Port Spatial Development and Theory of Constraints

Wing Yee Tracy Chan[1], *and Tsz Leung Yip*[2]*

[1] Department of Logistics and Maritime Studies, The Hong Kong Polytechnic University, Hong Kong
Email: mstracychan@hotmail.com

[2] Department of Logistics and Maritime Studies, The Hong Kong Polytechnic University, Hong Kong
Phone: (852) 2766 4631
Fax: (852) 2330 2704
Email: lgttly@polyu.edu.hk

* *corresponding author*

Abstract

Ports in different regions look for further developments to improve their ports to compete with others and deal with the demand of sea transport. A common way to deal with the increasing demand of sea transport and competing with adjacent ports is to expand the port. Due to the lack of structural guidance on this concentration-deconcentration issue, this paper aims at proposing a decision framework to determine whether a port development should be at the original site or a new site. In particular, a port spatial development model is developed based on Bird's Anyport Model and the Theory of Constraints (TOC). A framework of decision making is further formulated by considering major constraints (geographical, economic, and supporting constraints). In a systematic manner, the framework includes four steps for making decisions of port spatial development: port planning, site consideration, analysis, and decision making. Using Taiwan's Keelung and Taipei ports as case studies, the paper investigates the conditions in deciding whether port development would spatially concentrate or de-concentrate. The case studies suggest that the framework developed in this paper provides guidance for port spatial development decisions. The decision framework is readily expanded and modified to include other important constraints on port development.

Keywords: Port development, Theory of constraints, Ports, Concentrated, Taiwan

1. Introduction

Ports in different regions accomplish further developments to improve their ports to compete with others and deal with the demand of sea transport. Some ports aim to have the world's top container port throughput. Hong Kong and Singapore ports have competed with each other over decades. As China develops, ports in China have become strong competitors to them. In 2008, the world's busiest port was Singapore which handled 29.9 million TEUs, followed by Shanghai port 28 million TEUs, Hong Kong 24.3 million TEUs, Shenzhen 21.4 million TEUs, and Pusan 13.4 million TEUs. In order to be leading ports and provide better services, ports, such as Singapore and Hong Kong, maintain the high quality of port infrastructure and improve their port services from time to time.

Some ports will cooperate with other ports to enhance competition and improve their quality of services and infrastructure. Ningbo port and Zhoushan port in China are combined to enhance competitiveness. This cooperation maximises the location advantages, obtains benefits via sharing resources and complements the development each other. Hong Kong and Shenzhen also cooperate to develop the ports in the Pearl River Delta. As China develops, the Chinese market becomes more important. Shenzhen has two major ports, one is Yantian port to the east of Shenzhen, and the other is Shekou port to the west. The cooperation between Shenzhen and Hong Kong ports is Hong Kong's investment in Shenzhen and the Pearl River Delta port terminals. For example, a Hong Kong company, Hutchison-Whampoa, helped develop the Yantian container port to work closely with regions to coordinate inter-port links (Gallagher, 2002).

However, the usual way to deal with the increasing demand of sea transport and compete against competitors is to expand the port in the original site. For instance, in 1998 Shekou port in Shenzhen had only 2 berths to handle containerships and 200,000 m^2 of terminal facilities. But in 2008, the port expanded to have 7 berths and 1,060,800 m^2 of terminal facilities. The port of Los Angeles in the USA had 18 berths and 3,190,000 m^2 of terminal facilities in 1998. However, after the port development, this increased to 29 berths and 6,477,336 m^2 of terminal facilities in 2008.

The above indicate that port development is an important strategy for ports against competitors and to meet the demand of sea transport. Ports are required to look for a location to further develop their port. The location can be an area near to its original site or at another site. This paper aims to find out how and why the further port development will or will not be separated from the original site.

2. Literature Review

Port development has been studied in the past and there are many studies on the relationship between a port and a city. A well-known theory is the Anyport Model, which was developed by Bird (1963) to describe how port infrastructures evolve in time and space (also see Rodrigue, 1998). There are three major stages in a port development process: setting, expansion and specialisation. In the setting stage, the port development is strongly dependent on geographical considerations. In the expansion stage, industrial growth impacts on port activities. For instance, quays are expanded to handle the growing amounts of freight and passengers as well as larger ships. Port-related activities will also be expanded to include industrial activities. This expansion mainly occurs downstream. In the specialisation stage, the port development will involve the construction of specialised piers to handle freight, such as containers, ores, and coal. Some ports will move away from their original setting to increase their handling capacities. The expansion area is usually adjacent to downtown areas. The original developed site may become obsolete and be abandoned.

