Container Terminal Planning Rules – A Study of Mega Operators

Tao CHEN
Assistant Professor
Department of Logistics and Shipping Management
Kainan University, Taoyuan, Taiwan
No. 1, Kainan Road, Taoyuan, Taiwan
FAX:+886-3-3412361
E-mail: chentao@mail.knu.edu.tw

Abstract: Most of the studies on container terminal planning are conducted from a bottom-up approach; the operational data in terminal operations have been collected and used as bases to estimate possible strategies for deploying terminal facilities to handle increasing container traffic. The drawback to a bottom-up approach, however, is that the output can only apply to specific terminals under certain conditions. To compensate for the shortcomings of this technique, we adopt the top-down approach to break down terminal planning rules by long-term observation of the development of mega terminal operators. Two Hong Kong based mega-terminal operators, Hongkong International Terminals (HIT) and Modern Terminal Ltd. (MTL), were selected as the samples. The objective of this study is to determine the terminal planning rules followed by mega-operators and consequently provide practical references for terminal operators. Together with analysis generated from the bottom-up approach, terminal operators will be able to thoroughly examine terminal planning rules and make the best choice for the deployment of terminal facilities.

Key Words: Terminal planning rules; Mega terminal operator; Top-down approach.

1. INTRODUCTION

Since the emergence of container terminal, most of the studies on container terminal planning have been conducted using the bottom-up approach. For example, UNCTAD set simplified rules regarding terminal planning for developing countries based on assumptions on most terminal operation and management factors despite the many uncertainties in this division. Therefore, most studies that followed have implemented simulation technology using operational data collected from terminal operations to examine terminal planning, and estimate possible strategies for deploying terminal resources and facilities to handle expected traffic. However, because of the gaps between past and current developments in terminal management and technology, efforts have failed to meet practical needs. The mega-terminal operators first emerged in the 1970s, since then, container traffic handled by mega-operators, such as the operators in Hong Kong, has increased from a quarter million TEUs in 1975 to over six million in 2010. When reviewing the development of mega-terminal operators, the issue of whether any rules for terminal planning exist emerges.

To make up for the deficiencies of the bottom-up approach, this study examines terminal planning using the top-down approach, and scrutinizes terminal planning rules by analyzing the relationship between container traffic and the development of terminal strategies. Achieving this objective necessitates long-term observation of the development of corresponding strategies used by terminal operators to handle increasing container traffic. To
determine whether terminal planning rules exist, two mega-terminal operators in Hong Kong were chosen as samples. Using statistics software and information on terminal operators in container traffic and major facilities from 1975 to 2009, this study breaks down and quantifies the relationships between container traffic and each of the major terminal facilities. Our results can provide reliable and practical guidelines and references for comprehensive and long-term planning. Terminal operators can compare the strategies generated from both bottom-up and top-down approaches for efficient decision making.

There are five sections in this paper: Section 2 is an introduction to terminal systems and major issues in terminal planning. Relevant studies are reviewed and compared. The research design is explained and major findings described in detail in Section 3. Section 4 contains the comparison between the planning rules of the two mega-operators. The implications of the planning rules are also illustrated. Section 5 summarizes the contribution and conclusion of this study, together with its limitation and recommendations for future research.

2. LITERATURE REVIEW AND TERMINAL PLANNING

2.1 Operations in the Terminal

From the viewpoint of logistics flow, a container terminal is the interface between sea and land transportation. It comprises two major segments: the quayside, where the transfer of containers between the quay and the containership is carried out; and the container yard, where the transfer of containers between the quay and the yard occurs. The combination of quay and yard area determines the container terminal. In general, at least five major issues are considered in container terminal planning, namely, quay length, terminal area, storage capacity of the terminal, and the number of quay cranes and transtainers deployed. Two types of equipment are required to handle the container traffic within a container terminal: quay cranes and transtainers. The number of quay cranes and transtainers and their operation efficiency determine the efficiency of container transfer in the quayside and yard, as well as the handling capacity of the container terminal.

