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Review Article

Critical Literature Review into Planning of Inter-Terminal Transport: In Port Areas and the Hinterland

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Nowadays, the major ports around the world usually consist of multiple terminals and service centers which are often run by different operators. Meanwhile, inland terminals have been also developed to reduce port congestion and improve transport efficiency. The integrated planning of inter-terminal transport (ITT) between the seaport and inland terminals helps in providing frequent and profitable services, but also could lead to higher overall planning complexity. Moreover, the ITT system usually involves multiple stakeholders with different or even conflicting interests. Although an increasing number of studies have been conducted in recent years, few studies have summarized the research findings and indicated the directions for future research regarding ITT. This paper provides a systemic review of ITT planning: we examine 77 scientific journal papers to identify what kind of objectives should be achieved in ITT system planning, which actors should be involved, and what methodologies can be used to support the decision-making process. Based on the analysis of the existing research, several research gaps can be found. For example, the multi-modality ITT systems are rarely studied; cooperation frameworks are needed in the coordination of different actors and quantitative methodologies should be developed to reflect the different actors' financial interests.

1. Introduction

The continued growth of containerized transport volumes necessitates an expansion in scale and accessibility of container ports, as well as an improvement in their throughput productivity. Consequently, major ports such as Shanghai and Rotterdam are investing in an increasing number of interconnected terminals of different types (deep-sea terminals, barge terminals, railway terminals, and empty depots) and sizes. Meanwhile, multiple types of terminals have been developed in the hinterland and these terminals are connected by different combinations of modalities (road, rail, barge, and sea).

The development of the multi-terminal system increases the complexity of the transport process. Ideally, after arriving at a terminal in a port, export containers should be transferred to deep-sea transport and import containers could be transported to the hinterland destination directly. In reality, containers are often moved between several terminals in the seaport. Firstly, the implementation of intermodal transport requires transshipment between modalities, which can only be achieved by inter- and/or intra-terminal transport. Secondly, freight consolidation operations are performed in certain terminals. For example, feeder vessels are used to gather containers from multiple maritime terminals in a port area to a barge service center, where containers are loaded onto inland vessels and sent to the hinterland.

Therefore, the inter-terminal transport (ITT) could lead to several planning problems such as terminal location, freight consolidation, container inventory, coordination between terminal operations and transport, etc. Moreover, multiple stakeholders are involved in the planning, which makes it complex to balance their different interests.

This paper reviews the studies of ITT in the port area and in the hinterland, seeking to identify research gaps. Problems related to ITT have been studied and reviewed from

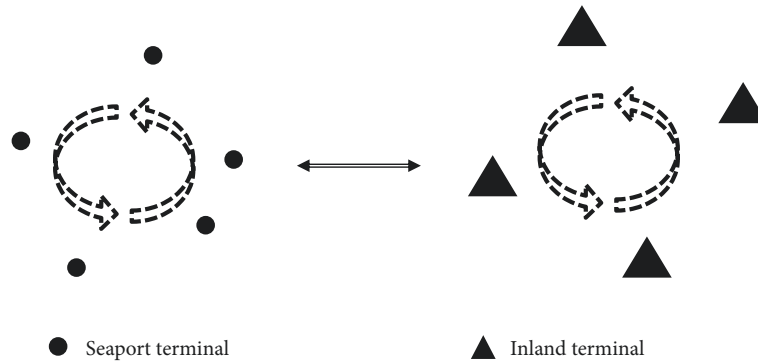● Seaport terminal   ▲ Inland terminal

FIGURE 1: Schematic representation of an ITT network.

different perspectives. For example, the optimal location for a hub terminal was studied by Racunica and Wynter [1]; Jeong et al. [2] investigated the freight and vehicle flow in an inland transport network; Vis and De Koster [3] reviewed the transshipment operations in container terminals. In their research, ITT was seen as the connection between different modalities, but the ownership of the ITT system and the organization of the ITT service were not discussed.

Heilig and Voss [4] reviewed the ITT between maritime terminals. The authors first discussed where ITT is required in the port area and then addressed several objectives of an efficient ITT system. The authors analyzed the approaches used in the literature and proposed several important research topics for further research.

Apart from ITT between maritime terminals, ITT in the hinterland also influences the transport process. According to Notteboom and Rodrigue (2005), the growth of port terminals and functional areas is limited by several local constraints, e.g., land use and environmental factors; thus, some seaport functions are moved to the hinterland. At the same time, the change of the production system and consumption market also favors the extension of port functions to the hinterland with multiple inland terminals, which could better serve the regional market. Therefore, apart from the ITT in the port area, we also discuss the connection between terminals in the seaport and in the hinterland.

