

MARITIME CLUSTER EVOLUTION BASED ON SYMBIOSIS THEORY AND LOTKA-VOLTERRA MODEL

WEI ZHANG^a; JASMINE SIU LEE LAM^{b1}

^a Division of Infrastructure Systems and Maritime Studies, School of Civil and Environmental Engineering, Nanyang Technological University, Singapore. Email: wzhang2@e.ntu.edu.sg

^b Division of Infrastructure Systems and Maritime Studies, School of Civil and Environmental Engineering, Nanyang Technological University, Singapore. Email: sllam@ntu.edu.sg

¹ Author for correspondence

Over the past few years, the concept of cluster has been regarded and adopted as a useful policy tool in analyzing maritime industry development. However, there is a lack of studies on the theoretical development of maritime cluster evolution in the existing literature. The paper aims to investigate the dynamic symbiosis derived from maritime cluster evolution. The research leads to a new path to investigate maritime cluster by employing the symbiosis theory in ecology and Lotka-Volterra model. The paper firstly develops the concept of maritime cluster classification and evolution. Then, it analyses the compatibility and analogy of biotic community with maritime cluster. In order to study the interaction relationships among maritime sectors, Lotka-Volterra model is introduced. The model is used to group the revenues of maritime sectors in pairs. These revenues are in turn grouped into the numbers of comparative pairs accordingly. The model is further advanced to forecast the trend of maritime clusters, by studying the existence of an equilibrium point and its stability with the estimated functions. The original approach would deepen the understanding on maritime cluster and stimulate future research. The study also draws insights for policy makers in maritime nations.

Key Words: Maritime cluster; Cluster evolution; Symbiosis theory; Lotka-Volterra model; Maritime nation

1. Introduction

Cluster theory has been identified and adopted over the past two decades as a tool for better understanding the economic activities in service and knowledge-based regional economies. Clustering is viewed to enhance the advantage of competitiveness [1]. It generates productivity, reflects innovation abilities and embodies the transmission of new business information. These are the very reasons that industries tend to carry on organizing mode in the form of cluster [2]. The notion of industry cluster has played an active role in economics and has identified as a determinant attribute on formulating business strategies and industrial policies [3-5].

Maritime cluster is a type of industry cluster which possesses a very dynamic nature. The concept of maritime cluster is associated with dynamic connotations with different development functions. World major maritime clusters such as London, New York, Hong Kong, Shanghai, Singapore and Rotterdam are identified on the basis of an assessment for the maritime services offered and most of the clusters are in the categories of Alpha and Beta World Maritime Cities [6]. This method has been applied to construct “Roster of World Cities” [7] and discussed extensively in various Global and World Cities Research Bulletins. Besides, some of these clusters are identified as the competitors to the London maritime cluster. They have recognized maritime services as the principal feature of the cluster or take maritime services as a strategic objective within cluster [8]. These clusters evolve over time in terms of the composition of maritime services provided. Such kind of changing functions, from another point of view, reflects quite different stages of economic and social development. As such, any static and definitive claims of what a maritime cluster should be, seem to be imprecise. However, based on the existing literature, little addresses the evolutionary connotation for maritime cluster, which would depend on the change and development of port functions and maritime services. This paper aims to study the evolution of maritime cluster through both conceptual development and suggesting an applicable theory. It studies the symbiosis theory and Lotka-Volterra model by referring to biological science. They can be taken as a useful tool for empirical analysis on maritime cluster evolution in the future.

2. Evolution and classification of maritime cluster

Referring to maritime cluster, such as its definition, formation in different context and the linkages among various maritime sectors, some main findings can be drawn from the current literature. First, there is no standard definition for maritime cluster. Though the scope of a maritime cluster can be very wide, the key is how to find the driving force to identify it [9-13]. With regards to the formation of maritime cluster, three main groups can be identified, namely shipping, maritime services and ship industry, surrounded by facilitating associations, educational and research institutions and political bodies [14-21]. As to the linkages and relationship within a maritime cluster, though connections among various sectors should be identified [22], the key is to figure out the probable significant role of clustering in the overall development of maritime cluster from sustainability perspective [23, 24].

