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The Establishment and Solution of Coupling model on Coordinated Scheduling of Handling Facilities in container terminals

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Abstract: The logistics operation of container terminal can be exploded into several subsystems which are correlative, these subsystems connect by some handling facilities. This paper study the coordinated scheduling of three main kinds of facilities-Quay Crane(QC),Yard Truck(YT) and Yard Crane(YC), use multidisciplinary variable coupling design optimization method(MVCDO) to build YT coordinated scheduling coupling model based on QC, obtain the YT coordinated scheduling scheme faced multi- working lanes. This paper presents a new way of studying the coordinated scheduling of handling facilities in container terminals through building coupling model.

Keywords: container terminals, handling facilities, coordinated scheduling, multidisciplinary variable coupling design optimization method, coupling model.

1. Introduction

With the rapid increase of economic globalization, more and more production operation and resource allocation activities are worldwide. The position and function of modern ports have occurred profound changes in the social economic development, these ports become important rely that keep a national economy to effectively participate in the economic globalization and possess dominate position in international competition. In order to meet the increasing containers throughout and shipping companys high service level requirement, its urgent to build highly efficient container transportation system, improve the internal logistics operation efficiency in container terminals.

The logistics operation of container terminal is a complicated system, it can be exploded into several subsystems which are correlative, such as berth subsystem, loading and unloading subsystem, storage subsystem and horizontal transportation subsystem etc. There are three main kinds of handling facilities in the loading and unloading operation in container terminals-QC,YT and YC, the main feature in loading and unloading operation of the three facilities is that they need pairwise cooperate, collaborative operate, and connect mentioned subsystems. The coordinated scheduling of handling facilities can reduce the resource waste due to the idle facilities mutually wait, form fluent port container logistics system, improve the logistics operation efficiency in container terminals.

Many domestic and foreign scholars have a lot of research on handling facilities problem in container terminals, and have obtained abundant research achievements. The existing papers which study the number configuration problem in container terminals are combining simulation model. Yang Jing-lei et al.(2003) study on the simulation of a dynamic multilevel queuing network for container terminals, the network is presented for Waigaoqiao container terminals of port of shanghai, and composed of a roadstead, berths, quay cranes ,yards, yard cranes and trucks, the optimal equipment allocation is obtained by analyzing the simulation indexes. Han Xiao-long et al.(2005) study resources Allocation in Container Terminal Charge/ Discharge Operation, firstly build Berth Allocation Model(BAM), then build Berth Quay-crane Allocation Model(BQAM), then present models for yard trucks and gantry crane allocation in container terminal adopting dual cycle and pool strategy, finally, give a simulation system in container terminal charge/discharge operation. The existing papers which study the dispatch problem in container terminals most

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container terminal charge/discharge operation. The existing papers which study the dispatch problem in container terminals most aim at one subsystem or single equipment. Kim et al(2003) assume the time of single vessel arrive and leave is known, the QCs are always practicable, use MIP describe QC scheduling, build model which the objective function is to minimize completed time of some vessel and obtain the optimal QC number. Han-Xiao long(2005)study the number of Yard Cranes in container terminal charge/discharge, present the network flow model and suggest a minimum flow algorithm. Yang Jing-lei(2006) constructs logistics routing optimization model in container terminals which targets in the minimum route of container trucks, to seek the optimal route of container trucks under the condition of satisfying the requirement of container yard storage and vessel handling operation. Iris et.al (2005) study minimum the vehicle number under time-window in container terminals, Every container job has its working time-window, using simulation model to estimate the solution.

Recently, some papers also study the coordinated scheduling between two facilities. JI Ming-jun et al(2007)study a United Optimization of Crane Scheduling and Yard Trailer Routing in a Container Terminal, consider the transportation time an QC working time, propose the shortest YT routing model based on minimum the total time. CAO Jinxin et.al(2010) study integrated quay crane and yard truck schedule problem in container terminals, consider one QC, deploy some YT, as minimum the last complete time objective function, formulate mix-integrated model. Another paper of cao.et.al(2010) study the integrated yard truck and yard crane scheduling problem(i-YIYCSP). Some foreign scholars also study the coordinated scheduling of handling facilities, Kim et al(2004) study AGV dispatch problem in automated port, given the number of QC and the work sequence of QC, synchronization handle QC and AGV, use the position and transportation time of containers to make sure the dispatch way of AGV. Henry et al(2005) study integrate scheduling problem of handle facilities, synchronization consider QC,AGV and YC, propose MLGA and GAPM algorithm to obtain a better solution. As the above mentioned, the existing papers main aim at single facilities, halfway paper study collaborative operate, but these researches are short of entirety, have not achieved coordinated scheduling well. This paper aims at these problems, use multidisciplinary variable coupling design optimization method to build coupling model, presents a new way of studying the coordinated scheduling of handling facilities in container terminals, concretely:

(1) to consider the coordinated scheduling of handling facilities in container terminals, study the YT coordinated scheduling based on QC and YC coordinated scheduling based on YT.

