

Cooperative Optimization of Yard Crane Deployment and Truck Appointment Based on Two-way Transmission of Information

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Abstract: The truck appointment system has been widely applied in the terminal consolidation and configuration process. The “appointment-to-scheduling” mode of the traditional appointment mechanism causes the one-way transmission (from trucker to terminal information platform) of scheduling information. Based on this situation, this paper presented a new mechanism of truck appointment-the co-appointment, which integrated the truck appointment process and the dynamic deployment of yard crane. In co-appointment, information of yard crane deployment and terminal busy level will be fed back to the truck drivers to support their decision making. A bi-level hybrid genetic algorithm was developed to optimize yard crane deployment. Comparing with traditional appointment mechanism and quota-based appointment mechanism, the experimental results demonstrated the effectiveness and robustness of co-appointment on flattening the peak working and decreasing the turnover time of trucks.

1. Introduction

Yard cranes are the bottleneck resource of container terminal operating system. Reasonable crane allocation and deployment scheme can significantly enhance the terminal's container turnover capability and save queuing time. The arrival time of truck is in the form of non-stationary during the period of consolidation and configuration, mainly as follows: during peak hours, yard cranes are overloaded; during off-peak hours, yard cranes are idle. So that resource is underutilized. Taking advantage of clear and accurate truck appointment which can obtain the specific arrival time of appointed trucks is the essential to optimize yard crane resource allocation information. Nowadays, mobile Internet technology is developing rapidly, based on the balance of trucks arrival time and the

rational allocation of yard crane resource, co-appointment is established with the solution of yard crane deployment which promotes to change the traditional operation mode.

Many scholars have made a lot of researches on the establishment of the programming model and the algorithm development. A two stage yard crane workload partitioning and job sequencing algorithm for container terminals(Guo, X. and Huang, S Y. 2012) developed a two stage algorithm yard crane resource configuration. Experimental results showed that the proposed algorithm had higher computational accuracy and lower time complexity. Dynamic Space and Time Partitioning for Yard Crane Workload Management in Container Terminals(Guo, X. and Huang, S Y. 2012) proposed a time-division algorithm and a space-division algorithm for yard crane to optimize the average waiting time of the truck for the dynamic resource scheduling problem.

There are also a lot of research reports in the field of appointment optimization. Time appointment mode and congestion charging are the main research objects, and queuing theory analysis model and simulation model become the main tools to describe the container terminal operating system. Based on the unsteady queuing theory, Using time-varying tolls to optimize truck arrivals at ports(Chen et al. 2011)established a two-stage model to optimize the truck arrival and congestion charges respectively; Optimization model for appointment of container trucks with non-stationary arrivals(Xu et al.2014) used non-stationary queuing theory and backlog post-stationary estimation method to develop a truck booking strategy, established a multi-objective optimization model for gate-to-yard two-phase terminal truck appointment and designed an improved NSGA-II algorithm to solve the model. A model and its algorithms for truck congestion toll at container terminals(Zeng et al.2015) solved the optimal congestion charging amount on the premise of considering the game relationship among the terminal operators, truck drivers and the government.

The above-mentioned papers related to yard crane deployment mostly focus on the improvement of algorithm. Traditional truck appointment is employed as a framework to optimize period quotas and time-varying charges, which did not consider the yard crane configuration and truck booking collaborative optimization. In this paper, the allocation and deployment for yard crane is dynamically integrated into the appointment process. The appointment process is completed synchronously with the allocation optimization of yard crane resource and a two-layer hybrid genetic algorithm is developed to solve the resource optimization problem.

2. A New Mechanism of Truck Appointment

Drivers are most concerned about the queuing time at the gate and the waiting time inside the terminal. If they can get the estimated turnover time within the expected arrival period, they can get an auxiliary decision on the appointment. Based on the Simulation Optimization of Consolidation and Configuration in Container Terminals Based on Cooperative Appointment(Shao et al.2016), this paper presented the co-appointment embed the yard crane scheduling optimization process into the simulation process of turnover time. The core of the co-appointment is information sharing and feedback,the operation includes:

In the first stage, the trucker decides the expected arrival period which is a subinterval of the scheduling horizon. Then trucker makes the appointment to the terminal information platform,

including the vehicle information, operation information (empty/heavy containers delivery and empty/heavy container pickup) and other information, and gives the expected arrival period.