Although terminal operators now handle considerably heavier container traffic than in the 1970s, the container berth’s physical size has not changed accordingly. In most terminals, the quay length assigned for each berth has remained within 300–330 m. Meanwhile, the area of land occupied by terminal operators has been virtually unchanged (within 12–15 ha) because of the unavailability of land for expansion. Unlike land, the number and variety of yard equipment can be expanded upon pressing need, although data collected from terminal operators show that the number of quay cranes deployed for terminal operations has largely been the same. Three quay cranes for a one-berth terminal and seven cranes for a two-berth terminal is a common allocation up to the present. Terminal operators have deployed more transtainers for yard operations to handle increasing container traffic. This leads us to the question, how many berths, quay cranes, and transtainers are needed, and how much land and storage capacity is required to accommodate increasing container traffic? Our objectives in this study stem from this question.

1 There are three types of transtainers, namely, straddle carrier (S/C), rubber-tyred gantry (RTG), and rail-mounted gantry (RMG). Most Asian terminals use RTG and RMG in their yard operations.
2.2 Literature Review

The first reports found focus on terminal planning and operations are the UNCTAD handbook and Port Planning and Development (Frankel), but both of them provided simplified planning rules to be followed by terminal operators in developing countries for long-term management of container traffic. The rules were created based on assumptions on most operation and management factors, which ignored the dynamic nature of the business environment and the differences between terminal characteristics. Most studies thereafter implemented simulation technology as the major tool in analyzing operational data collected from terminal operations; the simulations were conducted to determine possible strategies for terminal planning and their effect on operations (Gambardella et al.; Yun et al.; Legato and Mazza; Lee et al.; Sgouridis and Makris; Petering et al.; Kim et al.). However, because of the complexity of the interactions in multi-berth terminal operations, and the gaps between past and changing trends, studies have been limited to small to medium terminals, where container traffic range is contained to only half a million to two million TEUs.

Furthermore, a comprehensive literature review was conducted by Stahlbock and Voß. Few studies have been found to provide comprehensive analysis of terminal planning, but some studies focused on a part or several aspects of terminal planning and their effect on terminal operations. For example, a number of researchers examined land utilization strategies and its effect on operational efficiency (Kim and Hong; Chen and Chu) These studies comprehensively analyzed container terminal land utilization, strategies in transtainer deployment, and storage capacity, thus providing detailed analyses and practical references for yard planning. Others focused on planning and efficiency issues concerning yard operations and provided reliable guidance for yard planning (Ballis and Abakoumkin; Zhanga et al.; Linna et al.; Vis; Soriguera and Robuste; Imai et al.; Kozan; Lee et al.; Nang). Some researchers expressed interest in the strategies and issues concerning quay and berth operations (Yun and Choi; Park and Kim; Kim and Park; Nishimura and Papadimitrious; Etsuko et al.; Bransilav and Park; Bish et al.; Moorothy and Teo; and Bierwirth and Meisel). Their findings provide in-depth and comprehensive understanding of the interactions between berth planning and quay operations. As a summary, the research scopes of related studies can be categorized into several areas: the first covered all of the major terminal planning issues; the second research scope focused on berth planning and its effects on operations; and the third focused only on yard planning and operations. Occasionally, some studies that focus on the abovementioned scopes also cover the issue of terminal land requirement.
3. RESEARCH FINDINGS

3.1 Bottom-Up and Top-Down Approach

As discussed in literature review, from the perspective of terminal planning, there are several critical points been ignored by academics. The first is that most studies focused on one or several terminal operations or planning items only, and methodologies selected mostly are simulation or utilization of quay length (Huang et al.), and failed to provide a comprehensive and reliable report covering all major items in terminal planning.

