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Research on Integrated Scheduling Model for Handling Operation System of Dry Bulk Cargo Port

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Abstract: In this study, we integrated schedule the port operations based on the overall ideology to achieve the global optimization of the port operation. Firstly, determine the integration strategy of the dry bulk cargo port handling system by analyzing the work flow and integration principle; secondly, the integration scheduling model of this system is developed; finally, a genetic algorithm is described which is applied to solve a spectrum of numerical examples in order to illustrate the model.

Key words: Dry bulk cargo, port handling operation, integrated scheduling, genetic algorithm

INTRODUCTION

With the development of economic, the demand for resources is increased in our country, especially the growing demand for dry bulk mainly transported by sea. In order to improve the efficiency and performance of the operations, the port has gradually evolved to specialization and enlargement (Henesey *et al*., 2004; Zhang *et al*., 2010). There are two ways to improve the efficiency: Increase in resource; reasonable scheduling of handling work (Woo and Kim, 2011; Zeng and Yang, 2009). The increase in resource is affected by the port size and technical parameter (Park *et al*., 2011). Hence, under the condition of limited resource, how to schedule the port handling work reasonably has become a hot issue in academic circles and industrial circles in recent years.

Many scholars has studied port scheduling problem from three aspects: berths allocation, handling machine scheduling and resource optimization (Stahlbock and Voß, 2008; Vis and de Koster, 2003). On the berths allocation, Wang and Lim (2007) transformed NP berths allocation problem into a multi-stage decision-making process; and then used the directional random search algorithm to allocate the berths. On the handling machine scheduling, Tavakkoli-Moghaddam *et al*. (2009) studied that the quay crane schedule is a NP problem, then used mixed integer programming to develop the model, genetic algorithms and simulation are given (Tavakkoli-Moghaddam *et al*., 2009). Legato *et al*. (2012) enriched the model and then carried out numerical simulation by using the branch and bound method and Petri Net. About the yard resource optimization, Chen and Lu (2012) discussed the problem of container exports to the other side and then divided the problem into two phases respectively, using mixed integer programming and mixed the other algorithms to simulation. Given the containers stacked state and demand, Rodriguez-Molins *et al*. (2012) used a heuristic search method to simulate and optimize taking the total box operation minimization as the optimization goal.

However, because of interplay of the links in the system, the urgent need to coordinate the various aspects can improve the port operations efficiency (Petering, 2011; Weyns and Holvoet, 2008; Lee and Kim, 2010). Zhou and Kang (2008) present berth and quay crane allocation optimization model to minimize the dwell time, considering the randomness of the arrival time and processing time. Lee *et al*. (2011) focused on the container port operating system with multiple terminals, taking containers horizontal transport costs minimization as the goal.

MODELING

The dry bulk cargo port handling operation process mainly includes unloading operation (ship to yard) and loading operation (yard to ship). It can be abstracted to a space movement from a position state to another position status by the handling equipment (Nishimura *et al*., 2005). Hence, the handling system mainly includes the ship berthing dock or departure, the loading and unloading cargo work, belt transport and shipment, yard heap take the crib. The conceptual model of integrated scheduling in the handling system is developed by analyzing the work flow and influencing factor, as shown in Table 1.

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Table 1: Conceptual model of integrated scheduling

	Dry bulk cargo port handling system integrated scheduling		
Objects	Determine berth	Shipunloaders allocation	Stackers allocation
Influence factors	Ship length, ship draft, arrival time, cargo type, berth number, berth length, draft depth	Shipment, cargo type, shipunloader number, shipunloader ability, belt capacity	shipment, cargo type, stacking position, yard layout, stacker number, stacker capacity, belt capacity
Constraints	Berth physical condition, shipunloader usage	Shipunloader usage, belt capacity, shipment= workload	Stacker usage, belt capacity, shipment = workload
Objective	Minimize the stay time of all ships in scheduling		

Hypothesis: The hypothesis are given as follows:

H1: The loading volume of the arriving ship is known
H2: The arrival ship must be served only once
H3: Each berth can only service one ship at the same time and there is no shifting berth
H4: Berth length is not less than the length of the ship
H5: The berth depth is not less than the ship draft depth
H6: Assign shipunloader to service the ship until berthing and all shipunloaders operations do not interfere with each other
H7: Each shipunloader can only service one ship at a time
H8: All shipunloaders cannot be mutually spanning
H9: The number of shipunloader assigned to the ship cannot exceed the maximum number of shipunloader allowed
H10: Once the shipunloader begin to work, it cannot shift berth until the end of the work
H11: When the same shipunloader services different ships, the movement time of shipunloader can be ignored and the beginning time of shipunloaders serviced the same ship cannot be the same, but the end of time is the same
H12: The operating efficiency of the shipunloader is the same
H13: The conveying speed of the belt is constant
H14: The Stacker operating efficiency is the same
H15: Stockpiling pile position enough to pile up the cargo volume unloaded from ships