In the second stage, after receiving the driver's request and related information, terminal information platform calculate the turnover time over his expected arrival period using a simulation system. As an output, turnover time function is fed back to the trucker to support his decision-making (as shown in Figure 1).

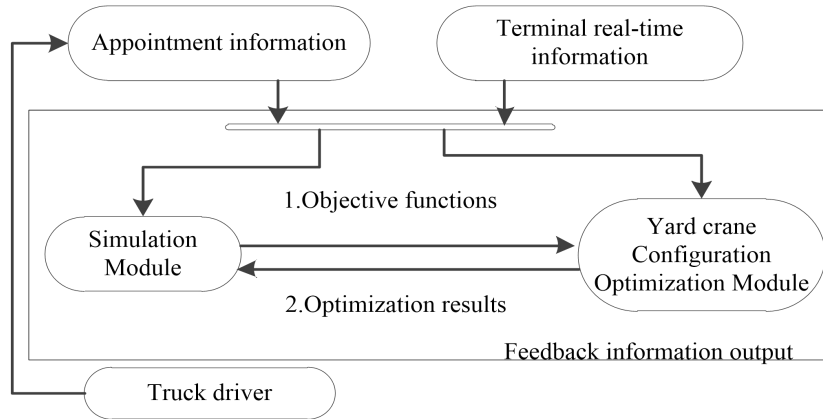


Figure 1: Flow-logics for turnover time estimating.

In the third stage, the driver receives feedback, determines the arrival time referring to the feedback, and finally submits to the terminal information platform to end the appointment.

Set i_n as the truck n , which is expected to arrive at the period of $[T_n^1, T_n^2]$, then the function $y = f(t)$, $T_n^1 \leq t \leq T_n^2$ means the turnover time of i_n from arrival to departure. The turnover time is the valuation resulting from the combined deployment optimization algorithm. Theoretically, y is a continuous function, but considering the cost of time, we discretize the expected arrival period. In the interval of $[T_n^1, T_n^2]$, we use T_n^1 as the initial point, constant σ as the equal interval to select a number of discrete moments, and then put it into the simulation model to calculate the turnover time $f(t)$. The time point corresponding to the minimum value y is used as the appointment arrival time. If the minimum are not unique, then choose the smallest one of those.

In the second step of the co-appointment, the container terminal platform adds the optimized appointment algorithm to the simulation of the turnover time of the truck. In other words, whenever a new external truck is scheduled to arrive, it will trigger the yard crane resource allocation algorithm and push the simulation results containing the optimization scheme to the truck driver. Usually, drivers in the co-appointment tend to choose the shorter turnover time in the expected arrival period as the appointing arrival time, so based on the profitability, the system reduces the peak operation effectively. Based on the updated appointment information, the optimization algorithm also constantly updates and optimizes yard crane resource allocation and scheduling scheme.

3. Optimization Modeling and Algorithm

In the whole operation process, the total amount of tasks undertaken by different blocks is different, and the arrival time of external trucks corresponding to the tasks assigned by each blocks is also unbalanced, which makes the blocks have a strong dynamic demand for yard crane equipment.

In the co-appointment mechanism, the yard crane configuration scheduling is a continuous optimization problem. The time dimension cannot be discretized intuitively, or the scheduling horizon cannot be divided into time intervals with equal length, so the main consideration of this paper is the optimization of the allocation of equipment in different working paths based on the assignment of the yard crane task section and the time section within the same working path. Taking the block as the minimum optimization unit, the decision variables are divided into two parts: the yard crane deployment and the corresponding time interval deployment. The assumptions are as followed:

- (1)The maximum number of yard cranes is 2 assigned to each block;
- (2)The interference of two cranes working in one block is not considered;
- (3)All the blocks use rubber-tired gantry crane, which can be arbitrarily dispatched in different blocks.