The second argument for bottom-up approach is the huge gap between the result of academic studies and the demand of terminal operators. For example, the designed berth capacity of major container terminals in East Asia has been jumped from around 300,000 TEUs in 1990s to around 750,000 TEUs in 2000s, but berth capacity of the container terminal analyzed by most academic studies are lowered than 400,000 TEUs. As a consequence, the output of academic studies could not meet the demand of terminal operators with designed capacity of 750,000 TEUs. The top-down approach analyzing terminal operators with outstanding performance in berth throughput (for example, 600,000 TEUs), could shorten the gap between academic studies and industry demand effectively, and provide reliable and practical guidelines and terminal rules to be learned by modern terminal operators.

3.2 Sample selection

As discussed in above section, the top-down approach analyzes terminal planning rules based on container traffic handled to break down the strategies regarding facilities and resources deployed by the operator. To provide valuable insights, the top-down approach must be implemented on two grounds. The first is that the operator selected must be a “foretype” or “typical case,” - a practice that could be learned by most operators from the perspectives of time and container traffic. That is, the operator must have experience handling smaller volumes to millions of TEUs of container traffic. The second is the long-term observation of strategy development. Based on measurements of container traffic, Hong Kong has handled the highest volume for decades. Most of the containers are handled by two mega-operators, Hongkong International Terminal (HIT) and Modern Terminal Ltd. (MTL), which were selected as the “typical cases” for this study. Data on the development strategies of HIT and MTL were collected from their websites and the Containerisation International Yearbook. Meanwhile, because of the geographic advantage, Hong Kong has been the gateway of Southern China for decades, and most of the containers handled are transship or transit ones. Consequently, the dwell time for container storage in the terminal is shorter than that in other ports. The operational performance of these operators are also outstanding, take HIT for example\(^2\), the gross quay crane moves (per hour) ranges between 31 to 35, the average truck turn-around time is 45 minutes and the average vessel operating rate is 73 moves per hour.

Between 1975 and 2009, container traffic handled by MTL increased more than 16-fold, from around 360,000 TEUs in 1975 to around 5.8 million TEUs in 2009. Simultaneously, the container traffic handled by HIT increased 15-fold, from 380,000 TEUs in 1975 to more than 8.4 million TEUs in 2009. Unlike the leniency accorded to increase in traffic, there is a serious restriction on land expansion in Hong Kong, and both HIT and MTL have expanded

\(^2\) Operational information is provided by HIT in March, 2011, the operational information of MTL is not available.
quay length and terminal areas around only three to four times since 1975. As alternative strategies to overcome land restriction, HIT and MTL have upgraded yard operating systems accordingly. For example, HIT has modified its yard system from RTG to a combination of RTG and RMG, while MTL has modified its yard system from straddle carrier (S/C) to RTG. As a result of yard system modifications, HIT has expanded the number of transtainers 10-fold, and MTL has expanded by 2.5 times.

3.3 Data Collection

For the purpose to break down the strategies of mega-operators in the deployment of terminal facilities and resources to handle increasing container traffic, a comprehensive long-term study of the development of two Hong Kong terminal operators is required. The following information concerning terminal planning between 1975 and 2009 were collected:

1. Traffic (or throughput) handled by the terminal operators, measured in TEUs per year;
2. Quay length of the terminal, measured in meters;
3. Number of quay cranes deployed, measures by the number of QCs;
4. Area occupied by the terminal operators, measured in hectares;
5. Number of transtainers deployed for terminal operations, measured by the number of transtainers (TTs);
6. Storage capacity of the terminal, measured in TEUs.

The above information is to be used to break down the relationships between container traffic and major items in terminal planning from top-down approach by using statistics software. Analysis of these issues of terminal information is expected to reveal the rules of terminal planning adopted by both mega-operators. For example, from a planning perspective, what are the corresponding strategies regarding land and storage? From an operational viewpoint, how many quay cranes and transtainers have been deployed to manage increasing container traffic? This study uses correlation and linear regression analyses to quantify the relationship between container traffic and all of the major issues in terminal facilities.

