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Optimisation for job scheduling at automated container terminals using genetic algorithm ☆

Bradley Skinner [a], Shuai Yuan [a,*], Shoudong Huang [a], Dikai Liu [a], Binghuang Cai [a], Gamini Dissanayake [a], Haye Lau [b], Andrew Bott [b], Daniel Pagac [b]

[a] School of Electrical, Mechanical and Mechatronic Systems, Faculty of Engineering and Information Technology (FEIT), University of Technology, PO Box 123, Sydney, NSW 2007, Australia
[b] Patrick Technology Systems, 4b Lord Street, Botany, NSW 2019, Australia

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ABSTRACT

This paper presents a genetic algorithm (GA)-based optimisation approach to improve container handling operations at the Patrick AutoStrad container terminal located in Brisbane Australia. In this paper we focus on scheduling for container transfers and encode the problem using a two-part chromosome approach which is then solved using a modified genetic algorithm. In simulation experiments, the performance of the GA-based approach and a sequential job scheduling method are evaluated and compared with different scheduling scenarios. The experimental results show that the GA-based approach can find better solutions which improve the overall performance. The GA-based approach has been implemented in the terminal scheduling system and the live testing results show that the GA-based approach can reduce the overall time-related cost of container transfers at the automated container terminal.

1. Introduction

Both the capacity and frequency of container carrying ships arriving at seaport container terminals have increased steadily during the past several decades (Günther & Kim, 2006; Steenken, Voß, & Stahlbock, 2004). The efficiency of container transfers must be as high as possible so as to reduce costs to terminal operators and increase the productivity of the terminal. This requires efficient use of yard vehicles to load, unload and transfer containers during the transportation process.

Automating container terminals to some extent is a trend in container terminal operations (Kim, Won, Lim, & Takahashi, 2004; Liu, Jula, Vukadinovic, & Ioannou, 2004). Increasing automation of yard vehicles not only reduces the labour costs of terminal operators, but also has the potential to increase the efficiency of container transport. Nevertheless, as compared with human operated yard vehicles there is an ongoing requirement to ensure a high degree of coordination and efficiency for all material handling equipment participating in the transportation process. As a result efficient operation of automated yard vehicles in a terminal area is a challenging problem of terminal management.

Seaport container terminals around the world currently employ a multitude of container handling equipment. Quay Cranes (QCs) are commonly used in seaports for uploading/unloading containers to/from ships on the quay-side. Different seaports use different kinds of yard vehicles for transferring containers within the ports. The Straddle Carrier (SC) is one of the most common types of yard vehicles for such container transfer. They can pick-up/set-down containers autonomously without a human operator in the yard area. At the Patrick AutoStrad container terminal (Fig. 1), a fleet of fully autonomous SCs are used for container transport (Nelmes, 2005) (Fig. 2). More than twenty autonomous SCs are issued high level commands from a central computer system located at the port. The navigation system allows the SCs to travel along any planned trajectory while performing collision detection. These SCs are the only vehicles to transfer containers among QC area, yard area and the truck (TK) area which makes this terminal unique when compared with current seaports that use human operated SCs for container transporting.

At the Patrick AutoStrad container terminal, like many other seaport terminals, one of the main tasks of a fleet of SCs is to serve the QCs such that the maximal QC turn-around rate can be achieved (Nelmes, 2005; Yuan et al., 2009). This will reduce the ship berthing time and increase the terminal productivity. Moreover, the SCs also need to serve the trucks which are used

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* Corresponding author. Tel.: +61 295143142; fax: +61 295142655.
E-mail addresses: Brad.Skinner@uts.edu.au (B. Skinner), shuai.yuan@uts.edu.au (S. Yuan), Shoudong.Huang@uts.edu.au (S. Huang), Dikai.Liu@uts.edu.au (D. Liu), Binghuang.Cai@uts.edu.au (B. Cai), Gamini.Dissanayake@uts.edu.au (G. Dissanayake), h.lau@patrick.com.au (H. Lau), a.bott@patrick.com.au (A. Bott), d.pagac@patrick.com.au (D. Pagac).

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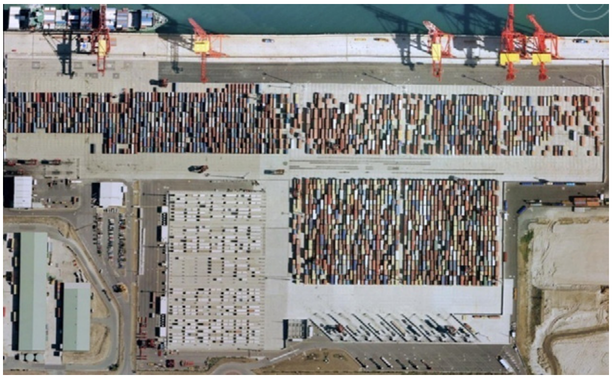

Fig. 1. Satellite view of the Patrick AutoStrad container terminal within the Port of Brisbane at Fisherman Islands Australia [Google Earth].

