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Study on the Construction of Digital Twin-Oriented Operation Ecosystem Model of Large-Scale Comprehensive Port

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Abstract. The operation of a large-scale comprehensive port is characterized by multi-cooperative units, multi-cargo types and multi-application scenarios. In view of this, the analysis and research on port-centered ecosystem can promote the understanding of port operation mechanism and provide theoretical basis for the construction of digital twin system of large-scale comprehensive port. To clarify the boundary of digital twin system and the digital twin content, this paper analyzes and determines the external ecological participants of large-scale comprehensive port, classifies and stratifies the ecological participants of port operation, and refines the basic characteristics of the operation ecosystem model. Ecological participants are organically linked by the ecological relationship of port operation, and the construction logic of port operation ecosystem model is combed, which enriches the model base, knowledge base and rule base of port digital twin.

Keywords. Comprehensive port, digital twin, ecological member relationship, ecological model, ecological characteristics of port operation

1. Introduction

The concept of ecosystem was first put forward by A.G. Tansley, a British plant ecologist, in 1935, which is a complex of many natural factors representing biology and environment. This concept is considered as a functional unit in ecology and widely used in related ecological research [1]. In the subsequent research, the ecology and related theories are mainly used for the analysis and understanding of port ecological niche in port industry. The research conclusions of this paper may assist the integration and implementation of digital twin technology in port industry.

Digital twin is a kind of technology that integrates multi-physical, multi-scale and multi-disciplinary attributes, with real-time synchronization, faithful mapping and high fidelity, and can realize the interaction and fusion between the physical world and the information world. Constructing port ecological model can better optimize the digital twin port system, which can dynamically reflect activities of port system. In this way, dynamic graphics can be used to describe the changing process of complex port production activities, so as to improve the port operation process and data visualization

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degree. The rational use of this technology can promote the interconnection of production business data, equipment status data and external environment data, so that the physical environment can be highly integrated with virtual model. By taking post-event recovery actions, it provides the fidelity needed to truly predict port performance, improving the overall efficiency of the port operation ecosystem [2-5]. Therefore, a full understanding of port ecology is the premise of constructing an ecosystem model.

In the field of ecology, all kinds of separable categories in port ecology are called port ecological species, and the collection of many entities of such species is called port ecological population. Operating entities in port production and operation and upstream and downstream participants around port production and operation constitute a biological community with port as the core and specific operation business as the context in a certain area. Zhao Nan et al. analyzed the survival relationship between ports and the relationship strategy of competition and cooperation from the perspective of ecological niche, and calculated the intensity of competition between ports by measuring the overlap of port ecological niche [6]. Port ecosystem can be considered as a sum of the interrelation and interaction between the business entity community with port as the core and the external environment. Port operation ecology takes the basic loading and unloading business as the core, including the sum of upstream and downstream production and operation entities that interact with the core business in terms of goods and information, regulatory agencies authorized by laws and regulations and their relationships. This ecology is embedded into the operation of global logistics ecology in the form of a subset, and goods and information interact with global logistics ecology via upstream and downstream peripheral members of port operation. Port operation ecology relies on port logistics function, plays the role of core hub node, and has an impact on direct and indirect participants in upstream and downstream ports.

2. Analysis of Members in Port Operation Ecology

Starting from the needs of digital twin port construction, the granularity is unified according to its operation (management) entities on the basis of combing, analyzing and summarizing the core business and ecological participants of port operation. Finally we can determine a total of 20 members in port operation ecosystem, including port, container terminal, dry bulk terminal, liquid bulk terminal, break bulk terminal, pilotage, tugboat, barge, freight station, tally, warehousing, maritime affairs, border inspection, customs, transportation, highway, railway, pipeline, shipping company (forwarder) and shipper (agent). Combined with analysis and induction, these members can be divided into core function layer, port function layer and ecological support layer from inside to outside. As figure 1 shows Structure Chart of Members in Port Operation Ecosystem.

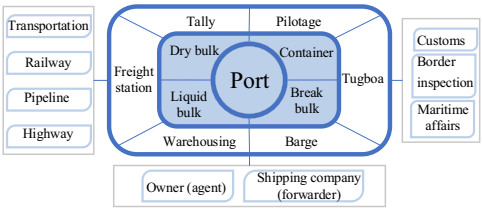

Figure 1. Structure Chart of Members in Port Operation Ecosystem.