A schematic representation of the ITT network studied in our research is shown in Figure 1. The ITT network consists of several terminals in the seaport and its hinterland. In the seaport, the terminals are interconnected, then, the seaport terminals are connected to multiple inland terminals (direct connections are excluded in the search). The ITT differs from general transport as ITT service always involves one or multiple intermediate terminals between the origin and destination terminals. In the view of freight bundling (see [5] and Kreutzberger, 2010 for introductions of different bundling networks), ITT network could be a line network, a hub-and-spoke network, a trunk line with collection and distribution network or a mix of these networks.

In this research, we seek to answer the question of what kind of ITT system is needed and which stakeholders should be considered in ITT planning. We also extend the literature review into the hinterland of port areas and analyze the

differences between ITT in port areas and hinterlands. Thus, our paper identifies research gaps of ITT in:

(1) Planning problems and objectives in the ITT system

(2) ITT stakeholders responsibilities in ITT system planning and the coordination between different actors

(3) Methodologies and theories used in ITT system planning

This paper is organized as follows: in Section 2, the search strategy is discussed; in Section 3, we analyze the search result; in Sections 4 and 5, we review the research related to ITT; and in Section 6, we conclude the review and propose suggestions for further research.

2. Search Strategy

To analyze the transport between terminals from a comprehensive perspective, we performed a literature search for studies that have been published in scientific journals using Scopus, Web of Science, ScienceDirect, and Google Scholar databases. To ensure the robustness of the search, different combinations of search strings (see Table 1) were used to identify relevant research and the search field was set as title, keywords, and abstract. It is notable that Google Scholar will search these keywords in full text [6] and result in a large number of papers. According to Google [6], the search results will be ranked based on the relevance; thus, when the number of search results is larger than 100, only the first 100 journal papers will be selected and analyzed. A similar searching process can be found in Brakewood and Watkins [7].

The search was conducted in March 2019, and 528 papers were retrieved from the databases. After removing the duplicates, 406 papers remained. Then we checked the title and abstract of these papers which reduced the number of papers to 87. We read these papers in full and checked the bibliographies for additional literature (snowballing). In the end, 77 papers were included in our research. We do indeed neglect the grey literature (such as reports written in the framework of European research project for instance) because our focus is on scientific papers.

TABLE 1: Search strings, databases, and search results.

Keywords	Database	Number of search results	Duplicates removed	Title and abstract	Final result
Inter-terminal AND transport	Scopus	13			
	Web of Science	12	29		
	ScienceDirect	6			
	Google Scholar	22			
Container transport AND multi-terminal	Scopus	11			
	Web of Science	7	34		
	ScienceDirect	6			
	Google Scholar	34			
Freight transport AND multi-terminal	Scopus	20			
	Web of Science	9	24		
	ScienceDirect	3			
	Google Scholar	24	406	87	77
Container transport AND seaport	Scopus	25			
	Web of Science	29	115		
	ScienceDirect	9			
	Google Scholar	100			
Freight transport AND seaport	Scopus	44			
	Web of Science	25	150		
	ScienceDirect	8			
	Google Scholar	100			
Container terminal AND transport AND network	Scopus	66			
	Web of Science	62	176		
	ScienceDirect	25			
	Google Scholar	100			

Table 2: The geographical focus of reviewed papers.

Geographical Focus	Port ITT	Hinterland ITT
Unknown/conceptual	8	12
Europe	18	24
Asia	4	7
North-America and Europe	-	1
North-America	-	1
Latin-America	-	1
Pacific (Australia)	-	1
Total	30	47

In the searching and checking process, we selected papers based on the ITT definition given in the Introduction: (1) the transport network covers terminals in the seaport and its hinterland; (2) the transport process always involves intermediate terminals. Therefore, we excluded these studies on single terminal or port, studies on point-to-point transport, studies focusing on inland transport networks without seaport connections, or the studies covering transport between multiple seaports.

3. Descriptive Analysis of Search Results

3.1. ITT in the Port Area and in the Hinterland. Both port network and inland networks have been studied by the 77 papers. 30 of these studies focus on ITT operations in port areas (further referred to as port ITT) and 47 papers focus on planning ITT system in an inland transport network (further referred to as hinterland ITT). Table 2 demonstrates the geographical focus of both port ITT and hinterland ITT. We can find that most of the studies are based on the European network and only European and Asian port ITT systems have been studied.

Among the 22 port ITT studies with a specific geographical focus, 15 of them investigate the terminals in Maasvlakte 1&2, Rotterdam port. Other port ITT networks have been studied including the port of Hamburg, Antwerp, Singapore, and Tianjin. Hinterland ITT systems in the hinterland of Rotterdam, Antwerp, and Campanian region, Italy have been investigated more intensively as there are 19 papers focusing on these areas.

3.2. Research Level of the ITT Problem Studied in the Literature. Generally, studies can be classified into three categories: strategic, tactical, and operational. A strategic study usually focuses on long-term decisions such as infrastructure layout and fleet configuration. A tactical study focuses on planning problems with a weeks- or months-long duration, such as barge rotations and train timetables. An operational study aims at solving problems that occur on a daily basis, such as vehicle routing and crane scheduling. In this review, we classify the reviewed papers by their planning horizons as either strategic or tactical/operational studies because some operations such as barge (un)loading in multiple terminals may take several days and some tactical problems such as vessel rotation planning are interrelated with terminal handling operations.

