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Research on Integrated Scheduling Optimization of Multi Equipment in Container Terminal

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Abstract. Container transportation is key for cross-border trade, it matters much in global transport. Terminals are system hubs, their loading capacity directly limit transport efficiency and logistics cost. To boost terminal efficiency, this paper first study quay crane scheduling in mixed mode and system scheduling in single mode. We put forward sequence constraints, equipment adjustment time and collision rules, then build integer programming model. We use genetic algorithm and Johnson heuristic to solve these problems. Experiments compare with lower bounds prove the algorithms work well, they can solve large-scale problems too. Based on above research, this paper study mixed-mode system scheduling. We set up integer model, analyze solutions via extended graph and use original sequence search method. We design two-level tabu search algorithm, experiments show mixed mode improve system efficiency far more than single mode.

Keywords: Container terminal, integrated scheduling, loading and unloading mixing

1. Introduction

With international trade growing active, standard containers are safe, cheap and efficient tools, they become main global logistics method [1]. Container ports need badly improve operation capacity to build smooth cargo flow chains. Large ports worldwide keep upgrade hardware facilities, they also try to raise management and decision levels for max efficiency, terminal efficiency mostly depend on loading-unloading system [2]. Optimize equipment scheduling and cut ship operation time can reduce vessel stay time, improve terminal competitiveness, it also increase ship turnover and lower shipping company costs. So good scheduling are vital for container terminals [3]. Container terminals are transport hubs, they finish cargo transfer by loading systems, main equipment include quay cranes, internal trucks and yard cranes, with berths and yards as facilities (see Fig.1).

Terminal operations start when ships berth, quay cranes load export containers to ships or unload import ones to trucks. Yard cranes move containers between trucks and yards, internal trucks transport them between quay and yard cranes [4]. So equipment scheduling is a complex multi-stage operation, each stage have parallel equipment, objects are all ship containers, loading-unloading follow fixed processes. This problem extend production scheduling, it have four key features: Equipment must be in position to work, adjustment time depend on task sequences. There have sequence constraints, like unload before load in the same bay. Adjacent quay cranes can't cross each other and need keep safe distance. No buffer between stages, downstream stagnation cause upstream

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blocking, mixed mode may lead to deadlock. Based on problem focus, this paper first study quay crane mixed scheduling and single-mode scheduling, then research integrated scheduling under mixed mode.

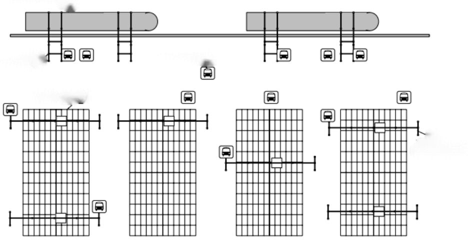

Figure 1. Layout diagram of container terminal

2. Basic assumptions

Disjunctive graph is a common tool for scheduling research, it show resource relations in scheduling clearly. Fig.2 is the traditional disjunctive graph model G=(V,C,D) for simple production system scheduling problems.