In the operation ecology with port as the core, port, as an important link of logistics industry, needs to combine upstream and downstream ecological members to improve the operation ecology and realize the rapid transmission of materials and information. Port operation ecology is an interdependent and mutually promoting large-scale system, and all members of the ecology need to coordinate and cooperate closely for common goals.

2.1. Characteristics of Members in Port Operation Ecology

The port operation ecology is analyzed based on ecological theory. On this basis, members of port operation ecosystem are considered as the main research objects for the analysis of their business, ecological niche function and mutual effect. According to the business and operational entities, the system hierarchy is divided and the analysis dimensions are summarized. The operation mechanism of port operation ecosystem can be deconstructed into an analysis of the functions, interrelations and influences of all members. In this way we can analyze and describe the participants of operation ecosystem with the port as the core in such dimensions as ecological function, supply subject, core business, affected members and characteristic analysis, thus laying a foundation for the construction of digital twin port. The Analysis of Characteristics of Port Operation Ecology is shown in table 1.

Table 1. Analysis of Characteristics of Port Operation Ecology.

	Basic characteristics	Classification of attribution	Ecological members
Port Operation Ecology System	Ecological function	Core functions	Port, container terminal, dry bulk terminal, liquid bulk terminal and break bulk terminal
	Supply subject		
	Core business	Port services	Pilotage, tugboat, barge, freight station, tally and warehousing
	Affected members	Ecological support	Maritime affairs, border inspection, customs, transportation, highway, railway, pipeline, shipping companies (forwarder) and shipper (agent)
	Characteristic analysis		

2.2. Analysis of Member Relationship in Port Operation Ecology

After analyzing the ecological functions, core businesses and affected objects of port operation ecology members, we can outline the interaction among members of the operation ecosystem with port operation as the core. These members form the ecological operation mechanism by doing business, so as to guide the construction of digital twin port and the operation of various elements.

In the port operation ecology, each member holds certain special resources and capabilities, and relies on the input of resources or services from other members connected with its business chain to support their own output to the next link of the chain. Therefore, to ensure the stable operation of port hub function, all members need to maintain business cooperation with neighboring members and minimize the resistance to the operation of logistics industry chain due to their own reasons. Win-win cooperation is the operation background of long business chain such as port operation. Cooperation enables ecological members to work together spontaneously for

common goals or interests in a specific field, and both parties can obtain expected resources or services through business collaboration. But because of the different niche in the port transportation industry chain, the cooperation among different categories of members also has different rights and interests distribution. Nevertheless, the port industry players should also understand the interaction of ecological participants with the concepts of symbiosis and dependence, enhance the service capabilities in all aspects, and promote the efficient and smooth logistics and transportation with the port as the core node. This paper specially discusses the relationship mode beneficial to the port operation from the perspective of the core layer of the port.

2.2.1. Symbiosis

Symbiosis is a kind of membership relationship in which ecological members benefit each other and coexist with each other. When one dies, the other cannot survive on its own. Symbiosis among symbiotic units is manifested in the sharing of homogeneous resources and the complementarity of heterogeneous resources, and this symbiotic relationship promotes the optimization of resource allocation and efficiency improvement of each symbiotic unit [7]. We can see that it is a strong association attribute of interests. Both sides have common interests and goals, and share the pressure of survival. In the port operation ecology, the symbiosis attribute is the dominant relationship among members.

2.2.2. Dependency

In the port operation ecology, dependency is also a mutual-benefit relationship, while the niche of one side is more competitive and more dependent on the industry of the other. When this relationship disintegrates for objective reasons, both sides can survive but suffer losses to varying degrees.

According to the ecological theory and the actual observation results, there are some niche overlaps within and among the ecological species in the port operation ecology. The overlap of ecological niches inevitably leads to the competition for resources. Due to the overlap of hinterland, the ports in the same port group also have competition and cooperation relations, which affect the development of a single port or even the whole port group [8]. In case of dependency, entities with weak energy in port operation ecology are more inclined to form alliances to share upstream business information and expand access to resources in order to minimize the impact of competition from various aspects. In the port operation ecology, the entities of such type of ecological members can increase their own capacity and improve their service capabilities, or combine with upstream and downstream to develop into a logistics integration solution provider. Ports can take advantage of the hub position in the industrial chain, actively develop platforms, and empower all participants in the operation ecology.