Parameters setting: The parameters are set as follows:
Decision parameters include:

- $i \in I = \{1, 2, \ldots, m\}$ Indicates the berths set
- $j \in J = \{1, 2, \ldots, n\}$ Indicates the ship (expected to be arriving) set during scheduling
- $k \in K = \{1, 2, \ldots, c$ Indicates the port shipunloader set
- $a \in A\{1, 2, \ldots, s\}$Indicates the stacker set
- $g \in G$ Indicates the number of rows in the yard, $h \in H$ indicates the number of columns in the yard
- S_i Indicates the starting time of berth i in scheduling period
- H_i Indicates the restriction physical water depth of berth i
- B_i Indicates the length of berth i
- Q_j Indicates the maximum number of shipunloader allowed service for ship j
- C_j Indicates the loaded cargo volume of ship j
- T_{ij} Indicates the operating time in berth i for ship j
- h_j Indicates the draft depth of ship j
- l_j Indicates the length of ship j
- A_j Indicates the arrival time of ship j
- E_k Indicates the operating efficiency of shipunloader k
- E_b Indicates the operating efficiency of belt conveyor
- E_a Indicates the operating efficiency of stacker a
- X_{ef} Indicates the cargo volume in stacking (e, f):

$$x_{ijp} = \begin{cases} 1, \text{When ship j is assigned to berth i,} \\ \quad \text{and is the pth ship this berth has serviced;} \\ 0, \text{other.} \end{cases}$$

$$y_{jkq} = \begin{cases} 1, \text{When shipunloader k is assigned to ship j,} \\ \quad \text{and is the qth ship this ship unloader has serviced;} \\ 0, \text{other.} \end{cases}$$

$$z_{jar} = \begin{cases} 1, \text{When stacker a is assigned to ship j,} \\ \quad \text{and is the rth ship this stacker has serviced;} \\ 0, \text{other.} \end{cases}$$

Decision variables include: Depends on the decision variables, state variables include:

$$M_i = \sum_{j \in J} \sum_{p=1}^{n} x_{ijp}, \forall i \in I$$

Indicates the ship number berthing in berth I:

$$N_j = \sum_{k=K} \sum_{q=1}^{m} y_{jkq}, \forall j \in J$$

Indicates the shipunloader number that severing ship j:

$$R_k = \sum_{j \in J} \sum_{q=1}^{n} y_{jkq}, \forall k \in K$$

Indicates the task number of shipunloader k:

$$W_j = \sum_{a\in A}\sum_{r=1}^{m} z_{jar}, \forall j \in J$$

Indicates the stacker number that severing ship j:

$$Y_k = \sum_{j\in J}\sum_{r=1}^{n} z_{jar}, \forall a \in A$$

Indicates the task number of stacker a.

- U_{jkq} Indicates the starting time when shipunloader k services the qth ship j
- V_{jkq} Indicates the ending time when shipunloader k services the qth ship j
- T_{jkq} Indicates the service time that shipunloader k services the qth ship j
- U_{jar} Indicates the starting time when stacker a services the rth ship j
- V_{jar} Indicates the ending time when stacker a services the rth ship j
- T_{jar} Indicates the service time that stacker a services the rth ship

Objective function: Based on the parameters set above, the objective function is developed (see Eq. 1).

$$T = \min\left\{\sum_{i\in I}\sum_{j\in J}\sum_{p=1}^{n}(S_i - A_j)x_{ijp} + \sum_{i\in I}\sum_{j\in J}\sum_{q=1}^{m}\left[\left(U_{jkq} - V_{jk(q-1)}\right) + T_{jkq}\right]y_{jkq}\right\} \quad (1)$$

Constraints:

$$\sum_{i\in I}\sum_{p=1}^{n} x_{ijp} = 1,\ \forall j \in J \quad (2)$$

Constraint Eq. 2 ensure that all arriving ships must be served, that is must be berthed:

$$\sum_{j\in J} x_{ijp} \le 1,\ \forall i \in I, p = 1,\ldots,n \quad (3)$$

Constraint Eq. 3 ensure that any berth can only service one ship at the same time:

$$\left(H_i - h_j\right)x_{ijp} \ge 0,\ \forall i \in I, j \in J, p = 1,\ldots,n \quad (4)$$