(2) to use multidisciplinary variable coupling design optimization method to analyze the coordinated scheduling of handling facilities, build the coupling model on coordinated scheduling.

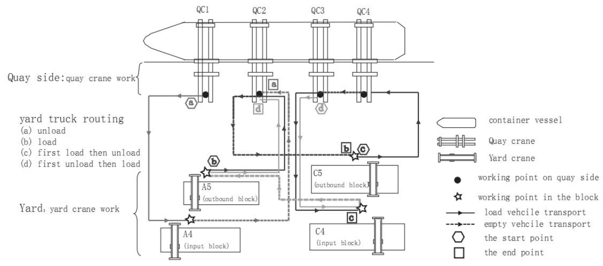

Figure 1 The operation style of the three handling facilities in container terminals.

(3) to use iteration circular algorithm to resolve coupling model, obtain the optimal results of the coupling model on coordinated scheduling.

2. Problem descriptions

The container terminals is important node in container logistics system, include every function of logistics service: transportation, warehouse, transfer, packing, circulate processing and

information processing. With the continuous development of modern logistics, terminals hold more and more vital position in container logistics system, following which the throughput of containers increase, it needs to raise logistics operation efficiency of container terminals. It can be achieved by reasonable deployment of internal logistics resources and logistics operation optimization of these resources in container terminals, these activities could increase the competitive strength of container terminals inevitably. According to the difference of inbound containers and outbound containers(Not consider transfer containers), divide the container logistics operation flow into two situation:1) inbound containers: vessel anchor at berth-QC unload containers from vessel- YT transport-YC stow and extract- The client take containers 2) outbound containers: containers enter the yard C YC stow and extract-YT transport- QC load containers into vessel- vessel leave port. It can be seen that QC, YC and YT are the main facilities to connect above logistics operation contents, the reasonable coordinated scheduling of the three facilities has a strong impact on entire terminal operation efficiency. The operation style of the three handling facilities in container terminals which considered in this paper is like fig1.

As shown in fig2.1, this paper consider several QCs, namely the scheduling which faced multi- working lanes. Using Rail-mounted Gantry Crane(RMGC) in yard, namely YCs can only move between blocks in the same line. YTs transport as dual-circulate, namely have four transportation way: a)only load b)only unload c) first load then unload d)first unload then load. The coordinated operation relationship between QCs, YTs and YCs is shown in fig2.

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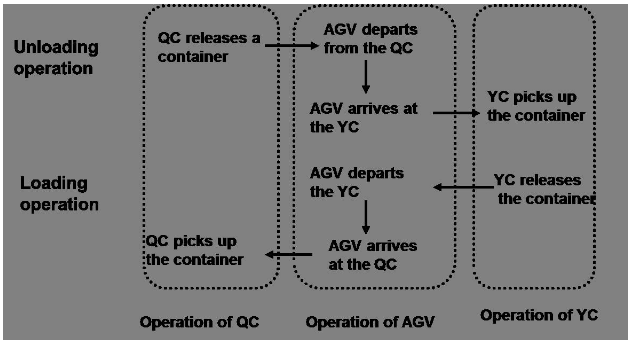

Figure 2 The coordinated operation relationship between QCs, YTs and YCs.

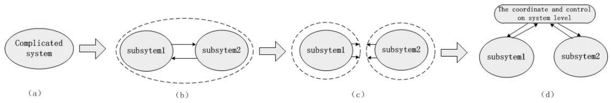

Figure 3 The total thought of multidisciplinary variable coupling design optimization method.

This paper use multidisciplinary variable coupling design optimization method(MVCDO), the total thought of this method is: for a complicated system(fig3(a)); Firstly, divide it into several subsystems which belong to different disciplinary; After decomposition of system(fig3(b)), the systems design task divide into subsystems design task, each subsystem can build relatively independent mathematical model according to respective design rule and systems design requirement in its disciplinary field. Then, in order to optimization design the subsystems independently, decompose the couple relationship of subsystems, make the subsystems independent completely, like this, every subsystem has its independent and integrated optimization model included itself optimization objective, design constraints and design variables, it can be designed independently(fig3(c));Later, set coordinated control optimization on system level, coordinate and control the couple relationship of variables between subsystems (fig3(d)); Finally, obtain the integrated suitable results on system level which match the couple relationship between subsystems.

