Dispatching Policy Selection and Orbit Design in the Low Viaduct Rail Transportation System

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ABSTRACT
In order to raise the handling efficiency at container terminals, a new operation process, the Low Viaduct Rail Transportation System, has been designed in China. Compared with the traditional process, it has the advantages of less pollution, higher operation efficiency, and less complicated production management system. This paper studies the design of the orbit system and the dispatching policy in the Low Viaduct Rail Transportation System. A simulation model is established by means of the software EM-Plant. The main criteria such as operation efficiencies, waiting times and utilities of the facilities under different dispatching policies and orbit lengths are obtained and analyzed after running the model. Finally, the suggestions of dispatching policies are put forwarded.

Keywords: container terminals; handling process; trolley vehicle; simulation

With the rapid development of container transportation, it has been becoming more and more important to raise the operation efficiency at container terminals. New loading/unloading systems are being studied for raising operation efficiency and reducing operation costs.

There are basically two kinds of container terminals: non-automatic and automatic ones. In non-automatic container terminals trucks are usually used to move the containers from the landside of the terminal to the stack yard. In the automatic container terminals, Advanced Guidance Vehicles (AGVs) are used. An advanced and complicated information system is required to control the AGV operation process. AGV system promotes the automatic level, reduces the cost of human resources and raises the efficiency. However, the investment in an AGV system is rather high. So, AGVs are usually used in the container terminals where the cost of human resources is high.

The low viaduct rail system is a new loading/unloading process at container terminals. It will substitute the diesel engine-driven vehicles, including trucks, AGVs and other kinds of transport tools which are used at container terminals till now. It has the advantages of low pollution, high efficiency,
less complicated controlling system, and lower investment compared with AGV.

1. LITERATURE REVIEW

The existing studies on the horizontal transportation vehicles at container terminals are focused on AGV. Gobal and Kasilingam (1991)\(^1\) established a simulation model to estimate the least number of AGVs needed for satisfying the demand. Y Chen et al. (1997)\(^2\) studied the allocation problem of AGVs and solved the problem in terms of a heuristic algorithm. Kim and Bae (1999)\(^3\) studied the allocation problem of AGVs by introducing the starting times of the events. Bose et al. (2000)\(^4\) studied the allocation problems of multi-vessels and minimized the total waiting time of quay cranes by genetic algorithm. Thomas Winter (1999)\(^5\) considered both stowage planning for the vessels and the allocation problem of the trucks, and minimized the total driving distance of the trucks in an one quay crane system by building an MIP model. Kozan and Preston (1999)\(^6\) studied the allocation problem of trucks and minimized the total staying time of the vessels at a container terminal.

Because of the complexity and stochastic characteristics of the operation process in harbors, the optimal models are usually NP-hard problem and are difficult to be solved. The simulation method is becoming popular to be applied. Pietro Canonaco et al (2007)\(^7\) studied the allocation problem at container terminals by simulation. Matthew E.H, Peteringa and Katta G. Murtyb (2008)\(^8\) shows the relationship between the efficiencies of the quay cranes and the length of the blocks of the stack yards and the number of the stack cranes. Qingcheng Zeng and Zhongzhen Yang (2009)\(^9\) developed an simulation model to solve the dispatching problems. San Youji et al. (2005)\(^10\) simulated the planning of a container terminal in terms of the EM-plant software. Chin I Liu et al. (2004)\(^11\) evaluated on the performance of AGVs at the container terminals under two different layout. A.A. Shabayek and W.W. Yeung (2002)\(^12\) estimated the costs and evaluated the number of berths needed for a harbor in Hong
Kong in terms of simulation. L.M. Gambardella et al. (2001)[13] checked the results of the optimal models for the operation process by simulation in order to make the stack cranes and trucks well matched. Ballis A. and Abacoumkin C (1996)[14] established a simulation model to evaluate the layout of a harbor. Won Young Yun and Choi Y.S. (1999)[15], Ramani K.V. (1996)[16], analyzed the operation process by simulation. Won Young Yun (1999)[17] analyzed the efficiencies of the facilities at a container terminal by simulation.

Few studies have been found on the dispatching problem of the trolley vehicles in a low viaduct rail system.