There is an extension to the Anyport Model by Notteboom and Rodrigue (2005), who commented that the model does not explain the recent rise of seaport terminals that primarily act as transshipment hubs in extensive maritime hub-and-spoke, collection, and distribution networks, and it also does not include the inland dimension as a driving factor in port development dynamics. Therefore, Notteboom and Rodrigue (2005) introduced the fourth stage in port development – Regionalisation, where *"inland distribution becomes of foremost importance in port competition, favoring the emergence of transport corridors and logistics poles. The port itself was not the chief motivator for and instigator of regionalization. Regionalization resulted from logistics decisions and subsequent actions of shippers and third party logistics providers"* (Notteboom and Rodrigue, 2005, p.311).

Apart from that, Ducruet (2007) studied how port-cities integrate land and sea networks, port and urban functions, logistics activities, and intermodal potentials. It was found that the closer the ports are to the hinterland, the less their port-city equilibrium is realised, given the concentration of flows and the indirect dependence on inland markets. Wang and Olivier (2007) studied the relationship of different global supply chains (GSCs) with port development. They mentioned 6 requirements for ports and shipping: 1) type of cargo, 2) volume, 3) flexibility in using alternative ports or terminals, 4) environment considerations, 5) vertical integration including port facilities, and 6) horizontal clustering in space.

However, firstly, there is no study whether the port expansion should be developed at the original port site or not (Issue 1). Secondly, it has not explained when developing a port at the original port site or another one, which constraints affect the port spatial development (Issue 2). Ng and Pallis (2007), who studied the impact of political culture on the differentiation of port strategies in addressing proximity, pointed out that the political culture must partly affect port strategies and development. Ng and Pallis (2007) also provided a framework for analysing the port management reforms and governance, such as considering the original port structure and strategies with the environment. This framework provided an idea and insight on analysing the relationship between the site and the environment in a port development.

In order to further address the above two issues and study the port spatial development, Taiwan is selected as a case study in this paper.

3. Methodology

3.1. Research Question and Propositions

This paper tries to find out how and why the port development will be separated from the original port site based on the Anyport Model by considering the constraints, which may affect the decision of this port spatial development. The research questions and propositions are as follows:

Research question: How and why will the port development be separated from the original port site?

> *Proposition 1: If there is no constraint against the development at the original site, then the port will be developed at the original site.*
>
> *Proposition 2: If there is a significant constraint against the development at the original site, then the port will be developed at another site.*

In order to examine the above propositions, the Theory of Constraints (TOC) will be used to analyse the constraints affecting the decisions of the port spatial development.

3.2. Theory of Constraints

TOC is a management methodology, which provides a thinking process for decision makers or managers. Many companies of all sizes in the world use TOC. The managers use TOC to understand their businesses and obtain a sense of control, and then they are able to take the correct actions, because TOC provides a consistent framework for diagnosing problems (see Mabin, Forgeson and Green, 2001). The TOC methodology contains a wide range of concepts, principles and tools. It enables different industries to apply it as long as they want to improve their performance (e.g. Lockamy and Spencer 1998). Mabin, Forgeson and Green (2001) studied TOC in a common area for different kinds of companies. They put TOC assisting with the change management, since there are similar situations in both topics, where resistance is involved. When a company wants to change, there is resistance to make the change difficult; TOC can be a tool and thinking framework to find out the constraints and solutions.

Some scholars also applied TOC in the events of supply chains. Rahman (2002) pointed out that the TOC provides a thinking process approach in developing strategies in supply chains. It not only helps to identify critical success factors in supply chain management, such as supply based management, communication, and trust among channel participants, but also to understand causal relationships between these constraints. Simatupang, Wright and Sridharan (2004) applied the TOC approach to overcome difficulties in realising the potential benefits of supply chain collaboration. The supply chain members used the framework of TOC to find out the potential benefits of supply chain collaboration. Since the managers were required to achieve the overall goal, which was to increase throughput and at the same time reduce inventory and operating expense, the managers had to quickly identify and remove the constraints and ensure that their company could continue to meet changing customer requirements accurately. Therefore, collaborative replenishment policy and collaborative performance metrics had been used to overcome the constraints.

As TOC is a useful tool to assist decision making and a powerful management methodology to find out the constraint and causal relationships, this paper uses TOC to develop the framework to determine the constraints affecting the port spatial development.

