Synergy of ports and cities in the Chengdu-Chongqing Economic Circle and the influencing factors

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ABSTRACT
The synergetic development level of port and city is an important index to measure the radiation effect of the port. Through systematic analysis and study at the development level of port-city systems in the Chengdu-Chongqing Economic Circle, this paper constructed a synergistics-based synergy degree model and proposed an index system of synergy degree measurement for a port-city complex system based on a coupling coordination degree model. Results show that the ports and cities in the Chengdu-Chongqing Economic Circle are still far from high-level synergetic development. In general, the comprehensive synergetic development level of the ports and cities are rising, in which Chongqing ranks the top and is still in a rising trend. The comprehensive development level of Luzhou and Yibin is also on the rise, but the gap between them and Chongqing is becoming bigger. The synergetic development level of port and city is an important index to measure the radiation effect of port and constructs a synergistics-based synergy degree model for a complex system and proposed an indicator system of synergy degree measurement for a port-city complex system based on a coupling coordination degree model from the perspective of systematics.

1. Introduction
Ports accelerates the collection and distribution of goods in hinterlands and drives local economic development in cities which in return provides necessary products, services, and markets for ports (Bingru & Xin, 2019). The rapid development of modern port cities, implementation of major national strategies, port scale and urban space expansion, and synergetic development of ports and cities co-existing in limited space under the condition of resources shortage is of great importance to and exerts far-reaching influence on improving the economic growth of port cities along with promoting the development of ports. The coordination relationship between ports and cities has become a foothold to improve the comprehensive development ability of port cities and realize the sustainable development of port cities, which has attracted extensive attention from experts and scholars (Houming et al., 2015).

The scholars have carried out early research on the synergetic relationship between ports and cities and achieved certain results. For example, Jung (2011) established the relationship model between port throughput indicator and city economic indicator, and studied the development and change of a port’s contribution to city economy growth taking the major port cities of South Korea as the research object. Hesse and Rodrigue (2004) pointed out through analysis that the interaction and coordination between a port and regional economy is an important prerequisite and guarantee for the development of a port economy and the function of port to the economic development of the city which it relies on is determined through research on the mechanism relationship between a port and city. William Seabrooke et al. analysed the direct and indirect economic effects of the activities of a port on the city from the perspective of historical evolution or horizontal (Comtois, 1994; Seabrooke et al., 2003; van Klink, 1998). Hayuth (1988) and Slack (1990) discussed and analysed the synergy between a port and hinterland economy from the perspective of the traffic link between a port and hinterland. Pablo Coto-Millan et al. calculated the influence of the Port of Santander on the economy of Santander and its hinterland based on the statistical data of Santander and the Port of Santander in 2005 (Coto-Millan et al., 2010). Ducruet and Lee measured the correlation between ports and cities based on the data of 653 regions from 1970 to 2005 (Ducruet & Lee, 2006). Chinese scholars on this subject started relatively late. Ma et al. (2021), Zhang et al. (2021) and Kong and Liu (2021) analysed the coordination status of port and city systems using the coordination degree...
model by constructing an evaluation indicator system of a port and city development. However, some of the indicators have high requirements for the data and are difficult to obtain, so (Nian et al., 2017; Sdoukopoulos & Boile, 2020; Zhao et al., 2017) calculated the degree of synergy between ports and cities based on the grey correlation model. (Ganbin & Lin, 2015; Lei et al., 2018) analysed the characteristics of port-city coupling and coordinated development of five cities along the Yangtze River in Anhui Province based on the coupling and coordination model which can be used to better analyse the internal relationship between a port and city.

In addition, the author has indicated through statistics that the regions and ports in China have carried out port-city synergy research as shown in Figure 1. It can be seen from the figure that some research has been carried out and much attention has been paid to the port-city synergy of five major port clusters in China: namely the Bohai Rim, Yangtze River Delta, Southeast Coast, Pearl River Delta and Southwest Coast from north to south. In contrast, less studies have been made on the synergetic relationship between ports and cities along inland rivers and they mainly involve Anhui-Jiangsu section of the lower reaches of the Yangtze River. With the implementation of Yangtze River Economic Belt and the ‘Belt and Road Initiative’ strategy and the planning and construction of Chengdu-Chongqing Economic Circle, research on the port-city synergetic development of the upper reaches of Yangtze River will be conducive to the port-city synergetic development of western China. This will promote the common prosperity of the ports and cities and further improve the interaction between the Yangtze River Economic Belt and the Silk Road Economic Belt strategies which will definitely draw extensive attention.

