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MULTI AGV SCHEDULING PROBLEM IN AUTOMATED CONTAINER TERMINAL

Jian Jin^{1,2} and Xiao-Hua Zhang³

Key words: automated container terminal, dynamic scheduling, multi AGV scheduling, genetic algorithm.

ABSTRACT

In this paper we propose a dynamic multi automated guided vehicle (AGV) scheduling method based on the scheduling properties of automated container terminal handling systems. In multi-AGV scheduling, the composition of AGV handling time and the precedence order of certain tasks are major constraints. Taking these into consideration, we design a genetic algorithm (GA) for a dynamic multi-AGV scheduling model to minimize completion time and standard deviation of handling time of quay cranes (QC), and validated the proposed model through numerical experiment. We expect this model to be significant for multi-agent scheduling of discrete production systems.

I. INTRODUCTION

Automation of container terminals has been a popular field of research in recent years. Mi et al. proposed a ship identification algorithm to identify cargo ships automatically (Mi et al., 2015) and a fast human-detection algorithm to supervise the unmanned surveillance areas in automated container terminals (Mi et al., 2014). Further research into human detection in automated container terminals (Mi et al., 2015) has been significant. Zhao et al. (2015) proposed a workflow-based vehicle-mounted task control system. This research provides hardware and modeling support for automated container terminal management and design. Another important area of research is algorithms in the handling process.

The horizontal transportation handling process connects quayside and container yard operations, the efficiency of which affects significantly the total handling efficiency of the container terminal. The major concern of horizontal transporta-

tion is the scheduling problem.

Scheduling of AGVs or trucks can be divided into static scheduling and dynamic scheduling based on the trigger mechanism. Static scheduling assumes that the arrival time of tasks and the travel time of vehicles are definite or can be predicted precisely; thus, the entire schedule can be calculated in advance. Dynamic scheduling assumes that arrival time and travel time cannot be predicted precisely, which is more in line with the actual situation in most automated container terminals. Thus, the scheduling is performed sequentially during the handling operation.

Static scheduling can create an overall coordinated arrangement of different sequences in the container terminal handling system to optimize the total operation efficiency. Dkhil et al. (2013) researched combination scheduling of handling equipment in automated container terminals to minimize the number of AGVs needed. Rashidi and Tsang (2011) proposed an AGV scheduling model based on the minimal flow model. Kim and Bae (2004) proposed an integer programming model of static AGV scheduling in automated container terminals minimizing the total delay time and total travel cost of AGVs. Zhang et al. (2005) developed a vehicle scheduling model based on a fixed quay crane handling sequence, minimizing QC waiting time. Lee and Tan (2010) proposed a mixed integer programming model of vehicle scheduling for large transfer terminals, taking QC and yard crane (YC) operational capability into account, which minimized the maximum task completion time. Chen and Lu (2013) proposed a constraint optimization model for combination scheduling of QC, YC, and vehicles in container terminals. Angeloudis and Bell (2010) proposed a rolling horizon strategy to solve the AGV scheduling problem under uncertain circumstances, in which the scheme of a given period is scheduled based on the implementation of the previous period. Moussi et al. (2012) and Le et al. (2012) proposed a model for straddle carrier scheduling for the same kind of container terminal, solved with different algorithms. Nguyen and Kim (2009) proposed a mixed integer programming model for AGV scheduling, minimizing handling delay and total AGV travel time.

In dynamic scheduling, a new scheduling process is triggered to allocate a vehicle to an unassigned task when a new task arrives or a task is finished. Jing and De (2006) proposed a scheduling strategy combining QC task queue balancing and