Most of the port ITT studies focus on tactical and operational problems while most hinterland ITT studies are on the strategical level. Among the 30 port ITT research papers, apart from the 2 literature survey papers, 8 papers are strategical focusing on terminal design, ITT fleet, and information system, and 20 papers are tactical/operational focusing on berth allocation, barge rotation, and land vehicle routing; see Figure 2(a). Among the 47 hinterland ITT research papers, there are 2 literature survey papers, 30 strategical research papers focusing on terminal design and terminal allocation, and 15 tactical/operational research papers focusing on barge rotation, and service network design; see Figure 2(b).

3.3. Distribution by Year of Publication. We selected 30 port ITT papers and 47 hinterland ITT papers and these papers were published between 1999 and 2019, see Figure 3. We noticed that the number of port ITT studies remained relatively small before 2015. However, in 2016 and 2017, 14 papers were published, which accounts for almost half of the total number.

4. Port ITT

This section reviews the port ITT studies and analyzes the planning problems, actors involved, and methodologies used in decision making. As is shown in Figure 1, the port ITT studies discuss the seaport terminal operations and the transport between these seaport terminals. We reviewed 30 papers and analyzed the planning problems covered, the stakeholders involved, and the methodologies used in these papers.

4.1. Port ITT Planning Problems

4.1.1. Port ITT Strategical Planning Problems: Terminal Design and Fleet Configuration. The terminal layout could affect the port ITT demand. In some cases, if terminals are connected with all modalities and have enough handling capacity, the port ITT demand could be reduced. Ottjes et al. [8] compare three terminal configurations: compact configuration, dedicated configuration, and combined configuration. The compact and dedicated configurations are two extreme situations where all terminals are either connected with multiple modalities or with a single modality. The combined configuration represents the planned layout of the Rotterdam Maasvlakte terminals: both compact and dedicated terminals exist. The results show that the number of ITT vehicles in use in the dedicated configuration is two times larger than in the compact configuration. Evers and De Feijter [9] investigate whether each terminal should be equipped with the facility to handle feeders (decentralized ship service) or the feeders should be handled in a single service center (centralized ship service) to reduce the ship service time. The results show that the centralized service can reduce the vessel average in-port time while using the same number of ITT vehicles.

Choosing proper ITT fleet could also reduce the ITT related costs. Different transport modes have different advantages and limitations. Generally, road transport is widely used because it provides the fastest delivery with flexibility. But

Port ITT

Terminal Design
ITT Fleet
Information System

Berth Allocation
Vehicle Routing

6%

27%

67%

- Strategical
- Tactical and operational
- Literature Review

(a)

Hinterland ITT

Network Design
Terminal Design

Freight Consolidation
Barge and Train
Scheduling

4%

32%

64%

- Strategical
- Tactical and operational
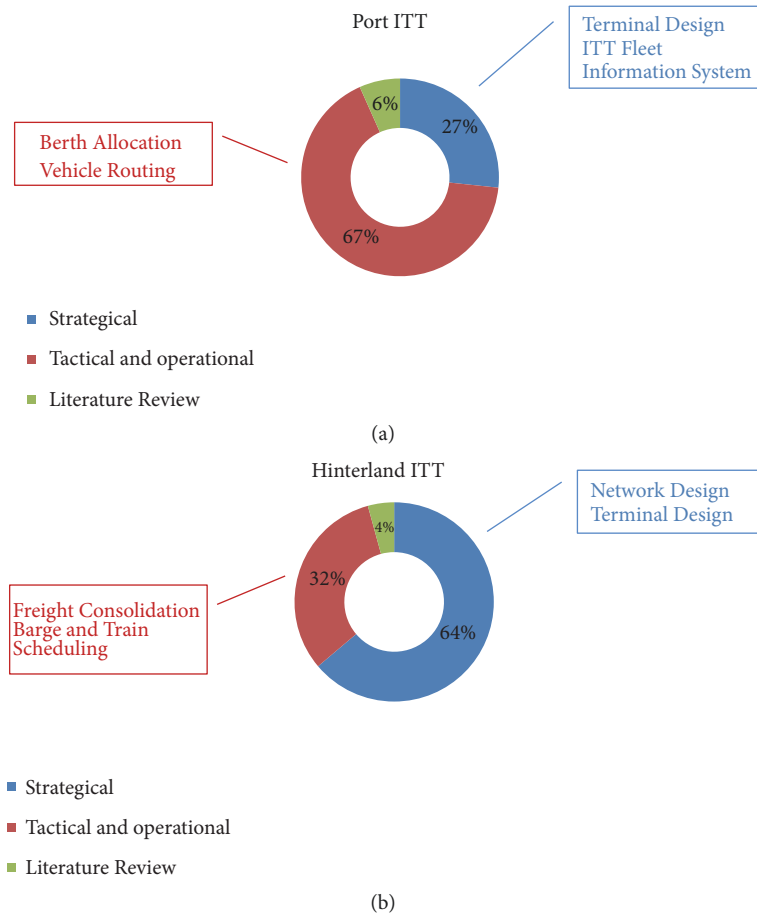- Literature Review

