Figure 6: Gantt chart of initial warehouse planning

4.3.2 Plan-correction phase

This paper assumes that the chemical group received an urgent small-batch delivery order in the morning. The negotiated delivery time is 290, and the delivery number of each manufacturer is 4, 5, 8, 6, and the service time window is [180,207], [134,169], [228,266] and [68,98], respectively. This section compares the scheduling results with and without synchronized decision-making.

- Synchronization results

The addition of delivery orders will have an impact on the operation of the industrial park at all stages. At this time, the dynamics will trigger the MR-CD synchronization control mechanism, which is re-optimized through the CO algorithm. Table 7 shows the revised scheduling results of the SHIP Fleet. It can be seen from Figure 7 that the pick-up vehicles can still provide services to the manufacturers in time at the maximum loading rate. Besides, as shown in Figure 8, in the case of the least use of the aisle, both new and original orders can be delivered in time.

Table 7: The result of the corrected route planning

No	Route	Vehicle Type	Loading Rate	Warehouse Entry Time
1	0-4(2)-1(1)-3(4)-0	1	73.3%	174
2	0-2(5)-4(3)-3(2)-0	2	87.5%	304
3	0-4(6)-2(4)-4(4)-0	1	80%	100
4	0-2(1)-1(4)-2(6)-4(1)-2(2)-1(2)-0	2	100%	152
5	0-1(6)-3(1)-4(5)-3(6)-0	2	92.5%	232
6	0-1(5)-2(3)-3(3)-3(5)-1(3)-0	2	92.5%	350