The concept of maritime cluster, based on the literature reviewed above, is not once-and-for-all. The performance and composition of maritime cluster are so dynamic that it is interesting to examine its evolution and conduct comparative studies, which cannot be found in the existing literature. These changing performances reflect the various functions and roles that maritime clusters play in different regions and eras. Furthermore, taking an overall review throughout world major maritime clusters stated above, it can be observed that most maritime clusters developed from port production since the early stage. It is

meaningful to find out if maritime cluster functions are evolved with the changing port functions. Ports are identified to vary significantly in roles and functions, institutional structuring and operational and managerial practices in different categories or generations evolving with time [25-27]. As such, this study carries out the theoretical development of maritime cluster classification and its evolution with special consideration of port functions accordingly (see table 1).

Insert table 1 about here

There are four types of maritime cluster that we identify. In the first type, maritime activities within maritime cluster focus on shipping and port with mainly cargo loading and discharging functions. Such functions are local and territory dependent. The relationship and connection among and within maritime sectors are simple and rather loose. As for commercial consideration, different maritime activities do not act together congruously, regardless of other performers' reactions when making the decision. Users are more familiar with individual sectors or various port services, rather than the maritime cluster in its entirety. London and Rotterdam were the pioneers of the first type maritime cluster. Dublin in Ireland and Selangor in Malaysia at their current status [12, 21] are considered in this category.

In the second type, maritime cluster is the centre for cargo allocation and value-added processing. It consolidates and distributes cargoes initially, including on the spot of industrial processing, combining, grouping, packing and commercial marketing. It is the typical centre of logistics and cargo allocation, aiming to provide value-added production and services. In this type, the geographic scope is regional and larger than port only in type one. Maritime activities in this stage are also carried out in and around port of the second generation [25, 26]. The port presents as a transport, industrial and commercial service centre. Thus ports are active in providing industrial or commercial services to their users, which are reached further than the traditional loading/discharging activity. Besides, port policies, legislation and development strategies are made with a broader conception and managerial attitude. In this case, some maritime sectors develop and expand towards their hinterland with industries accordingly. As such, Type 2 maritime cluster is not limited as a transport centre but an industrial and commercial centre. It performs not only the function of transportation, but has close relationships with trade partners and even municipality. Such close relationships present in a reciprocal way. On one hand, trade partners can access to various maritime activities swiftly and conveniently. Such as traders take port as the value-added centre and shift their cargo transformation facilities there. On the other hand, maritime activities depend on the resources provided by the surrounding city, such as land, energy, water, manpower and inland transport connection. For example, Hong Kong and Singapore were the creators of this type, followed up with New York, Rotterdam and London [8, 16, 28], which completed the functional transition to the industrialised era, whilst Osaka and Kaohsiung are current examples.

The third type of maritime clusters emerged in the 1980's in the background of world trade changing its pattern and developed in depth and in dimension, which called for an extensive transport network. Such type of maritime cluster resulted from world-wide large scale containerization and intermodalism combined with the growing requirement of supply chain management. As network expansion required firstly by this new trade pattern, maritime cluster adapts itself to allocate the integrated resources accordingly. It combines the resources ranged in not only the products and capital but the intangible information and technology [29]. These activities are carried out in a much larger geographical area than

Type 1 and Type 2 maritime clusters, and the sphere of influence is regional or even global. Maritime cluster plays a special role in the global/regional supply chains for its capacity of processing and distributing information. Such characteristic satisfies the new international trade pattern which involves in before, after and even during the production process. With various kinds of resources, it engages actively in the international flow of factors of production. Maritime cluster is regarded as the supply chain hub in global/regional economic and trade market, enjoying largely the economies of density and scope by the effect of hub-and-spoke system. Hong Kong, Rotterdam and Singapore are leading examples of this type of maritime cluster [16, 28, 30-34].

In the 1990s, the fourth-generation port concept was proposed with characteristics of physically separated but linked through common operators or administration [26]. It results largely from both vertical and horizontal integration adopted by transport operators. However, Type 4 maritime cluster at this stage appears with its new function as a maritime service centre instead of taking port and physical cargo logistics as core activities. The concept of local or regional territory vanishes. As different from the former three types, Type 4 maritime cluster can provide services to users who are very far away from the location where the cluster is centred. Though maritime clusters come in a wide variety of forms depending on the mix of maritime activities that make up the cluster and their relative weights within the cluster, the most distinguished characteristic for Type 4 is knowhow and the workforce's expertise upon that knowledge the international maritime services depend. Maritime services in this category are provided in a wide range, such as ship finance, maritime law, marine insurance, ship registry, ship chartering and ship brokering, to meet the comprehensive requirements of modern maritime business. London represents a typical example [8, 35-37].