The coordinate scheduling problem of handling facilities in container terminals belongs to the coordinate and deployment complicated of resources in complicated operation system. Therefore, we can use MVCDO to analyze this problem. The analysis train of thought in this paper is: Firstly, divided complicated problem into connected but owning different optimization objectives subproblems. Secondly, build mathematical model of sub-problem respectively. Thirdly, use public design variable to connect sub-problems, build coupling model on coordinated scheduling of handling facilities. Finally, obtain the integrated optimal results on coordinated scheduling problem.

According to the reality operation process, it can be known that the number of QC determine by berth planning and load/unload planning, the QCs work schedule determine by stowage planning and space planning. Therefore, this paper analyze the scheduling of handling facilities under the number and work schedule of QC known, concretely, analyze the YT coordinated scheduling based on QC and the YC coordinated scheduling based on YT. This paper divide the complicated coordinated scheduling problem into studying number deployment sub-problem and transportation mode sub-problem, build deployment sub-model and dispatch sub-model which both have public design variable firstly. In other words, although these submodels have different optimization objectives, connect by public design variable, thereout, build coupling model on coordinated scheduling to achieve the couple relationship between sub-models, and the relationship is no- hierarchy. When build coupling model, set coordinate control optimization on system level to control the optimization process of sub-model and coordinate the couple relationship between sub-models. Through iteratively circular calculate to update the value of public design variables, obtain the optimal number and scheme of handling facilities finally.

3. The establishment of coupling model on YT coordinated scheduling based on QC

As described above, the QCs schedule is known, due to the expensive operation cost, it wouldnt change the QC work schedule arbitrarily. Consider enough number of YT to ensure container jobs to be completed based on QC work schedule, simultaneously, decrease the number of YT as much as possible. According to these consideration, This section divide YT coordinated scheduling problem into YT dispatch sub-problem and YT deployment sub-problem firstly, build sub-model respectively, then, use public design variable to connect sub-models, and set coordinate control optimization on system level to meet the QC work sequencing, thereout, build coupling model on YT coordinated scheduling based on QC. The concretely formulation is shown as follow:

The known condition:

1) The number of QC(namely the work lane of load/unload operation)

2) QC work schedule (namely the job load/unload sequencing of each work lane)

3) The transportation time between QCs and blocks

4) The ready time of QCs to complete the container jobs

5) YT transport as dual-circulation mode

6) The handle time of YC

Interrelated assumption:

1) The inbound containers and outbound containers stack in different blocks

2) YT can transport one container one time

3) YC is always available

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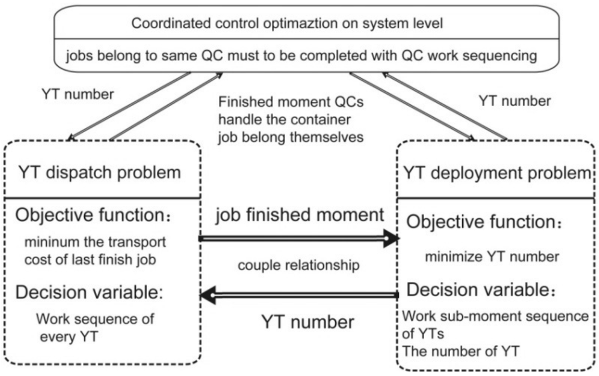

Figure 4 The total thought of multidisciplinary variable coupling design optimization method.

4) Not consider the blockade between YTs and the concrete bay in blocks which stack container jobs

In the study of YT coordinated scheduling based on QC, use the number of YT, the complete time of each job and the sub-moment that QC complete jobs. As shown in fig4. The objective function of YT dispatch sub-model is the total delay time due to the two-way wait between QC and YT, namely minimize the total delay time of container jobs at quay side, the idle time of handling facilities at quay side is shortest. The objective function of YT deployment sub-model is to minimize the number of YT. Set coordinate control optimization on system level, make sure the jobs belong to same QC to be completed with QC work sequencing.Input the initial YT number into YT dispatch model to calculate, obtain YT work sequencing, output the completed time that QCs handle the jobs that belong to themselves, judge them matched the coordinate control optimization or not. If not matched, return to dispatch sub-model, adjust parameter to solve again. If matched, input the completed time into YT deployment sub-model to calculate, output YT number and the completed sub-moment, judge them matched the coordinate control optimization or not. If not matched, return to deployment sub-model, adjust time-window, solve again. If matched, input new YT number and completed sub-moment into YT dispatch sub-model to calculate, obtain new YT work sequencing, output new completed time that QCs handle the jobs that belong to themselves. Iteratively and circularly calculate like this ,namely solve the coupling model on YT coordinated scheduling. Finally, obtain the optimal YT number and YT scheme.