3.3. Evaporating Clouds Method of TOC

"*Evaporating Clouds method is used to model the assumptions that block the creation of a breakthrough solution*" (Stein, 1997, p.50). In this evaporating clouds method, there should be at least two different routes to achieve a desired objective. In order to achieve the objective, there are at least two different, yet necessary, conditions which are required to be met. Therefore, defining problems is to define requirements. A compromise must exist, and it is shared by the requirements. In order to satisfy the requirements, there is a

requirement to do prerequisites which may conflict each other. That means two prerequisite exist, where the conflict arises. The evaporating cloud, which contains the above ideas, is shown in Figure 1 (Goldratt, 1990). More detailed discussion on the evaporating clouds method can be found in Goldratt (1990).

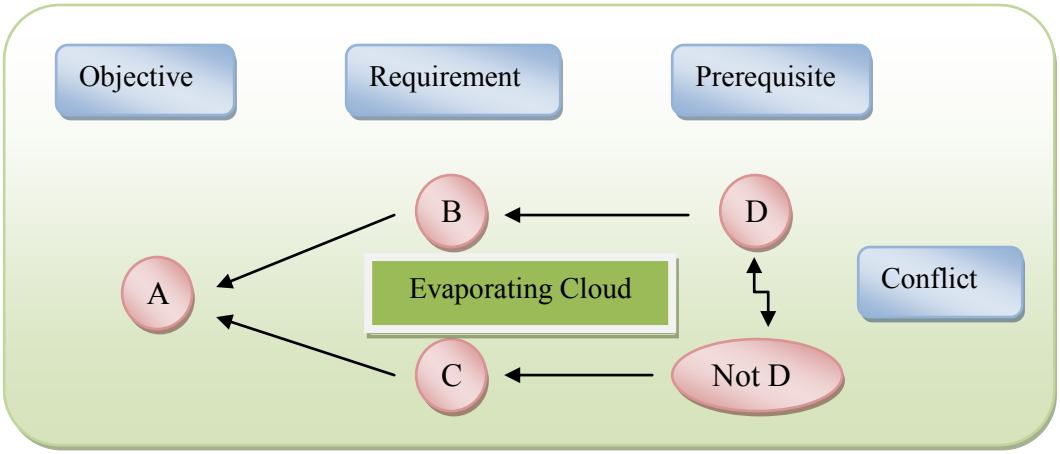

Figure 1 Evaporating Cloud

4. Port Spatial Development Model

4.1. Port Spatial Development

Many countries have formulated their own plan of port development. Some ports are developed in similar spatial settings, but some are not. There are 2 major different types of port spatial development in Taiwan Keelung port and Kaohsiung port. It is an interesting situation for a detailed study to find out the reasons why the port develops in a packed manner (original site) or a loose manner (another site).

Using the ports in Taiwan as a case, port spatial developments can be classified as two types – (1) concentrated port development and (2) deconcentrated port development.

- Concentrated port development means a port's expansion and development remains at or near the original site.
- Deconcentrated port development means a port's expansion and development is moved to a new location while still retaining the original site.

Keelung port in Taiwan is treated as a deconcentrated port development because it includes Keelung main port (main port), Taipei port and Su Ao port (sub-ports). On the other hand, the development of Keelung main port, Taipei port, or Su Ao port can be treated as a concentrated port development when only considering one single port. Kaohsiung port is treated as a concentrated port development because all terminals are developed in a packed area.

According to the Anyport Model (Notteboom and Rodrigue, 2005), the port infrastructures evolve in the site over different stages, which are the setting stage, the expansion stage, and the specialisation stage. However, referring to Taiwan Keelung port, the further port development could not evolve at the original site. When Keelung port was planning to expand its port in order to meet the demand of sea transport, there were alternatives as to whether the expansion was located near to the original site (Keelung main port) or the expansion was located at another site (Taipei port). Therefore, a decision maker was required to consider whether to separate the development from the original site or not (Figure 2).