(b)

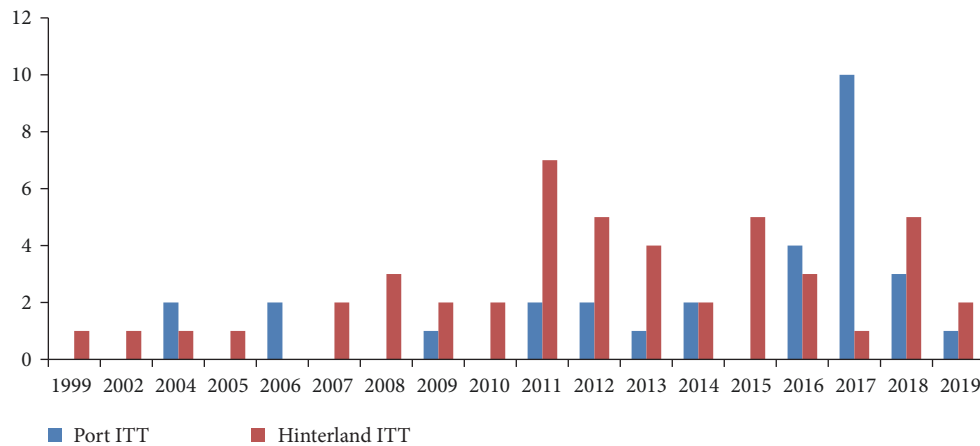FIGURE 2: Research levels of port ITT (a) and hinterland ITT (b).

FIGURE 3: Distribution of journal papers by year of publication.

Gharehgozli et al. [10] point out that some special vehicles, such as multi-trailer system (MTS), require a private road, and some vehicles, such as Automated Guided Vehicle (AGV) and Automated Lifting Vehicle (ALV), require a private road as well as a control system. Waterway transport is the most economical transport mode but requires a longer transport time. Barges are usually used to transport containers among several terminals in a port. But the handling and waiting time is relatively long and highly affected by the rotation plan [11]. Railway transport has a lower transport cost compared to road transport and a higher transport speed compared to waterway transport. However, rail transport also requires complicated handling operations and long handling time, which lead to high ITT costs [12].

Information systems play a fundamental role in the ITT planning. Both centralized and decentralized systems have been studied. Heilig et al. [13] introduce the usage of a centralized communication system with a cloud-based server and a mobile application. The core of this platform is routing optimization, which includes fixed vehicle costs, variable vehicle operating costs, and penalty costs for late delivery. The result of the optimization is presented by a WebApp to enable the ITT provider to monitor the position of their trucks and to interact with drivers by sending and receiving messages. The truck drivers, in turn, use a MobileApp, which collects GPS information and displays their optimized sequence of transport orders. In reality, a centralized communication system may be hard to achieve because both terminal operators and transport providers compete with each other, and sharing information could be unacceptable [11]. Therefore, a multi-agent scheme is tested in Douma et al. [14], Douma et al. [11], and Douma et al. [15]. In the scheme, different levels of information exchange are examined: (1) no information, i.e., barges visit the terminals according to the shortest path; (2) yes/no, i.e., a barge can ask whether a certain arrival time is acceptable to the terminal operator; and (3) waiting profiles, i.e., terminals give barges information about maximum waiting time a barge has to wait for every possible arrival time. The results indicate that the waiting profiles work well compared to a centralized system.

Four major research gaps can be identified in the strategical planning. Firstly, the layout of terminals should be further evaluated considering infrastructure investment and potential ITT cost. Coordinated terminal and ITT infrastructure design may reduce the ITT demand or meet the ITT demand with minimal service cost and time. Nevertheless, ITT demand reduction could be infeasible in practice: the construction of a compact terminal or centralized ship service center may increase the investment for the terminal operator.

Secondly, the future study may pay more attention to the detailed data collection or estimation of port ITT demand between different seaport terminals. Currently, most research makes assumptions on the transport demands between different types of seaport terminals; e.g., 1% of the total transshipment containers in deep-sea terminals will use the ITT system [10]. If the demand data is not available in planning for the future ITT network, estimation should be made based on the overall planning of terminal type, terminal layout, terminal capacity, and coordination between terminal operators and transport operators. We noticed that, in De Lange [16] and Gerritse [17], transport demand between terminals is estimated based on the terminal capacity, port throughput, and the potential growth. The estimation could be further improved based on the realistic development of terminals. Moreover, some European research projects, e.g., ETIS Plus, have developed models and tools to forecast transport demand for large-scale network work. These methodologies could be used in ITT demand estimation.