3.1. YT dispatch model(Model I)

Parameters:

t_{ij} need to be discussed classified, transport time t_{ij} means the interval time between YT arrive at one QC which job i belong it to wait for QC handle job i and the same

M	the total number of all jobs.
K	the total number of all YTs
Q	the total number of all QCs
S_i	the ready time that QC can handle job i which belongs this QC
q_i	the qc number of job i
b_i	the block number of job i
h_{qi}	QC handling time of job i
h_{yi}	YC handling time of job i
L_i	if job i need to load container,$L_i = 1$ if job i need to unload container,$L_i = 0$
TQ_{ij}	YT transport time from QCi to QCj
TB_{ij}	YT transport time from BLOCKi to BLOCKj
TBQ_{ij}	YT transport time between BLOCKi and QCj
t_{ij}	transport cost from job i to job j, this paper use transport time to mean transport cost
w_{ij}	the delay time cost that caused by handling j after complete job i

finish job i then move to another QC which job j belong it to wait for QC handle job j. Assume that YCs are always used, thus dont consider YCs and YTs waiting time in block. t_{ij} would have different value because different handling mode, in case of YT have four transport mode: a) unload only b) load only c) load then unload d) unload then load, corresponding four calculate function as follow respectively as (3.1.1),(3.1.2),(3.1.3),(3.1.4).

$$t_{ij} = h_{qi} + TBQ_{b_i q_i} + h_{yi} + TBQ_{b_i q_j}, \quad if\ L_i = 0\ and\ L_j = 0 \tag{3.1.1}$$

$$t_{ij} = h_{qi} + TBQ_{b_j q_i} + h_{yi} + TBQ_{b_j q_j}, \quad if\ L_i = 1\ and\ L_j = 1 \tag{3.1.2}$$

$$t_{ij} = h_{qi} + TQ_{q_i q_j}, \quad if\ L_i = 1\ and\ L_j = 0 \tag{3.1.3}$$

$$t_{ij} = h_{qi} + TBQ_{b_i q_i} + h_{yi} + TB_{b_j b_j} + h_{yj} + TBQ_{b_j q_j}, \quad if\ L_i = 0\ and\ L_j = 1 \tag{3.1.4}$$

And the delay condition have two type:
1) YT arrive lately, QC wait for YT, as (3.1.5)
2) YT arrive early, YT wait for QC, as (3.1.6)

$$w_{ij} = \alpha(S_i + t_{ij} - S_j),\ if\ S_i + t_{ij} - S_j \geq 0 \tag{3.1.5}$$

$$w_{ij} = \beta(S_j - S_i - t_{ij}),\ if\ S_j - S_i - t_{ij} \geq 0 \tag{3.1.6}$$

Set α, β as delay time cost coefficient under this two conditions, they are 0-1 random digital, need to be adjusted in the calculating process under coordinate control optimization constraints.

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y_{ijk} binary, if YT k transport job j after job i, $y_{ijk}=1$ else $y_{ijk}=0$

f_{ij} binary, if job i is the first job of YT k, $f_{ij}=1$ else $f_{ij}=0$

l_{ij} binary, if job i is the last job of YT k, $l_{ij}=1$ else $l_{ij}=0$

Decision variable:
Objective function:

$$\min\sum_{i=0}^{M}\sum_{j=0}^{M}\sum_{k=0}^{K}w_{ij}y_{ijk} \quad (3.1.7)$$

S.t.

$$\sum_{i=0}^{M}f_{ij}=1,\ 0\le k\le K \quad (3.1.8)$$

$$\sum_{i=0}^{M}l_{ij}=1,\ 0\le k\le K \quad (3.1.9)$$

$$\sum_{k=0}^{K}f_{ij}+\sum_{k=0}^{K}l_{ij}\le 1,\ 0\le i\le M \quad (3.1.10)$$

$$\sum_{j=0}^{M}\sum_{k=0}^{K}y_{ijk}+\sum_{k=0}^{K}l_{ij}=1,\ 0\le i\le M \quad (3.1.11)$$

$$\sum_{i=0}^{M}\sum_{k=0}^{K}y_{ijk}+\sum_{k=0}^{K}f_{ij}=1,\ 0\le j\le M \quad (3.1.12)$$

$$\sum_{i=0}^{M}y_{ijk}+f_{jk}=\sum_{i=0}^{M}y_{jik}+l_{jk}, \quad (3.1.13)$$
$$0\le j\le M,\ 0\le k\le K$$

$$S_iy_{ijk}\le S_j, \quad (3.1.14)$$
$$0\le i\le M,\ 0\le j\le M,\ 0\le k\le K$$

Equation(3.1.7) is objective function of Model I,means minimize the total delay time of jobs at quay side, namely minimize the two-way waiting time between QCs and YTs. Constraint (3.1.8) means there is only one first job of each YT. Constraint (3.1.9) means there is only one last job of each YT. Constraint (3.1.10) means, to each job, it is impossible to be both first job and last job. Constraint (3.1.11) means for each job, the follow job can only finish by one YT. Constraint (3.1.12) means for each job, the former job can only finish by one YT. Constraint (3.1.13) means for middle jobs, need to be transport balance, which means input equal output. Constraint (3.1.14) means the follow job start moment cant be small than the former job in the same job sequence.