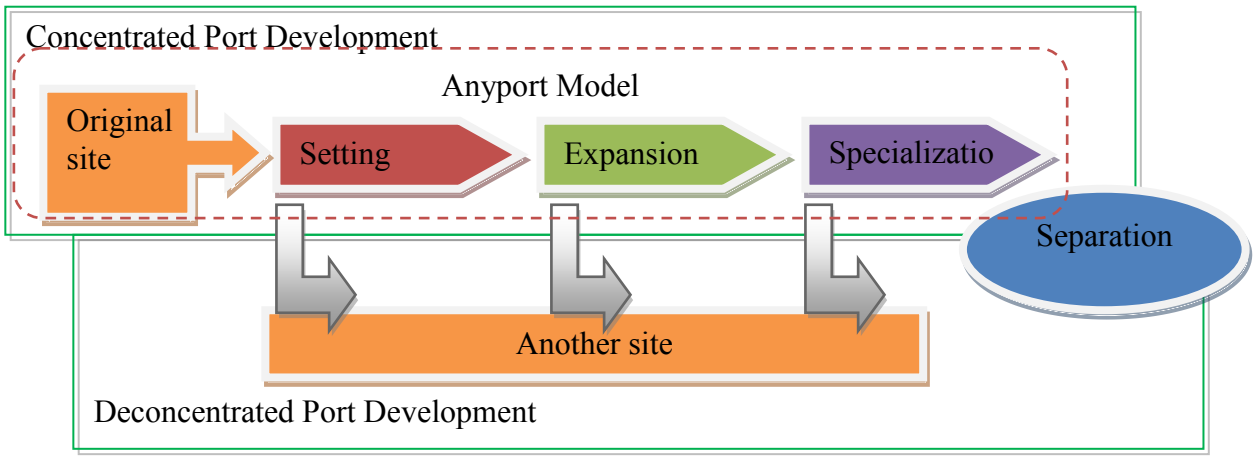

Figure 2 Port spatial development model

In the earlier stage, Keelung port was considering to further expand its port near to the original main site. A possible expansion area was in the western area of the original main site. However, this project was held and is pending. The port has found another site as a sub-port of Keelung port to further develop their port activities and functions. This site is known as Taipei port, which is isolated from Keelung main port but near Taoyuan and Taipei cities.

This case shows that during the expansion stage of the Anyport Model, the Keelung main port was not further expanded at the original site but looked to develop at another site. This separation makes the Keelung main port development move from the concentrated port development mode to the deconcentrated mode.

The problem is whether a planner should choose the concentrated mode (development at the original site) or the deconcentrated mode (development at another site)? The original site, where the port planner chooses, is fit to the original environment. Under this environment, another site is unfit to be developed. When the environment is changing, such as increasing cargo volume and vessel size, the port is required to further develop; therefore, the planner needs to consider whether the original site or another site is fit to the new environment.

Then, another problem is incurred. A planner needs a framework to assist his decision systematically. The paper will use the TOC tool to develop a decision framework for port spatial development.

4.2. TOC Analysis for Port Spatial Development

This paper uses the Theory of Constraint (TOC) to develop the framework about the decision of port development. That means using TOC to determine whether the further development should separate from the original site.

Firstly, there is a requirement to identify which constraints affect the decision of port spatial development or cause this conflict to occur. Secondly, the evaporating clouds method is used to find out the possible solutions of each constraint, and then the best solution can be selected from all constraints.

Loo and Hook (2002) discussed that the container terminal area in Hong Kong remained at the same location because of the delay in building the ninth Container Terminal since 1993 while Hong Kong's container volume continued to grow from 1993 to 2000. It implies that a port development is not only affected by one single constraint. This paper selects the major constraints, which should be considered for the port spatial development. The constraints (Table 1) can be classified as three core constraints, which are geographical constraint, economic constraint, and supporting constraint.

Table 1 Constraints of Port Spatial Development

Core Constraints	Sub-Constraints	Elements
Geographical constraint	Landside	Earthquake area
		Development spare
	Airside	Bad weather
	Seaside	Water depth
Economic constraint	Cargo sources	Hinterland
		Transshipment
	Cargo volume	Trend
Supporting constraint	Supporting package	Transportation
		Human resource
	Green production	Environmental impact
	Government planning	Control power
	Port operation	Terminal operators

For the geographical constraint, there is a requirement to consider landside, airside, and seaside sub-constraints. For the landside, the natural conditions, such as hill or earthquake area, may limit the port development. For example, if there is a hill near the port, it may restrict the building of a new facility. In the airside, the weather conditions, especially typhoons, can affect navigation. During a strong typhoon, bad weather is not favourable for navigation, vessels are restricted to enter, leave, or move within ports. In the seaside, the vessel size has been continually increasing in recent years, and more container ships are built to be over 10,000 TEUs vessels. It is preferable if an area has a deep water depth, as this can allow larger vessels to move in or out. Perhaps technology will become advanced; the area of natural advantages is not easy to discard.