Thirdly, there is no integrated analysis of integrated multiple-mode ITT systems. Existing literature focusses on the performance evaluation of one transport mode and finding the ITT fleet configuration with the best performance:

minimal number of vehicles needed, highest delivery punctuality, etc. For example, Duinkerken et al. [18] compare three road-based ITT systems (with AGV, ALV, and MTS, respectively) among the Maasvlakte terminals considering the lateness delivery rate. Future research should investigate the integrated ITT fleet with rail, road, and waterway vehicles.

Lastly, further research is needed to investigate the dynamics of the information systems when coordinating vehicles with and without appointments. The performance of the information system is only guaranteed when all users have access to the system and follow the instruction of the system. As indicated by Giuliano and O'Brien (2007), the truck appointment system has little impact on the truck waiting time at the terminals because few trips are performed with an appointment and terminal operators give no priority to the trips scheduled with an appointment.

4.1.2. Port ITT Tactical and Operational Planning Problems: Allocation Deep-Sea Vessels and Routing the ITT Vehicles. Tactical and operational planning usually aims at reducing the ITT timespan or costs. Several operations may affect the ITT timespan: transport, handling, storage, etc. The potential costs related to the ITT operation include vehicle energy consumption cost, vehicle hiring cost (crane, reach stacker, etc.), handling cost, storage cost, lateness delivery cost, etc.

To improve the ITT planning, existing research has tackled different problems.

Some research focuses on the allocation of deep-sea vessels to different terminals and quays. When a deep-sea vessel visits one terminal, some containers should be discharged and loaded onto another vessel or train in another terminal. At the same time, some export containers in another terminal must be loaded onto this vessel. Then, ITT is needed to move the containers between terminals. Additionally, containers waiting for the ITT must be stored in the terminal yard, which leads to extra storage cost. A proper assignment of deep-sea vessels may reduce the costs caused by ITT movements. Zhen et al. [19] study the terminal assignment for the vessel considering fuel consumption, ITT, and storage cost. Hendriks et al. [20] study a berth allocation problem among multiple terminals with an objective to minimize the quay crane operation cost and ITT cost. A comparison with a realistic allocation constructed by PSA Antwerp shows that a small modification can reduce almost 25% of the number of crane operations and more than 3% of the ITT cost.

Routing of ITT vehicles has also been studied. For the ITT barge and train, it is important to determine which terminals the vehicle should visit or stay. In some cases, trains and barges may visit multiple terminals for ITT movements. Caballini et al. [21] and Caballini et al. [22] study the rail cycle in the port aimed at minimizing the queuing time in multiple yards. Li et al. [23] use the inland vessel in ITT: when a vessel arrives at a terminal, both hinterland and ITT containers will be loaded and unloaded to/from the vessel. The objective of this research is to find the optimal vessel rotation plan with minimal travel time. Li et al. [24] also aim to minimize the travel time in the port. In their research, possible disturbance such as terminal equipment failure and sudden closing of terminals are also taken into consideration. For road vehicles,

the routing problem has been studied considering fuel costs, delay costs, emission costs, etc. For example, Jin and Kim [25] study the truck routing in Busan port with delivery time windows. A trucking company's profit from moving containers is maximized in the research while the truck usage cost and delay penalty are taken into account. Heilig et al. [26] extend the ITT truck routing optimization considering the emissions. Trucks are used to pick up and deliver containers, and all containers must be delivered. A multi-objective model is proposed to minimize the fixed vehicle hiring cost, vehicle traveling cost, lateness delivery penalty, and emission cost. Additionally, the depot at which the vehicle starts and ends its route also affects the ITT cost. Hu et al. [27] and Hu et al. [28] study the ITT vehicle routing problem integrated with railway transport to the hinterland and terminal operations.

Although considerable efforts have been made to tackle the port ITT tactical and operational planning, there are some questions to be further investigated. Firstly, railway ITT is rarely studied. Port terminals usually have rail yard on dock or rail connection to rail terminals, but it is not clear how to use these facilities in ITT to realize the benefit. Secondly, the ITT should be studied integrated with terminal operations especially the loading and unloading of the large capacity vehicles such as trains and vessels. Therefore, the objective of ITT should not only focus on the delivery of ITT demand but also take the upstream and downstream transport into consideration.

4.2. Port ITT Stakeholders. Four types of actors that could affect the port ITT planning have been discussed in the literature: the port authority, terminal operators, transport operators (could be a freight forwarder or a carrier), and the third party ITT provider. Hendriks et al. [20] and Lee et al. [29] focus on the situation when a terminal operator controls multiple terminals. The authors assume that the ITT fleet can be shared as a way to balance the transport demand and handling capacity among these terminals. In this case, the terminal operator will act as the central decision maker who determines the optimal ITT fleet and operation plan based on its own interest.