Solve Model,obtain YTs routing and dispatch program, and also can calculate r_i the finish moment of QCs handle the container job belong themselves as equation(3.1.15) .In which, r_pi means the finish moment of the former job of job i.

$$r_i=\begin{cases} S_i+t_{ij}, & if\ \sum_{k=0}^{K}f_{ik}=1\\ r_{p_i}+t_{ij}, & if\ \sum_{k=0}^{K}f_{ik}=0\ and\ \sum_{k=0}^{K}l_{ik}=0\\ r_{p_i}+h_{qi}, & if\ \sum_{k=0}^{K}l_{ik}=1\ and\ L_i=1\\ r_{p_i}+h_{qi}+TBQ_{b_iq_i}, & if\ \sum_{k=0}^{K}l_{ik}=1\ and\ L_i=0 \end{cases} \quad (3.1.15)$$

3.2. YT deployment model(Model II)

Each container job has its work time-window handling by QCs, it has the earliest finish moment QEi and the reality finish moment QLi, in this paper, use the two value form time-window [QEi,QLi), QEi is S_i, that is the earliest finish moment of job i, QLi is the moment QC finish the container i in work sequencing belong itself, namely r_i (obtain by model). Divide these time-window into n steps, each job can choose one moment to be finished among these n moment, in other words , change the dynamic problem (choose any moment to be finished among the time-window) into a static problem (choose a key moment to be finished) ,according to graph theory, formulate graph $G=(P,E)$, point P means the key moment QCs finish the container jobs belong themselves, $P=\{c_{11},\cdots,c_{1n},\cdots,c_{i1},\cdots,c_{in},\cdots,c_{J1},\cdots,c_{Jn}\}$, side $E=\{(g,h):g,h\in P\}$ means that one YT finish one job at moment g then finish another job at moment h, $g=c_{in}$ means that YT transport job i at n step sub-moment, $h=c_{jm}$ means that YT transport job j at m step sub-moment. Add dummy starting point s and ending point t, add arc (s,w) and (w,t) simultaneously ,$\forall w\in P$Take four container jobs for example, divide the time-window into two steps, gain network graph like fig5, see the dummy point as dummy finish moment, YT work time sequence must satisfy vehicle constrain and time-window constrain, obtain the least YT number by deciding the number of direct routing.

Parameters:

M the total number of all jobs.
S_i the earliest finish moment of job i
r_i the real finish moment of job i
t_{ij} transport cost from job i to job j, this paper use transport time to mean transport cost
N the step of time-window
C_{in} the sub-moment for YT to transport job i at n step
Y_{min} Minimum number of all work YTs
Y_{max} Maximum number of all work YTs

Decision variable:

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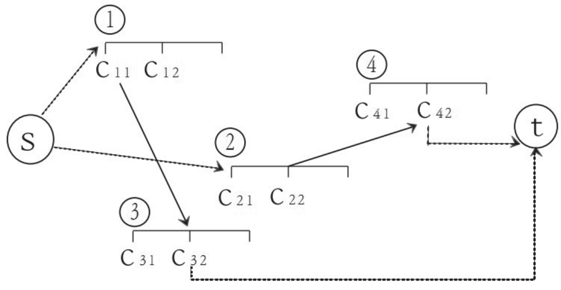

Figure 5 YT deployment model network graph.

z_{injmk} binary, if YT k finish job i at the moment of step n then finish another job j at the moment of step m, $z_{injmk} = 1$ else $z_{injmk} = 0$

f_{inj} binary, if job i is the first job of YT k,and YT k finish job i at the moment of step n, $f_{inj} = 1$ else $f_{inj} = 0$

l_{inj} binary, if job i is the last job of YT k,and YT k finish job i at the moment of step n, $l_{inj} = 1$ else $l_{inj} = 0$

v integers, the number of work YTs

d_k binary, if YT k work, $d_k = 1$ else $d_k = 0$

Objective function:

$$\min v \tag{3.2.1}$$

S.t.

