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Green vehicle technology to enhance the performance of a European port: A simulation model with a cost-benefit approach

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A B S T R A C T

In this paper, we study the impact of using a new intelligent vehicle technology on the performance and total cost of a European port, in comparison with existing vehicle systems like trucks. Intelligent autonomous vehicles (IAVs) are a new type of automated guided vehicles (AGVs) with better maneuverability and a special ability to pick up/drop off containers by themselves. To identify the most economical fleet size for each type of vehicle to satisfy the port's performance target, and also to compare their impact on the performance/cost of container terminals, we developed a discrete-event simulation model to simulate all port activities in micro-level (low-level) details. We also developed a cost model to investigate the present values of using two types of vehicle, given the identified fleet size. Results of using the different types of vehicles are then compared based on the given performance measures such as the quay crane net moves per hour and average total discharging/loading time at berth. Besides successfully identifying the optimal fleet size for each type of vehicle, simulation results reveal two findings: first, even when not utilising their ability to pick up/drop off containers, the IAVs still have similar efficacy to regular trucks thanks to their better maneuverability. Second, enabling IAVs' ability to pick up/drop off containers significantly improves the port performance. Given the best configuration and fleet size as identified by the simulation, we use the developed cost model to estimate the total cost needed for each type of vehicle to meet the performance target. Finally, we study the performance of the case study port with advanced real-time vehicle dispatching/scheduling and container placement strategies. This study reveals that the case study port can greatly benefit from upgrading its current vehicle dispatching/scheduling strategy to a more advanced one.

1. Introduction

Container terminals play a vital role in international supply chains, since container terminals are major interfaces to transfer/distribute containers (carrying 90% of non-bulk world trade goods as of 2009 (Ebeling, 2009)). How container ter-

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minals handle goods greatly influences emissions and final cost, because up to 50% of cost could be due to handling and logistics (Rodrigue et al., 2013, Chapter 5). Thus, improving container terminals efficiency is an important/practical issue (Ha et al., 2007). The growth in the global container market has made container terminals key hubs of global supply chain networks (Xin et al., 2014). Therefore, if a container terminal wants to be successful in this market, it should improve its performance and also be able to keep its operational costs at the lowest level (Soriguera et al., 2006). Moreover, with the growth of containerisation, container terminals have to face with the problems of limited space (Gambardella et al., 1998). Some container terminals, especially European ports, have difficulties to cope with congestions caused by the increase in equipment and activities in ports. Due to the limited available land, it is not possible to increase the area of container terminals despite the needs in increasing capacity (Henesey et al., 2006). Thus, the capability of equipment to perform in confined spaces has become an advantage.

Due to the aforementioned issues, container terminals have been looking for new technologies to improve their performance. The first step is to identify the most suitable sets of equipment. However, since the introduction of containers in 1960, identifying the optimal amount of equipment and capacity of container terminals has always been a challenging task due to the complex nature of the problem. One possible way to solve this challenging task is to use simulation. Simulation is a scientific approach to not only study a system without actually disturbing it (Demirci, 2003), but also to evaluate concepts that have not been used in the real world (Henesey et al., 2006; Yun and Choi, 1999). Therefore, for a container terminal, a simulation study can be carried out to predict the effect of applying different types of equipment, as well as the ideal amount of equipment to meet the performance target (Ha et al., 2007; Yun and Choi, 1999; Parola and Sciomachen, 2005; Bielli et al., 2006). This is the focus of this paper.

In this paper, we develop a simulation model to identify the optimal fleet size in terms of cost and performance to assist investment decisions for a European container terminal. We also investigate the impact of using a new type of automated vehicle called intelligent autonomous vehicles (IAVs) in comparison with trucks on the performance and cost in this terminal. Automated vehicles have been used in container terminals before. The most commonly used of automated vehicles are the automated guided vehicles (AGVs) which have been used in many European ports. The current generation of AGVs, however, have two limitations. First, they cannot pick up/drop off containers by themselves, resulting in increased expensive crane/vessel waiting time. Second, many of them need to follow a fixed track, which can be either a pre-programmed virtual path or a physical part guided by transponders. The purpose of the development of the IAVs (and similar vehicles, e.g. the IPSI AGV (Henesey et al., 2006) and automated lifting vehicle (ALV) (Vis et al., 2005)) is to partly alleviate these limitations. IAVs are a new type of AGV. They are developed in a European project entitled Intelligent Transport for Dynamic Environment (InTraDE).[2] IAVs are used to transport containers in container terminals. Below, we provide some key technical features of IAVs:

- IAVs have the ability to pick up/drop off containers by themselves if they are combined with a special table-shaped object named "cassette".
- IAVs offer flexibility in maneuvering in confined spaces (can move in any directions without having to turn thanks to 180-degree-rotation wheels).
- IAVs do not need any fixed track to follow. This is achieved thanks to the wireless link between the IAV and an intelligent virtual real-time simulator.
- An IAV benefits from an embedded sensor system to detect moving and static obstacles around itself. Thanks to this system an IAV can track targets with an accuracy of a centimetre.
- IAVs contain a global positioning system coupled with simultaneous localisation and mapping technology for navigation.
- An IAV contains eight full electrical and decentralised actuators, four for traction and four for steering. If an actuator fails, the IAV can still continue its assigned job, given that the rest of actuators can cover the failed actuator.
- IAVs can make platoons in which each IAV can follow one another and form a train of IAVs. The platoon can be led by a leader (usually a man driven vehicle).

The first two features of IAVs in the above list are the main focus of this paper. The ability to pick up and drop off containers is significant in improving performance because it helps reduce waiting time of vehicles and cranes. Instead of having to wait for vehicles to arrive, cranes can now drop off containers on top of an empty cassette, then continue picking up another container. The loaded cassette then can be picked up by the IAV at a later time. Similarly, when an IAV arrives, it no longer has to wait for a crane to give it the container. Instead, the IAV can go directly to one of the loaded cassettes, pick it up and transfer it to the destination. IAVs can also drop off the loaded cassettes on the ground for cranes to pick up later. The temporary space for the storage and transition of empty and loaded cassettes is called the buffer. By utilising the buffers, the waiting time of both cranes and vehicles can be decreased significantly. This can have a significant impact on the productivity and cost of container terminals.[3] Moreover, IAVs' better maneuverability can potentially shorten their travel routes. This can be achieved in confined places where trucks cannot turn due to the lack of enough space and hence have to take the long round routes. In contrast, IAVs could move in any directions without having to turn, hence can choose the shortest routes.

It should be noted that IAVs, IPSI AGVs and ALVs belong to the same modern class of automated vehicles that are able to pick up/drop-off containers by themselves. This is an emerging technology that requires in-depth studies to investigate its

[2] See http://www.intrade-nwe.eu/.

[3] A video illustrating how the IAVs work can be found in [https://www.youtube.com/watch?v=49vqrl1O0N8].