4. FINDINGS AND ANALYSIS

4.1 General Analysis

From an operational perspective, the container traffic of both HIT and MTL reflect a strong and positive correlation with all of the issues in terminal facilities (Table 1). To obtain comprehensive understanding of the correlations between the facilities and container traffic, the former was analyzed separately to identify its statistical relationship with container traffic.

The summary of the R-square and types of equation curves of these terminal facilities is presented in Table 2. Two analyses were conducted for the transtainers of MTL because the change in yard operating system from S/C to RTG in 1996 led to a huge change in the number of transtainers from 1990 to 1998. The first analysis was based on the original data (TT no_1), while the second (TT no_2) ignores the increasing number of MTL transtainers during 1993 to 1995 to obtain a more practical curve. The explanatory capacity of major items in terminal planning are strong, which means the regression results shown in Table 2 could be used as reliable and practical references to be learned by terminal operators.
Table 1. Summary of correlation analysis.

<table>
<thead>
<tr>
<th>Facility</th>
<th>Quay length</th>
<th>Yard area</th>
<th>QC_no</th>
<th>TT_no</th>
<th>Storage capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIT</td>
<td>Pearson Correlation 0.904**</td>
<td>0.918**</td>
<td>0.977**</td>
<td>0.953**</td>
<td>0.955**</td>
</tr>
<tr>
<td>N</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>MTL</td>
<td>Pearson Correlation 0.920**</td>
<td>0.897**</td>
<td>0.950**</td>
<td>0.711**</td>
<td>0.969**</td>
</tr>
<tr>
<td>N</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Table 2. Summary of statistical analysis of terminal facilities of HIT and MTL.

<table>
<thead>
<tr>
<th>Facility</th>
<th>Equation</th>
<th>R Square</th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>Sig</th>
<th>Constant</th>
<th>b1</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIT</td>
<td>Quay length</td>
<td>Log 0.935</td>
<td>417.23</td>
<td>1</td>
<td>29</td>
<td>0</td>
<td>-13031.93</td>
<td>1064.10</td>
</tr>
<tr>
<td></td>
<td>Yard area</td>
<td>Log 0.950</td>
<td>555.66</td>
<td>1</td>
<td>29</td>
<td>0</td>
<td>-375.10</td>
<td>30.38</td>
</tr>
<tr>
<td></td>
<td>QC no</td>
<td>Linear 0.954</td>
<td>598.60</td>
<td>1</td>
<td>29</td>
<td>0</td>
<td>6.01</td>
<td>5.019E-06</td>
</tr>
<tr>
<td></td>
<td>TT no</td>
<td>Log 0.972</td>
<td>1013.33</td>
<td>1</td>
<td>29</td>
<td>0</td>
<td>-602.57</td>
<td>46.37</td>
</tr>
<tr>
<td></td>
<td>Storage Capacity</td>
<td>Log 0.973</td>
<td>994.70</td>
<td>1</td>
<td>29</td>
<td>0</td>
<td>-404748.97</td>
<td>31109.63</td>
</tr>
<tr>
<td>MTL</td>
<td>Quay length</td>
<td>Linear 0.846</td>
<td>181.39</td>
<td>1</td>
<td>33</td>
<td>0</td>
<td>773.44</td>
<td>2.9082E-04</td>
</tr>
<tr>
<td></td>
<td>Yard area</td>
<td>Log 0.896</td>
<td>282.94</td>
<td>1</td>
<td>33</td>
<td>0</td>
<td>-359.49</td>
<td>29.13</td>
</tr>
<tr>
<td></td>
<td>QC no</td>
<td>Linear 0.903</td>
<td>307.97</td>
<td>1</td>
<td>33</td>
<td>0</td>
<td>4.82</td>
<td>4.4632E-06</td>
</tr>
<tr>
<td></td>
<td>TT no_1</td>
<td>S 0.711</td>
<td>81.32</td>
<td>1</td>
<td>33</td>
<td>0</td>
<td>4.53</td>
<td>-335181.32</td>
</tr>
<tr>
<td></td>
<td>TT no_2</td>
<td>Linear 0.923</td>
<td>286.97</td>
<td>1</td>
<td>24</td>
<td>0</td>
<td>42.53</td>
<td>9.8686E-06</td>
</tr>
<tr>
<td></td>
<td>Storage Capacity</td>
<td>Linear 0.938</td>
<td>500.59</td>
<td>1</td>
<td>33</td>
<td>0</td>
<td>4286.70</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Regression analysis was used to determine the linear relationship between all the issues in the terminal facility and container traffic. Table 3 shows the results of the regression analysis. The R-squares of the regression model for HIT and MTL are 0.974 and 0.958, respectively, which mostly explains the strategies for handling container traffic since 1975. This can further be used to estimate the strategies for handling future container traffic with high reliability. Table 4 presents the results of ANOVA analyses and Table 5 shows the coefficients of the regression model. The beta value of the model shows that for HIT and MTL, the number of quay cranes and storage capacity respectively have the best explanatory power, also indicating that these are critical factors influencing container traffic in each operator. The regression formulas consisting of the issues in the terminal facility are expressed as <formula HIT> and <formula MTL>. 

