Research on the Influence of Operator Fatigue Factors on Port Service Capability Based on Discrete System Simulation

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Abstract. With the continuous and stable development of the global economy, ports play a vital role as cargo transhipment hubs. Among them, the human factor of the operators in the port plays a decisive role in the port service ability. In order to explore the specific effects of different fatigue states of the quay bridge, yard bridge, and internal truck operators in the traditional container terminal on the port’s service capacity, seven test schemes are proposed, and computer simulation methods are used to build a simulation model of the terminal. Through a large number of simulation tests, it is concluded that the fatigue of different equipment operators has different effects on the operation efficiency of the terminal. If the three operators are fatigued at the same time, the operation efficiency of the terminal will be reduced by 17.27%, which will have a very negative impact on the overall operation of the terminal. Therefore, optimizing the scheduling of operators and avoiding fatigue operations will improve the port’s service capacity.

1 Introduction

The development of economic globalization has promoted more and more frequent international cargo transportation. The role of ports as an important node in international cargo transhipment has also become more prominent. The port is no longer a simple hub for cargo turnover, but has transformed into an important platform for international resource allocation. Operators in traditional container terminals are an important participating factor, and their work efficiency plays a vital role in the efficiency of terminal operations. There are many researches on container terminals, but the research on the fatigue factors of operators has always been an omission. This article is based on the research results of fatigue factors made by other scholars on basic data such as the reaction time of operators and the number of correct operations, and uses computer simulation technology (FlexSim) to establish a traditional container terminal model, compares seven schemes through simulation tests, and studies the impact of operator fatigue on port service capabilities.

2 Analysis of the influence of fatigue factors on work efficiency

Fatigue in the traditional definition mainly refers to the continuous energy consumption of workers after a long period of work, which in turn causes the physical and psychological status of the workers to change, and ultimately reduces the worker’s ability to work[1,2].

In the impact of fatigue on efficiency, there are many studies on fatigue driving, and the results obtained from the research are also universally applicable, and are suitable for the study of fatigue problems of terminal operators. In the research on fatigue driving, Ma Yanli[3] conducted experimental tests on the choice of reaction time, attention distribution value, correct operation times, operation stability and other aspects of car drivers during car driving, and obtained corresponding data results. According to the analysis of the results, it is concluded that the driver’s fatigue level will deepen with the increase of continuous driving time, and the two are positively correlated.

Through the relationship between the fatigue level of the operator and the driving characteristic evaluation index, the evaluation index values of the driving characteristic under different fatigue levels within the 95% confidence interval are determined as shown in the following Table 1.

<table>
<thead>
<tr>
<th>Work Time/min</th>
<th>80</th>
<th>120</th>
<th>190</th>
<th>210</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response Time/s</td>
<td>.63–0</td>
<td>.76–0</td>
<td>.86–1</td>
<td>1.04–1</td>
<td>1.14–2</td>
</tr>
<tr>
<td>Number of correct responses/Time</td>
<td>117–</td>
<td>104–</td>
<td>99–</td>
<td>91–</td>
<td>95–</td>
</tr>
<tr>
<td>Number of wrong actions/Time</td>
<td>122</td>
<td>108</td>
<td>105</td>
<td>104</td>
<td>125</td>
</tr>
<tr>
<td>Number of wrong actions/Time</td>
<td>.78–1</td>
<td>2.08–2</td>
<td>2.65–3</td>
<td>3.45–7</td>
<td>5.32–1</td>
</tr>
<tr>
<td>Number of wrong actions/Time</td>
<td>.18</td>
<td>.64</td>
<td>.85</td>
<td>.55</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Table 1. The relationship between continuous work time and work efficiency

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3 Terminal Simulation

3.1 The necessity of simulation applications

During the operation of the terminal, there will be time intervals during the production operation. In the operation process, both the personnel and the operating machinery will perform intermittent operations due to different factors. Whether it is the arrival time of container ships, the loading and unloading operations of terminal loading and unloading equipment, the transportation operations of horizontal vehicles, or the outbound operations of containers in the yard, they all have discrete characteristics [4,5].

In the research on the terminal operation system, the traditional method is to use mathematical models such as differential equations and difference equations to solve the problem. However, a dynamic and comprehensive analysis of the complex terminal operation system cannot be done, which easily causes the calculation results to be far from the actual situation. In the process of establishing the simulation model of the terminal system, many random factors can be considered, which cannot be realized in the mathematical model, and the simulation system allows users to observe the operating status intuitively. The embedding of optimization technology enables the model to continuously optimize itself during the operation process, and guide the final solution to achieve the optimal effect. In the simulation process, a large amount of information can be obtained, and the resources consumed in the process are the least, and the modification is also very convenient, which can be applied to the research of the terminal operation system [6,8].