In sum, this research devises the maritime cluster classification and evolution based on its changing functions, which are derived from the changing roles of port and the associated cargo shipping. This dynamic research topic would enhance the understanding of maritime cluster characteristics at different development stages. Especially, it addresses the main maritime sectors within the separate category and interplay among them in a new perspective which has not been addressed in the literature. The study also draws insights for policy makers in maritime nations for they can better understand the status of the maritime cluster in their country when compared with other clusters. Accordingly, the path of development can be charted with clear goal and strategy setting. Policy makers should have a clear map on the interaction among maritime sectors in the future. The next section will discuss the proposed symbiosis theory and Lotka-Volterra model in order to explore maritime cluster evolution through quantifying its formation.

3. Symbiosis theory in maritime cluster

As the conceptual development on maritime cluster evolution deployed above, the formation and function of maritime cluster are changing over time and geographical dimension. In this case, one problem pops up as to 'what is the future for maritime cluster', i.e. maritime cluster evolution. In this section, we adopt symbiosis theory originated from ecology and make an analogy with maritime studies. The aim is to study the relationships among sectors within a maritime cluster, which determine the formation and influence the evolution of maritime cluster.

3.1 Multi-mode interaction

The paper tries to investigate the relationships among maritime sectors, on the premise that the relationships among maritime sectors are unknown or uncertain and significant to the

cluster development. For the uncertain interactions, multi-mode framework is proposed and applied in technologies and economies [38-43]. A multi-mode framework is to evaluate the interaction among two or more maritime sectors, where the mode of interaction depends on the effect that one participant influences on another's growth rate. In contrast to the limited scope with only one mode, the multi-mode framework provides comprehensive interactional modes related to restricting or promoting one another's growth in the dynamic circumstances. By taking a step further towards applying this framework to the transitional effects, the interactions between maritime sectors transgress from one mode to another with the evolution of the whole maritime cluster [38]. For example, government used to support ship building and repair industries, which contribute to a large amount of tax revenue. However, with the consideration of the whole maritime cluster development within a region, such promotion scheme would suppress the full development of ship industry. Government may like to grow other maritime sectors in order to achieve holistic cluster development. Interactions between maritime sectors would change accordingly. Considering the rationale of studying the relationships among maritime sectors within the same maritime cluster, it is suggested that a multi-mode framework provides a rigorous setting for assessing the interaction of two or more sectors. More details will be given in section 4 when modeling is explored.

3.2 Symbiosis theory in biological science

Under the multi-mode framework, there are six relationships deriving from the ecological relationships. Therein two are oppositional, namely predation and competition; four are symbiotic, i.e. mutualism, commensalism, amensalism and parasitism. An ecological relationship is the relationship between interconnecting organisms in an ecosystem. Such relationship depends on the way the organism adapted to its environmental pressures on evolutionary bases [44]. The detailed explanation and relationship attribution are shown in table 2.

Insert table 2 about here

Symbiosis is close and often long-term interaction between different biological species. Though there are both oppositional and symbiotic relationships, the definition of symbiosis in ecology, broadly speaking, applies to any types of persistent biological interactions [46].

This research introduces symbiosis theory in biological science to the study of maritime cluster from the economic development point of view. The interactions and relationships among various maritime sectors appear to satisfy the symbiotic relationships according to the relationship attribution. However, we have to take a further step on the certain interactional way to forecast, scientifically and convincingly, the formation of maritime cluster along the evolutionary path. In the premise of different subjects, an analogical discussion for such interdisciplinary studies will enhance academic understanding, which will be carried out in the next subsection.

3.3 Analogy between biotic community in ecological system and maritime cluster

Interdisciplinary approaches in research can sometimes provide problems with exciting new insights. If analogies between two fields can be found and there is an empirical base to support such analogies, the paradigms and solutions of one research area can be applied to the problems of another area which is seemingly unrelated [39]. The concept of ecological

systems has been successfully applied in the fields of biological ecology [47], organizational ecology [48] and technologies [38, 39, 41, 43, 49, 50-52].