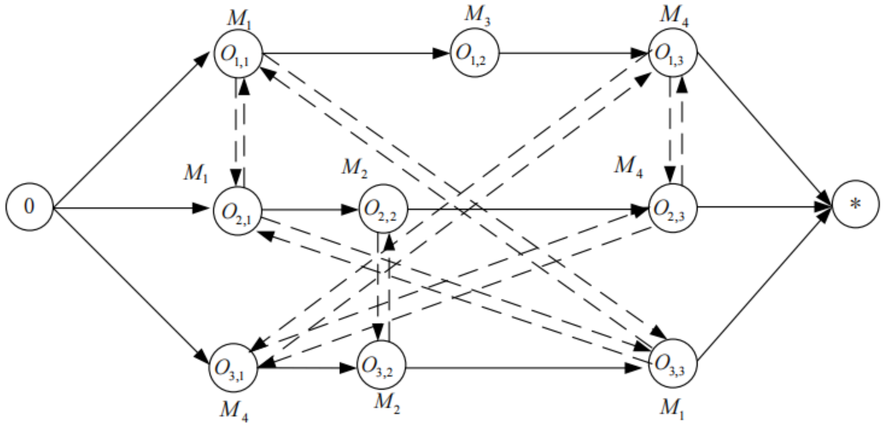

Figure 2. Illustration of traditional disjunctive graph

This model stand for a simple job shop scheduling problem with 4 machines and 3 jobs, their processing sequences are as follows [5]: Job 1: M1 → M3 → M4Job 2: M1 → M2 → M4Job 3: M4 → M2 → M1In disjunctive graph model G=(V,C,D), V is node set, it include all operation nodes and two virtual nodes (source node 0 and sink node *), source node 0 mean job start, sink node * mean job end. Weights of operation nodes are processing time, virtual nodes have zero weight. C is conjunctive arc set, shown as solid lines, they reflect operation sequences: arcs go from node 0 to first operation of each job, and from last operation of each job to node *. D is disjunctive arc set, shown as dashed lines; for any operations O and O′ on the same machine M but different tasks, we need add a pair of arcs OO′ and O′O.

3. Mathematical model fitting

$$\min C_{max} = \max_{j \in J, k=1,3} (C_{j,k}) \tag{1}$$

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$$\sum_{i\in M_k} x_{j,k,i}=1,\forall j\in J,\forall k\in\{1,2,3\} \tag{2}$$

$$C_{j,k+1}-p_{j,k+1}-\min_{j'\in J} s_{j',j,k+1}\geq C_{j,k},\forall j\in J^D,\forall k\in\{1,2\},\forall i\in M_k \tag{3}$$

$$C_{j,k}-p_{j,k}-\min_{j'\in J} s_{j',j,k}\geq C_{j,k+1},\forall j\in J^L,\forall k\in\{1,2\},\forall i\in M_k \tag{4}$$

$$y_{j,j',k,i}\leq 0.5\left(x_{j,k,i}+x_{j',k,i}\right),\forall j,j'\in J,\forall k\in\{1,2,3\},\forall i\in M_k \tag{5}$$

$$0.5\left(x_{j,k,i}+x_{j',k,i}\right)\leq y_{j,j',k,i}+0.5,\forall j,j'\in J,\forall k\in\{1,2,3\},\forall i\in M_k \tag{6}$$

$$y_{j,j',k,i}=y_{j',j,k,i},\forall j,j'\in J,\forall k\in\{1,2,3\},\forall i\in M_k \tag{7}$$

$$z_{j,j',k,i}+z_{j',j,k,i}=y_{j,j',k,i},\forall j,j'\in J,\forall k\in\{1,2,3\},\forall i\in M_k \tag{8}$$

$$z_{j,j',k,i}-u_{j,j',k,i}\geq 0,\forall j,j'\in J,\forall k\in\{1,2,3\},\forall i\in M_k \tag{9}$$

$$C_{j,k}-(C_{j,k}+p_{j,k}+s_{j,k,k})+(1-u_{j,j,k,i})H\geq 0,\forall j^{'},j\in J,\forall k\in\{1,2,3\},\forall i\in M_k \tag{10}$$

$$\sum_{j\in J} u_{j,j',k,i}=x_{j,k,i},\forall j\in J,\forall k\in\{1,2,3\},\forall i\in M_k \tag{11}$$

$$C_{j,k+1}-p_{j,k+1}\leq\left(C_{j',k}-p_{j',k}\right)+H\left(1-u_{j,j',k,i}\right),\forall j'\in J,j\in J^D,\forall k\in\{1,2\},\forall i\in M_k \tag{12}$$

$$C_{j,k-1}-p_{j,k-1}\leq\left(C_{j',k}-p_{j',k}\right)+H\left(1-u_{j',j',k,i}\right),\forall j'\in J,j\in J^L,\forall k\in\{2,3\},\forall i\in M_k \tag{13}$$

$$C_{j,1}-C_{j',1}+\left(1-v_{j,j'}\right)M\geq 0,\forall j,j'\in J,\forall i\in M_1 \tag{14}$$

$$C_{j',1}-\left(C_{j,1}-p_{j,1}\right)+\left(1-v_{j,j'}\right)M\geq 0,\forall j',j\in J,\forall i\in M_1 \tag{15}$$