3.2 Assumptions of the Simulation Model

1. In the process of loading and unloading the ship, follow the operation process of unloading first and then loading.
2. The total container capacity of a container ship is the container capacity that needs to be loaded and unloaded in the port area.
3. In the entire loading and unloading process, only two container sizes of 20 feet and 40 feet are considered, and other container sizes are not considered.
4. When carrying out the lifting operation of the export container, the situation that the container did not arrive at the yard on time is not considered, and the overturning operation is not considered during the import and export operations of the container.
5. The number of quay cranes, yard bridges, and inner trucks in the model is fixed. Each berth is equipped with two quay cranes, six inner trucks and three-yard trucks.
6. The model does not consider the situation of container ships turning to other ports for berthing operations while waiting for service.
7. In the model, all arriving ships need to carry out loading and unloading operations at the wharf.

3.3 Collecting of Simulation Data

The main parameters set in the model building process are shown in Table 2.

<table>
<thead>
<tr>
<th>Main Part</th>
<th>Statistics object</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berth</td>
<td>Berth 1 Ship Arrival Time</td>
<td>Random(Expo)</td>
</tr>
<tr>
<td></td>
<td>Berth 2 Ship Arrival Time</td>
<td>Random(Expo) 280min</td>
</tr>
<tr>
<td>Container</td>
<td>Number of Unloaded Containers</td>
<td>Percentage (20%,250) (70%,350) (10%,450)</td>
</tr>
<tr>
<td>Container</td>
<td>Container Stacking Position</td>
<td>Random</td>
</tr>
<tr>
<td>Container</td>
<td>Container Pickup Location</td>
<td>Random</td>
</tr>
<tr>
<td>Equipment</td>
<td>Number of Quay Cranes</td>
<td>4</td>
</tr>
<tr>
<td>Equipment</td>
<td>Number of Internal Trucks</td>
<td>12</td>
</tr>
<tr>
<td>Equipment</td>
<td>Number of Yard Cranes</td>
<td>6</td>
</tr>
<tr>
<td>Quay Cranes</td>
<td>Maximum Loading and Unloading Volume</td>
<td>38TEU/H</td>
</tr>
<tr>
<td>Quay Cranes</td>
<td>Average Speed</td>
<td>5m/s</td>
</tr>
<tr>
<td>Quay Cranes</td>
<td>Travel Distance</td>
<td>69m</td>
</tr>
<tr>
<td>Quay Cranes</td>
<td>Average Container Loading Time</td>
<td>45s</td>
</tr>
<tr>
<td>Internal Trucks</td>
<td>Average Speed</td>
<td>8m/s</td>
</tr>
<tr>
<td>Internal Trucks</td>
<td>Travel distance</td>
<td>455m</td>
</tr>
<tr>
<td>Yard Cranes</td>
<td>Maximum Loading and Unloading Volume</td>
<td>48TEU/H</td>
</tr>
<tr>
<td>Yard Cranes</td>
<td>Average Speed</td>
<td>1m/s</td>
</tr>
<tr>
<td>Yard Cranes</td>
<td>Travel Distance</td>
<td>53.47m</td>
</tr>
<tr>
<td>Yard Cranes</td>
<td>Average Container Loading Time</td>
<td>30s</td>
</tr>
<tr>
<td>Yard Cranes</td>
<td>Average Container Unloading Time</td>
<td>30s</td>
</tr>
</tbody>
</table>

3.4 Model Simulation Model Establishment

According to the previous assumptions on the model establishment conditions and the input of model data, the model running cycle is determined to be 604800s in one week. In order to ensure the stability of the model output data, 20 simulation runs are performed in each run cycle, which can effectively reduce the interference of other random factors on the model run results. The simulation model is shown in Fig 1.
3.5 Analysis of the Credibility of Simulation Running Data

In the output data of the model, statistics on the total number of containers loaded and unloaded at the terminal and the utilization rate of quay cranes, yard cranes, and internal trucks during the main operation period. Through the statistical analysis of the output of 100 running data results, whether it is the total container throughput of the terminal or the utilization rate of quay cranes, yard bridges, and internal trucks, they tend to be stable. It shows that the simulation model has strong credibility and can be used as the next step for the running simulation of the experiment.

The statistics of the average value of output data during the model running period are as following Table 3 and Fig 2.