Since this problem has been proved to be NP-Hard problem, using the traditional exacting algorithms will cost a lot. Therefore, this paper designs a bi-level hybrid heuristic algorithm based on genetic algorithm to solve the problem. The upper layer algorithm (outer loop) iteratively calculates the block configuration of corresponded yard crane, and the lower layer algorithm (inner loop) iteratively calculates the time interval assignment problem of corresponded yard crane resource.

Set d_n as the departure time of i_n , A_n as the appointed arrival time of i_n . The objective function is to minimize the total turnover time of external trucks, that is:

$$\min P = \sum_{n=1}^N (d_n - A_n) \quad (1)$$

Figure 2 shows the flow chart of the algorithm. In this paper, the simulation model calculates the inner and outer layer algorithm fitness function values combined with algorithm optimization techniques.

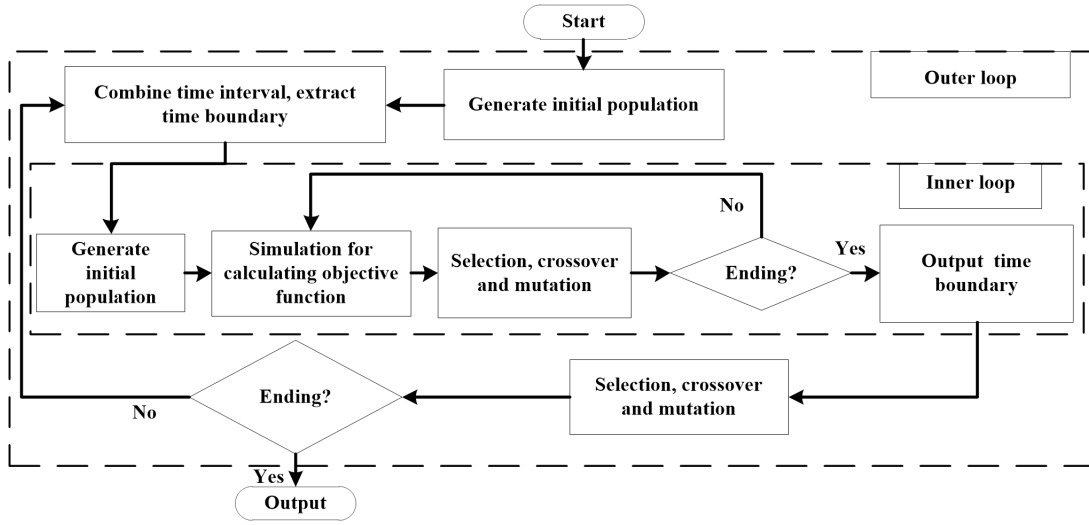


Figure 2: Flowchart of bi-level hybrid GA.

As mentioned above, the yard crane deployment for blocks belongs to the discrete optimization problem, but the time interval deployment based on the block assignment belongs to the continuous optimization problem. In the outer layer algorithm, this paper first describes these two problems by discrete data structure coding clearly, and then makes the discrete solution coding to continuity in the inner layer algorithm. Considering an example of time-window appointment mode (as shown in Figure 3), the scheduling horizon is 12hrs, the duration of the interval is 1h, and 4 blocks share 4 yard cranes. The scheduling horizon is equally divided into 12 subintervals at intervals of 1h. Each block is assigned with a real number corresponding to each subinterval, representing the number of yard cranes allocated to this block during this time interval. The total number of blocks is E , the total number of subintervals is F , the number of the matching yard cranes of the block e in the f sub-interval is ar_{ef} , there are constraints:

$$\sum_{e=1}^E ar_{ef} \leq J \quad f = 1, 2, \dots, F. \quad (2)$$

$$ar_{ef} \leq 2 \quad e = 1, 2, \dots, E; f = 1, 2, \dots, F. \quad (3)$$

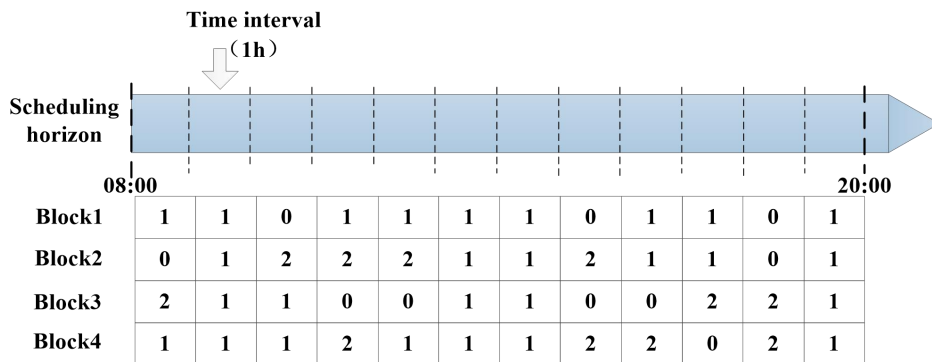


Figure 3: Solution coding of outer algorithm.

Considering the algorithm based on the co-appointment, because the appointment is not time-based, dividing the scheduling horizon into several equivalent time periods is contrary to the actual arrival condition. Therefore, if this algorithm is used in co-appointment, the extension adjustment needs to be performed on the time period. In other words, what needs to be decided is the resource allocation scheme for each block in continuous time periods. Therefore, the outer coding algorithm needs some conversion, and the first step is the merging of subintervals.

As shown in Figure 4, we merge the subintervals deployed with the same number of cranes in each block, then extract and transform the demarcation point to form an encoding of the inner layer algorithm. After the boundary is extracted, each block corresponds to a vector whose dimension is the combined number of boundaries of the current block, and the value is the time of the boundary. The coding of the inner algorithm becomes a combination of E vectors. Suppose the boundary number of e is bn_e , where the time value of the first b border is bu_b^e , and the inner loop coding can be expressed as a vector group:

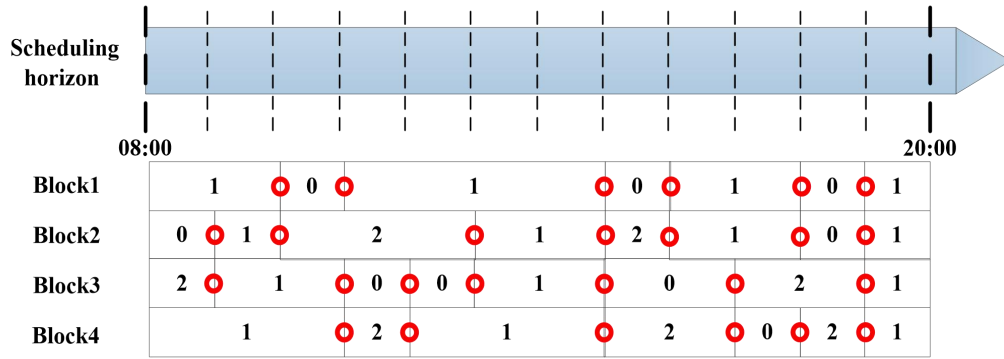


Figure 4: Solution coding of inner algorithm.

$$\begin{aligned}
 & [bu_1^1, bu_2^1 \cdots, bu_{bn_1}^1] \\
 & [bu_1^2, bu_2^2 \cdots, bu_{bn_2}^2] \\
 & \vdots \\
 & [bu_1^E, bu_2^E \cdots, bu_{bn_E}^E]
 \end{aligned} \tag{4}$$

In the iterative calculation of the algorithm, the case that the total number of scheduling yard crane surpasses the total number of the available will appear the inner loop coding, which is the unfeasible solution breaking the constraint condition (2), and the situation can be avoided by changing the decoding rules. Suppose the matching number of yard cranes at the time of t in the

scheduling horizon is ar_{et} , when $\sum_{e=1}^E ar_{et} > J$, t must be an element value (the time when the number of scheduling yard cranes increases or decreases) in formula (4).