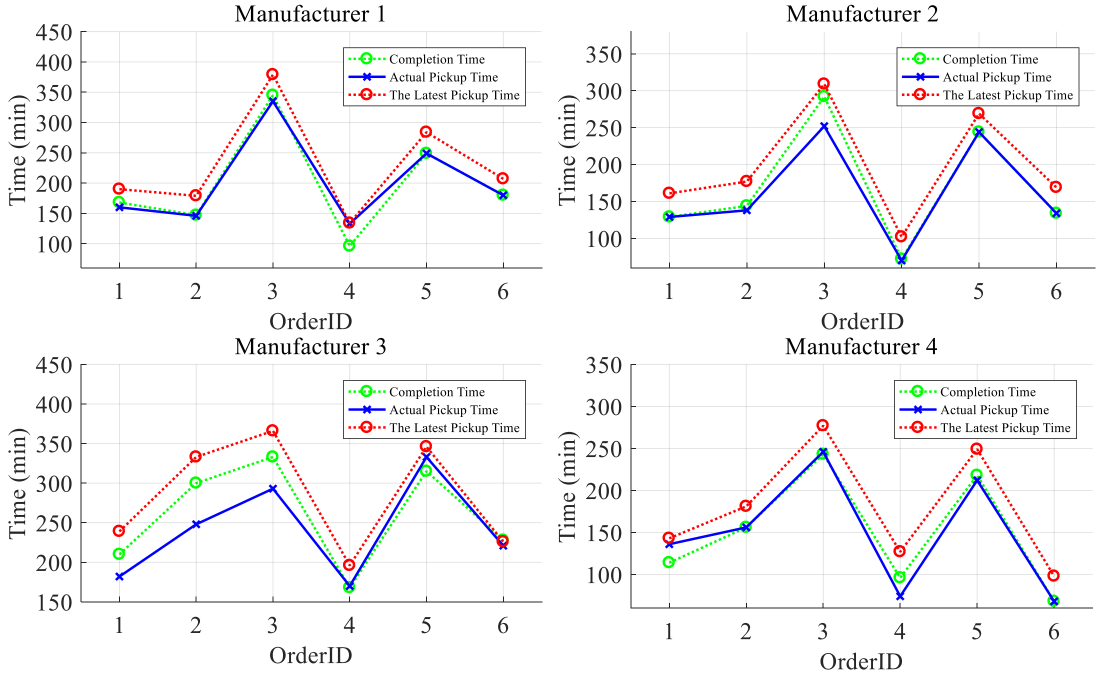

Figure 7: Corrected planning of vehicle arrival time

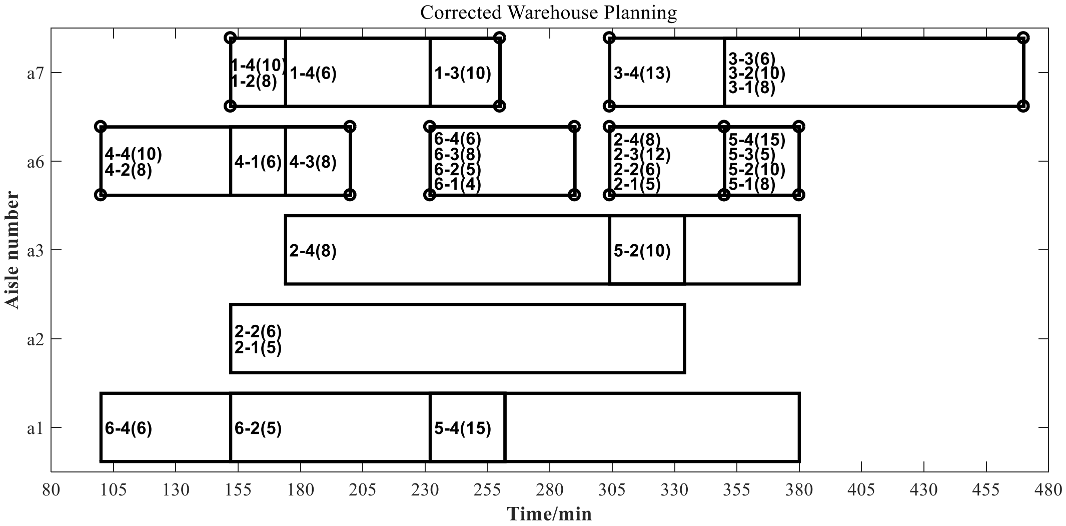

Figure 8: Gantt chart of corrected warehouse planning

- Comparative analysis of non-synchronization and synchronization results

Non-synchronization means that the newly added delivery orders are processed separately without changing the initial plan. Based on the initial logistics plan of subsection 4.3.1, the non-synchronization results are shown in Table 8 below.

Table 8: The comparison of results

Compared Items	Non-synchronization	Synchronization
Number of Vehicle Type 1/Type 2	4/3	2/4
Average Loading Rate	80.6%	87.6%
Number of Aisle Type 1/Type 2	3/2	3/2
Order On-time Delivery Rate	100%	100%

From the comparison in Table 7, it can be seen that the decision results of non-synchronization and synchronization can ensure that orders are delivered in time according to customer demand. Both SHIP Warehouse use the same number of the aisle. However, in the case of synchronized decision-making, SHIP Fleet can reasonably arrange to pick up vehicles at the maximum loading rate according to the results of the production offline, further reducing the overall operation cost. Therefore, the proposed solution can provide theoretical guidance for the process management of finished products in the actual industrial park.

5 Conclusion

This paper studies the MR-CD Synchronization problem that is crucial to improving the customer responsiveness of the industrial park system, and proposes PI enabled MR-CD synchronization solutions. To ensure that the system can still meet the delivery time required by customers after facing dynamic interference while ensuring the lowest overall operation cost. This synchronization solution can obtain real-time and accurate information based on the perception layer, to synchronized formulate the overall optimal logistics plan. Finally, the effectiveness of the program is verified through data simulation, and it can provide a feasible implementation framework and method for finished product logistics management in industrial parks.

For future work, we will further study the overall perception of the real-time status of the system in combination with a complex dynamic production environment. Explore the synchronization control mechanism with production as the core.

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