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nearest-first scheduling; this strategy was verified and validated using simulation. Jing (2010) proposed a dynamic vehicle scheduling model based on the rolling horizon strategy and solved with a GA. Cheng and De (2008) proposed a multi-objective fuzzy decision method to solve dynamic vehicle scheduling problems in face operation mode and gave a small scale numerical example. Zheng and De (2006) proposed a combined dynamic optimization method for vehicle scheduling between multiple QCs. Briskorn et al. (2006) developed a real-time scheduling method based on actual inventory to solve multiple QC AGV scheduling in automated container terminals. Simulation showed that taking AGV job finish time into consideration improves the total handling efficiency of container terminals (Briskorn and Hartmann, 2006). Grunow et al. (2005) proposed a dynamic scheduling method considering an AGV capable of carrying two 20 feet containers simultaneously; static and dynamic scheduling were compared using simulation (Grunow et al., 2006). de Koster et al. (2004) compared different dynamic scheduling methods in container terminals using simulation, finding that handling processes with traveling distance considered performed better than other scheduling methods.

To summarize, previous research on vehicle scheduling in container terminals has several flaws:

- (1) Static scheduling is not suitable for vehicle scheduling in container terminals. A container terminal is a large discrete system with plenty of uncertainty affecting its handling process. Static scheduling allocates all jobs before handling, so it cannot adapt to changes in the situation.
- (2) Global optimization is hard to achieve. Most previous research focused on allocating a job for a single vehicle at a time, which often leads to local optimization. Research in the field of dynamic multi-vehicle scheduling is rare.

Dynamic multi-vehicle scheduling is developed to avoid falling into local optimization. It needs precise predictions of handling time consumption in order to allocate following jobs. Because AGVs in automated container terminals have less interference than trucks in traditional container terminals, it is much easier to predict the remaining handling time for the current task of an AGV to make this method practical. In this paper, we develop a dynamic multi-vehicle scheduling strategy based on previous research to globally optimize QC efficiency and better QC balancing.

II. PROBLEM DESCRIPTION

1. Overview





Dynamic multi-AGV scheduling problem refers to allocating tasks for multiple AGVs simultaneously at a certain time to optimize handling efficiency and balance.

2. AGV Job Sequence

In practice, an AGV is scheduled based on an AGV job

Table 1. AGV job sequence example.

AGV	Remaining tasks	Current task finish time estimation (s)
1	0	0
2	1	80
3	1	120
4	1	223
5	1	340
6	2	621

-  AGV handling time of remaining task
-  AGV travel time from current position to QC
-  Waiting time of AGV
-  Handling time

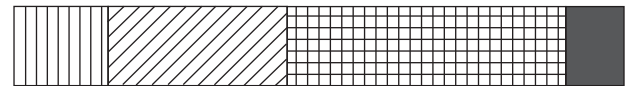


Fig. 1. Composition of AGV handling time in dynamic multi-AGV scheduling.

sequence, which is sorted by current task finish time. Table 1 shows an example of an AGV job sequence.

The remaining tasks have a sequential order; thus, multi-AGV scheduling must be dynamic and based on job sequence. To do this, the job allocation time and the number of AGVs allocated must be defined.

As for traditional single-AGV scheduling, the job allocation time should be the time the AGV finishes all its current tasks, to prevent AGV capability waste. Because the current task finish time in the AGV job sequence table is estimated, the time estimate for AGVs lower in the table tends to have more error. To prevent over-allocation, that is, allocating excessive AGVs ahead of schedule, the AGVs allocated to new tasks should be AGVs with 1 or fewer remaining tasks. For the example in Table 1, AGVs 1-5 should be scheduled at this time.

3. Properties of Dynamic Multi-AGV Scheduling

Since dynamic multi-AGV scheduling allocates job for multiple AGVs simultaneously, the AGV handling time differs from traditional single AGV scheduling, which in turn affects the QC handling time.

Fig. 1 shows the components of AGV handling time.

In addition, the sequential order of the tasks must be considered in the scheduling process. In fact, the sequence of tasks in the handling process in container terminals is defined before the handling process. Thus, the following constraints must be satisfied:

- (1) Tasks must be allocated in sequence.
- (2) A task can be allocated only when its predecessor has been allocated.

Table 2. QC task sequence.