The situation is also that the boundary corresponding to an element in E_t^1 is advanced. If the yard crane currently involved in E_t^0 is idle, the border is advanced to the moment t and the crane is moved to the block involved in E_t^1 .

For the initial solution, each column of the solution coding in outer layer algorithm is randomly generated. The inner layer algorithm generates an initial population by adding a random perturbation value θ to each boundary value for the same set of vectors.

Crossover operator: The outer algorithm uses two-point crossover, and the inner one uses arithmetic crossover, where the linear parameter α takes 0.5, and rearranges each vector of children individuals in ascending order (the purpose is to eliminate infeasible solution when $bu_{b+1}^e > bu_b^e$ happens).

Mutation operator: The outer layer algorithm uses traditional mutation methods to randomly access each column and adjust the value of each dimension of the vector under the premise of ensuring the total number of cranes; the inner algorithm still use the method of adding a random disturbance value θ to each boundary value. Roulette is used as selection operator.

According to the ideas above, the resource allocation scheme is updated with the submission of each truck driver's appointment, and after the appointment is completed, the optimization scheme is formed. Due to the drivers submit the exact time in the co-appointment, there will be deviation from their arrival time. Therefore, it is necessary to dynamically re-schedule the deployment in order to update the optimization deviation generated by the original scheme during the operations.

4. Numerical Experiment

As comparative strategies, the traditional appointment mechanism (TAM) and the equivalent appointment mechanism (EAM) are selected for experiments. The simulation period is from 0:00 to 12:00. The experimental setting of the 3 mechanisms is as follows:

(1) The TAM: The terminal makes no hard demand to truck drivers about arrival time. The actual arrival time of each truck obeys the average distribution in $[T_n^1, T_n^2]$;

(2) The EAM: The upper bound of trucks allowed to reserve for the time period is 25 (vehicles). According to the random order, the truck driver makes an appointment in turn, and the time period with the highest coincidence degree with the expected arrival period in the optional time period (the time period with vacancy) is regarded as the appointment period. The arrival time subjects to the hypodispersion in the time period;

(3) The co-appointment: As the actual arrival time of the truck deviates from the scheduled arrival time, the error radius ε is assumed to be 15 min, and the arrival time subjects to the hypodispersion in $[A_n - \varepsilon, A_n + \varepsilon]$.

Among basic parameters of numerical experiments, there are 300 trucks, 8 blocks, 8 yard cranes, 4 gates and 40 parking spaces. One block allows the maximum number of parking trucks is 7. The interval length is 180 minutes, and $(T_n^1 + T_n^2)/2$ subjects to a normal distribution with an expectation of 6:00 (simulation time) and a variance of 120 minutes. The time for handling passing formalities follows a negative exponential distribution with a parameter of 0.35 from Planning local container drayage operations given a port access appointment system (Namboothiri R. and Erera A L. 2008). Confirm shapes and select desired values. And the working time of single block is subject to general distribution with a parameter of 0.332. The upper limit of container quantity for each truck is 2 that random generate with equal probability. Confirm shapes and select desired values. The traffic congestion from gate/parking lot to the yard is not considered in the assumptions, and driving time assumes 150 seconds.

In order to verify the effectiveness of the algorithm, this paper respectively takes 6 kinds of combination optimization schemes for comparison. The waiting time estimation of algorithm A2

and A3 in the equivalent appointment mode uses the simulation model from Simulation Optimization of Consolidation and Configuration in Container Terminals Based on Cooperative Appointment (Shao et al. 2016), and the arrival time subjects to the hypodispersion of the time window.