Hence we now turn to the field of ecology to explore whether the concepts and principles of that field can offer analogies that would be useful in formulating a framework for evaluating relationships among various maritime sectors within a maritime cluster. The paper discusses several analogies to explore concepts that might be applicable to the domain of maritime cluster. The analogical comparison between maritime cluster and biotic community is shown in table 3.

Insert table 3 about here

The comparison between maritime cluster and biotic community is among seven perspectives, namely components, structure, functions and characteristics, evolution, environmental influence, adaptability and dynamic characteristics.

For the components category, maritime cluster includes various maritime sectors [16, 18-21], comparing with biotic community encompassing two or more populations of different species [45].

The components of these two comparison items also hold the positions in the hierarchy structure within their domains, viz. maritime economic society and ecological system respectively. An ecosystem consists of a biological community together with its abiotic environment, interacting as a system [53-58]. A community is an assemblage of two or more populations of different species occupying the same geographical area [45]. For maritime cluster, based on maritime cluster formation in the literature, it encompasses a wide range of maritime sectors, which includes the relevant maritime firms, institution or organizations inside of every sector, though the variety of firms, sectors or even clusters may expose totally different functions [14-16, 18-21].

Besides hierarchy structure, the relationship among components behave in the ways of inter-play and inter-influence, which means the growth rate of one population has impact on another's. Referring to the relationships stated in table 2, the feedback characteristics include positive, negative and neutral. Within a maritime cluster, various maritime sectors interact with each other. Some players promote one another to provide a wide range of quality maritime services. Taking ship building industry as an example, it is such a capital intensive industry that financial support is regarded as a necessary requirement. On another hand, banks obtain income from ship building industry, such as interest from mortgage loan. This is a positive-positive interaction. However, some sectors might have negative effect on other sectors. This may result from limited resources, such as land, public investment and emerging or substituting of other maritime services to meet the satisfaction of maritime cluster evolution and development, such as the example of government promoting one maritime sector but not another which was discussed in subsection 3.1. One population may interplay with some others, but not all the rest. That is why there exists rather weak or no direct connections among certain maritime sectors, so called the neutral feedback [24]. Species interactions within biotic communities are evident in food or feeding relationships. For this reason, not only the nutrition structure is depending on food chain but also the spatial characteristics are determined by resources within some geographical area. For maritime cluster, the agglomeration, designated within a geographic location, of maritime firms is the fundamental requirement for clustering, for it is at least being an industrial district, or simply as a geographic concentration of firms [10, 12]. Beside, a network among these maritime sectors is required in order to formulate a cluster [13]. Viewing maritime cluster as a whole, the network inside of maritime cluster is made

use to carry on value added maritime activities, by both individuals and sectors. Such network aims to generate more revenue along this value chain, by providing better maritime production and services, though such maritime activities would vary in different types of maritime clusters and different eras.

Ecosystem processes include mainly primary production, energy flow and biodiversity. It contains ecosystem services and can be direct or indirect, such as the erosion prevention of direct ecosystem services and nutrient cycles of indirect services [55]. For operation characteristics and functions of maritime cluster, it mainly means the cargo, monetary/value and information flows and service providers, which have been discussed in detail in the subsection of evolution and classification of maritime cluster, see section 2.

Ecology and evolution are considered sister disciplines in life sciences. The concepts of natural selection, development and adaptation for biotic community are thread equally into ecological and evolutionary theory [59]. Under the consideration of such evolutionary rules, both horizontal and vertical development are changing and developing. Horizontally, the process of each population is encountering from simple to complex or from lower level to higher level to better adapt to the environment. Such kind of species evolution will influence the whole community vertically. The community evolves to a larger scale and higher level. This shapes the evolutionary characteristics towards a much more complicated and improved group, with a strong and flexible advanced structure. Besides, the existing patterns of biodiversity have been shaped both by speciation and by extinction [60]. For the evolutionary pattern, however, the rule of natural selection is the only known cause of adaptation, which is regarded as the gradualism [61], but not the only known cause of evolution. On the other hand, non-adaptive causes of evolution include mutation and genetic drift [62], which possess the discrete characteristic.

