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Routing of Linear Motor based Shuttle Cars in the Agile Port Terminal with Constrained Dynamic Programming

Hyun Cheol Cho, Jin Woo Lee, Young Jin Lee, and Kwon Soon Lee*

Abstract: Linear motor (LM) based shuttle cars will play an important role in the future transportation systems of marine terminals to cope with increasing container flows. These systems are known as agile port terminals because of their significant advantages. However, routing for multiple shuttle cars is still an open issue. We present a network model of a container yard and propose constrained dynamic programming (DP) for its routing strategy with collision avoidance. The algorithm is a modified version of typical DP which is used to find an optimal path for a single traveler. We evaluate the new algorithm through simulation results for three shuttle cars in a mesh-type container yard.

Keywords: Agile port terminal, constrained dynamic programming, LMTT, routing.

1. INTRODUCTION

The progressive increase of container flows in marine terminals requires efficient conveyance systems, such as unmanned container trailers, automation guided vehicles (AGVs), and LM based shuttle cars [1]. The latter is the focus of much research on future transfer systems in marine applications because of its low maintenance cost and high reliability. However, its unique characteristics require highly complex routing with collision and deadlock avoidance for multiple shuttle cars.

Research for routing unmanned vehicles has provided interesting problems for engineering fields such as robotics, manufacturing, and port systems. In [2], the authors determined the shortest tour of a single free-ranging AGV, which is an incidence of the asymmetric traveling salesman problem, with a neural network approach. The authors in [3] proposed a control strategy to guarantee no collision between unmanned vehicles at the junction points. In [4], a routing algorithm for multi-mobile robots in transportation was explored with a modification of the "ant" optimization [5], which is based on a colony of cooperating agents. Norman [6] suggested a recursive search algorithm to repeatedly evaluate each feasible route when a vehicle encounters a workstation. The authors in [7] presented a methodology for solving the simultaneous dispatching and conflict-free routing of AGVs in manufacturing systems. More recently, Petri-net based modeling was proposed to handle conflict and deadlock in AGV systems [8,9].

Most of the research in this area has to date focused on AGV systems and has not provided solutions for LM based shuttle cars. Because the two systems have significant mechanical differences, it is not possible to use AGV research to solve problems associated with LM based shuttle cars. Thus, an innovative routing approach is required to operate LM systems with conflict and deadlock avoidance. We present a simple network model for multiple LM based shuttle cars. We also propose a novel scheme for their routing using constrained dynamic programming (DP), which is an extended version of typical DP [10]. We first obtain the optimal path for multiple cars, then check expected collisions, and finally select a suboptimal path for cars with low priority. We allow cars to stop in their paths since LM increases power for reactivation. Although currently few container terminals use LM, their use is expected to grow in the future because of their known advantages. Automatic container terminals using LM are known as Agile ports [11], and can be designed to handle 2,482,000 TEU (Twenty-foot Equivalent Unit containers) per year and serve one ship every 24 hours.

The remainder of this paper is as follows: In Section 2, we present a network model for a container terminal with multiple shuttle cars. In Section 3, we propose our DP routing algorithm. Simulation and discussion are respectively provided in Sections 4 and 5.

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Hyun Cheol Cho, Jin Woo Lee, and Kwon Soon Lee are with the Dept. of Electrical Engineering, Dong-A University, 840, Hadan 2-dong, Saha-gu, Pusan 604-714, Korea (e-mails: hyunccho@gmail.com, {jinwoo, kslee}@donga.ac.kr).

Young Jin Lee with the Dept. of Avionics Electrical Eng., Korea Aviation Polytechnic, 438, Egeum-dong, Sacheon, Korea (e-mail: airlee011@hotmail.com).

* Corresponding author.

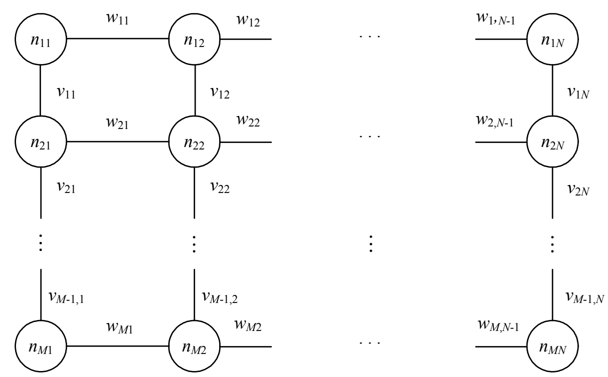
Fig. 1. Modeling of container yard.