For the measurement of the synergy development between the port and city complex system in the Chengdu-Chongqing Economic Circle, we will setup a measurement model of the synergy level of port and city development and construct the measurement index system of the synergy degree of the port-city complex system. We will select three port cities of Chongqing, Luzhou and Yibin as the research objects in the Chengdu-Chongqing Economic Circle and make an empirical study on the synergy development level of the port-city complex system.

Different from previous studies, the contributions of our paper include: (1) Previous studies have described the coordinated development status and comprehensive level of port and city economy, while our paper analyses and studies the dynamic changes and development trends of the synergy degree of the port-city complex synergy system. (2) Previous studies mostly focused on the research on the port city synergy relationship of the five major port groups in Chinese coastal areas, while our paper takes Chinese inland river port cities as the basic research unit to elaborate the port city synergy relationship in the Chengdu-Chongqing Economic Circle.

![Figure 1. Regions and major ports in China.](image-url)
2. Synergy degree model of a port-city complex system

In this paper, the synergy degree model of complex system based on order parameters is used to measure the synergy level between port and city development. The port-city complex system is a system with diversified internal structure, with the development, utilization and management of port resources as the core, the city as the carrier, the hinterland as the support, the transportation system as the artery. The port-city complex system includes two subsystems: port system and city economy. The development of the port subsystem and the city subsystem dominate the evolution and development of the port-city complex system. The synergy degree between the two subsystems can objectively reflect the synergy degree of self-organization of the port-city complex system.

The complex synergetic system of port development and city development is defined as the system $S$, and the sub-system as $S_i$, $i \in [1, 2]$. The indicator which can represent the development level of port and city sub-systems is selected as the order parameter. Let the indicator in the sub-system be $e_i = (e_{i1}, \ldots, e_{in})$, where $\alpha_{ij} \leq e_{ij} \leq \beta_{ij}$, and $\alpha_{ij}$ and $\beta_{ij}$ are the upper and lower limits of the component $e_{ij}$ of the indicator at the critical point of system stability and $e_{ij}$ is the component of the $j$th indicator of the $i$th system. If $e_{ij1}, \ldots, e_{ijn}$ is a positive indicator, the greater the value is, the higher the order degree of the system is. If $e_{ij1}, \ldots, e_{ijn}$ is a negative indicator, the greater the value is, the lower the order degree of the system is. The order degree determines the internal coordination level of the sub-system. The higher the order degree is, the higher the coordination degree is; the lower the order degree is, the lower the coordination degree is. The formula for calculating the order degree of subsystem index components $e_{ij}$ is:

$$
\mu_i(e_{ij}) = \left\{ \begin{array}{ll}
\frac{e_{ij} - \beta_{ij}}{\alpha_{ij} - \beta_{ij}}, & j \in [1, k] \\
\frac{\alpha_{ij} - e_{ij}}{\alpha_{ij} - \beta_{ij}}, & j \in [k + 1, n]
\end{array} \right.
$$

(1)

The above formula (1) defines the index of order degree $\mu_i(e_{ij}) \in [0, 1]$. The greater the value of $\mu_i(e_{ij})$ is, the greater the contribution of the component $e_{ij}$ to the system order degree is. The contribution degree reflects the degree of the indicator’s effect on the sub-system. The importance of each index to the coordination degree of the system is different. The total contribution of the component $e_{ij}$ of each index to the degree of order of the system is usually calculated by linear weighted sum or geometric average method. In this paper, the linear weighted sum method is used to calculate the total contribution:

$$
\mu_i(e_j) = \sum_{j=1}^{n} \lambda_j \mu_i(e_{ij}), \lambda_j \geq 0, \sum_{j=1}^{n} \lambda_j = 1
$$