Scheme A1 is the equivalent appointment mode under the original strategy A multiple-crane-constrained scheduling problem in a container terminal(Bish E K.2003) without adding yard crane scheduling optimization ,when scheme A4 is an original strategy of the co-appointment. Scheme A2 is a static optimization of yard crane initial dispatch using the proposed algorithm in this paper under the equivalent appointment mode. Scheme A3 regenerates deployment scheme at the beginning of each subinterval to form a dynamic scheduling based on the A2. Scheme A5 is a static optimization of yard crane initial dispatch using the proposed algorithm in this paper under the co-appointment mode. Scheme A6 regenerates deployment scheme at the beginning of each subinterval to form a dynamic scheduling based on the A5.

In this paper, we plan to use a plane layout with 8 blocks parallel distributed in 2 rows, then the yard is divided into 2 sections and each section contains 4 blocks. The yard crane transition time is set to 0.4h (1440s). The moving speed is set to 2m/s. The basic information for yards is as follows: There are 8 blocks, each block has 12 bays with 6 meters wide, and the interval of blocks is 18 meters (3bays). Since there is a truck flow in the interval area, we estimated the travel distance to 10 bays (60m).

Table 1 shows the comparison of six algorithms. It can be seen that, regardless of it is based on the segment appointment mode or the co-appointment, applying yard crane resource allocation algorithm is significantly better than the original strategy on all indexes, and the optimization rate is about 20%. In the two modes, In the two modes, based on the application of static optimization scheme, a dynamic optimization algorithm based on decision-making point is adopted, which corrects the prediction deviation of the simulation model for the arrival of external trucks. Using the real-time data to re-schedule the resource deployment scheme, the key indicators such as the average waiting time have been reduced by about 11% as well.

Table 1: Comparison of results.

Group	A1	A2	A3	A4	A5	A6
ANTSPL	9.75	7.80	6.86	3.25	2.60	2.49
ALQG 1	0.04	0.03	0.03	0.04	0.03	0.03
ALQG 2	0.04	0.03	0.03	0.04	0.03	0.03
ALQG 3	0.04	0.04	0.03	0.04	0.03	0.03
ALQG 4	0.04	0.03	0.03	0.04	0.03	0.03
ALQY 1	1.33	1.09	0.94	1.42	1.14	1.06
ALQY 2	1.53	1.27	1.08	1.89	1.51	1.33
ALQY 3	0.66	0.53	0.46	0.70	0.56	0.47
ALQY 4	0.81	0.75	0.57	0.87	0.70	0.60
ALQY 5	1.57	1.26	1.11	1.88	1.50	1.35
ALQY 6	0.21	0.16	0.15	0.34	0.27	0.24
ALQY 7	0.17	0.15	0.12	0.28	0.22	0.20
ALQY 8	0.14	0.13	0.10	0.22	0.18	0.16
ETWTM	1603.88	1383.10	1129.13	709.15	567.32	519.24
ANTT	13.11	11.49	9.23	7.64	6.11	5.88

Notation: ANTSPL: Average number of trucks staying at the parking lot;
 ALQG1: Average length of queue at gate1 (vehicles / second);
 ALQY1: Average length of queue at yard1 (vehicles / second);
 ETWTM: External truck waiting time mean(s);
 ANTT: Average number of trucks in terminal.

Figure 5 shows the curves about vehicle number in terminal. A2 and A5 use the same algorithm, while A3 and A6 use the same algorithm. It can be clearly seen from the figure that the two strategies adopting the co-appointment have a smaller number of trucks at terminal compared with the two strategies adopting the equivalent appointment mode, and obviously smooth the work peak. The overall task is also more evenly distributed in the scheduling horizon. In addition, the co-appointment has higher overall turnover efficiency and greatly reduces the truck waiting time at terminal.