Constraint Eq. 4 ensure that the berth depth is not less than the draft depth of the ship:

$$\left(B_i - l_j\right)x_{ijp} \ge 0,\ \forall i \in I, j \in J, p = 1,\ldots,n \quad (5)$$

Constraint Eq. 5 ensure that the length of the ship does not exceed the length of the berth:

$$\sum_{k\in K}\sum_{q=1}^{m} y_{jkq} = 1,\ \forall j \in J \quad (6)$$

Constraint Eq. 6 ensure that there is a shipunloader that can service for the ship:

$$1 \le \sum_{k\in K}\sum_{q=1}^{m} y_{ikq} \le Q_j \quad (7)$$

Constraint Eq. 7 ensure the shipunloaders number that ship assigned can be multiple but cannot exceed the largest number of shipunloader that the ship allows:

$$\sum_{q=1}^{m} y_{j(k-1)q} + \sum_{q=1}^{m} y_{j(k+1)q} - \sum_{q=1}^{m} y_{jkq} = \{-1,0,1\},\ \forall k-1,k,k+1 \in K, \forall j \in V \quad (8)$$

Constraint Eq. 8 ensure the shipunloader servicing for a ship is continuous and cannot be spanned:

$$\sum_{k\in K}\sum_{q=1}^{m} E_k T_{jkq} = C_j,\ \forall j \in J \quad (9)$$

Constraint Eq. 9 guarantees the shipunloader uninstall volume equal to the operating cargo volume of ship j:

$$T_{jkq} = V_{jkq} - U_{jkq} \forall j \in J, k \in K, q = 1,\ldots,m \quad (10)$$

Constraint Eq. 10 guarantee the service time of shipunloader k equal to the ending time minus the starting time:

$$U_{jkq} \ge V_{jk(q-1)} \forall j \in J, k \in K, q = 2,\ldots,m \quad (11)$$

Constraint Eq. 11 guarantee the starting time that shipunloader k services the qth ship is greater than or equal to the ending time that k services the q-1th ship:

$$\sum_{k\in K}\sum_{q=1}^{m} E_k y_{jkq} \le E_b,\ \forall j \in J \quad (12)$$

Constraint Eq. 12 guarantee that the total operating efficiency of shipunloader assigned to ship j does not exceed the operating efficiency of the belt, preventing the belt clogging:

$$\sum_{a\in A}\sum_{r=1}^{m} z_{jar} = 1,\ \forall j \in J \tag{13}$$

Constraint Eq. 13 ensures that there is stacker to operation in the yard:

$$\sum_{a\in A}\sum_{r=1}^{m} E_a z_{jar} \geq E_b,\ \forall j \in J \tag{14}$$

Constraint Eq. 14 ensures that the operating efficiency of the belt does not exceed the total operating efficiency of the stacker assigned to the ship j, preventing belt clogging:

$$\sum_{a\in A}\sum_{r=1}^{m} E_a T_{jar} = C_j,\ \forall j \in J \tag{15}$$

Constraint Eq. 15 ensure stacker stockpiles equal to the cargo volume ship j needed to be operated:

$$T_{jar} = V_{jar} - U_{jar} \forall j \in J, a \in A, r = 1,\ldots,m \tag{16}$$

Constraint Eq. 16 guarantee the service time of stacker a equal to the ending time minus the starting time:

$$U_{jar} \geq V_{ja(r-1)} \forall j \in J, a \in A, r = 1,\ldots,m \tag{17}$$

Constraint Eq. 17 guarantee the starting time that stacker a services the rth ship is greater than or equal to the ending time that a services the r-1th ship:

$$E_a T_{jar} \leq X_{gh},\ \forall a \in A, j \in J, g \in G, h \in H, r = 1,\ldots,m \tag{18}$$

Constraint Eq. 18 ensure that the operation volume of the stacker stack in (g, h) cannot exceed the cargo volume in (g, h):

$$\begin{aligned} &x_{ijp} \in \{0,1\},\ y_{jkq} \in \{0,1\},\ z_{jar} \in \{0,1\} \\ &\forall i \in I, j \in J, k \in K, a \in A, \\ &p = 1,\cdots,n, q = 1,\cdots,m, r = 1,\cdots,m \end{aligned} \tag{19}$$

Constraint Eq. 19 ensure that the variable is (0, 1) constraint.