(2)

Where, the weight coefficient $\lambda_j$ reflects the role of the corresponding index in the system operation process, which can be determined by entropy method. Let each indicator component has $m$ samples, and the value of the $t$th sample is $x_{jt}$. Next, the sample data is normalized as:

$$
x_t^j = \left\{ \begin{array}{ll}
x_t^j \frac{x_t^j - x_t^{j_{min}}}{x_t^{j_{max}} - x_t^{j_{min}}}, & \text{positive} \\
-x_t^j, & \text{negative}
\end{array} \right., \quad (j = 1, 2, \ldots, n; t = 1, 2, \ldots, m)
$$

(3)

Then, we get the normalized value:

$$
K_{jt} = \frac{x_t^j}{\sum_{t=1}^{m} x_t^j}
$$

(4)

The index information entropy value $g_j$ and the information utility value $w_j$ are given respectively as:

$$
g_j = -k \sum_{t=1}^{m} K_{jt} \ln K_{jt}, w_j = 1 - g_j
$$

(5)

The index weight coefficient is given by:

$$
\lambda_j = \frac{w_j}{\sum_{j=1}^{n} w_j}
$$

(6)

The calculation formula of the coupling coordination degree of a port-city system is as follows:

$$
C = 2 \sqrt{\frac{\mu_1(e_1)\mu_2(e_2)}{(\mu_1(e_1) + \mu_2(e_2))^2}}
$$

(7)

Then, the synergy degree of the port-city complex system is as follows:

$$
D = \sqrt{C \times F}
$$

(8)

where $F$ is the comprehensive coordination index of port development subsystem and urban development subsystem, reflecting the overall synergistic effect or contribution of the port-city system. The calculation formula of $F$ is:

$$
F = (\mu_1(e_1) + \mu_2(e_2))/2
$$

(9)

The synergy degree model of port-city complex system comprehensively takes into account the development of the two subsystems of port and city. It reflects the dynamic change process of port-city system interaction.
and development, and shows the synergy degree and change trend of the port-city complex system in a certain region. If the order degree of one subsystem increases greatly while the order degree of another subsystem decreases slightly or decreases, the whole system will appear incongruous.

3. Measurement indicator system for the synergy degree of the port-city complex system

The synergy indicator of the port-city complex system is the key parameter to accurately measure the synergy degree. The selected indicator should fully reflect the synergy development of ports and cities in the Chengdu-Chongqing Economic Circle and avoid information redundancy as far as possible. The previous studies have pointed out that synergy development is a dynamic process. The time dimension should be introduced to characterize the synergy degree of complex systems. Considering that the synergy differences between the input process and management process lead to differences in output synergy, the output synergy can be used to measure the synergy degree of the complex system.

Based on the analysis and comparison of the evaluation indexes in many studies on the evaluation of the synergy development level of ports and cities due to the different perspectives of researchers and the different availability of specific data, cargo throughput, container throughput, and wharf coastline length are selected to measure the port development level, and the three indicators of GDP, total fixed asset investment, and import and export volume are selected to measure the urban development level. This paper takes the Chengdu-Chongqing Economic Circle as the research scope and focuses on analysing the synergy degree of the complex system of Chongqing, Luzhou, and Yibin. The data of various indicators are obtained from the statistical yearbook of the Chengdu-Chongqing Economic Circle and the statistical yearbook of the local government.

Table 1. Researches on evaluation indicator system for port-city synergy.