2 DISPATCHING POLICIES IN A LOW VIADUCT RAIL SYSTEM

2.1 The Loading/Unloading Process

The traditional unloading operation process at a container terminal is as follows: A container is lifted from a vessel and put on a truck by a quay crane which is located on the landside of the terminal. Then, the truck moves to the stack yard, where a gantry crane lifts the container from the truck to the specific position in the yard. The loading operation process is similar to the unloading process but is in an opposite direction. The main differences of a low viaduct rail system from the traditional systems are as follows:

(1) When a container is lifted by a quay crane from a vessel, it is not directly put on a truck but on a low viaduct rail vehicle which will move to a proper position, and then is moved to a trolley vehicle by a low viaduct crane.

(2) The trolley vehicle rotates 90° with the container on it and then moves along an orbit to the specific position in the stack yard. It is a trolley vehicle instead of a truck to transport the container to the stack.
2.2 The Decision Problems for Dispatching

There are two rail orbits towards each block of the stack yard in the low viaduct rail system, one of which is longer than another. On either rail orbit there is a trolley vehicle. We are faced with two decision making problems.

(1) How long should the two rail orbits be? The longer the orbits are, the more convenient for the trolley vehicles to reach the specific positions, but the more space the orbits will occupy. So, the lengths of the two orbits are being decided.

(2) There are two trolley vehicles on the two rail orbits for each block. Which of the trolley vehicles should a low viaduct crane choose to put the container on? Generally speaking, when the destination of a container cannot be reached by the short orbit, the container has to be moved by the trolley vehicle on the long orbit. When the destination of a container can be reached by both orbits, the container can choose either of the two orbits. So, a decision on dispatching policy is needed to be made.

2.3 Dispatching Alternatives

The low viaduct rail system has been developed by ZPMC in China. In this system there are two orbits in each block of the stack yard, one of which is a long orbit (42 bay long) and the other is a shorter one (21 bay long). See Figure 2. Two alternatives are designed considering both being high efficient and practical.

The alternative 1 is as follows: If the destination of a container cannot be reached by the short orbit, use the trolley vehicle on the long orbit; if the destination of a container can be reached by either of the orbits, use the trolley vehicle on the short orbit.

The alternative 2 is as follows: If the destination of a container cannot be reached by the short
orbit, use the trolley vehicle on the long orbit. If the destination of a container can be reached by both of the orbits and the short orbit is idle, use the trolley vehicle on the short orbit; if the short orbit is busy, use the orbit which will become idle earlier.

3 THE SIMULATION MODEL

3.1 The Simulation Model

Because of the dynamic and random characteristics of the logistics process at a container terminal, the optimal models usually have too many variables and constraints. It is rather hard to get an exact solution of an optimal model. Many approximate algorithms have been developed, but it is still difficult for these algorithms to put the random and dynamic factors in consideration. Simulation is an efficient tool for complicated and stochastic systems and it is becoming a practical method for decision-makings at container terminals.

EM-Plant is an object-oriented simulation software for discrete event system developed by Tecnomatix Company. It is mainly used for simulation and optimization of the process of production and logistics. EM-Plant provides with some typical equipment library such as production machines, material transit machines and warehouses, which makes the establishment of a simulation model quite easily. Besides, EM-Plant also provides a special program language ‘Simtalk’ for controlling the simulation process.

A simulation model is established to simulate the logistics process of the low viaduct rail vehicles. The Em-Plant objects in this simulation model are as follows:

1. Transporter, including low viaduct rail vehicles, low viaduct lifting cranes, trolley vehicles and gantry cranes.
2. Tract, which presents the orbits
3. Store, which presents the yards.
4. Method, which is the relationship among events.

The input variables of the simulation model includes cycle of Quay Crane, velocity of low viaduct rail vehicle, velocity of low viaduct lifting crane, lifting/dropping time of yard crane, velocity of yard crane. And the output variable is the efficiencies of the quay cranes.

The simulation framework for unloading process in a low viaduct rail system at a container
terminal is shown in Figure 1. The loading process is similar but in an opposite direction. By simulating the process, the total time for loading/unloading a vessel and the number of the containers can be obtained. The average efficiencies of the quay cranes under different dispatching policies are calculated by formula (1).

\[ E(t) = \frac{W(t)}{t} \]  

Where \( E(t) \) is the average efficiency of the quay cranes, \( W(t) \) is the amounts of container operated by the quay cranes during the time \( t \), and \( t \) is the time.

