Measuring the Capacity of a Port System: 
A Case Study on a Southeast Asian Port

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Summary: By using a Southeast Asian multi-purpose port as a case study, this project enhances the investment decision-making process for port infrastructure. Two existing methodologies are successfully applied and modified, leading to the development of both an investment tool and a framework for selecting an optimal investment strategy to address capacity constraints within a port system.

Introduction

The global maritime network, consisting of tens of thousands of ships circumnavigating the world by sea and of strategically located ports across the globe, is an essential part of international trade, as “90% of all trade travels by water” (U.S. Port and Inland Waterways Modernization, 2012). Ocean-bound cargo of all kinds originates from a nation for export and must pass through ports prior to reaching its destination. A port system (as shown in Figure 1) is a collection of components bridging land and sea that work together to handle the cargo, which arrives sea-side by vessel at anchorage, is transferred land-side to the port terminal at the port’s berths, and is eventually transported by intermodal links to the hinterland.

As economies develop and trade routes change, a port system’s capacity may need to expand to accommodate future cargo volume demand. However, investment in port infrastructure requires large amounts of capital (sometimes USD billions) and these investment decisions must be made when facing various uncertainties impacting performance over the long life of these assets.
The objective of this project is to enhance the investment decision-making process for port infrastructure through the application and modification of existing methodologies and the development of both an investment tool and a framework for selecting an optimal investment strategy to address capacity constraints within a port system. The motivation for this project is to 1) extend the application of the two existing methodologies used in the research, 2) evaluate potential investment strategies under uncertainty, and 3) both improve the profitability and increase the capacity of the case study port, which is located in Southeast Asia.

**Identify Bottlenecks by Measuring Capacity**

First, the data analysis uses a modification of the existing methodology for the measurement of port capacity, recently developed by Dr. Ioannis Lagoudis at the Malaysia Institute for Supply Chain Innovation and Mr. James Rice Jr. at the Massachusetts Institute of Technology (MIT). A uniform approach for measuring capacity is applied at each component throughout the port system using two dimensions: static capacity, referring to the capacity at a point in time, and dynamic capacity, referring to capacity over a period of time. After applying the demand data to determine utilization levels, this approach (as shown in Figure 2) allows for the identification of cargo flow bottlenecks at the port and for the implementation of efficiency improvements, potentially through additional investment. Using this bottom-up screening model, the application of the methodology revealed 7 current or potential bottlenecks among the 22 port components at the case study port.

**Evaluate Strategies Under Uncertainty**

Second, the data analysis uses a modification of the existing methodology for the evaluation of investment strategies under uncertainty developed by Dr. Richard de Neufville at MIT and Dr. Stefan Scholtes at the University of Cambridge. The methodology initially identifies three scenarios of uncertainty possibly impacting future performance of the case study port. A modified version of a simulation screening model is then developed, running Monte Carlo simulations to forecast the expected profitability of each port component under these uncertainties. The results are displayed graphically as cumulative distribution curves.

Based on the simulation results, which also confirm the findings under the port capacity measurement methodology, the warehouse is selected as the constrained port component for which potential investment strategies are evaluated under uncertainty. Three potential investment strategies are selected: the warehouse in its current state, a new multi-level warehouse without flexibility for future expansion, and a new multi-level warehouse with flexibility for future expansion. The profitability metrics highlight that the investment strategy for a new 4 level warehouse with a flexible option is the optimal choice when compared with strategies of similar scale (i.e., number of levels). However, when...
the investment strategy for a 4 level warehouse with a flexible option is compared with its best alternatives (i.e., comparable strategies, but not on the same scale), the optimal investment strategy is actually for a non-flexible 5 level warehouse, as shown in Table 1.

Table 1: A comparison of investment strategies

<table>
<thead>
<tr>
<th>Number of Levels</th>
<th>Initial Capex*</th>
<th>ENPV</th>
<th>10% VaR</th>
<th>90% VaR</th>
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<tbody>
<tr>
<td>4</td>
<td>462</td>
<td>9,791</td>
<td>7,774</td>
<td>9,399</td>
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<tr>
<td>5</td>
<td>635</td>
<td>9,120</td>
<td>7,442</td>
<td>10,238</td>
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<tr>
<td>6</td>
<td>799</td>
<td>9,023</td>
<td>7,529</td>
<td>10,210</td>
</tr>
<tr>
<td>7</td>
<td>981</td>
<td>8,836</td>
<td>7,216</td>
<td>10,163</td>
</tr>
<tr>
<td>3, Flexible</td>
<td>366</td>
<td>8,836</td>
<td>7,477</td>
<td>9,879</td>
</tr>
<tr>
<td>4, Flexible</td>
<td>599</td>
<td>9,030</td>
<td>7,711</td>
<td>10,033</td>
</tr>
<tr>
<td>5, Flexible</td>
<td>666</td>
<td>9,026</td>
<td>7,777</td>
<td>10,034</td>
</tr>
</tbody>
</table>

* Initial Capex includes the cost of the flexible option, when applicable. Adapted from de Neufville & Scholtes (2011)

Discussion

Based on the research, both existing methodologies are successfully modified and applied to determine the optimal investment strategy. The finding that a non-flexible investment strategy is the best choice does not contradict de Neufville and Scholtes’s assertion for flexibility in engineering design, as de Neufville and Scholtes indicate that investment strategies with flexible options can often, but not always, increase value compared with non-flexible strategies under uncertainty (de Neufville & Scholtes, 2011). In addition, the results of the data analysis in this thesis are in line with the statement that “flexible designs often cost less than inflexible designs” (de Neufville & Scholtes, 2011).

Finally, a set of investment decision-making steps for port infrastructure are developed. Recommended refinements to the existing methodologies are also proposed.

Conclusion

Key findings of the research are presented.

- The existing methodologies can be improved through recommended refinements.

Specific findings related to the case study port:

- The methodology for measuring port capacity revealed that 7 of the 22 port components are current or potential bottlenecks.

- The simulation screening model narrows the focus on bottlenecks to the warehouse and the liquid bulk terminal. A bottleneck will occur at the liquid bulk terminal with a probability of approximately 40%, while a bottleneck will occur at the warehouse with a probability of over 95%. The warehouse is selected for further study.

- Based on the analysis, the optimal investment strategy is the 5 level non-flexible warehouse, outperforming a comparable 4 level flexible warehouse by an expected net present value of USD 90 mill. and with better 10% and 90% value-at-risk results. However, the investor should also consider other relevant factors before making a final investment decision.

- Based on an analysis of investment strategies built to the same scale initially (i.e., same number of levels), the investment strategy with the flexible option is preferable to the investment strategy without flexibility. The flexible option is valued at USD 205 mill. with a cost of just USD 24 mill., equal to 5% of the initial capital expenditure. There is a 55% probability that the flexible warehouse strategy will be more profitable than the non-flexible warehouse strategy and a 45% probability that the two strategies will result in similar profitability (i.e., greater upside and no additional downside risk).

Cited Sources