$$\left(1-v_{j,j'}\right)H\geq\sum_{i\in M_1} i\cdot x_{j,1,i}-\sum_{i\in M_1} i\cdot x_{j,1,i},\forall j,j'\in J,\forall B_j\leq B_{j'}-1,B_j,B_{j'}\in B \tag{16}$$

$$C_{j,k}-p_{j',k}\leq C_{j',k}-p_{j',k},\forall\left(O_{j,k},O_{j',k}\right)\in O^S \tag{17}$$

$$\sum_{j\in J} x_{j,3,i}\leq L_i,\forall i\in M_3 \tag{18}$$

To analyze feasible solution properties, we use disjunctive graph to study terminal equipment integrated scheduling. We can model this problem into disjunctive graph G=(V,C,D,W), as shown in Fig.3.

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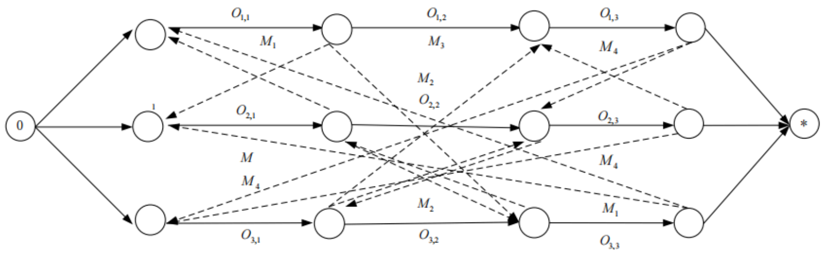

Figure 3. The extended disjunctive model for integrated scheduling problem of container handling system

Node set V include start ti and end hi of each operation i, plus two virtual nodes. C is conjunctive arc set, each arc represent an operation, shown as solid directed lines. D is disjunctive arc set, shown as dashed directed lines. For any two ops i and j on same equipment, add a pair of arcs: hi→tj and hj→ti. W is weight set: conjunctive arcs weight is their operation time, disjunctive ones is equipment adjustment time from continuous work. Rule for choosing disjunctive arcs: delete one from a pair and assign value to the remaining. The graph become a feasible solution for scheduling problem when meet the following conditions.

$$\Delta T = \Delta S_Q + \Delta C_I + \Delta C_Y \tag{19}$$

$$\Delta C_I = \sum_m \Delta t_m \left(\sum_{\Delta t_m, b\in B} \mu_b^I - N_I\right)/N_I - \sum_{m'} \Delta t_{m'} \left(\sum_{\Delta t_{m'}, b\in B} \mu_b^I - N_I\right)/N_I \tag{20}$$

$$\Delta C_Y = min\{\sum_m \Delta t_m (\sum_{\Delta t_m, b\in B} \frac{M_b^D}{M_b} \mu_b^Y - N_Y)/N_Y - \sum_{m'} \Delta t_{m'} \tag{21}$$

$$(\sum_{\Delta t_{m'}, b\in B} \frac{M_b^D}{M_b} \mu_b^Y - N_Y)/N_Y$$

$$\sum_n \Delta t_n \left(\sum_{\Delta t_n, b\in B} \frac{M_b - M_b^D}{M_b} \mu_b^Y - N_Y\right)/N_Y - \sum_{n'} \Delta t_{n'} \left(\sum_{\Delta t_{n'}, b\in B} \frac{M_b - M_b^D}{M_b} \mu_b^Y - N_Y\right)/N_Y\right\} \tag{22}$$

Quay crane's micro-order change affects capacity briefly. Ship bay workload is better: fewer than containers, micro-adjustment has little impact, especially single-mode bays. Local search without quay crane's macro-order needs no recalculation, saving much search time. Realized via C#.Net, tests with terminal data run on Pentium 2.4GHz/512M PC. Scale divided by total containers. Same scale has three groups: All, Half, Partial.