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### Table 3. Summary of the regression model.

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIT (a)</td>
<td>0.987</td>
<td>0.974</td>
<td>0.969</td>
<td>491684.507</td>
</tr>
<tr>
<td>MTL (b)</td>
<td>0.979</td>
<td>0.958</td>
<td>0.950</td>
<td>393491.055</td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), storage, quay_m, qc_no, tt_no, yard_ha  
b. Predictors: (Constant), storage, tt_no, yard_ha, quay_m, qc_no

### Table 4. Summary of ANOVA analyses.

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>Df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIT (a)</td>
<td>2.26E+14</td>
<td>5</td>
<td>4.51E+13</td>
<td>186.705</td>
<td>0.000</td>
</tr>
<tr>
<td>Residual</td>
<td>6.04E+12</td>
<td>25</td>
<td>2.42E+11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2.32E+14</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MTL (b)</td>
<td>1.01E+14</td>
<td>5</td>
<td>2.03E+13</td>
<td>130.816</td>
<td>0.000</td>
</tr>
<tr>
<td>Residual</td>
<td>4.49E+12</td>
<td>29</td>
<td>1.55E+11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1.06E+14</td>
<td>34</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), storage, quay_m, qc_no, tt_no, yard_ha  
b. Predictors: (Constant), storage, quay_m, qc_no, tt_no, yard_ha,  
c. Dependent Variable: Traffic

### Table 5. Summary of coefficients.

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIT</td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>594209</td>
<td>478661</td>
<td>1.241</td>
<td>0.226</td>
</tr>
<tr>
<td>Quay length</td>
<td>-1296</td>
<td>1646</td>
<td>-0.509</td>
<td>-0.787</td>
</tr>
<tr>
<td>Yard area</td>
<td>-24963</td>
<td>77540</td>
<td>-0.277</td>
<td>-0.322</td>
</tr>
<tr>
<td>QC no.</td>
<td>194904</td>
<td>38846</td>
<td>1.002</td>
<td>5.017</td>
</tr>
<tr>
<td>Transtainer no.</td>
<td>18833</td>
<td>18377</td>
<td>0.316</td>
<td>1.025</td>
</tr>
<tr>
<td>Storage capacity</td>
<td>-185</td>
<td>44</td>
<td>-0.196</td>
<td>-4.164</td>
</tr>
<tr>
<td>MTL</td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>554410</td>
<td>416185</td>
<td>1.332</td>
<td>0.193</td>
</tr>
<tr>
<td>Quay length</td>
<td>-709</td>
<td>575</td>
<td>-0.224</td>
<td>-1.232</td>
</tr>
<tr>
<td>Yard area</td>
<td>-24943</td>
<td>10087</td>
<td>-0.385</td>
<td>-2.473</td>
</tr>
<tr>
<td>QC no.</td>
<td>39733</td>
<td>47090</td>
<td>0.187</td>
<td>0.844</td>
</tr>
<tr>
<td>Transtainer no.</td>
<td>2838</td>
<td>5709</td>
<td>0.035</td>
<td>0.497</td>
</tr>
<tr>
<td>Storage capacity</td>
<td>89</td>
<td>15</td>
<td>1.349</td>
<td>5.798</td>
</tr>
</tbody>
</table>