As for the maritime cluster development process, the cluster would evolve from physical operations to the advanced operation of global/regional supply chains, or even service oriented activities which are operated by highly advanced human capital and information flow covering more maritime activities. According to the changing functions of maritime cluster discussed in section 2, it can be seen that a number of maritime clusters are on their way of providing more specialized and professional maritime services, with differential characteristics for different maritime clusters. For example, London tries to “maintain and enhance the UK’s position as the world’s premier maritime centre” [63]. However, Singapore puts its mission not only on the development of “international maritime centre (IMC)” but also a “premier global hub port” [64]. The changing functions of maritime cluster are normally gradual throughout the whole development path. However, there are still abrupt and significant changes during the development process, such as the invention and application of container, so called the containerization. As a result, the number of employment in seaport terminals has reduced dramatically. Instead of a large amount of stevedores required in ports, workers with proficient skills in operating advanced port facilities are in higher demand. Containerization not only reduces the workforce required in ports but also speeds up the circulation and turnover of international trade, both in cargo and information aspects. It, in turn, makes global supply chains more feasible and accelerates the formation and development of Type 3 maritime cluster.

The process of natural selection is gradual and non-random. By way of such process, the biological characteristics of one population are common in some degree, though each individual can be reproduced by different bearers. This process is regarded as a key mechanism of evolution [61]. Looking at the world famous maritime clusters, the UK is the leading centre worldwide in the supply of a broad range of professional and business services to the international maritime community, that are largely concentrated in London.

According to the IFSL report [65], London and the UK is a leading source of capital and expertise for marine insurance, ship-chartering, shipping finance, ship classification, legal and accounting services and dispute resolution. In addition a wide range of other skills and facilities are based there. This is the very evidence that the superior will survive better.

In ecology, adaptability has been described as the ability to cope with unexpected disturbances in the environment [66]. Regarding maritime cluster, since it is not the maritime firm agglomeration only [12], it is the presence of public support mechanisms operated by the government and regional stakeholders, through which actors share a common vision of growth and innovation strategies [10]. In the case of organizational management, it has the ability to change something or oneself to fit to occurring changes. For example, in the study on maritime cluster classification, different maritime clusters have different functional emphasis, though most of them emphasizing port function at the very beginning of development.

Population would survive and develop in the community through natural selection, which is to continuously adapt to change through variation in their biological composition and distribution. Given the great diversity among organisms on earth, most community or ecosystems only change very gradually, as some species would disappear while others would move in [55]. Such dynamic characteristics are quite similar to maritime cluster. Since maritime industry is the derived demand of economic development and international trade, it emerges as the requirements for sea transportation. According to the analysis in section 2, for example, in order to feed the advanced demands of logistics and global or regional supply chain, cluster enlarges its functions as the key node in this activity in type 3.

Based on the comparison and analysis above, it is analogical between biotic community and maritime cluster. As such, it is valuable to take an attempt to apply symbiosis theory into the study of maritime cluster.

4. Application of Lotka-Volterra model in maritime cluster studies

Researchers in biology and ecology have already developed the mathematical formulations for ecosystems to identify the proper competition variables. Logistic function and equations in Lotka-Volterra model are typical examples. Scientists in mathematical ecology have worked out wide-ranging solutions to the studies of interacting species, even many of these scientists are from other research domains [49]. The following part discusses how to apply the Lotka-Volterra model in maritime cluster studies.

4.1 Process of Lotka-Volterra model in maritime cluster

The Lotka-Volterra model uses the logistic equation as basis, plus a term accounting for the interaction with the other species. Based on the analogy between biotic community and maritime cluster, it is proposed that the clustering relationship and evolutions of various sectors within a maritime cluster correspond to the original condition of Lotka-Volterra model. That is, the interaction between two species can be expressed in two differential equations as follows, which contain all fundamental parameters that affect the growth rate of both species [40-42, 50, 67].

$$\frac{dX}{dt} = (a_1 - b_1X - c_1Y)X = a_1X - b_1 X^2 - c_1XY \quad (1)$$

$$\frac{dY}{dt} = (a_2 - b_2Y - c_2X)Y = a_2Y - b_2 Y^2 - c_2YX \quad (2)$$

In which,

X and Y represent the populations of two maritime sectors. These can be expressed in several ways, such as revenue [20] and number of people employed [68, 69] in maritime sectors. The suitability of the chosen parameters is a key concern. Though there is no prior research on maritime cluster for Lotka-Volterra model, the parameters can be derived from the existing literature on maritime cluster reviewed above.