3. Construction Method of Port Operation Ecosystem Model

We consulted many researches on species, population and ecosystem in nature by ecological theory for the construction of port operation ecosystem model, and combined the concepts in these researches with the port operation mode, forming a cognitive method with the core business of port and wharf and the operation of related

ecological members as the main perspective. In this cognitive method, the service supply set formed by the core operations of container terminal, dry bulk terminal, liquid bulk terminal and break bulk terminal and port's core services maps the main consumers of this part of services, i.e. participants of port operation ecology, and then merges to form the "biological community" in port operation ecology. On the basis of analyzing the ecological niche of "biological community" and their relationship, the hierarchical structure of port operation ecology members is constructed, and the port operation ecosystem model based on this cognitive method is produced, which guides the construction of digital twin port. The schematic diagram of the port operation ecosystem model is shown in figure 2.

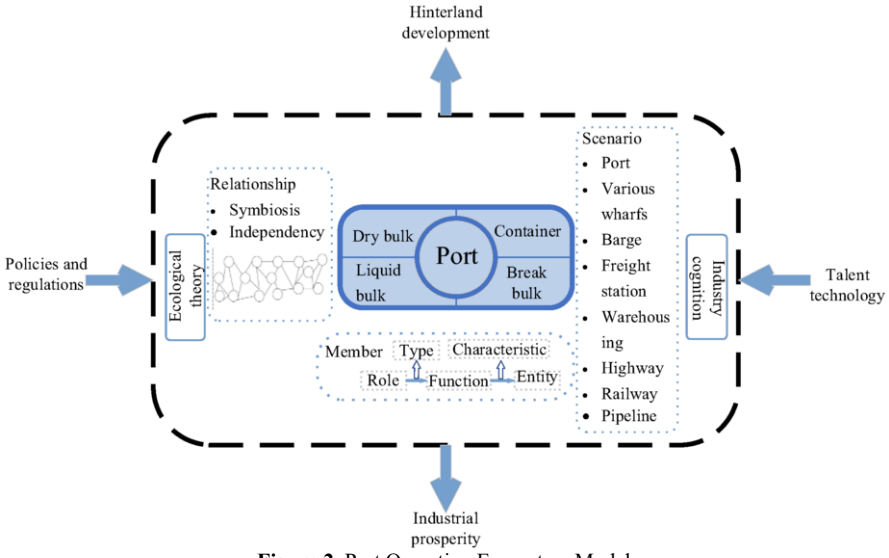

Figure 2. Port Operation Ecosystem Model.

Members in the port operation ecosystem model are the core analysis objects of the ecosystem. Based on the cognition of the basic operation business and its services of ports, the related parties involved in each business chain constitute the main body of ecological participants. In order to complete the logistics function of port hub, each member in the port operation ecology needs to activate the corresponding function given by ecological niche, and different operation entities play their respective roles at different nodes of the business chain.

While the ecological members complete the port logistics business according to their respective ecological functions, the ecological members inevitably connect with each other, resulting in the interaction of carriers. When the interaction among members is solidified for a long time in actual operation, this relationship affected by the subjective and objective environment of the whole ecology will form a paired relationship model, which has certain analysis and induction value and can be used to further understand the development of this industry and the comprehensive service of ports.

The cognition and understanding of ecological theory and port operation constitute the analysis basis of port operation ecological members, and support the construction of port operation ecosystem model. As an important link of global logistics and

transportation, port operation ecology inevitably produces external factors and is affected by the environment outside the ecological boundary. The effect outside the boundary described here comes from two main dimensions. First of all, beyond the logic of port operation, policies, planning, commerce, trade and other factors impose a direct or subtle impact on the operation ecology. Secondly, logistics industry members outside the port's core business chain also have an impact on the upstream and downstream of port hub operations as service producers or consumers. Such effect is reflected in the port operation ecology through the response of ecological members.

4. Conclusion and Prospect

For the purpose of building digital twin ports, we analyzed the members of port operation ecology and their relations by using ecological theory, and studied the theoretical method of building a large-scale comprehensive port operation ecosystem model in this paper. The research conclusions provide a basis for the research on port digital twin in the aspects of port operation business model and member cooperation mechanism. At present, the research and application of digital twin in port industry mainly focus on the wharf operation level. With the progress of the research on port operation ecology, the application scope of digital twin in port industry will be expanded to a certain extent.

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