In the economic constraint, if increasing trades occur near the port or in its hinterland, this can imply and assume that the cargo volume will be increased. The demand of requiring sea transport will increase, given that the trades will lead to the product flows via sea transport instead of air or road transport. Therefore, it is believed that a port planner will expand terminals near to this original site in order to capture the potential profit from sea transport. Thus, there are two sub-constraints in this economic constraint. One sub-constraint is cargo sources; whether an area will have cargoes is dependent on its connectivity to the cargo sources. The cargoes can come from the hinterland or other countries. Another sub-constraint is cargo volume. If the amount of cargo is not large enough to support the expansion, it is better not to expand the port. To check whether there is sufficient cargo volume for a port development or not, a planner can forecast the future cargo volume. For example, forecast can be conducted by using regression analysis on the past data of gross domestic product (GDP) and port throughput.

The supporting constraint includes four sub-constraints – supporting package, green production, government planning, and port operation. The supporting package is required near a potential developed area because the operation of the terminals cannot be run without infrastructural connection and man power. Another sub-constraint is the green production sub-constraint; if the development can produce a green effect, it is often preferred. Otherwise, a planner should choose another site, which has smaller environmental impact on human beings and nature. A high control from the government on port operation can also be a sub-constraint to develop a site.

These constraints with the elements can be the constraints of developing and expanding a port.

5. Results and Discussion

After completing the evaporating clouds for different constraints, in order to find out which way of port development is better for the planner to choose, this paper assigns marks to different situations for the constraints under the port development:

- Situation 1: if there is no way to solve the constraints to achieve the objective of port development, then the planner does not prefer this development; no marks go to the constraint.
- Situation 2: if the constraint can be solved by taking major mitigation measures, it will be relatively better than Situation 1; one mark is given for the factor.
- Situation 3: if the constraint can be solved without taking major mitigation measures, the planner prefers to choose this development; two marks are allowed for the factor.
- Situation 4: if the constraint can be solved with significant benefits, the planner mostly prefers this development; three marks are assigned for the factor.

While the details are not reported here, the result is summarised in Table 2. There are higher marks (18 marks) for deconcentrated port development as more objectives can be achieved by geographical, economic, and supporting constraints in Taipei port, compared to the marks for concentrated port develop in the Keelung port expansion area (14 marks). This result is supported by the fact that the Taipei port site has been chosen for development.

Table 2 Case of Port Spatial Development

Constraints of port spatial development	Objectives	Concentrated port development - Keelung Port expansion area	Deconcentrated port development - Taipei Port
Geographical Constraints	Allow large vessel to access	1	2
	Space for building terminals	1	1
	Similar or less risk in navigation & port operation	2	2
Economic Constraints	Closer to cargo sources	2	3
	Cargo growth	2	2
Supporting Constraints	Access to market	1	2
	Minimising environmental impact	1	2
	Man power for daily operation	2	2
	Flexibility in decision making	2	2
Results		14	18

Remarks:
0 mark = The constraint is unsolvable against the objective.
1 mark = The constraint can be solved with major mitigation measures.
2 marks = The constraint can be solved without major mitigation measures.
3 marks = The constraint can be solved with significant benefits.

Therefore, a planner can use TOC to design whether the further port development should be developed at the original site, or should be separately developed at another site in the different stages of the Anyport Model – Setting, Expansion, and Specialisation stages. By combining the idea of the Anyport Model and TOC, a port spatial development model is formed as in Figure 2.

In this port spatial development model, if in the setting stage, the TOC analysis shows that development at another site is better than at the original site, and then there is a separation, which means the port will move to another site for the development. The deconcentrated port development should be resulted. Otherwise, there will be a concentrated port development that means a planner will continually do the development at the original site until the expansion stage is reached, and the planner is required to make the decision of port spatial development again with using TOC. After the expansion stage, the decision making process will be taken again in the specialisation stage.

To assist the port spatial development model, there are four steps for making a decision on port spatial development (Figure 29). The four steps are: (1) port planning, (2) site consideration, (3) analysis, and (4) decision making.