Task sequence	Predecessor task
1	/
2	1
3	2

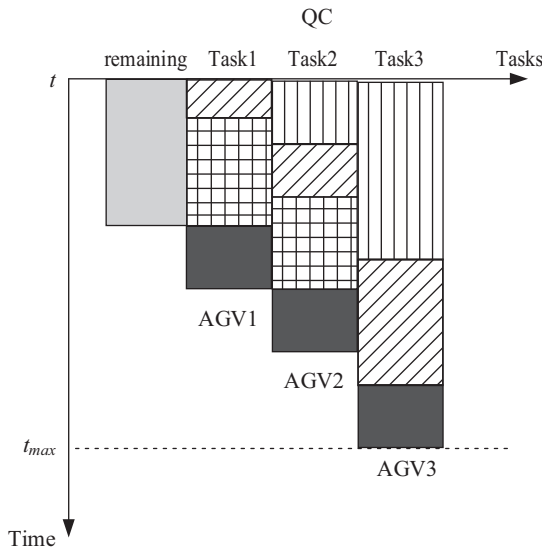
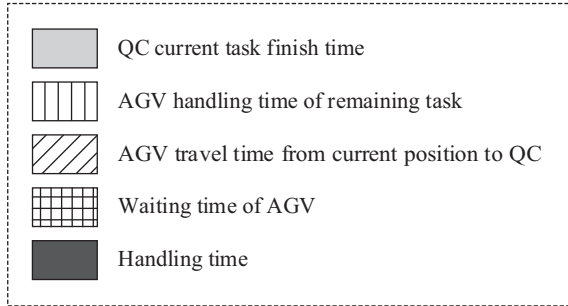
**Fig. 2. Gantt chart of dynamic multi-AGV scheduling.**

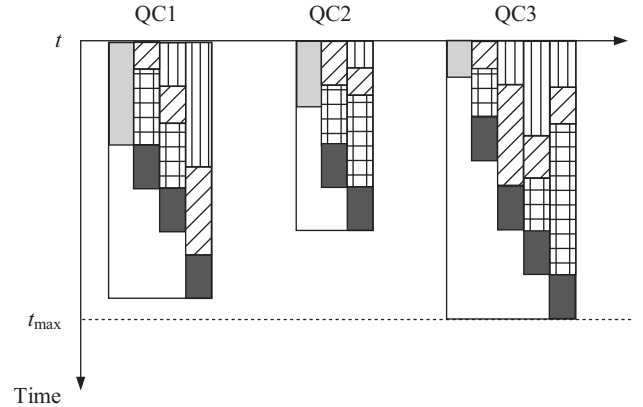
Table 2 shows a task sequence of a QC with predecessor tasks. Fig. 2 shows a feasible AGV scheduling plan for this task sequence. The effects of AGV handling time composition can be seen in Fig. 2, and t_{\max} is the QC finish time in this scheduling plan.

Considering these properties of the problem, the solution for scheduling n AGVs at time t is to find a schedule minimizing the completion time t_{\max} and standard deviation of handling time of multiple QCs which satisfies the actual constraints. Fig. 3 shows a feasible solution to a 7 AGV scheduling problem.

III. MODELING

1. Model Assumptions

We make the following assumptions:

**Fig. 3. Feasible solution to an AGV scheduling problem.**

- The QC handling time of each task is only related to the task, and not relevant to the handling equipment.
- There is no failure of the handling equipment.

2. Adaptive Equalization

- Dimensions

i : represents AGVs, $i = 1, 2, 3, \dots, I$, I is the set of all AGVs.

j : represents QCs, $j = 1, 2, 3, \dots, J$, J is the set of all QCs.

k, k' : represent tasks, $k, k' = 1, 2, 3, \dots, K$, K is the set of all tasks, and $K = I * J$.

- Parameters

P_j : 0 or 1 parameter, denotes if j is prime way; 1 is true, 0 is false.

R_i : Handling time of remaining task of AGV i .

Q_j : Handling time of remaining task of QC j .

H_k : Handling time of task k .

$B_{kk'}$: 0 or 1 parameter, denotes if k' is the predecessor task of k ; 1 is true, 0 is false.