The transport operator, such as the barge operator, may also provide ITT service. For example, Douma et al. [11] and Li et al. [23] study the cases that a barge visits multiple terminals in the port. In Li et al. [23], the barge operator makes a rotation plan and could decide how much extra ITT container the barge could transport.

A third party ITT provider is usually assumed to provide ITT service. For example, Hu et al. [27] propose a truck-based ITT system connecting 18 terminals in a port area. Duinkerken et al. [18] compare different types of vehicle used in the shared ITT system in Maasvlakte, Rotterdam. In this case, the ITT provider will dispatch the vehicle considering all terminals' transport demand.

Two research gaps can be identified respect to the actors involved. Firstly, the coordination between terminal operators and multiple transport operators must be further studied. Jacobsson et al. [30] investigate the coordination between terminal operators and road hauliers regarding the road hauliers' access to seaport terminals. The authors also point out that the communication between different hauliers should be further studied.

Secondly, when multiple ITT providers are involved, it is not clear how to share the responsibilities in facility investment, operation organization, or the revenue from the ITT service. As in the case of Jin and Kim [25], the several trucking companies could work in a collaborative way by sharing transport orders and capacities; however, the share of the revenue still remains to be investigated. Further research is needed to clarify the cost and benefit for different actors in investing and using the ITT.

4.3. Methodologies and Theories Used in Port ITT Planning. Simulation, mathematical programming, and case study have been used in the existing research. Simulation tools are widely used to evaluate the performance of different terminal layout and fleet configuration. For example, Ottjes et al. [8] simulate a multi-terminal system with different factors such as ITT infrastructure, sea berth length, stacking capacity, etc.; Duinkerken et al. [18] test the performance of ITT systems with MTS, AGV, and ALV, respectively. Mixed integer programming (MIP) is usually used to formulate the ITT operations, such as vehicle routing and crane scheduling, and find the optimal plan. For example, Hendriks et al. [20] propose a MIP model aimed at balancing the quay crane workload for unloading vessels over terminals while minimizing the ITT cost; Schepler et al. [31] present a MIP model taking into account feeder vessels, inland waterway barges, trains and trucks routing among multiple terminals and aimed at minimizing the weighed turnaround time. A case study research can be found in Hansen [12]. The author analyzes the main characteristics of train services and railway facilities of container terminals at seaports and presents an innovative automated rail inter-terminal transport system.

Theories such as queuing theory, control theory, and game theory have been used in the literature. Queuing theory is applied to reflect the relations between different subsystems considering the potential disturbance. For example, Caballini et al. [21] focus on port rail operations including container transport between the stacking yard and the internal rail yard in a maritime terminal, train loading and shunting at the internal yard, and train traction between the internal yards and to the external yards. The number of containers changing their states (e.g., moved from storage yard to internal rail yard) is restricted by the productivity of the terminal resource using queueing theory. The queues' length is determined by the arrival rates, initial conditions, and service rate of terminal resources. Similar research can be found in Caballini et al. [22] and Mishra et al. [32].

Some other researchers also investigate the integration of control theory with optimized planning. Zheng et al. [33] and Zheng et al. [34] study the control of waterborne AGVs used in ITT. In Zheng et al. [33], the online model predictive control optimizations for smooth tracking are integrated with a mixed-integer quadratic programming problem considering distance-to-go and time-to-go at each sampling step. Then, in Zheng et al. [34], the authors consider the control of the waterborne AGV fleet integrated with an optimization model to minimize the weighted sum of waterborne AGV

deployment cost, energy consumption, emissions, total travel time, and delivery delay.

Gharehgozli et al. [10] integrate simulation and game theoretical methods to find the optimal ITT service with different providers. In that research, coalitions of terminal operators and transport scenarios are first defined; then, a simulation is used to determine the number of vehicles needed to meet the transport demand; next, game theoretic concepts are used to determine stable coalitions and to divide costs and benefits for each transport mode fairly between the stakeholders; lastly, the annualized investments in ITT infrastructure are compared with the cost savings that can be realized.

Two research gaps can be identified in methodologies and theories in port ITT planning: firstly, the financial interests of stakeholders were rarely considered. Actors such as port authority and transport operators may be involved, but their benefit of investing the ITT system is not clear. Therefore, a methodology that could reflect both the costs and savings for different actors should be further developed. Secondly, the ITT operations should be more precisely formulated. Several simplifications have been applied in modeling the ITT operations like container handling time, transport time, and costs. For example, the productivity of shunting yards could be hard to accurately estimate in Caballini et al. [21], Caballini et al. [22]; and Mishra et al. [32] only consider homogeneous vehicle capacity and no congestion was taken into account. These simplifications and assumptions keep the problem solvable but may result in losing accuracy.

