A COORDINATION MODEL FOR SEAPORTS AND ITS APPLICATION IN THE BEIBU BAY AREA
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Abstract: This paper studies the port development from the perspective of coordination which is different from previous work. For the first time the concept of coordination was introduced to evaluating the seaport development path. We applied an improved coordination degree model to such work which contains two categories of coordination: the coordination between a port and its local economy, and that between neighboring ports. Results from a case study in the Beibu Bay Area were analyzed, including explanations for influences of various sequential parameters. Sensitivity analysis shows the model is more robust to upper limits variations than to lower ones. The calculation results for ideal situations in future years prove the effectiveness of the model and imply some of their additional uses. Improvements of the model are suggested in terms of the selection of sequential parameters and the consideration of dynamic evolution of neighboring ports.

Key words: coordination, seaport performance, local economy, Beibu Bay

1 Introduction

Port development is an important issue which contains two parts: competition and coordination. Former research has been intensively focused on competition. Malchow and Kanafani (2001) employed the discrete choice model to port selection and discussed corresponding influencing factors. Tai and Hwang (2005) used Gray Decision Model to rank the relative competitiveness of major ports in East Asia from the viewpoint of container liners. Other tools, such as Game Theory (Cao 2003), vector error correction model (Fung 2001), and Analytical Hierarchy Process (Yeo and Song 2003), have also been applied. Yet rarely is there any paper discussing the coordination of port and local economy, as well as that between neighboring ports.

In other fields, attentions have been paid to coordination by researchers. The model derived from Synergetics developed by H. Haken (1977) was, in particular, applied to a couple of areas. Meng (2000) studied the practicability of the coordination model and gave a brief example. Liu et al. (2005) used this model to analyze the coupling degrees between urbanization and environment. Recently such a model has been introduced to transportation. Zhao et al. (2006) employed it to study the relationship between urban transportation and land use. Unfortunately no specific examples are found in the latter two papers. In port research, Yang (2004) mentioned such a concept; detailed studies are hardly seen either in theory or in practice.
An attempt is thus made in our study to build a model for coordination analysis in the port area. Details of a coordination model are presented in the next section. In Section 3, the model is applied to the Beibu Bay Area. Results are discussed in the following section. In the end, conclusions are given and further studies are directed.

2 Methodologies

According to Synergetics (H. Haken, 1977), only slow relaxation variables play the role of changing system structure and functions. They are defined as the inner sequential parameters determining system evolution towards orderliness. Their organizational process and corresponding effect can be described as follows:

\[ \dot{q} = Aq + B(F)q + C(F) \]  

\[ q = (q_1, q_2, \ldots, q_n) \] represents a system’s sequential parameters; \( F \) denotes effects from the outside. \( A, B(F), \) and \( C(F) \) are corresponding matrices, and there are:

\[ \lim_{F \to 0} B(F) = \lim_{F \to 0} C(F) = 0 \]  

The coordination effects among the sequential parameters are therefore only determined by the self-organization of the system when effects from the outside disappear. In fact, it is just under such a condition that the concept of system coordination is more widely used. This condition is also the basis of our research.

We assume that a system contains \( k \) sub-systems \( S_j, j=1,\ldots,k \). For the \( j \)th sub-system, its sequential parameters are \( e_j = (e_{j1}, e_{j2}, \ldots, e_{jn}) \). \( \alpha_{ji}, \beta_{ji} \) are the lower and upper limits for every sequential parameter. It is generally supposed that for \( e_{j1}, e_{j2}, \ldots, e_{jl} \), the larger their values, the higher the orderliness of the sub-system; by contrast, for \( e_{jl+1}, \ldots, e_{jn} \), larger values of the parameters lead to a lower level of orderliness. The orderliness of the sequential parameter \( e_{ji} \) is defined as follows:

\[ u_j(e_{ji}) = \begin{cases} \frac{e_{ji} - \beta_{ji}}{\alpha_{ji} - \beta_{ji}} & i \in [1,l] \\ \frac{\alpha_{ji} - e_{ji}}{\alpha_{ji} - \beta_{ji}} & i \in [l+1,n] \end{cases} \]  