N_{jk} : 0 or 1 parameter, denotes if task k has been allocated to QC j ; 1 is true, 0 is false.

- Decision variables

X_{ik} : 0 or 1 parameter, denotes if task k is allocated to AGV i ; 1 is true, 0 is false.

S_k : Start time of task k .

E_k : Finish time of the predecessor task of task k .

C_k : Preparation time of task k .

F_k : Finish time of task k .

The start time of task k is determined by E_k (the finish time of the predecessor task of task k) and C_k (the preparation time of task k). S_k is the larger of E_k and C_k . E_k has two different conditions: When k has a predecessor task, E_k is the finish time of the predecessor task. When k has no predecessor task, E_k is the current task finish time of allocated QC j of task k . These relationships can be denoted by the following equations:

$$S_k = \max(E_k, C_k) \quad (1)$$

$$E_k = \begin{cases} \sum_{k'} F_{k'} B_{kk'} & \sum_{k'} B_{kk'} = 1 \\ \sum_i Q_j N_{jk} X_{ik} & \sum_{k'} B_{kk'} = 0 \end{cases} \quad (2)$$

$$C_k = \sum_i \left(R_i + \sum_j W_{ik} N_{jk} \right) X_{ik} \quad (3)$$

$$F_k = S_k + H_k \quad (4)$$

3. Objective Function

To build the objective function, we consider:

a. minimizing completion time

$$f_1 = \min_k \max \left(\sum_i X_{ik} F_k \right) \quad (5)$$

b. minimizing standard deviation of handling time of QCs

$$f_2 = \min \frac{1}{J} \sqrt{\sum_j \left(\max_k \left(\sum_i X_{ik} F_k N_{jk} \right) - \overline{F_{\max}} \right)^2} \quad (6)$$

where $\overline{F_{\max}}$ is the average finish time of all tasks of each QC

$$\overline{F_{\max}} = \frac{\sum_j \max_k \left(\sum_i X_{ik} F_k N_{jk} \right)}{J} \quad (7)$$

The total objective function is

$$f = \alpha f_1 + \beta f_2 \quad (8)$$

where α and β are the weights of two sub-objectives, and $\alpha + \beta = 1$. In practice, the balance of operation lines is more important, so a bigger β ($\alpha < \beta$) is suggested.

4. Constraints

The following constraints apply:

a. An AGV can be allocated to one and only one task.

$$\sum_{k=1}^K X_{ik} = 1 \quad (9)$$

b. Each QC task can only be allocated to once.

$$\sum_{i=1}^I X_{ik} \leq 1 \quad (10)$$

c. The schedule is based on a logical sequence of tasks, which

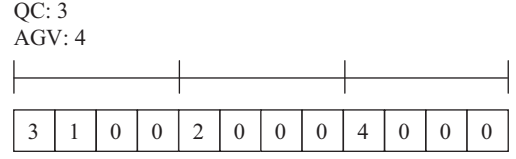


Fig. 4. A feasible chromosome.

means a task k can only be scheduled once its predecessor task has been scheduled.

$$X_{ik} = 0 \quad \text{iff} \quad \sum_{ik'} X_{ik'} B_{kk'} = 0 \quad \text{and} \quad \sum_k B_{kk'} = 1 \quad (11)$$

d. The prime way of operation must be busy, which means the prime way cannot be idle.

$$\max_k \sum_{i=1}^I X_{ik} F_k N_{ij} P_j > 0 \quad (12)$$

IV. ALGORITHM AND NUMERICAL ANALYSIS

The dynamic multi-AGV scheduling problem is a combinatorial optimization problem. Traditional methods find it hard to reach a feasible solution in affordable time. A GA is proposed to solve this problem. In this chapter, the core part of the GA is illustrated, and this algorithm is analyzed through numerical experimentation.