$\frac{dX}{dt}$ and $\frac{dY}{dt}$ mean growth rate of X and Y at time t.

X_2 and Y_2 terms represent the same maritime sector interacting internally with itself.

XY and YX show different maritime sectors interacting with one another.

a_1 and a_2 are the logistic parameters of geometric growth for the maritime sectors 1 and 2, when they are living alone.

b_1 and b_2 are the growth effects of internal interaction within each maritime sector. They also represent the limitation parameters of niche capacity of X and Y. Niche capacity is the up limit and a target for the growing maritime sector. It shows where a maritime sector aims to be at the end of the growth process and it should not vary over time [49].

c_1 and c_2 are generally called the coupling coefficients. They are the interaction parameters with the other sector.

The multi-mode form can be illustrated by the coefficients c_1 and c_2 for the case of two maritime sectors. The types of competitive roles can be told according to the signs of c_1 and c_2 [49], so the multi-mode form could be revealed for the case of two species in table 4.

Insert table 4 about here

It should be noticed in table 4 that there is an extra relationship attribute, namely neutralism, included in the measurement for multi-mode interaction by the signs of interaction parameters. This is because that both pure competition and neutralism are falling into the same relationship attribution category of positive-negative. Based on the discussion for feedback characteristics in table 3, we have to consider neutralism which might exist between some of the paired sectors. In a practical maritime cluster, a range of sectors have to be linked. This means any one sector has to interact with other sectors, at least one of them. Or else, such “any one sector” is not included in the cluster. But the finding on interaction has to be empirically tested. After empirical analysis, there might be no interactions found between any two sectors. Such kind of relationship is so-called neutralism. In the mathematical formulations of the Lotka-Volterra model, the sign of interaction parameter is 0, which means there is no interaction between the two investigated maritime sectors.

As the measurement for maritime cluster is discrete time data, it is necessary to convert the continuous Lotka-Volterra model into a discrete time version. Equations (1) and (2) could be transformed into difference equations [70]:

$$X_{(t+1)} = \frac{\alpha_1 X_{(t)}}{1 + \beta_1 X_{(t)} + \gamma_1 Y_{(t)}} \quad (3)$$

$$Y_{(t+1)} = \frac{\alpha_2 Y_{(t)}}{1 + \beta_2 Y_{(t)} + \gamma_2 X_{(t)}} \quad (4)$$

In which,

$X_{(t+1)}$ and $Y_{(t+1)}$ represent the populations of two maritime sectors at time (t+1).

$X_{(t)}$ and $Y_{(t)}$ represent the populations of two maritime sectors at time t.

α_1 and β_1 are the logistic parameters for the single sector X, when it is living alone.

α_2 and β_2 are the logistic parameters for the single sector Y, when it is living alone.

γ_1 and γ_2 express the magnitude of the effects that revenue from X has on the growth rate of revenue from Y and revenue from Y has on the growth rate of revenue from X.

The relations between coefficients of continuous Lotka-Volterra model and those of the transformed difference Equations (3) and (4) [42] are:

$$a_i = \ln \alpha_i \quad (5)$$

$$b_i = \frac{\beta_i \alpha_i}{\alpha_i - 1} = \frac{\beta_i \ln \alpha_i}{\alpha_i - 1} \quad (6)$$

$$c_i = \gamma_i \frac{b_i}{\beta_i} = \frac{\gamma_i \beta_i \ln \alpha_i}{\beta_i \alpha_i - 1} = \frac{\gamma_i \ln \alpha_i}{\alpha_i - 1} \quad (7)$$

In which,

i represents maritime sector X or Y.

The sign of γ_i must be the same as the sign of c_i since $\frac{\ln \alpha_i}{\alpha_i - 1}$ is always positive if $\alpha_i > 0$ and $\alpha_i \neq 1$ in Equation (7). Therefore, the type of competitive roles in table 4 can be determined according to the sign of γ_i .