Table 3. Terminal Container Throughput

<table>
<thead>
<tr>
<th>Container /TEU</th>
<th>Berth-1 load</th>
<th>Berth-2 load</th>
<th>Unload</th>
<th>Total throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>5016</td>
<td>4950</td>
<td>10001</td>
<td></td>
<td>19967</td>
</tr>
</tbody>
</table>

Fig. 2. Utilization of Each Equipment

4 Simulation experiment and data analysis

4.1 Experimental hypothesis

Taking the drivers of quay cranes, yard cranes, and internal trucks in the fatigue state during the operation of the terminal as the research object, analyse the influence of their working efficiency in the fatigue state on the overall operation efficiency of the terminal.

In view of the difference in manual operation of machinery during the operation of the terminal, the following seven assumptions are made.

Hypothesis 1: During the operation, the quay crane driver is fatigued, and the yard crane and internal truck drivers are working normally.

Hypothesis 2: During the operation, the internal truck driver is fatigued, and the quay and yard crane drivers are working normally.

Hypothesis 3: During the operation, the yard crane drivers are fatigued, and the quay and internal truck drivers are working normally.

Hypothesis 4: During the operation, the quay crane and internal truck drivers are fatigued, and the yard crane drivers are working normally.

Hypothesis 5: During the operation, the quay crane and yard crane drivers are fatigued, and the internal truck drivers are working normally.

Hypothesis 6: During the operation, the yard crane and internal truck drivers are fatigued, and the quay crane drivers are working normally.

Hypothesis 7: During the operation, the drivers of the quay crane, the internal truck and the yard crane are all fatigue.

Assuming that the driver’s work fatigue is set: quay cranes and yard cranes are mainly used to add fatigue coefficients in the process of manually grabbing and unloading containers. Internal trucks add a fatigue factor to the driving speed during heavy-load transportation and empty-load transportation. The fatigue coefficient setting is shown in the Fig 3.

Fig. 3. Fatigue Coefficient Setting

4.2 Data Analysis

The total throughput of the terminal under each experiment condition is as shown in Fig 4 below.

Table 4. Quay crane fatigue, Yard crane fatigue VS Both quay crane and yard crane fatigue

<table>
<thead>
<tr>
<th>Fatigue object</th>
<th>Throughput/TEU</th>
<th>Rate of decline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y.C</td>
<td>19758</td>
<td>1.05%</td>
</tr>
<tr>
<td>Q.C</td>
<td>16728</td>
<td>16.22%</td>
</tr>
<tr>
<td>Y.C &amp; Q.C</td>
<td>16529</td>
<td>17.22%</td>
</tr>
</tbody>
</table>

Through the comparison and analysis of the data in the Table 4, it is found that the fatigue of both the quay crane and yard crane drivers is reduced by 199 TEU in terms of container throughput and 1.19% in efficiency compared with the fatigue of the quay crane driver only. Compared with the efficiency reduction value of the
original scheme, the work efficiency of quay crane and yard crane drivers’ fatigue is reduced by 17.22%, and the work efficiency of only quay crane driver fatigue is reduced by 16.22%.

When both the quay crane and yard crane drivers are fatigued, compared with the fatigue of the yard crane driver only, the container throughput is reduced by 3229 TEU and the efficiency is reduced by 16.34%. Compared with the efficiency reduction value of the original scheme, the work efficiency of both quay cranes and yard crane drivers’ fatigue is reduced by 17.22%, and the work efficiency of only yard crane driver fatigue is reduced by 1.05%.

The comparison shows that when both the quay crane and yard crane drivers are fatigued at the same time, the reduction in the fatigue efficiency of each party is greater than the difference in the original plan, that is, when both parties are fatigued, the work efficiency of each party will be further reduced.

(2) Yard crane fatigue, Internal truck fatigue VS Both yard crane and internal truck fatigue

<table>
<thead>
<tr>
<th>Fatigue object</th>
<th>Throughput/TEU</th>
<th>Rate of decline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y.C</td>
<td>19758</td>
<td>1.05%</td>
</tr>
<tr>
<td>I.T</td>
<td>19954</td>
<td>0.07%</td>
</tr>
<tr>
<td>Y.C &amp; I.T</td>
<td>19734</td>
<td>1.17%</td>
</tr>
</tbody>
</table>

Through the comparison and analysis of the data in the Table 5, it is found that the fatigue of both the internal truck driver and yard crane driver is reduced by 24 TEU in terms of container throughput and the efficiency is reduced by 0.12% compared with the fatigue of yard crane only. Compared with the efficiency reduction value of the original scheme, the work efficiency of both the yard crane and the internal truck drivers’ fatigue is reduced by 1.17%, and the efficiency of only the internal truck driver fatigue is reduced by 1.05%.