$$\frac{1}{M}\sum_{i=0}^{M}\sum_{n=0}^{N+1}\sum_{j=0}^{M}\sum_{m=0}^{N+1} Z_{injmk} \le d_k \tag{3.2.2}$$

$$\le \sum_{i=0}^{M}\sum_{n=0}^{N+1}\sum_{j=0}^{M}\sum_{m=0}^{N+1} Z_{injmk},$$

$$0 \le k \le Y_{max}$$

$$\sum_{k=0}^{Y_{max}} d_k = v \tag{3.2.3}$$

$$\sum_{i=0}^{M}\sum_{n=0}^{N+1}\sum_{k=0}^{Y_{max}} f_{ink} = v \tag{3.2.4}$$

$$\sum_{i=0}^{M}\sum_{n=0}^{N+1}\sum_{k=0}^{Y_{max}} l_{ink} = v \tag{3.2.5}$$

$$\sum_{i=0}^{M}\sum_{n=0}^{N+1} f_{ink} \le 1,\ 0 \le k \le Y_{max} \tag{3.2.6}$$

$$\sum_{i=0}^{M}\sum_{n=0}^{N+1} l_{ink} \le 1,\ 0 \le k \le Y_{max} \tag{3.2.7}$$

$$\sum_{k=0}^{Y_{max}} f_{ink} + \sum_{k=0}^{Y_{max}} l_{ink} \le 1, \tag{3.2.8}$$

$$0 \le i \le M,\ 0 \le n \le N+1$$

$$\sum_{n=0}^{N+1}\sum_{j=0}^{M}\sum_{m=0}^{N+1}\sum_{k=0}^{Y_{max}} Z_{injmk} \tag{3.2.9}$$

$$+\sum_{n=0}^{N+1}\sum_{k=0}^{Y_{max}} l_{ink} = 1,\ 0 \le i \le M$$

$$\sum_{m=0}^{N+1}\sum_{i=0}^{M}\sum_{n=0}^{N+1}\sum_{k=0}^{Y_{max}} Z_{injmk} \tag{3.2.10}$$

$$+\sum_{m=0}^{N+1}\sum_{k=0}^{Y_{max}} f_{jmk} = 1,\ 0 \le j \le M$$

$$\sum_{m=0}^{N+1}\left(f_{jmk} + \sum_{i=0}^{M}\sum_{n=0}^{N+1} z_{injmk}\right) = \tag{3.2.11}$$

$$\sum_{m=0}^{N+1}\left(l_{jmk} + \sum_{i=0}^{M}\sum_{n=0}^{N+1} z_{jmink}\right),$$

$$0 \le j \le M,\ 0 \le k \le Y_{max}$$

$$C_{in} z_{injmk} \le C_{jm}, 0 \le i \le M, \tag{3.2.12}$$

$$0 \le n \le N+1,\ 0 \le j \le M,$$

$$0 \le m \le N+1,\ 0 \le k \le Y_{max}$$

$$t_{ij} z_{injmk} \le |C_{jm} - C_{in}| \tag{3.2.13}$$

Equation (3.2.1) is the objective function of Model I-I, means minimize work YT number; Constraint (3.2.2) means if YT k work, $d_k = 1$ else $d_k = 0$; Constraint (3.2.3) means the total work YT number equal work YT number; Constraint (3.2.4) means that starting point has v YTs; Constraint (3.2.5) means that ending point has v YT-s; Constraint (3.2.6) means the number of first job of each YT less than one. Constraint (3.2.7) means the number of last job of each YT less than one. Constraint (3.2.8) mean-s, to each job, it is impossible to be both first job and last job. Constraint (3.2.9) means that for each job, it can only choose one moment in the follow job time-window; Con-straint (3.2.10) means that for each job, it can only choose one moment in the former job time-window; Constrain-t (3.2.11) means middle points must be input and output balance; Constraint (3.2.12) means the follow job finish moment cant be small than the former job in the same time sequence; Constraint (3.2.13) means the interval time be-tween former and follow job for one YT cant be small than transport time between the two jobs.

3.3. Coupling model on YT coordinated scheduling

Based on above sub-models, it needs to coordinate dis-patch sub-problem and deployment sub-problem, obtain the overall optimal results on YT coordinated scheduling. Use iteratively and circularly calculate, update the value of

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public design variable continuously. Set coordinated control optimization on system level, control the optimization process and coordinate the couple relationship between sub-models better. We can compute the moment r_i-when QC actually finish job i that belongs to itself from Model I, namely this moment obtain from model evaluate. The earliest completed moment is S_i, this moment obtain from QC actual operation. If r_i= S_i, achieve optimization, jobs have on delay. By limiting the relationship between the two value ,we can written-out judge function(3.3.1) and(3.3.2) of coordinated control optimization on system level, make sure the jobs belong to same QC to be completed with QC work sequencing.

$$r_i - r_{i-1} \geq S_i - S_{i-1} \quad (3.3.1)$$
$$(C_{jm} - C_{in})z_{injmk} \geq S_j - S_i \quad (3.3.2)$$

Equation (3.3.1) means that the actually completed time-lag between former and following jobs cant be less than the earliest completed time-lag. Equation (3.3.2) means that the time-lag of actually completed sub-moment in time-window between former and following jobs cant be less than the earliest completed time-lag.