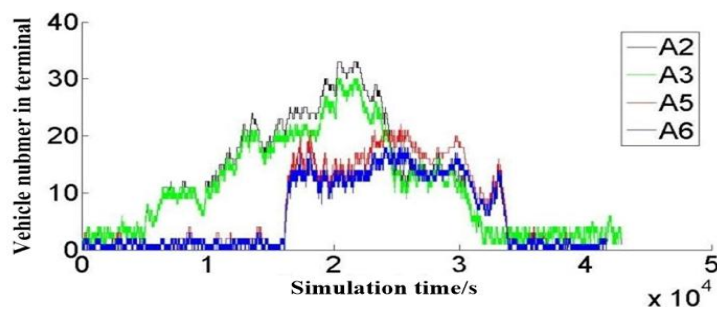
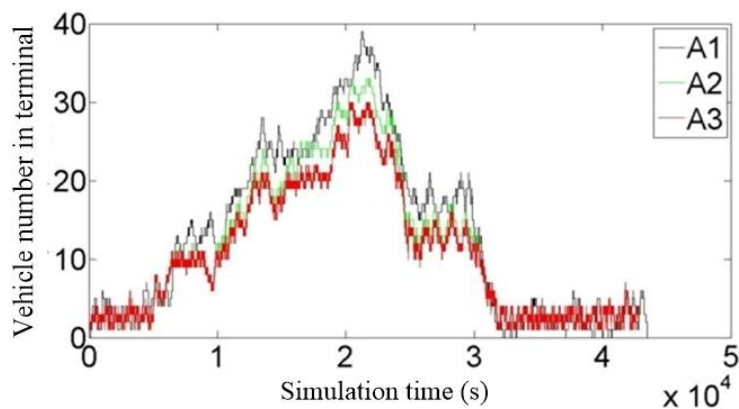


Figure 5: Comparison of curves recording vehicle number in terminal.

Figure 6 describes curves recording vehicle number in terminal for three different optimization strategies in two appointment modes. It can be seen that compared with the original strategy, algorithms A2 and A5 show significant advantages in overall simulation process with a high turnover rate both in peak and valley. Compared with algorithms A2 and A5, though the algorithms A3 and A6 presented a slightly higher number of trucks at terminal during the work valley after the dynamic deployment optimization strategy was added, there was a significant drop in peak hours, which proves that the dynamic optimization strategy can rectify the arrival deviation and has the better effect of balancing work peak.



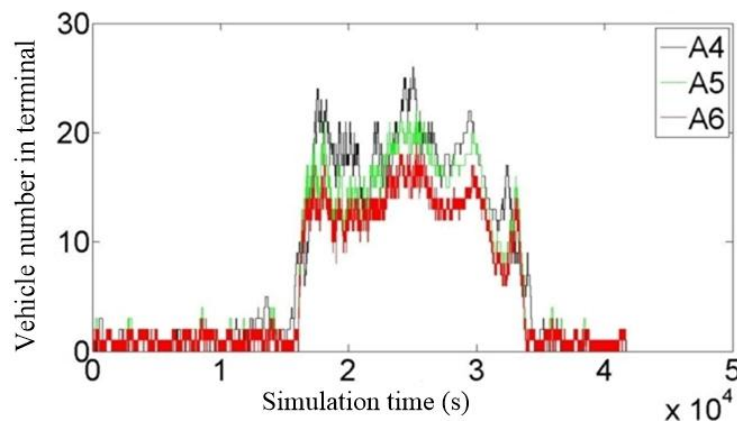


Figure 6: Comparison of curves recording vehicle number in terminal.

5. Conclusions

In this paper, the optimization of yard crane resource allocation is integrated with the truck appointment mechanism. Firstly, based on the interconnection of terminal and truck information, co-appointment is proposed. Secondly, in order to optimize the resource allocation and deployment, the simulation mathematical model built in Simulation Optimization of Consolidation and Configuration in Container Terminals Based on Cooperative Appointment(Shao et al.2016) is adopted and a two-layer hybrid genetic algorithm is developed to solve the problem. This paper embeds it in the co-appointment and outputs the optimal deployment of the yard crane at the same time as the appointment is completed. Through a series of numerical experiments, with the comparison with the traditional appointment mode and the equivalent appointment mode, this paper shows the validity of the co-appointment which integrates the yard crane resource allocation.

Acknowledgments

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