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Table 1. Data in the all group

Size	LB	SDSL	Gap0	mis	mis+ta	Gap1	Gap 2	ran	ran+ta	Gap 3	Gap4
50	5028.2	5526.6	9.9%	5708.7	5535.1	10.1%	3.1%	6140.9	5732.9	14.0%	7.1%
100	10808.2	11967.3	10.7%	12136.7	11842.2	9.6%	2.5%	12922.5	12122.3	12.2%	6.6%
150	15916.8	17701.3	11.2%	18358.9	17634.8	10.8%	4.1%	19001.0	18226.5	14.5%	4.3%
200	22077.0	24338.6	10.2%	24804.2	24223.0	9.7%	2.4%	26173.7	24668.5	11.7%	6.1%
250	27985.0	30935.3	10.5%	32277.0	30710.2	9.7%	5.1%	32878.7	31472.0	12.5%	4.5%
300	34075.4	37104.4	8.9%	38859.9	37186.4	9.1%	4.5%	40525.9	38743.8	13.7%	4.6%
350	41008.1	45263.0	10.4%	46089.9	45195.6	10.2%	2.0%	50143.4	46601.7	13.6%	7.6%
400	47418.1	51631.0	8.9%	53799.9	51680.9	9.0%	4.1%	56398.2	53241.4	12.3%	5.9%
450	54971.9	60114.1	9.4%	62977.5	60012.5	9.2%	4.9%	64129.5	60568.6	10.2%	5.9%
500	60524.5	66365.7	9.7%	70333.4	66540.2	9.9%	5.7%	72961.2	67121.7	10.9%	8.7%
550	70217.0	76816.4	9.4%	80497.8	76178.7	8.5%	5.7%	81894.0	78502.7	11.8%	4.3%
600	77657.3	84773.0	9.2%	90032.6	84848.9	9.3%	6.1%	92960.0	85019.3	9.5%	9.3%
650	87613.2	95317.8	8.8%	101554.6	95437.7	8.9%	6.4%	103676.5	96067.5	9.7%	7.9%
700	98309.0	106812.9	8.7%	112141.7	107107.7	9.0%	4.7%	116764.9	108729.5	10.6%	7.4%
750	108109.1	117191.3	8.4%	124346.2	116559.9	7.8%	6.7%	126728.8	119611.8	10.6%	6.0%

Table 2. Data in the half group

Size	LB	sdsl	Gap0	mis	mis+ta	Gap1	Gap 2	ran	ran+ta	Gap 3	Gap4
50	5124.0	5763.5	12.5%	4321.3	4232.4	-17.4%	2.1%	5243.6	4388.6	-14.4%	19.5%
100	10406.5	11748.5	12.9%	8981.8	8815.3	-15.3%	1.9%	10601.3	8827.6	-15.2%	20.1%
150	16219.4	17218.2	6.2%	14529.4	13771.2	-15.1%	5.5%	16410.2	13831.4	-14.7%	18.6%
200	21695.5	25005.0	15.3%	19519.1	18643.0	-14.1%	4.7%	22760.3	19291.7	-11.1%	18.0%
250	27812.7	29845.1	7.3%	25320.2	24511.4	-11.9%	3.3%	27818.7	24247.2	-12.8%	14.7%
300	35245.9	38490.0	9.2%	33322.7	31760.2	-9.9%	4.9%	37495.0	32806.9	-6.9%	14.3%
350	41650.7	45784.9	9.9%	39077.9	37614.8	-9.7%	3.9%	43500.6	38564.2	-7.4%	12.8%
400	49126.5	54114.6	10.2%	46928.5	45093.3	-8.2%	4.1%	52228.7	46574.2	-5.2%	12.1%
450	49854.5	55788.4	11.9%	48913.5	46668.7	-6.4%	4.8%	53462.2	48264.2	-3.2%	10.8%
500	66155.2	71841.9	8.6%	66235.6	62510.1	-5.5%	6.0%	71001.6	64646.8	-2.3%	9.8%
550	69585.1	74135.9	6.5%	69730.5	66321.7	-4.7%	5.1%	77028.5	70287.2	1.0%	9.6%
600	77727.0	85079.2	9.5%	83163.1	77628.2	-0.1%	7.1%	84683.9	77027.1	-0.9%	9.9%
650	87670.9	95484.1	8.9%	92949.0	87031.0	-0.7%	6.8%	97658.4	89792.5	2.4%	8.8%
700	98647.3	110191.1	11.7%	105940.1	100028.9	1.4%	5.9%	111487.4	103767.3	5.2%	7.4%
750	109037.1	119207.8	9.3%	118804.8	110825.4	1.6%	7.2%	123703.7	114434.7	5.0%	8.1%