5. Hinterland ITT

This section reviews the research of hinterland ITT. The focus is put on the transport between seaport terminals and multiple inland terminals and the terminal operations in both seaport and inland terminals; see Figure 1. The 47 reviewed studies mainly focus on maximizing the transport volume while reducing the related costs by using properly designed networks and terminals. Stakeholders such as port authority, terminal operator, and transport operators are involved in the hinterland ITT planning. Optimization models, case studies, and simulation systems are used in these papers.

5.1. Planning Problems

5.1.1. Hinterland ITT Strategical Planning: Network Design and Terminal Development. On a strategical level, the existing research covers three important topics: determination the network design, such as the location of the hub terminal and the function of terminals, evaluation of the network and service performance, and impediments in network development.

In terms of network design, hub-and-spoke networks have been intensively studied and implemented to increase the service frequency and reliability. Cost factors, including terminal development cost, transport costs, and terminal handling costs, are widely considered in the network design. The location of the hub terminal is crucial to reduce the cost of the ITT network. Racunica and Wynter [1] propose a model to formulate the hub-and-spoke network for intermodal freight transport on dedicated or semi-dedicated freight rail lines. Both the hub terminal development cost and transport cost are taken into consideration. Limbourg and Jourquin [35] focus on a rail-road hub-and-spoke network, where pre- and post-haulages are performed by road transport and inter-hub haulage is performed by rail. The research aims at finding the optimal hub terminal locations on the European transport network with the lowest transport and transshipment costs. Konings et al. [36] investigate the location of the terminal as well as the impact of using different vessel size, vessel type, service frequency, etc. The authors conclude that a hub-and-spoke network can be used to improve the barge transport connecting Rotterdam port and its hinterland.

The function of terminals may also influence the cost of the ITT network. Dry ports can be seen as special inland hub terminals with seaport terminal functions which could relieve port congestion and reduce freight transport emission [37–39]. Therefore, hinterland ITT network with dry ports has also been discussed with transport cost, terminal operation cost, and other factors, such as societal benefits and users' choice preference. For example, Iannone and Thore [40] investigate the situation that parts of ports operations are moved to inland dry ports and a lower total costs (transport costs, inventory holding costs, and terminal and customs operation costs) can be achieved. Iannone [41] studies the transport system in the Campanian region, Italy, which includes two interports. The author claims that the customs facilitation between seaports and interports could be conducive to expand the hinterland of the Campanian seaports and improve the competitiveness of the regional logistics system.

Apart from network design, existing studies also evaluated the performance of hinterland ITT regarding system performance, sustainability, resilience, etc. For example, Konings and Priemus [42] analyze the barge transport connecting seaport and hinterland. The authors point out that visiting multiple terminals with small handling volumes in the port is time-consuming and negatively affects terminal productivity. The authors also argue that direct transport from seaport to destination terminal is less attractive due to the small transport volume and waterway restrictions. Janic et al. [5] evaluate the sustainability of rail-based ITT with 20 indicators including network size, frequency, terminal time, etc. Suggestions are made to make a network "promising"; e.g., routes should cover a wide spectrum of distances, from extremely short to extremely long, and frequency should be sufficient to serve expected demand, regular, and available as needed.

Awad-Núñez et al. [43] assess the sustainability of the location of a dry port taking into account 17 different types of factors, which are related to the environment, economic, social, accessibility, and location, would influence the sustainability of the dry port. The authors proposed a multi-criteria decision analysis framework: weighting these factors with expert scoring and using an artificial intelligence model based on Bayesian network to reduce the arbitrariness of the weights.

Chen et al. [44] evaluate the resilience of the port-hinterland transport network by simulating how the transport process would recover after unconventional emergency events which could damage the transport facilities. Recover activities such as using an adjacent dry port and rail shuttle, transporting by road, and waiting for temporary repair are, respectively, tested in the study.

Meanwhile, several impediments have been identified by the existing research. Roso [45] investigates the development of the dry port in Sydney and points out that the infrastructure construction (rail and road), land use, and environmental and institutional impediments are the common impediments in dry port development. Iannone [41, 46] argues that policymakers could improve the port-interport system with more adequate regulations and more effective and intelligent organizational schemes and regional logistics marketing initiatives. Jeevan et al. [47] conduct a survey for Malaysian dry port stakeholders to examine the influential factors of Malaysian dry port operations. The results indicate that improving the information system is most important for dry port operations, and modernizing and upgrading current capacity in dry ports should be included as one of the main agenda items.

One research gap can be identified in hinterland ITT network strategical studies: the external effects of these transport modalities and services. Several external effects such as emissions, accidents, and congestions have been studied with single-modal transport systems, but are often neglected in multimodal transport system with different vehicles, terminals, and transshipment operations. Bektaş et al. [48] review the role of operational research in green transport and point out that the methodologies and tools can be developed to consider the dynamics of the energy consumption based on traffic conditions, infrastructure, and other external influences. Future research should find ways to internalize these costs.