2. MODELING OF CONTAINER YARD

LM based shuttle cars move along a monorail in the container terminal to convey container boxes among several workstations. We model the container yard in [11] for the cars with a mesh network topology (see Fig. 1). This model does not include gates through which containers flow, ships traffic in and out of the yard, and buffers for gates and trains. We modify the terminal model only to represent paths and workstations for shuttle cars. In Fig. 1, nodes n_{ij}, i=1,···, M, j=1,···, N, indicate workstations where a crane loads or unloads container boxes to shuttle cars. Links between two nodes represent a feasible path for a shuttle car. Each link has weights $w_{ij} > 0$, i=1,···, M, j=1,···, N-1 and $v_{ij} > 0$, i=1,···, M-1, j=1,···, N, which represent the expected transit time between two nodes for a shuttle car. These weights are regarded as costs in our routing problem. For simplicity, we ignore service time at the workstations and other costs associated with transit between workstations.

3. CONSTRAINED DP ALGORITHM FOR ROUTING OF SHUTTLE CARS

Routing of the shuttle cars in Fig. 1 involves finding the shortest path given a starting node $s \in n_{ij}$ and a destination node $d \in n_{ij}$ where $s \neq d$. For a single shuttle car in the network of Fig. 1, the solution is easily obtained using a typical DP algorithm. However, routing for multiple cars raises the possibility of collision. This is simply defined as two or more cars simultaneously occupying the same segment or workstation within the same time interval. For instance, consider states c_1 at time t_1 and c_2 at t_2 of two shuttle cars with mathematical expressions as

$$c_1(n_1, w_1, v_1, t_1), \quad c_2(n_2, w_2, v_2, t_2), \tag{1}$$

where n_1, $n_2 \in n_{ij}$, i = 1,···, M, j = 1,···, N, w_1, $w_2 \in w_{ij}$, i = 1,···, M, j = 1,···, N-1 and v_1, $v_2 \in v_{ij}$ i = 1,···, M-1, j = 1,···, N. For this case, we mathematically define its possible collision with three conditions as follows: 1) $n_1 = n_2$ at $t_1 = t_2$, 2) $w_1 = w_2$ at $t_1 = t_2$, and 3) $v_1 = v_2$ at $t_1 = t_2$. If placed in one of these conditions, we infer that the cars are possibly conflicted. Thus, conflict-free routing is possible by selecting a suboptimal path for cars with lower priority to avoid collision.

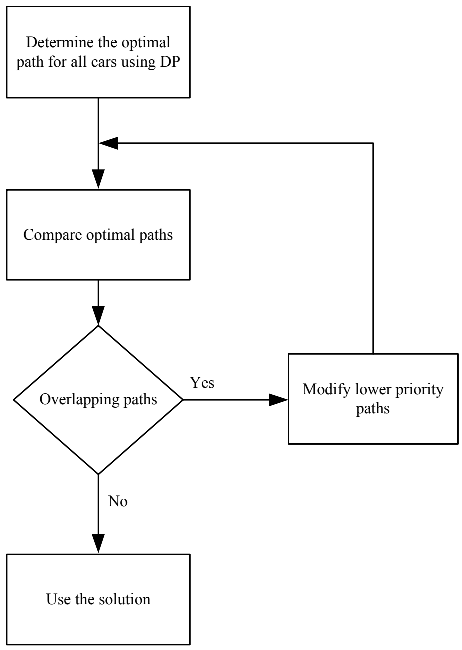

Fig. 2. Flowchart of a constrained DP algorithm.

We propose a constrained DP algorithm for routing of multiple shuttle cars with collision avoidance. First, we determine optimal paths for all shuttle cars by means of a typical DP algorithm under each starting node and destination. Next, we compare optimal paths to detect any identical paths in the same time interval, which would result in a collision. If no collision node is expected, the optimal paths are directly applied for each car as its route. Otherwise, the optimal path is only used for the highest priority car and alternative paths are sought for cars with lower priority. For simplicity, we assume that priority of cars is initially given. A DP is iteratively run until we obtain a satisfactory path excluding the collision node for the cars with lower priority. The proposed algorithm is schematically summarized in Fig. 2.

4. SIMULATION RESULT

Consider the mesh network with four vertical and five horizontal nodes shown in Fig. 3. The weights of the network are randomly selected as integer numbers in [1,5]. We assume that there are three cars in the network with starting nodes, s_1=2, s_2=20, s_3=17 and destinations d_1=20, d_2=6, d_3=5. We apply a typical DP algorithm for this simulation scenario to obtain the distinct shortest paths for each car given in Table 1. The time history of the solution is illustrated

Table 1. Optimal paths for each car by DP.

Car No.	Optimal path	Path Duration
Car I	2-3-8-9-10-15-20	10 min
Car II	20-15-14-13-12-7-6	11 min
Car III	17-18-13-14-15-10-5	9 min

Table 2. Optimal paths for each car by constrained DP.