Dependent Variable: Traffic
Traffic\textsubscript{1} = 594209 – 1296 X\textsubscript{1} – 24963 X\textsubscript{2} + 194904 X\textsubscript{3} + 18833 X\textsubscript{4} + 38 X\textsubscript{5} \quad \text{(HIT)}

Traffic\textsubscript{2} = 554410 – 709 X\textsubscript{1} – 24943 X\textsubscript{2} + 39733 X\textsubscript{3} + 2838 X\textsubscript{4} + 89 X\textsubscript{5} \quad \text{(MTL)}

Where
\begin{itemize}
    \item X\textsubscript{1} is Quay length;
    \item X\textsubscript{2} is Yard area;
    \item X\textsubscript{3} is QC number;
    \item X\textsubscript{4} is Transtainer number;
    \item X\textsubscript{5} is Storage capacity
\end{itemize}

4.2 Implications
The most challenging task in terminal planning is to find the best combination of strategies to meet the demand of the terminal for optimal productivity and efficiency. The planning rules established by the terminal operator should meet the challenges of stringent business and operating environments. To meet the abovementioned demands, the practices and successful experiences of mega-operators in Hong Kong for over three decades would be a valuable reference for terminal operators worldwide in terminal planning. The management skills and terminal technology of HIT and MTL far exceeds that of other terminal operators; thus, the planning rules of the two operators can be treated as standards or benchmarks.

Regarding expected terminal throughput that the planning rules covered, the suggestions made by both UNCTAD [1] and Frankel [2] are applicable only to terminals with container traffic of less than 500,000 TEUs. The planning rules of the mega-operators established in this study can be used as practical and reliable references by container terminals with expected container traffic ranging from one million to over six million TEUs, and can fulfill the expectations of most terminal operators worldwide. For studies concerning simulation in terminal planning and operations, the planning rules can be compared with the results generated from the bottom-up approach. Furthermore, researchers will also be able to perform in-depth examinations of the effects of intangible factors, such as terminal policy and improved management skills, based on the planning rules found.

5. CONCLUSIONS, LIMITATIONS AND FUTURE RESEARCH
This paper investigated all of the major items in terminal planning and broke down the terminal planning rules by analyzing the relationship between container traffic and the corresponding strategies adopted by mega-operators in handling the increasing container traffic from 1975 to 2009. Results reveal the terminal planning rules that account for the high reliability of HIT and MTL, which can provide practical guidance and serve as reliable references for terminal operators worldwide that handle container traffic ranging from half a million to around seven million TEUs. By comparing the results of simulation analysis and top-down approach, terminal operators will be able to select the strategy that best fits their needs.

The mega-operators in Hong Kong are unique in terms of business environment. For example, owing to the pressure of managing increasing container traffic with limited land, the dwell time for container transit in the terminal is much shorter than that in other ports. Both HIT and
MTL have implemented the most advanced terminal management systems with huge investments in research and development. All of these factors make HIT and MTL outstanding operators, so that the terminal planning rules found in this study can be used as reliable and practical references or benchmarks for terminal operators with different business environments, terminal management systems, and technology. For future research, the sample coverage should expand to other mega-operators worldwide to determine the differences in terminal planning rules as business environments, management, and technology differ. Further, this study has examined only the rules of tangible items of container terminal planning, and has not touched on the effect of intangible factors, such as terminal policy, information technology, modern equipment, labor quality, business environment, and so on, which would be interesting topics for future research.

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