| Author (published in) | Research Method | Port Development Indicator | City Development Indicator | Other Indicators |
|-----------------------|----------------|---------------------------|---------------------------|-----------------|
| Jiang et al. (2011)   | PICCS coordination degree model | Container throughput ✔️ | Port output value, average overstock time of ship ✔️ | Proportion of the port in the city's economy ✔️ |
|                       |                | Shoreline length ✔️       | average handling efficiency at berth ✔️ | Proportion of the port cargo volume in the total cargo volume ✔️ |
|                       |                | Cargo throughput ✔️       | Port throughput gap ✔️ (gap between throughput demand and throughput) | Port investment rate, GDP increase ✔️ |
|                       |                | Other Indicators          | Number of quayside container cranes, number of container liner routes ✔️ | Total retail sales of consumer goods, local fiscal revenue ✔️ |
| Yang & Pan (2011)     | Coupling PU-SD model | ✔️                         | ✔️                         | ✔️              |
| Pan et al. (2012)     | Coupling system model | ✔️                         | ✗                         | ✗               |
| Fan et al. (2015)     | Synergy degree model of complex system | ✔️                         | ✗                         | ✗               |
| Sun et al. (2018)     | Cross-spectrum analysis | ✔️                         | ✗                         | ✗               |
| Bi et al. (2020)      | RCI indicator | ✔️                         | ✗                         | ✗               |
Table 2. The index system of port-city synergy level evaluation.

| Indicators                  | Meaning                                                                                                                                 |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| Port Development            |                                                                                                                                        |
| Container throughput (10,000TEU) | It reflects the total amount of standard containers loaded and unloaded through the quay in the port area which is the basis of port development planning and fundamental construction. It can be used to measure the international trade market demand of the city where the port is located. |
| Cargo throughput (10,000t)  | It is an important indicator to measure the economic scale of a port to reflect the capacity of the port to handle goods.                  |
| Shoreline length (100m)     | It reflects the number of ships that can dock at the same time.                                                                         |
| City Development            |                                                                                                                                        |
| GDP (CNY 100 million)       | It reflects the economic output capacity.                                                                                               |
| Investment in fixed assets  | It reflects the influence of logistics on city's economic development.                                                                    |
| Total import and export     | It directly reflects the value of foreign trade cargo throughput at the port, indicating the development of port-centered industry and the structure system of import and export products. |

Table 3. Weight coefficient of the order parameter component.

| Name of Order Parameter Component | Order Parameters of Port Development Sub-system | Weight Coefficient (λ) |
|-----------------------------------|-----------------------------------------------|------------------------|
| Container throughput (10,000TEU)  | 0.30965                                       |                        |
| Cargo throughput (10,000t)        | 0.406047                                      |                        |
| Shoreline length (100m)          | 0.284303                                      |                        |
| GDP (CNY 100 million)            | 0.255847                                      |                        |
| Investment in fixed assets       | 0.276974                                      |                        |
| Total import and export          | 0.467172                                      |                        |

4. Calculation of synergy degree

4.1. Calculation of indicator weight coefficient

The weight coefficient of indicators for port development and city development sub-systems of cities in the Chengdu-Chongqing Economic Circle is calculated as shown in Table 3. It can be seen from Table 3 that the weight coefficient of the three indicators of port development are 0.3096, 0.4060 and 0.2843 respectively. That is, the proportions of container throughput, cargo throughput and shoreline length are 30.96%, 40.60% and 28.43% respectively. The weight coefficient of the three indicators of city development is 0.2558, 0.2769 and 0.4671 respectively. That is, the proportion of GDP, investment in fixed assets and total import and export is 25.58%, 27.69% and 46.72% respectively.

4.2. Calculation of sub-system order degree

The order degree of the port development and city development sub-systems of Chongqing, Luzhou and Yibin from 2009 to 2018 is calculated according to Formula (1), where $\alpha_{ij}$ and $\beta_{ij}$ are 110% of the maximum and minimum values of the three port order parameters respectively.

The order degrees are shown in Table 4. On the whole, Chongqing has the highest order degree of port and city development, followed by Luzhou and Yibin. From the perspective of time change trend, the order degree of Yibin port development and city development showed an overall rising trend, but their development degree was different, the port development increased greatly while the city development increased slightly. The order degree of Luzhou port development and city development is...
Figure 3. Order degree of Luzhou sub-system.

Figure 4. Order degree of Chongqing sub-system.

also on the rise, but there is a big gap between them. The improvement of port development is large, while the development of the city is slow, and the gap between them shows a narrowing trend in 2017. The order degree of the port development and the city development in Chongqing has been increasing significantly, and the two kinds of development are relatively balanced.