It is proposed that future studies can seek to verify the reciprocal in fluency of maritime clustering evolutions two by two in pairs of maritime sectors within maritime cluster. While the revenues are in turn grouped into some comparative pairs, these pairs of system equations (3) and (4) are examined separately to determine the mutual inter-industry impacts in maritime cluster.

In order to find the equilibrium state and trajectory changes over time, the stability of equilibrium should be identified. It requires the results of equations (1) and (2) to be equal to zero, meaning that there are no simultaneous changes over time for a particular maritime sector.

4.2 Application areas

Nowadays, there are various types of maritime clusters in the world possessing dynamic characteristics with various cluster formations and functions. As such, the composition of maritime sectors in future concerns the strategy direction of every cluster. According to the discussion above, symbiosis theory and Lotka-Volterra model can be taken as a useful tool to investigate maritime cluster evolution in the aspects of its formation.

The conceptual development on maritime cluster classification and evolution shows that the performances of cluster functions are wide-ranging. For example, London is regarded as the fourth type of maritime cluster, which concentrates on various service sectors, such as ship broking which is the biggest contributor to UK maritime services overseas earnings, ship finance which generates significant overseas earnings as well, marine insurance, legal services and educational institutions [65]. These sectors are the key concern for London maritime cluster. However, Shanghai, being the Type 3 maritime cluster, aims to be the International Financial Centre and International Shipping Centre [71]. As such, when determining the maritime sectors in the future, the application of symbiosis theory and Lotka-Volterra model in London case can be carried out through paired sectors between each of five sectors mentioned above. As for Shanghai maritime cluster, study may emphasize on the interactions not only between shipping finance and other maritime sectors, but every shipping service sector and other maritime sectors.

In order to forecast the cluster formation in the future, it is necessary to verify the interrelationships between paired maritime sectors. Within a time range in the recent years, the revenue, which is a crucial part of financial statement analysis, and number of people employed, which is the important impact of maritime cluster to regional economy and society, can be chosen as the indicators. Data collection can be obtained from various secondary sources, such as International Financial Services London (IFSL) for London maritime cluster and Shanghai International Shipping Institute for Shanghai's case. As a

result, the reciprocal can be verified through the interaction parameters indicated in table 4. Besides, in order to test the satisfaction of stable conditions for equilibrium points among maritime sectors, equilibrium analysis can be conducted through coefficients a_i , b_i and c_i .

All in all, it is not only necessary to investigate maritime cluster evolution and formation through the reciprocal influence among sectors, but feasible to apply symbiosis theory and Lotka-Volterra model into practical study.

5. Conclusions

The paper presented the study on the evolution of maritime cluster. It thoroughly developed an original maritime cluster connotation, especially in the classification and evolution of maritime cluster from the perspectives of the changing functions. In order to explore empirical analysis in the maritime clustering quantitatively, the study proposed symbiosis theory and Lotka-Volterra model to investigate the reciprocal influence among maritime sectors. With the cross-disciplinary theory and model, originated from ecology, this research provides a useful reference for maritime cluster forecasting in view of the evolution process. It also draws insights for maritime clusters to handle the formation development, especially for those on their way to be maritime service centres. This study, by providing these new perspectives by conducting conceptual development, theoretical applicability and model feasibility, contributes to the existing literature in which the evolution of maritime cluster is seriously under researched.

The research findings presented are based primarily on the conceptual and theoretical aspects. This framework could be applied in the empirical study on maritime cluster evolution in future research work. It is expected to identify the interactions among maritime sectors in a cluster, by forecasting the evolution process quantitatively. With empirical analysis confirming such analogies, the paradigms and solutions in biotic community could be applied to deal with problems occurring in maritime cluster.

As a whole, this paper advances maritime cluster study to a new and important area, as well as contributes to practical and policy suggestions on the dynamic development path of maritime cluster.

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Table 1 Maritime cluster evolution and classification.