Input the moment r_i-when QC actually finish job i that belongs to itself from Model I into equation(3.3.1), if not matched, return to Model I to calculate again. In section3.1, we mention to adjust , in calculate process. Use coordinated control optimization to calculate the value of , again to satisfy equation(3.3.1) as much as possible.

Input the sub-moment C_{jm} and C_{in}-when QC actually finish job i that belongs to itself in time-window into equation(3.3.2), if matched, input the new number of YT into Model I, if not matched, return to Model II, delete those sub-moment which is not fit from time-window, adjust time-window then calculate again to satisfy equation(3.3.2) as much as possible. And assign the sub-moment which is fit to S_i- the ready time that QC can handle job i which belongs this QC as a input cause for Model I. In this way, Model I and Model II are constrained by coordinated control optimization on system level.

From the above three section, we build coupling model on YT coordinated scheduling. Among them, YT dispatch model and YT deployment model are no-hierarchy, if given initial YT number , touch off YT dispatch model to calculate firstly, if given initial completed time-window, touch off YT deployment model to calculate firstly, the calculate sequence should not influent the results of optimal YT number and scheme.

4. Case study and results

In order to ensure the feasibility of coupling model on YT coordinated scheduling, we use example to verify. Assume that there are 4QCs, 16 container jobs, initially given 4YTs, fix the handle time of YC 1 minute, QC work scheduling, handle time and the earliest completed time of jobs are shown in table 1, use(i,k) /ik remarks job i of QC k. YT transport the container unloaded by QC1 and QC2 to A5 block, transport the container unload by QC3 and QC4 to C5 block, transport the loaded container from A4 to QC1 and QC2, transport the loaded containers from C4 to QC3 and QC4. And the transport interval time between QCs and blocks is shown in table2. N in Model II set 4.

Table 1 QC work schedule(time unit: min)

QC1				QC2			
Job	U/L	h_{qi}	S_i	Job	U/L	h_{qi}	S_i
11	U	1.1	0	12	L	1.5	4.5
21	U	1.2	2.1	22	U	1.2	4.7
31	U	1.0	4.3	32	U	1.3	6.9
41	L	1.4	6.7	42	U	1.0	9.2
51	L	1.3	9				
QC3				**QC4**			
Job	U/L	h_{qi}	S_i	Job	U/L	h_{qi}	S_i
13	L	1.3	3.3	14	U	1.1	0
23	L	1.4	5.7	24	U	1.3	2.1
33	L	1.2	7.9	34	L	1.4	4.8
				44	L	1.5	7.3

Table 2 QC work schedule(time unit: min)

	QC1						
QC1	0	QC2					
QC2	0.5	0	QC3				
QC3	1	0.5	0	QC4			
QC4	1.5	1	0.5	0	A4		
A4	3.5	3	3.5	4	0	A5	
A5	4	3.5	4	4.5	0.5	0	C4
C4	3	2.5	2	2.5	0.5	1.5	0
C5	3.5	3	2.5	3	1	0.5	0.5

Using the data in table1 and table2 to gain U/L, h_{qi} and S_i, and according to the t_{ij} and w_{ij} calculate rule, calculate the t_{ij} and w_{ij} between jobs.

Based on ILOG Cplex12.2 optimization, use c# language, obtain results as follow:

It can be seen from table 3 that The total delay time of jobs at quay side increase with YT number increase.

Synthesize talbe3 and table4, after all iteration, obtain the optimal YT number is 4,also obtain the optimal YT scheduling scheme that satisfy the QC work schedule as much as possible, the scheme is shown in table5. which can be used to draw a gantt chart shown in fig6.

5. Conclusion

The logistics operation of container terminal is a complicated system, it can be exploded into several subsys-

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Table 3 Results of YT dispatch model

Case	Initial YT	ObjectValue (Delay time)	Scheduling scheme
1	4	13.22 min	YT1:(1,4)(3,1) YT2:(1,3)(2,1)(5,1)(4,2) YT3:(1,1)(4,1)(2,2)(3,4) YT4:(1,2)(2,3)(2,4)(3,3)(3,2)(4,4)
2	5	7.82 min	YT1:(1,4)(3,1) YT2:(1,4)(2,4)(3,3)(3,2)(4,4) YT3:(3,1) YT4:(1,3)(2,1)(5,1)(4,2) YT5:(1,1)(4,1)(2,2)(3,4)
3	6	4.01 min	YT1:(1,2)(2,3) YT2:(1,3)(2,1)(5,1)(4,2) YT3: (2,4)(3,3)(3,2)(4,4) YT4:(2,2)(3,4) YT5:(1,1)(4,1) YT6:(1,4)(3,1)
4	7	1.68 min	YT1:(3,3) YT2:(3,1) YT3:(2,2) (3,4) YT4:(1,3)(2,1)(5,1)(4,2) YT5:(1,2)(2,3) YT6:(1,4)(2,4)(3,2)(4,4) YT7:(1,1)(4,1)
5	8	1.20 min	YT1:(1,1)(4,1) YT2:(3,3) YT3:(1,2)(2,3) YT4:(2,2)(3,4) YT5:(5,1)(4,2) YT6:(1,3)(2,1) YT7:(3,1)(3,2)(4,4) YT8:(1,4)(2,4)