To integrate the contribution of the sequential parameters to the sub-system there exist several combination forms. We adopt the geometric mean to measure the orderliness of the \( j \)th sub-system, for the sake of its practicability (Liu et al. 2005).

\[ u_j(e_j) = \sqrt[n]{\prod_{i=1}^{n} u_j(e_{ji})} \]
To judge to what extent two or more sub-systems coordinate with each other, a frequently used coordination indicator (Meng et al. 2000, Zhao et al. 2006) is:

\[
cm = \theta \sqrt[1]{ \prod_{j=1}^{k} [u_j'(e_j) - u_j^0(e_j)] } \quad \text{with} \quad \theta = \frac{\min_j [u_j'(e_j) - u_j^0(e_j) \neq 0]}{\min_j [u_j'(e_j) - u_j^0(e_j) \neq 0]}, \quad j = 1, 2, ..., k
\] (5)

Evidently \( cm \in [-1, 1] \). A larger value of \( cm \) indicates a higher level of coordination degree. If \( cm \) is negative, the system will be in an uncoordinated state. However, for time series data with an increasing order, \( cm \) are very likely to be always in an increasing trend. The true coordination relations would thus be twisted. It is illustrated in the next section. As an alternative, we introduce the Capacitive Coupling in Physics to system coordination whose general form is shown as follows:

\[
C_n = \left( \frac{u_1 \cdot u_2 \cdots u_k}{\prod_{i=1}^{k} (u_i + u_j)} \right)^{1/k}
\] (6)

\( C_n \) is the coordination degree among \( k \) sub-systems, and we have \( C_n \in [0, 1] \). The coordination degree increases with the value of \( C_n \). A notable advantage of Formula (6) is that the potential problem mentioned above can be largely avoided.

3 Data and Modeling

The Beibu Bay is our case study area, where the development of its seaports, mainly Fangcheng and Beihai, has experienced remarkable increases during the past decade. The performance of Fangcheng port is a representative (fig. 1). Meanwhile, its local economy has also witnessed continuous growth (fig. 2).

![Figure 1. Cargo traffic in the port of Fangcheng](image1.png)

![Figure 2. Economic growth of Fangcheng city](image2.png)
To measure how the port development coordinates with its local economy, we firstly formed a port-economy (P-E) system including two parts: one is the port sub-system with port export (PE) and import (PI) as the sequential parameters ($e_{11}$ and $e_{12}$). Container export (CE) and import (CI) were considered as well ($e_{13}$ and $e_{14}$). The other is the local economy sub-system, where GDP, governmental revenue (GR), fixed asset investment (FAI), GDP per capita (GDPC) were selected ($e_{21}$, $e_{22}$, $e_{23}$, $e_{24}$). Data were collected from 1993 to 2002; for each year the coordination degree was calculated. Obviously, the $e_{ij}$s above are 'positive' sequential parameters since a larger value of each one would add to the benefits of either sub-system. We therefore adopted the first form in (3). Lower limits were set half of the parameters values in the base year (1993); upper limits were predetermined as 1.5 times the largest values.

Based on economic and port development forecast (2010 and 2020), in those years coordination degrees were also calculated, following the same limits settings. Due to the lack of FAI forecasting data, the past years coordination degrees were recalculated without FAI to facilitate comparison. The results are given in fig. 3.

We then chose Fangcheng and Beihai to form a port-port (P-P) system. For each port sub-system, sequential parameters are port export (PE), port import (PI), and container throughput (CT). Calculation results are also shown in fig. 3.

Fig. 3 contains three additional curves whose values are the results of using the traditional coordination indicator as mentioned in section 3 and are comparatively low. Although we will see later it is the relative values rather than the absolute ones that make sense for coordination, the unexceptional rising trends of these curves do distort the real situations. Relevant evidence can be found in the following sections.