Compared the fatigue of both yard crane and the internal truck drivers with the fatigue of only internal truck driver, the container throughput is reduced by 220 TEU and the efficiency is reduced by 1.10%. Compared with the efficiency reduction value of the original scheme, the work efficiency of both the yard crane and internal truck drivers’ fatigue is reduced by 1.17%, and the work efficiency of only the yard crane driver fatigue is reduced by 0.07%.

The comparison shows that when both the yard crane and the internal truck are fatigued at the same time, the reduced value of the efficiency of each party is basically the same as the difference in the original plan, that is, when both parties are fatigued, the operating efficiency of each party is basically unchanged.

(3) Quay crane fatigue, Internal truck fatigue VS Both quay crane and internal truck fatigue

<table>
<thead>
<tr>
<th>Fatigue object</th>
<th>Throughput/TEU</th>
<th>Rate of decline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q.C</td>
<td>16728</td>
<td>16.22%</td>
</tr>
</tbody>
</table>

Comparing the data in the Table 6, when both the quay crane and the internal truck drivers are fatigued, the container throughput is reduced by 193 TEU and the efficiency is reduced by 1.15% compared with only the quay crane driver is fatigued. Compared with the efficiency reduction value of the original scheme, the work efficiency of both quay crane and internal truck drivers fatigue is reduced by 17.19%, and the work efficiency of quay crane driver fatigue is reduced by 16.22%.

Compared the fatigue of both quay crane and the internal truck drivers with the fatigue of only internal truck driver, the container throughput is reduced by 3419 TEU and the efficiency is reduced by 17.13%. Compared with the reduction in efficiency of the original scheme, the work efficiency of both quay crane and internal truck drivers’ fatigue is reduced by 17.19%, and the work efficiency of internal truck driver fatigue is reduced by 0.07%.

The comparison shows that when the quay crane and internal truck drivers are fatigued at the same time, the reduction in the efficiency of each party is greater than the difference in the original plan, that is, when both parties are fatigued, the efficiency of each party will be further reduced.

(4) Internal truck fatigue, Both quay crane and yard crane fatigue VS Both quay crane, yard crane and internal truck fatigue

<table>
<thead>
<tr>
<th>Fatigue object</th>
<th>Throughput/TEU</th>
<th>Rate of decline</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.T</td>
<td>19954</td>
<td>0.07%</td>
</tr>
<tr>
<td>Q.C &amp; Y.C</td>
<td>16529</td>
<td>17.22%</td>
</tr>
<tr>
<td>Q.C, Y.C &amp; I.T</td>
<td>16518</td>
<td>17.27%</td>
</tr>
</tbody>
</table>

Through the comparison and analysis of the data in the Table 7, it is found that the fatigue of the internal truck, yard crane and quay crane drivers, the container throughput is reduced by 11 TEU and the efficiency is reduced by 0.07% compared with both the quay crane and yard crane drivers are fatigued. Compared with the efficiency reduction value of the original scheme, the work efficiency of quay crane, yard crane and internal drivers’ fatigue is reduced by 17.27%, and the work efficiency of both quay crane and yard crane drivers’ fatigue is reduced by 17.22%.

Compared the fatigue of quay crane, yard crane and internal truck driver with the fatigue of only the internal truck driver, the container throughput is reduced by 3436 TEU and the efficiency is reduced by 17.22%. Comparing the efficiency reduction value of the original scheme, the work efficiency of quay crane, yard crane and internal truck drivers’ fatigue is reduced by 17.27%, and the work efficiency of only the internal truck drivers’ fatigue is reduced by 0.07%.

It can be seen from the comparison that when the quay crane, yard crane and internal truck drivers are
fatigued at the same time, the reduction of the efficiency of all parties is greater than the difference in the original plan, that is, when the three parties are fatigued, the efficiency of all parties will be further reduced.

(5) Yard crane fatigue, Both quay crane and internal truck fatigue VS Both quay crane, internal truck and yard crane fatigue

<table>
<thead>
<tr>
<th>Fatigue object</th>
<th>Throughput/TEU</th>
<th>Rate of decline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y.C</td>
<td>19758</td>
<td>1.05%</td>
</tr>
<tr>
<td>Q.C &amp; I.T</td>
<td>16535</td>
<td>17.19%</td>
</tr>
<tr>
<td>Q.C, Y.C&amp;I.T</td>
<td>16518</td>
<td>17.27%</td>
</tr>
</tbody>
</table>

Comparing the data in the comparison table 8, when the quay crane, yard crane and internal drivers are fatigued the container throughput is reduced by 17 TEU and the efficiency is reduced by 16.40%. Comparing the efficiency reduction value of the original scheme, the work efficiency of quay crane, yard crane and internal truck drivers’ fatigue is reduced by 17.27%, and the work efficiency of yard crane and internal truck drivers’ fatigue is reduced by 17.19%.