1. Chromosome Design

To ensure every AGV can be scheduled in extreme conditions, the length of the chromosome should be $I \times J$. Fig. 4 shows a feasible chromosome. Depending on QC and AGV numbers, the chromosome is divided into J sectors; each sector has I genes and each gene denotes a task that is strictly sequenced by a predecessor constraint. The value of each gene denotes the AGV allocated to this task. According to the predecessor constraint, the gene value in each chromosome sector must be strictly ascending. Unscheduled tasks are denoted by the value 0.

2. Crossover

The crossover strategy is illustrated in Fig. 5. First, select two chromosomes randomly, and select multiple genes randomly. These genes should have the same value in these two chromosomes. Then, insert each selected gene into the other chromosome's 0 value gene, and vice versa. Considering that the two chromosomes may violate the predecessor constraint after this crossover, the chromosomes must be fixed by moving the violated gene left until the constraint is satisfied.

3. Mutation

The mutation process is illustrated in Fig. 6. Select multiple genes with a value other than 0, replace their value into an unscheduled AGV (gene with 0 value), and shift left to satisfy the predecessor constraint.

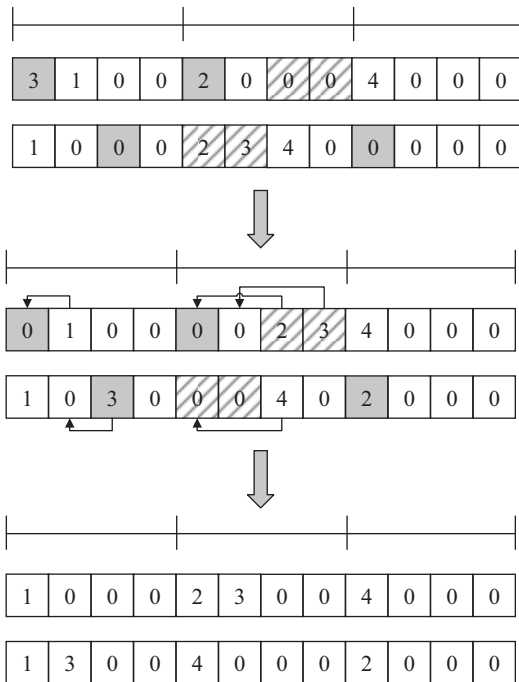


Fig. 5. Crossover process.

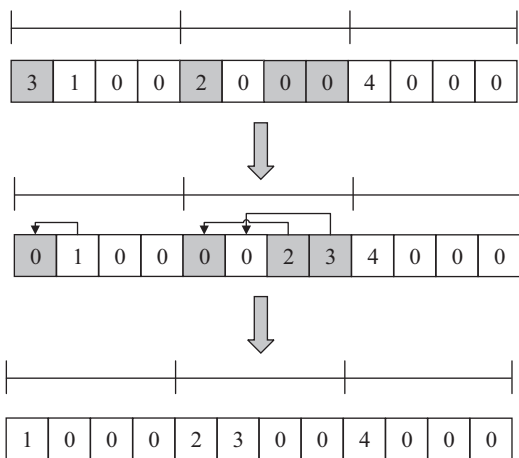


Fig. 6. Mutation process.

4. Numerical Experiment

We choose an example of scheduling 8 AGVs for 5 QCs. Table 3 is the AGV job sequence table. The AGV travel time to each QC is shown in Table 4. The current task finish time of each QC is shown in Table 5. The parameter setting for the GA is as in Table 6, and the objective function weight set is $\alpha = 0.3, \beta = 0.7$.

The solution of the proposed GA is shown in Fig. 7. The two objective functions valued 570 and 29.7, and the total objective value is 191.79. The convergence curve of GA is shown in Fig. 8, which shows that this GA converges at around 540 iterations.

The second objective function denotes the balance of

Table 3. AGV job sequence.

AGV	Remaining tasks	Current task finish time estimation (s)
1	0	0
2	1	85
3	1	90
4	1	260
5	1	350
6	1	360
7	1	410
8	1	440

Table 4. AGV travel time to each QC (seconds).