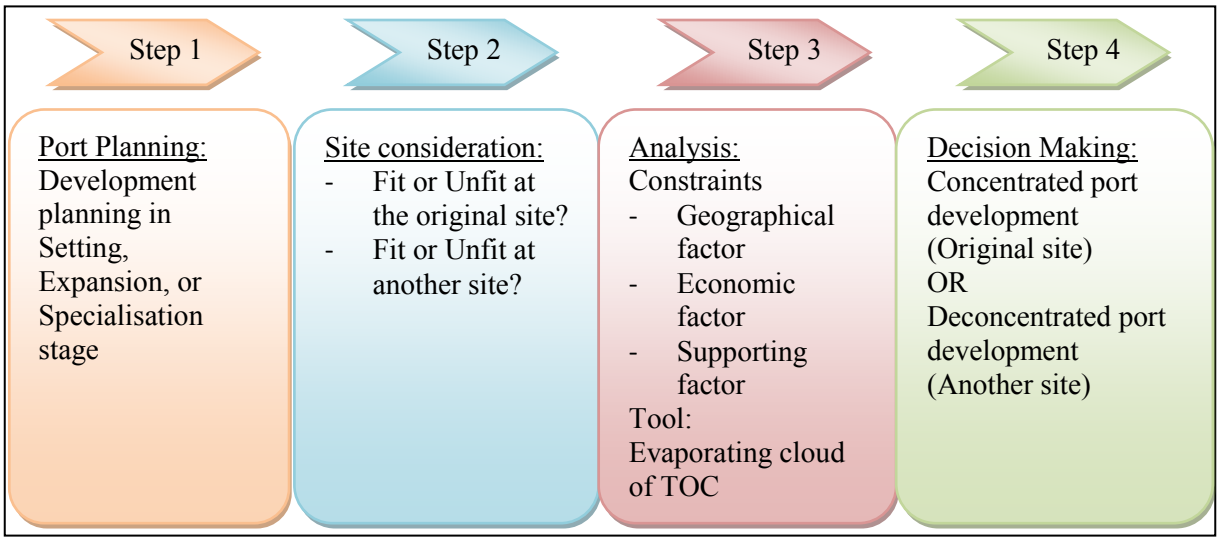

Figure 3 Decision Framework of Port Spatial Development

In Step 1, a port planner is seeking a port development. This can be in the setting, expansion, or specialisation stage in the Anyport Model. In Step 2, the port planner will consider whether the development is suitable to be completed at the original site or another site, so that the planner is required to find one more site as another site in this step. After having the options, in Step 3, the planner should indentify what geographical, economic, and supporting constraints there are. These constraints are constraints that affect the decision of port spatial development. Then, the port planner can use evaporating clouds of TOC to do the analysis. Step 4 is decision making. After the analysis, the output provides the information to make the decision. The planner can base the decision on the results from the TOC analysis to choose a concentrated port development (development at the original site) or deconcentrated port development (development at another site).

6. Conclusions

Ports look for further development sites from time to time in order to deal with the increasing demand of sea transport and become more competitive. The port spatial developments are classified in two types: concentrated port development mode and deconcentrated port development mode. In the case of studying the Keelung port and Kaohsiung port in Taiwan, Keelung port (including Keelung main port, Taipei port, and Su Ao port) in Taiwan is treated as a deconcentrated port development. The Keeling port has taken the concentrated port development mode when only considering one single port. Kaohsiung port has taken the concentrated port development mode. This paper has developed a framework of port spatial development to determine whether a planner should choose concentrated or deconcentrated port development, as well as how a planner can make this decision.

Under the Taiwan case, Keelung port has two port development plans. One is to further expand its port near to the original main site. Another is to find another site as a sub-port of Keelung port. The Theory of Constraint (TOC) has been used to deal with the identified problems. The TOC is used to test whether a planner should separate the further port development from the original site or not. The major constraints affecting the decision of port spatial development are included as three core constraints, which are geographical constraint, economic constraint, and supporting constraint. The evaporating cloud method has been used to study the constraints in order to find out the possible solutions, and then to select the best one. After analysing the constraints, the paper identifies that there are higher marks (18 marks) for a deconcentrated port development at Taipei port because more objectives can be achieved by the geographical, economic, and supporting constraints, and with the concentrated port development – the Keelung port

expansion area obtained lower marks (14 marks).This result is supported by the fact that the Taipei port is chosen to be developed and the project of Keelung port expansion is on hold.

This paper not only shows that a planner can use TOC to design whether the further port development should be developed at the original site or another site, but also develop a framework, including the port spatial development model and four steps for making a decision on port spatial development, which is based on an idea for the Anyport Model and TOC. Under this framework, in different stages of the Anyport Model – Setting, Expansion, and Specialisation stages, the port development will be separated to develop at another site if the TOC analysis shows that the development at another site is better than at the original site.

As a result, the research question (How and why will the port development be separated from the original port location?) is answered by Proposition 1 (If there is no constraint against the development at the original site, then the port will be developed at the original site.) or Proposition 2 (If there is a significant constraint against the development at the original site, then the port will be developed at another site.).

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