Car No.	Optimal path	Path Duration
Car I	2-3-8-9-10-15-20	10 min
Car II	20-15-14-13-12-7-6	11 min
Car III	17-18-13-8-9-4-5	11 min

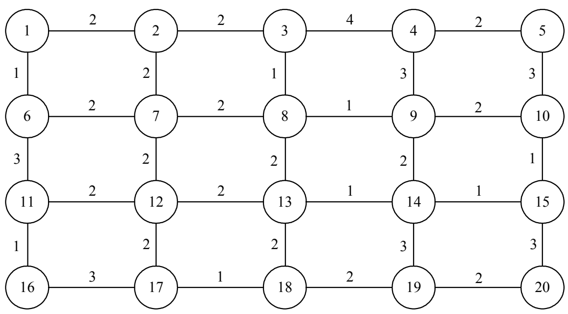

Fig. 3. Network with 4 by 5 mesh.

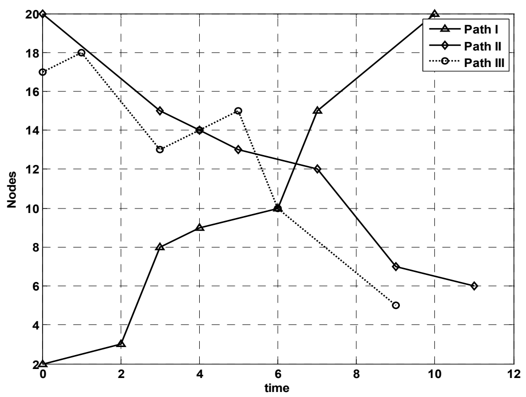

Fig. 4. Time histories of each shuttle car by DP.

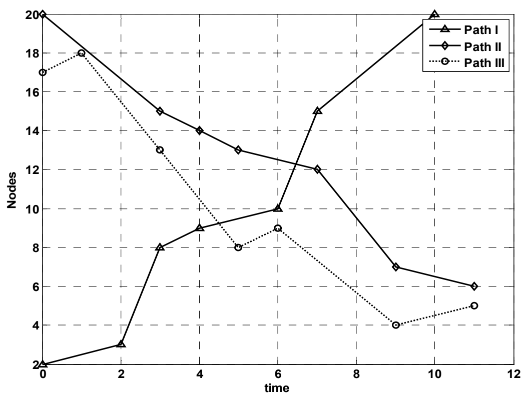

Fig. 5. Time histories of each shuttle car by constrained DP.

in Fig. 4. This picture shows two conflicts: *car* II and *car* III are both in node 14 at 4 min, and *car* I and *car* III are in node 10 at 6 min. If we constrain these nodes and rerun the DP algorithm to obtain a suboptimal solution for path 3, then the path of *Car* III is given in Table 2. From this result, travel time for *car* III is increased by 2 minutes, while the two other paths are unchanged (see Fig. 5).

5. CONCLUSION

We present a network model for LM based multiple cars in marine terminals and propose a novel algorithm for their collision free routing. A DP algorithm is iteratively run until we obtain suboptimal paths that eliminate the collision associated with the optimal DP solution. We demonstrate the results using simple simulation scenarios which have several operational constraints.

Future work will include modeling and optimal routing for a more complex port system represented by a more complex network topology. We will also apply queuing theory and consider the effect of service time on the model.

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Hyun Cheol Cho received the B.S. from Pukyong National University in 1997, the M.S. from Dong-A University, Korea, in 1999, and the Ph.D. from the University of Nevada-Reno, USA, in 2006. He is currently a Post-doc Researcher in the Dept. of Electrical Engineering, Dong-A University. His research interests are in the areas of control systems, stochastic systems, neural networks, and embedded systems.

Jin Woo Lee received the B.S. degree from Kyungnam University in 1998, and the M.S. and Ph.D. degrees from Dong-A University, Korea in 2000 and 2006, respectively. He is currently a Post-doc Researcher in the Dept. of Electrical Engineering, Dong-A University. His research interests are image processing, adaptive control, intelligent control, and automatic port systems.

Young Jin Lee earned the B.S., M.S., and Ph.D. degrees from Dong-A University, Korea, in 1992, 1994, and 2000, respectively. He is currently a Professor in the Dept. of Avionics Electrical Eng., Korea Aviation Polytechnic College. His research interests are fault diagnosis, control systems, immune algorithm, and automatic port systems.

Kwon Soon Lee received the B.S. from Chungnam National University, Korea in 1977, the M.S. from Seoul National University, Korea in 1981, and the Ph.D. in the Dept. of Electrical and Computer Engineering from Oregon State University, USA, in 1990. He joined the Department of Electrical Engineering, Dong-A University, Busan, Korea, as an Assistant Professor from 1982 to 1994. Since October 1, 1994, he has been with the Division of Electrical, Electronics, and Computers at Dong-A University, Busan, Korea, where he is currently a Professor. He has authored or coauthored over 150 articles in archival journals and conference proceedings. His research interests include all aspects of port automation systems, intelligent control theory, and application of immune algorithm, etc. He is a responsible person of the National Research Laboratory nominated by the Korean Ministry of Science and Technology, the Team Leader of the New University for Regional Innovation (NURI) in Dong-A University, and Director of the International Cooperation Department at the Regional Research Center (RRC) in Korea.