3.2 The Simulation Results

The simulation model is run in terms of the software EM-Plant. Firstly, the operation process in a two-quay-crane and two-block system is simulated for ten hours. The results are shown in Table 1.

Table 1 shows that the efficiencies under two different dispatching alternatives are quite similar when the length of the short orbit is half of that of the long orbit. The reachable area using the vehicle on the short orbit is almost equal to the reachable area using the vehicle on the long orbit in both alternatives. So, the operation tasks are almost equal on both orbits. However, as the length of the short orbit increases, the operation tasks dispatching on the short orbit will become more and more than that on the long one. That will lead to the longer total waiting time of the quay cranes because the short orbit is too busy. Table 2 shows the efficiencies using two different dispatching alternatives when the length of the short orbit is two thirds of that of the long orbit.

Table 2 shows that the total efficiency using dispatching alternative 2 is about two TEU per hour higher than that using alternative 1 when the length of the short orbit is two thirds of that of the long orbit. It is because the operation tasks under alternative 2 are more balanced between the two orbits so that the total waiting time of the quay cranes will be reduced.

4 SENSITIVITY ANALYSIS

In the low viaduct rail transportation system, if the short orbit is too short, the operation tasks
dispatched on the long orbit will be much more than that on the short orbit, which will lead to a longer waiting time of the quay cranes. On the other hand, when the length of the short orbit is increased, which is good for the balance of the tasks between the two orbits, the loss of the area of the stack yard will be increased. So, the increase of the length of the short orbit is based on the loss of the area of the stack yard. It is significant to design a reasonable length of the short orbit.

A simulation model is established. It simulates the operation process using twenty alternatives in which the short orbit is supposed to be 1, 2, 3, ..., 20 bay long, respectively. The results are shown in Figure 3.

4.1 Design the Short Orbit under Dispatching Alternative 1

When the dispatching alternative 1 is used, the total efficiency of the quay cranes will rise with the increase of the length of the short orbit at first. Then, when the length of the short orbit arrives at a fixed point, the total efficiency will go down with the increase of the length of the short orbit. Figure 3 shows the influence of the length of the short orbit on the total efficiency. It shows:

(1) When the dispatching alternative 1 is used and the length of the short orbit increases from zero, the total efficiency of the quay cranes will rise. It is because the short orbit will take more tasks so that the long orbit will become less busy and the total waiting time of the quay cranes will decrease.

(2) When the length of the short orbit arrives 24-bay long, the total efficiency will reach the maximal value.

(3) When the short orbit continues to increase from 24-bay long, the total efficiency will go down. It is because the short orbit takes all the tasks in its reachable area. When its length is too long and its reachable area becomes too large, its tasks will exceed those of the long orbit more and more.
The unbalanced tasks between the two orbits will lead to the over-crowded short orbit and longer waiting time of the quay cranes.

4.2 Design the Short Orbit under Dispatching Alternative 2

When the dispatching alternative 2 is used, the total efficiency of the quay cranes will rise with the increase of the length of the short orbit. It is because when the short orbit becomes longer, more orbit resources will be available. The short orbit will cover larger area in the stack yard. As a result, it will take more tasks that were taken by the long orbit. So the long orbit will become less busy and the waiting time of the quay cranes will decrease. The curves in figure 3 do not look very smooth, which results from the random numbers in simulations and will not affect the trend.

4.3 THE ECONOMICAL LENGTH OF THE SHORT ORBIT

As above discussion, when the length of the short orbit is equal to or shorter than 24-bay long, the total efficiencies in both alternatives will rise with the increase of the length of the short orbit. However, the increase of the length of the orbit will occupy more area of the stack yard. The increased efficiency is obtained at the sacrifice of the area of the stack yard. So, when designing the length of the short orbit, both efficiency and economy should be taken into consideration. It is obvious from figures 3 that the total efficiency reaches the maximal point when the short orbit is 24-bay long in alternative 1. In alternative 2, although the total efficiency rises with the increase of the length of the short orbit all the time, the ascending trend will becomes slowly when the length of the short orbit is longer than 26 bays. Considering the loss of the stack yard, the economical and reasonable length of the short orbit can be taken as 26 bays.