METHODOLOGY

The variables of port integrated scheduling problem are numerous and the constraints are complex. It is difficult to solve such objective optimization problem for traditional optimization methods. However, genetic algorithm has a broader solution set and global search capability, beginning with the solvable groups to search; and it also has fast convergence to quickly filter out the inappropriate solutions. Therefore, we use genetic algorithm to solve this mathematical model. The design of genetic algorithm should consider the level of each sub-scheduler and the links among them which will directly affects the efficiency of the operation and the final result. The design of chromosome encoding should consider the berth the ship berthing in and the service order. Since one berth can only serve one ship at a time, the chromosome gene cannot be repeated.

COMPUTATIONAL EXPERIENCE

Description: A dry bulk cargo port has 3 berths; there are 6 shipunloaders in this dock and the work efficiency of each shipunloader is 2000t/h; the work efficiency of the belt conveyor is 6000 t/h; there are 3 rows and 4 columns in the yard with 5 stackers; the work efficiency of each stacker is 3600 t/h; stacker D1, D2, D3 are responsible for stacking line 1, 2; while stacker D4, D5 are responsible for stacking line 2, 3.

Parameters setting: The information of berths and arrival ships are shown in Table 2 and 3.

The stacking and available stacker are shown in Table 4.

Here, we use Matlab to program and compute the example, getting the optimal solution.

Results analysis: The scheduling plan of arrived ships is shown in Table 5.

Table 2: Information of berths

Berth	Length (m)	Depth (m)
B1	180	12
B2	200	13
B3	220	15

Table 3: Information of arrival ships

Length (m)	Draft (m)	Arrival time	Cargo capacity (million tons/100)
185	11.0	3:00	4.5
173	8.6	8:00	3.0
210	14.0	11:00	6.0
164	8.0	14:00	2.0
191	12.0	17:00	5.0
179	9.7	20:00	4.0

Table 4: Ship corresponding stacking and available stacker

Ship	Stacking	Available stackers
1	(1, 2)	D1, D2, D3
2	(2, 1)	D1, D2, D3, D4, D5
3	(2, 3)	D1, D2, D3, D4, D5
4	(2, 4)	D1, D2, D3, D4 D5
5	(3, 2)	D4, D5
6	(1, 4)	D1, D2, D3

*, *Denotes the row, column of a stacking

Table 5: Scheduling plan of arrived ships

1		2		3		4		5		6	
B2		B1		B3		B1		B2		B3	
-		-		-		-		-		20:00-21:00	
-		-		-		-		17:00-17:20		_	
3:00		8:00		11:00		14:00		17:20		21:00	
X4	3:00-10:30	X1	8:00-13:00	X4	11:00-21:00	X1	14:00-17:20	X1	17:20-1:40	X4	21:00-3:40
X5	3:00-10:30	X2	8:00-13:00	X5	11:00-21:00	X2	14:00-17:20	X2	17:20-1:40	X5	21:00-3:40
X6	3:00-10:30	X3	8:00-13:00	X6	11:00-21:00	X3	14:00-17:20	X3	17:20-1:40	X6	21:00-3:40
D1	3:00-10:30	D4	8:00-13:00	D2	11:00-21:00	D4	14:00-17:20	D4	17:20-1:40	D1	21:00-3:40
D2	3:00-10:30	D5	8:00-13:00	D3	11:00-21:00	D5	14:00-17:20	D5	17:20-1:40	D2	21:00-3:40
10:30		13:00		21:00		17:20		Next day 1:40		Next day 3:40	
7.5h		5h		10h		3.33h		8.67h	7.67h		

-: Indicates that the ship has not this item

In one scheduling period, the sum of stay time for all ships was:

$$7.5\ h+5\ h+10\ h+3.33\ h+8.67\ h+7.67\ h = 42.17\ h$$

Compare the above model with the separate scheduling principle. In the separate scheduling, the number of the shipunloaders the other ship used is ignored which will cause that a ship would not be served after berthing in. The validity of the proposed model and genetic algorithm was verified.

CONCLUSION

The study has focused on the dry bulk cargo port handling operating system. By considering the influence factors, we determined the scheduling strategy of the system. Then the conceptual and mathematical model was developed. Finally, genetic algorithm was designed to solve the integrated model and the numerical example was used to prove the validity of the model.

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