	Type 1	Type 2	Type 3	Type 4
Scope of activities	Cargo loading and discharging, Cargo storage and distribution, transportation facilities, navigational service-Quay, waterfront area and distribution channel	Logistics in value-added processing for cargo: initially consolidating and distributing products, nearby industrial processing, combination, grouping, packing and commercial marketing	Concentration and distribution of factors and production and information, relating to economic, financial, technological, communicational and international trade aspects	Variety of maritime services provided: shipping services, regulators, industry associations, intermediate services, support services
Operation characteristics	-Cargo flow -Simple individual service -Low value-added	-Cargo transformation -Combined services -Improved value-added	-Cargo/information distribution -Multiple service package	-Feature in maritime services -Operated by highly advanced human capital
Decisive factors	Labour/ natural conditions/ capital	Capital	Technology/knowhow	Knowhow
Main functions	Cargo handling and distribution	Value-added processing	Key node in global/regional supply chains	International maritime service centre
Position of port in maritime cluster	-Conservative -Changing point of transport mode	-Expansionist -Transport, industrial and commercial centre	-Efficiency oriented -Integrated transport centre and logistic platform for international trade	-Maritime service oriented -Varied positions in different maritime clusters
Current examples	Dublin (Ireland), Selangor (Malaysia)	Kaohsiung (Taiwan), Osaka (Japan)	Antwerp (Belgium), Hamburg (Germany), Hong Kong (China), New York/New Jersey (USA), Piraeus (Greece), Rotterdam (Netherlands), Shanghai (China), Singapore, Tokyo (Japan)	London (UK), Oslo (Norway)

Source: Authors.

Table 2 Two species population interaction.

Mode of interaction	Explanation	Relationship attribution
Pure competition	Organisms compete for the same resources. Both organisms are harming each other.	Negative-negative relationship
Predator-prey	One organism hunts and eats the other organism.	Positive- negative relationship
Mutualism	Organisms benefit from each other.	Positive- positive relationship
Commensalism	One organism benefits from another organism which is not affected.	Positive- neutral relationship
Amensalism	One organism is harmed while the other is not affected.	Negative-neutral relationship
Parasitism	One organism (the parasite) benefits while the other(the host) is harmed	Positive- negative relationship

Source: Authors, based on Morin [45].

Table 3 Analogies between maritime cluster and biotic community in ecology.

Comparison items	Maritime Cluster	Biotic Community	
Components	Maritime sectors	Biotic population	
Structure	Hierarchical structure	Maritime firm, maritime sector, maritime cluster, maritime economic society	Species, population, Biotic community, Ecological system
	Relationship among components	Inter-play & inter-influence	Inter-play & inter-influence
	Feedback characteristics	Positive , negative and neutral feedback	Positive, negative and neutral feedback
	Spatial characteristics	Territory determinant	Strong resources but weak territory determinant
	Nutrition/value structure	Value chain	Food chain
Characteristics and Functions of operations/processes	Cargo flow, monetary/value flow, information communication, producing and service activities, boost economic development	Species flow, energy flow, material cycling, information flow, biological production, resources decomposing, keep ecological balance and biodiversity	
Evolution	Evolutionary process	From simple to complex, from small scale to large scale	From simple to complex, from low to high
	Evolutionary characteristics	Expanding and improving of maritime industry chain	Complicating and improving of morphological structure in different levels
	Evolutionary particularity	Specialization enhancement	Specialization and degradation
	Evolutionary pattern	Gradual or discrete evolution	Gradual or discrete evolution
Environmental influence	Select the superior and eliminate the inferior, acclimatization	Natural selection, Survival of the fittest	
Adaptability	Capable of some self-adaptive ability	Capable of some self-adaptive ability	
Dynamic characteristics	Emerging, forming, developing, evolutionary	Occurrence, forming, developing, evolutionary	

Source: Authors, by referring to sources cited within subsection 3.3.

Table 4 Multi-mode relationships according to the signs of interaction parameters.

c₁	c₂	Type	Explanation
+	+	Pure competition	Both species suffer from each other's existence.
+	-	Predator-prey	One of them serves as direct food to the other.
-	-	Mutualism	It is the case of symbiosis or a win-win situation.
+	0	Amensalism	One suffers from the existence of the other, who is impervious to what is happening.
-	0	Commensalism	One benefits from the existence of the other, who nevertheless remains unaffected.
0	0	Neutralism	There is no interaction.

Source: [42].