Fig. 2. Fully autonomous straddle carrier transporting a 40-foot container from the quay-side as part of a buffer-to-yard task.

to transfer containers between customers and the seaport terminal such that the truck waiting time is minimised. Furthermore, the seaport operator would like SCs to perform less urgent yard-to-yard container transportation jobs (e.g. yard maintenance) as part of their yard management strategy.

We presented a mathematical model of the integrated SC path planning and task allocation in yard operations (yard jobs) in (Liu & Kulatunga, 2007; Yuan et al., 2010). This mathematical formulation was extended in (Yuan et al., 2011) by including QC and TK related jobs and then solved by a proposed job grouping strategy (Yuan et al., 2011). The job grouping approach groups jobs based on time-critical requirements, so as to enhance the time related performance. One advantage of the job grouping approach is that it integrates both the scheduling and path planning algorithms for all jobs and SCs. However, this grouping approach has a short planning horizon, which may end up with a local optimum solution. The employed path planning algorithm (Halpern, 1977; Lau, Pratley, Liu, Huang, & Pagac, 2008) has been well-studied and can effectively deal with routing and collision avoidance in actual terminals. Solving the scheduling problem with longer planning horizon using a global optimisation approach is expected to give better solution (higher productivity) in automated container terminals such as the Patrick AutoStrad Terminal.

This paper presents a genetic algorithm (GA)-based optimisation approach to solve the SC scheduling problem for container handling in the Patrick AutoStrad Terminal. In this paper, the problem of scheduling SCs has subtle but significant differences to the multiple travelling salesman problem (MTSP) (Bektas, 2006) and Pick-up and Delivery Problem (PDP) (Savelsbergh & Sol, 1995). Firstly, both MTSP and PDP do not have sequence constraints on visiting cities or nodes and salesmen or vehicles are normally allowed to conduct jobs in any order. In our problem the job sequence has to be taken into account particularly for QC and TK related jobs. Secondly, MTSP and PDP do not have to deal with constrains such as servicing QCs and TKs, which tends to add complex timing dependence for related jobs. Due to the timing dependence of all resources (i.e. SCs, QCs and TKs), it is not suitable to use time-window based approaches (e.g. MTSP with time-window and PDP with time-window) to deal with the correlated job sequence and timing constraints. Thirdly, our performance metrics are based on practical operations at the Patrick AutoStrad Terminal which are different from the general MTSP and PDP.

Objectives in our model are not only related to SCs (e.g.: minimising total travel time which is a linear function), but also include the performances of QCs and TKs (e.g.: minimising QC waiting time and TK waiting time which are non-linear functions). Previous approaches (Bektas, 2006; Dumas, Desrosiers, & Soumis, 1991; Li & Lim, 2001; Park, 2001; Ruland & Rodin, 1997; Savelsbergh & Sol, 1995) to solving the MTSP and PDP are often designed for linear objective functions with linear constraints and thus cannot be directly used to with our model and solve the practical problem at Patrick AutoStrad Terminal. In this paper, the comprehensive problem model presented in (Yuan et al., 2011) is modified as a job scheduling problem which deals with correlated job sequence and timings. Five practical performance metrics are formulated which are directly related to the operations at the Patrick container terminal. A modified genetic algorithm (GA) is presented to handle the job sequence and timing constraints and improve the scheduling performance of container transfers at the automated container terminal.

The paper is organised as follows. Section 2 provides a brief overview of related work in scheduling problems for the transportation process within automated seaport container terminals. Section 3 presents the modified mathematical model of the job scheduling. In Section 4, we discuss the GA-based approach. Section 5 presents the experiments and the compared performance. Finally, Section 6 provides a conclusion and summary of the study.

2. Literature review

2.1. Container handling in transhipment

Within a seaport environment an effective schedule for the transhipment of containers requires efficient allocation and scheduling of quay-side, yard and land-side resources. Although the operation of these resources is typically decoupled from each other the efficiency of the overall transhipment process is significantly affected by their operation, particularly if there is a high level of automation involved.

A quay crane scheduling problem (QCSP) considers the starting and finishing time of each job (e.g., loading and unloading a container) in a set of jobs assigned to quay cranes servicing a vessel. Kim and Park (2004) proposed an analytical formulation of the QCSP. Using a meta-heuristic search algorithm called GRASP, near optimal solutions were found. In addition, a lower bound on the optimal performance was proposed using the branch and bound method. However, these studies assume complete availability of yard resources when transporting containers from the yard to the quay crane loading area, i.e., the scheduling of yard vehicles are not taken into account.

A yard vehicle scheduling problem considers the starting and finishing time of each yard job (e.g., moving a container from its current position to a different position in the yard or to a QC or a truck) in a set of yard jobs assigned to a fleet of autonomous straddle carriers servicing quay cranes and trucks. The problem is to minimise the utilisation of straddle carriers in the transhipment process while finding a feasible and efficient schedule. This