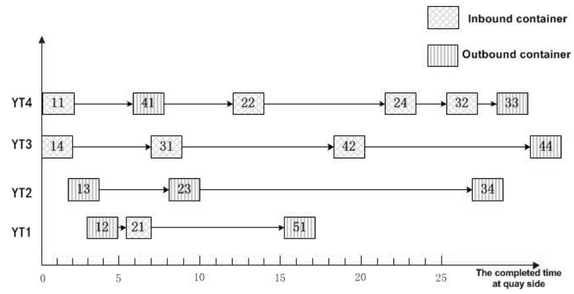

Figure 6 The optimal YT scheduling scheme.

Table 4 Results of YT deployment model

Case	ObjectValue (Result YT)	Scheduling scheme
1	5	YT1:(1,2)(3,1)(5,1) YT2:(1,4)(2,3)(2,4)(3,4) YT3:(2,1)(4,4) YT4:(1,3)(2,2)(3,3) YT5:(1,1)(4,1)(3,2)
2	4	YT1:(1,4)(3,1)(3,4)(4,4) YT2:(1,3)(2,1)(3,2)(5,1)(3,3) YT3:(1,1)(4,1)(2,4) YT4:(1,2)(2,2)(2,3)(4,2)
3	5	YT1:(1,2)(4,2) YT2:(1,4)(4,1)(3,2)(3,3) YT3:(2,4)(2,2)(5,1) YT4:(1,3)(2,1)(2,3) YT5:(1,1)(3,1)(3,4)(4,4)
4	5	YT1:(1,2)(2,2)(5,1) YT2:(1,4)(4,1) YT3:(2,4)(2,3) YT4:(1,3)(2,1)(3,2)(4,4)(3,3) YT5:(1,1)(3,1)(3,4)(4,2)
5	5	YT1:(1,2)(2,1)(3,3)(4,2) YT2:(1,4)(3,4)(2,2) YT3:(2,3)(2,4) YT4:(1,3)(3,1)(4,4) YT5:(1,1)(4,1)(3,2)(5,1)

Table 5 Results of iteration calculate of coupling model on YT coordinated scheduling

Iteration	Object Value	
Generation	Model I	Model II
1	1.20min	8
2	1.68min	7
3	4.01min	6
4	7.82min	5
5	13.22min	4
6	9.87min	4
7	9.73min	4
8	6.73min	4
Final Scheduling scheme		
YT1:(1,2)(2,1)(5,1)		
YT2:(1,3)(2,3)(3,4)		
YT3:(1,4)(3,1)(4,2)(4,4)		
YT4:(1,1)(4,1)(2,2)(2,4)(3,2)(3,3)		

tems which are correlative, these subsystems connect by some handling facilities. And the wide use of automation and information technology, the relationship between handling facilities is closer, the coordinated operation is increasingly, its necessary to coordinate the various handling facilities so as to improve the overall logistics operating efficiency. This paper based on these, study coordinated scheduling of the most important three kinds handling facilities in container terminal: QC,YT and YC. Because of the complexity of the study, this paper use multidisciplinary variable coupling design optimization method(MVCDO) to analyze the handling facilities scheduling problem, build handling facilities coordinated scheduling coupling model, finally obtain the YT coordinated scheduling scheme.

This paper has some improvement of study coupling model on coordinated scheduling of handling facilities in container terminals. It also needs in-depth study in following aspects:

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1) This paper assume that QC scheduling is known, we can add the QC scheduling into coordinated scheduling of handling facilities in future research.

2) Since the importance of quay side operation, this paper assume that YC scheduling cant affect YT route to avoid delay QC work. But in reality condition, YC work must affect QC work, hence, we can add the influence of YC scheduling on YT and QC scheduling in future research.

3) This paper mainly use MVCDO to analyze the coordinated scheduling problem of handling facilities, hence, only design small example to verify this method. We can use this train of thought to study this kind of problem, bring in heuristic algorithm to solve massive problem in future research, make the research results have more practical value.

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