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Table 3. Data in the partial group

Size	LB	sdsl	Gap0	mis	mis+ta	Gap1	Gap 2	ran	ran+ta	Gap 3	Gap4
50	5155.3	5868.8	13.8%	4890.2	4684.0	-9.1%	4.4%	5615.9	4633.5	-10.1%	21.2%
100	10548.8	11721.6	11.1%	9511.3	9154.2	-13.2%	3.9%	10896.0	9536.1	-9.6%	14.3%
150	16029.8	18057.2	12.7%	14781.8	14393.2	-10.2%	2.7%	17401.0	14795.1	-7.7%	17.6%
200	21834.3	23968.8	9.8%	20443.3	19810.9	-9.3%	3.2%	22958.6	19976.2	-8.5%	14.9%
250	27957.4	31505.0	12.7%	27150.4	26344.3	-5.8%	3.1%	32193.7	27037.7	-3.3%	19.1%
300	34442.0	38110.5	10.7%	33664.4	32385.1	-6.0%	4.0%	36771.0	33109.1	-3.9%	11.1%
350	40677.0	45006.8	10.6%	41763.5	40091.7	-1.4%	4.2%	45617.3	41022.8	0.9%	11.2%
400	47231.9	51726.9	9.5%	51184.4	48696.4	3.1%	5.1%	52623.1	47864.7	1.3%	9.9%
450	54393.9	58780.4	8.1%	55332.5	53230.0	-2.1%	4.0%	60319.6	54975.9	1.1%	9.7%
500	66931.2	73389.0	9.7%	71582.1	66650.3	-0.4%	7.4%	74083.3	68223.0	1.9%	8.6%
550	69974.3	76654.3	9.6%	74523.8	71478.9	2.2%	4.3%	80100.6	73480.0	5.0%	9.0%
600	78616.3	84511.9	7.5%	86306.5	81737.4	4.0%	5.6%	90241.3	83820.7	6.6%	7.7%
650	88241.0	96997.5	9.9%	96471.8	92424.8	4.7%	4.4%	101046.0	94453.2	7.0%	7.0%
700	97549.9	105591.5	8.2%	102636.9	99688.2	2.2%	3.0%	112977.4	104251.6	6.9%	8.4%
750	110184.9	119443.0	8.4%	118992.7	114571.3	4.0%	3.9%	125554.1	116696.8	5.9%	7.6%

Table 4. Comparison of calculation time

Size	mis+ta (s)	ran+ta(s)
50	15.9	18.4
100	58.5	79.3
150	139.7	120.4
200	244.6	294.1
250	308.1	406.9
300	434.8	513.7
350	651.3	665.5
400	892.8	1046.2
450	1077.3	1297.3
500	1324.1	1574.6
550	1752.2	1720.1
600	2261.9	2605
650	2711.9	3388.6
700	3533.8	4010.7
750	4532.4	4974.5

Main part of total ship operation time is fixed. As problem scale grow, percentage gaps between optimal solution, lower bound and single-mode solution inevitably shrink. But saved time is still notable. In Half group, 750 containers save over 8000 seconds via dual-cycle. Partial group also has average saving exceed 4000 seconds.

4. Conclusion

This paper study container terminal integrated scheduling, mainly model and solve quay crane scheduling with genetic algorithm, single-mode scheduling via JLS algorithm (gap ≤5% for big scales), and dual-cycle scheduling with two-level tabu search, tests prove mixed mode better;

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terminal scheduling is a hot topic, future research focus on truck assignment-path integration, mixed yard storage, automatic terminal scheduling (new tech like high-low bridges bring new needs) and mixed-operation theoretical extension, which help other scheduling problems.

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