4.4 A Comparison between the Two Dispatching Alternatives

A comparison between the two dispatching policies is made as follows:
(1) When the short orbit is equal to or shorter than 24-bay long, the total efficiencies of the quay cranes in the two alternatives are quite similar. The total efficiencies in both alternatives are very close and they rise with the increase of the length of the short orbit.

(2) When the short orbit is longer than 24-bay long, the total efficiencies of the quay cranes in the two alternatives will change on the opposite directions. The total efficiency in alternative 1 will descend with the increase of the length of the short orbit; while the total efficiency in alternative 2 will ascend with the increase of the length of the short orbit. In this case, when the short orbit is longer than 24 bays and continues to increase, the tasks taken by the short orbit in alternative 1 will become heavier and heavier than those in alternative 2 and the total waiting time of the quay cranes will become longer. However, the tasks taken by the short orbit in alternative 2 is still similar to the long orbit because a task with a reachable destination is dispatched to the orbit which will become idle earlier in alternative 2.

5 CONCLUSIONS AND SUGGESTIONS

The dispatching policies and the design of the orbits in the Low Viaduct Rail Transportation System are discussed by simulating the handling process at container terminals. The main conclusions and suggestions are as follows.

(1) The Low Viaduct Rail Transportation System is a new operation process at container terminals. It has the advantages of less pollution, higher operation efficiency, less complicated production management system.

(2) The length of the short orbit directly affects the balance of the tasks between the two orbits, which will have influence on the total efficiency of the quay cranes. Simulations show that when the short orbit is equal to or shorter than 24-bay long, the efficiencies in alternative 1 and 2 will be
quite close. Considering alternative 1 is more practical, alternative 1 is suggested and the best length of the short orbit is suggested to be 24-bay.

(3) When the length of the short orbit is longer than 24-bay, the efficiencies of alternative 2 is larger than that of alternative 1. In this case, alternative 2 is suggested and the economical and reasonable length of the short orbit is suggested to be 26-bay.

This paper studies the dispatching policies and the lengths of the rail orbits in a Low Viaduct Rail Transportation System by simulation. Exact methods will be tried in further studies to obtain more exact conclusions. Besides, some of the data in the simulation model are not drawn from the real systems because the system is new and is lack of materials. The modifications and tests are needed by using data from the real time operations.

References:


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Figure 1: The Unloading Process in a Low Viaduct Rail System at a Container Terminal

An import container  → A quay crane lifts the container and puts it on the platform  → The workers take off the hooks and come back to the safe area  → Is the low viaduct rail vehicle on the position?

Waiting  → No

Has the trolley vehicle been on the position?

Yes  → The low viaduct crane lifts the container

No  → The low viaduct crane puts the container on the trolley vehicle

Yes  → The low viaduct crane puts the container on the trolley vehicle

The trolley vehicle rotates 90° with the container on it

The trolley vehicle moves on the position in the stack yard.

Has the gantry crane been on the position?

Yes  → The gantry crane lifts the container and puts it on the specific position

No  → The gantry crane lifts the container...

End
Figure 2: A Bird’s View of the Orbits and the Trolley Container Vehicles on a Block

Figure 3: A Comparison of the Total Efficiencies between the Two Dispatching Alternatives

Table 1: The Efficiencies When the Length of the Short Orbit Is Half of the Long Orbit

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Efficiency of Quay Crane 1 (mov/h)</th>
<th>Efficiency of Quay Crane 2 (mov/h)</th>
<th>Total Efficiency of Quay Cranes 1 and 2 (mov/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>35.22</td>
<td>31.49</td>
<td>66.71</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>35.92</td>
<td>30.93</td>
<td>66.85</td>
</tr>
</tbody>
</table>

Table 2: The Efficiencies When the Length of the Short Orbit Is 2/3 of the Long Orbit

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Efficiency of Quay Crane 1 (mov/h)</th>
<th>Efficiency of Quay Crane 2 (mov/h)</th>
<th>Total Efficiency of Quay Cranes 1 and 2 (mov/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>35.47</td>
<td>32.13</td>
<td>67.60</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>35.75</td>
<td>34.00</td>
<td>69.73</td>
</tr>
</tbody>
</table>