Compared the fatigue of quay crane, yard crane and internal truck driver with the fatigue of only the yard crane driver, the container throughput is reduced by 3240 TEU and the efficiency is reduced by 16.40%. Comparing the efficiency reduction value of the original scheme, the work fatigue efficiency of only the yard crane driver is fatigued reduced by 1.05%, and the work efficiency of only the yard crane drivers’ fatigue is reduced by 1.05%.

The comparison shows that when the quay crane, yard crane and internal truck drivers are fatigued at the same time, the reduction of the efficiency of all parties is greater than the difference in the original plan, that is, when the three parties are fatigued, the efficiency of all parties will be further reduced.

(6) Quay crane fatigue, Both yard crane and internal truck fatigue VS Both yard crane, internal truck and quay crane fatigue

<table>
<thead>
<tr>
<th>Fatigue object</th>
<th>Throughput/TEU</th>
<th>Rate of decline</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1.17%</td>
</tr>
<tr>
<td>Q.C, Y.C&amp;I.T</td>
<td>16518</td>
<td>17.27%</td>
</tr>
</tbody>
</table>

Comparing the data in the comparison Table 9, when the quay crane, yard crane and internal drivers are fatigued the container throughput is reduced by 3216 TEU and the efficiency is reduced by 16.30% compared with the fatigue of both yard crane and internal truck drivers. Compared with the original efficiency reduction value, the work efficiency of quay crane, yard crane and internal truck drivers’ fatigue is reduced by 17.27%, and the work efficiency of both yard crane and internal truck drivers’ fatigue is reduced by 1.17%.

Compared the fatigue of quay crane, yard crane and internal truck driver with the fatigue of the quay crane driver, the container throughput is reduced by 210 TEU and the efficiency is reduced by 1.26%. Comparing the efficiency reduction value of the original scheme, the work efficiency of quay crane, yard crane and internal truck drivers’ fatigue is reduced by 17.27%, and the work efficiency of only quay crane drivers’ fatigue is reduced by 16.22%.

The comparison shows that when quay crane, yard crane and internal truck drivers are fatigued at the same time, the reduction in efficiency of all parties is greater than the difference in the original plan, that is, the efficiency of all parties will be further reduced when the three parties are fatigued.

In summary, the impact on the operation efficiency of the terminal is sorted as follows: quay crane, yard crane and internal truck drivers are fatigued (17.27%)> quay crane and yard crane drivers are fatigued (17.22%)> quay crane and internal truck drivers are fatigued (17.19)> quay crane driver is fatigued (16.22%)> yard crane and internal truck drivers (1.17%)> yard crane driver is fatigued (1.05%)> internal truck driver is fatigued (0.07%).

5 Conclusion

In this paper, the system simulation software FlexSim is used to simulate and model the operation system of the traditional container terminal, and the following conclusions are obtained through a large number of simulation experiments.

(1) During the operation of the terminal, the overall work fatigue has the greatest impact on the operation efficiency of the terminal. Compared with the loading and unloading operations of quay cranes, yard cranes, and internal trucks drivers under normal conditions, the container throughput of the terminal during the operation cycle is reduced by 3438 TEU, and the overall operation efficiency is reduced by 17.27%.

(2) Among the effects of operator fatigue on the operation efficiency of the terminal, the fatigue of the quay crane driver has the greatest impact on the operation efficiency of the terminal. During the operation period, the container throughput is reduced by 3239 TEU and the terminal operation efficiency is reduced by 16.22%.

(3) In the work fatigue of multiple operators, not only will the operation efficiency of the entire terminal be reduced, but the efficiency reduction value of each work fatigue machine is greater than the efficiency reduction value of one person when the work is fatigued. When the drivers of quay cranes, yard cranes, and internal trucks are fatigued, they will have interactive effects, which will further reduce their respective efficiency.

Through the simulation experiments results, it can be seen that optimizing the scheduling of terminal operators and avoiding fatigue operations has a vital impact on the port service capacity. The research conclusions obtained can provide reference for the reasonable scheduling of port managers.
References