AGV	QC1	QC2	QC3	QC4	QC5
1	50	30	45	100	130
2	60	25	55	110	140
3	160	130	110	55	20
4	150	125	90	40	65
5	80	60	65	90	110
6	130	110	85	45	40
7	90	70	100	159	180
8	120	80	30	65	90

Table 5. Current task finish time of QCs (seconds).

QC1	QC2	QC3	QC4	QC5
80	120	450	210	0

Table 6. GA parameter setting.

Population size	Iteration	Crossover possibility	Mutation possibility
100	1000	0.8	0.05

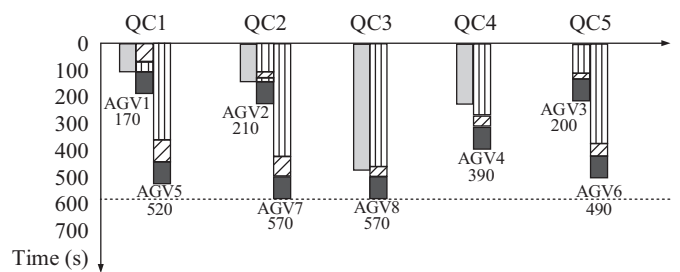


Fig. 7. Solution of proposed GA.

operation lines, and it is more important than the first objective in practice, so robustness analysis of the second objective is performed. The proposed method was used to solve 100 different numerical examples to analyze the robustness. Fig. 9 shows the histogram of the standard deviation of QC working time. It generally shows a left-skewed distribution of the

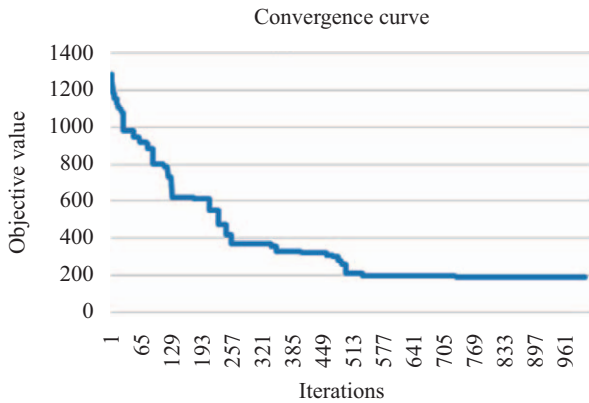


Fig. 8. Convergence curve.

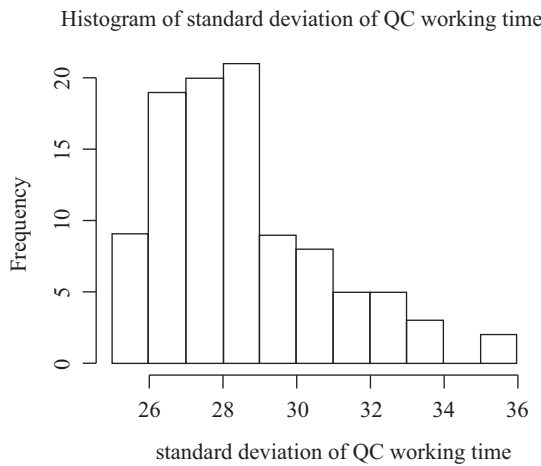


Fig. 9. Histogram of standard deviation of QC working time.

standard deviation, centered at 28. The moderate deviation shows that this GA has good robustness on objective 2.

V. CONCLUSIONS

In this paper, we analyzed the deficiency of single and static vehicle scheduling methods based on previous horizontal transportation scheduling research, and proposed a dynamic multi-AGV scheduling method to better meet the demand of automated container terminal operation and to offer a new idea of horizontal transportation scheduling. The major contributions are listed below:

- a. Scheduling for multiple AGVs (horizontal transportation vehicles) simultaneously to obtain better globally optimized solutions.
- b. A dynamic scheduling model minimizing completion time and standard deviation of QC handling time (to get more balanced handling time).
- c. A GA with specified crossover, mutation, and fix mechanisms, verified to be valid and robust through numerical experiment.

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