![Figure 3. Coordination degrees of the chosen systems](image)

4 Discussions

A first observation of fig. 3 is that the curves of P-E system with and without FAI, in spite of the differences in absolute values, reflect almost the same development trend. An obvious low point appears in both curves in 1997, which can be explained by the considerable decline the CT suffered in that year (from 4280 TEU in 1996 to no more than 2900 TEU), whereas the local economy enjoyed a continuous and steady increase. In effect, the throughput recession already began in 1995 in CT. After 1997, the CT began to recover, and a sharp raise happened in 2000 (CE from 2184 in 1999 to 8362 TEU, CI from 2675 to 7559 TEU). Consequently a
steep rise occurs. The results in 1999 and 2001 show FAI seems not to significantly impact on the coordination degrees. Such a viewpoint is also supported by the petit difference between the two curves in terms of slope in other periods.

What about other sequential parameters? Fig. 4 shows 8 cases. Each was calculated in the absence of one sequential parameter respectively. Although absolute values vary, the global trend largely remains the same. More precise observation helps us filter out the curves not considering PE, PI, CE, and CI. It seems that port performance is more influential in describing the P-E system coordination evolution.

In the curve representing the P-P system, two low points in 2000 and 2004 can be interpreted as follows: in 2000 the CT of Beihai dropped incredibly from 6954 TEU to only 827 TEU; that in Fangcheng, by contrast, enjoyed a three-time increase (from 4859 to 15921 TEU). After a short recovery, the CT in Beihai again suffered a big depression in 2003 and 2004, causing severe decline of the coordination degrees.

![Figure 4. Coordination degree calculation in different cases for the P-E system](image)

We also find the elimination of any sequential parameter in the P-P system alters the results considerably (fig. 5), especially in 2000 and 2004. Thus all sequential parameters greatly affect port performance and therefore the coordination evolution.

In addition, the P-E system’s coordination values for 2010 and 2020 tend to approach 1, indicating in the target years port performance seems almost perfectly in accordance with the city’s economic prosperity. Since port development planning is usually based on economic situation forecasting results, the application of the model could thus be extended to assisting port planners in evaluating whether and to what extent their forecast coordinates with that of local economy in their planning work.

![Figure 5. Coordination degree calculation in different cases for the P-P system](image)
The final two points representing the P-P system's coordination degrees in 2010 and 2020 are also interesting in that they are relatively close to 1. This is because the forecasting results of PE, PI, and CT show planners' inclination for port development. Considering the geographical conditions and development trends, Fangcheng is identified as a regional maritime hub, whereas Beihai is its feeder port. On the other hand, limits parameters, $\alpha_{ji}$ and $\beta_{ji}$, also to some extent reflect this relation. These are the reasons that the coordination for the target years seems almost perfect.

But do different limits values greatly change the coordination degrees? Numerical analysis results are given in fig. 6 and 7. In the P-P system, upper limits variations hardly affect the results; in the P-E system, the evolution of coordination almost follows the same trend with the variations of upper limits. The order of coordination degrees therefore remains. Lower limits effects are more complicated. The relative order is maintained in smaller intervals. This is especially true in the P-P system in 1997 and 2000, where both ports' CT were not proportional to other performance indicators (CE, CI). In 1997 Fangcheng's CT was only 2/3 of that in the base year. Low values make coordination more sensitive to lower limits variations.

5 Conclusions
The uniqueness of this research is that it regards port development issues from coordination rather than competition; our work includes two categories: coordination between a port and its local economy, and that between neighboring ports. Capacitive Coupling is proven to be more reliable than traditional means in our case study, and the coordination model can be used to assess whether and how port development forecast coordinates with that of local economy. Upper limits variations seem not to greatly influence coordination for both systems; however, this does not apply to
lower limits, especially for years when sequential parameters are abnormally low.

Some aspects of our studies deserve further work. First, sequential parameters selection in this paper was on an empirical basis. It is necessary to develop some principles to determine which parameters should be selected. In our case study, port performance seems to be more influential than local economy in the P-E system. This may be partly because the four selected economy sequential parameters are closely related and very likely to be functionally overlapped; therefore the remove of one of them has less impact than expected. Further consideration of sequential parameters selection could be extended to port infrastructure scale and level which represent the port supply side; on the economy sub-system part, indirect economic hinterland might well be included. Secondly, recent dynamics of relative positions of neighboring ports should be incorporated into the model to more accurately evaluate the real situations of port development. For example, upper and lower limits could be defined as time-dependent variables, rather than predetermined parameters. Such a potential would be an interesting area of future research.

References
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