4.3. Calculation of coordination degree of the port-city complex system

Taking the order degree of the above two sub-systems of port and city development into Formula (7), the coordination degree of the two sub-systems of port and city development in Yibin, Luzhou, and Chongqing can be obtained as shown in Table 5 and Figure 5. It can be found that from 2009 to 2018, the coordination degree of port and city development sub-systems in Chongqing was about 0.5, with only slight fluctuations. In recent years, the coordination degree of the two sub-systems in Yibin declined slightly, while the coordination degree of the two sub-systems in Luzhou increased significantly.

4.4. Calculation of synergy degree of the port-city complex system

Taking the coordination degree of the above two sub-systems of port and city development into Formula (8), the synergy degree of the port-city complex system in

Table 5. Coordination degree of port and city development sub-systems.

|          | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Yibin    | 0.4995| 0.4994| 0.4988| 0.5000| 0.4992| 0.4851| 0.4520| 0.4429| 0.4479| 0.4483|
| Luzhou   | 0.1741| 0.2628| 0.3001| 0.3299| 0.3393| 0.3433| 0.3512| 0.3566| 0.3947| 0.4150|
| Chongqing| 0.4796| 0.4914| 0.4998| 0.4972| 0.4998| 0.4991| 0.4998| 0.4993| 0.4989| 0.5000|

Figure 5. Coordination degree of port and city development sub-systems.
Table 6. Synergy degree of port-city complex system.

|        | 2009   | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   | 2017   | 2018   |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Yibin  | 0.0531 | 0.0710 | 0.0802 | 0.0922 | 0.1056 | 0.1272 | 0.1507 | 0.1645 | 0.1745 | 0.1786 |
| Luzhou | 0.0590 | 0.0862 | 0.1049 | 0.1208 | 0.1390 | 0.1627 | 0.1787 | 0.1937 | 0.2160 | 0.2040 |
| Chongqing | 0.3437 | 0.3788 | 0.4233 | 0.4718 | 0.5564 | 0.5989 | 0.5931 | 0.6225 | 0.6458 | 0.6599 |

Figure 6. Synergy degree of port-city complex system.

Yibin, Luzhou and Chongqing can be obtained as shown in Table 6. From 2009 to 2018, the comprehensive synergy level of port and city development in the three cities was continuously improving. From the perspective of the different cities, Chongqing showed the highest level of comprehensive synergetic development with a rising trend. The comprehensive development level in Luzhou was higher than that of Yibin. But the gap of synergy degree between Luzhou and Chongqing was still enlarging.

5. Conclusions

For the measurement of the synergy development between the port and city complex system in the Chengdu-Chongqing Economic Circle, we established a measurement model of the synergy level of port and city development, constructed the measurement index system of the synergy degree of the port-city complex system. We selected three port cities of Chongqing, Luzhou and Yibin as the research objects, and collected the sample data from 2009 to 2018. We makes an empirical study on the synergy development level of the port-city complex system in the Chengdu-Chongqing Economic Circle and the main conclusions are as follows.

(1) On the whole, the order degree of Chongqing Port City is higher than that of Luzhou port City, while that of Luzhou Port City is higher than that of Yibin port City. From the perspective of time change trend, the order degree of port and city development in Yibin and Luzhou shows an overall upward trend, but the port development has a large improvement rate while the urban development has a small improvement rate. In contrast, the order degree of port and city development in Chongqing showed a sharp upward trend, and the port and city development was relatively balanced.

(2) The coordination degree of the two subsystems of Chongqing port development and city development is maintained at about 0.5, with only slight fluctuations, indicating stable development. In recent years, the coordination degree of the two subsystems of Yibin port and city has decreased slightly, but the overall coordination degree is still around 0.5. The coordination degree of the two subsystems of Luzhou port and city has increased obviously, and the gap compared to the development of Chongqing and Yibin became smaller.

(3) The comprehensive synergetic development level of ports and cities in Chengdu-Chongqing Economic Circle is in a state of continuous improvement. Among them, the synergetic degree of Chongqing port-city complex system is the highest, which is still in a rising trend. The synergy degree of Luzhou and Yibin port-city complex system is also on the rise, but the gap between them and Chongqing is still widening.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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