5.1.2. Hinterland ITT Tactical and Operational Planning: Transport Network Design. In a tactical and operational level, the existing studies have been focused on the service network designing, i.e., providing profitable transport service with a given infrastructure network. To reduce the hinterland ITT cost and maximize the profit for the transport operators, the following topics have been discussed.

The first research topic is freight flow consolidation. Different consolidation networks have been studied and their economic performances have been evaluated. Trip and Bontekoning [49] discussed the possibility to integrate small transport flows into the intermodal system at an inland rail terminal. The authors could find a feasible solution with feeder trains to bundling freight flow from outside the economic core areas but point out that it could be hardly profitable to run the feeder trains. Jeong et al. [2] consider the European rail system as a hub-and-spoke network, and the freight flow could go through any number of hub(s). The authors develop a mathematical model to determine which hub(s) to use to reduce total costs including transport cost, handling delay-time cost at hubs, waiting time costs, consolidation costs, etc. Konings [50] points out that the

barge operator could improve its productivity and hence gain substantial additional revenue if the number of terminal visits in the port could be reduced. A similar conclusion can be found in Caris [51] ; the authors propose a consolidation network that inland vessels only visit one or several hub terminals in the port area of Antwerp. The results show that, by reducing the visiting terminals, the turnaround time of inland shuttle services can be reduced; sea terminals may operate more efficiently.

Another important research topic is the rotation plan of barges and trains, i.e., which terminals barges and trains should visit and what operations should be performed in these terminals. For inland waterway transport, the vessel may visit multiple terminals along the river. The rotation plan is made to maximize the operator's revenue based on transport demand, transport cost, and container handling cost; see Zheng and Yang [52]. An et al. [53] study the barge transport between the seaport and several inland waterway terminals. The authors assume that the barge service is provided between the seaport terminal and any inland waterway terminal. Besides the fuel cost and container handling cost, the authors also consider a terminal entering cost and a fixed route cost due to the waterway condition. In the optimal solution, direct transport, service between seaport terminal and an inland waterway terminal, and transport covering multiple terminals are provided. Maras [54] and Maras et al. [55] also investigate the barge routing along the inland waterway, aiming at maximizing the profit of the barge company considering shipping cost, terminal handling cost, and empty container related cost.

For railway transport, Lupi et al. [56] identify the railway path from seaport to its hinterland with a proposed cost function, considering travel time and service cost per train. Crainic et al. [57] mathematically formulate the rail shuttle service connecting seaport terminals and dry ports. With a given fleet, the proposed model could help the operator to find the optimal service plan. Van Riessen et al. [58] focus on intermodal transport from port terminals to the hinterland. The authors propose a model aimed at generating a weekly schedule for both self-owned and subcontracting intermodal transport fleet with the lowest transport cost, transfer cost, and delay penalty.

Additionally, Fazi and Roodbergen [59] discuss how would demurrage and detention fees affect the container transport from seaport to inland terminals. It is assumed that, by charging demurrage and detention fees, shippers will be motivated to move containers out of the seaport. However, the research shows that these charges will negatively affect the transport cost and dwell time; meanwhile, these charges also limit the usage of barge transport. The authors also suggest that a combined demurrage and detention charges, which applies a single free period for both demurrage and detention, could result in shorter dwell time.

Several research gaps can be identified in the hinterland ITT tactical and operational planning. Firstly, integration and collaboration between multiple terminals and vehicles are rarely studied. Feng et al. [60] investigate the communication between the terminal and barge operator; a mediator is proposed to coordinate multiple barges and terminals.

Similar research is needed to coordinate multiple terminals and vehicles: schedule terminals' handling operation plan and the vehicles' routings. Secondly, freight consolidation and vehicle scheduling are rarely studied with a multi-modality fleet. With the integration and cooperation between different transport operators, it is possible that there is an intermodal transport operator who provides multi-modal transport. Therefore, further research on multi-modality transport could help the intermodal operator provide more competitive service. Thirdly, rail service between the seaport and dry port is rarely studied in tactical or operational level. As mentioned in Crainic et al. [57], decisions must be made such as service area, freight assignment to operated service, the schedule of the service, etc. Given the diversity of the dry port in terms of location and operations, further research is needed to provide deeper insight into the feeder service organization.

5.2. Hinterland ITT Stakeholders. Generally, three types of actors have been discussed in the hinterland ITT literature: policymaker, transport operator (freight forwarder and/or carrier), and terminal operator. The policymaker could be a regional or national government agency that provides subsidy, determines the land use, makes regulations, or owns the infrastructure; the freight forwarders organize the transport in cooperation with terminal operators and transport operator, who runs a fleet of transport vehicles. Specially, in the railway transport system, there could be an infrastructure manager who is responsible for infrastructure construction and maintenance. In the intermodal transport system, the transport between seaport terminals and inland terminals can be performed by seaport terminals, inland terminals, and a third party [61]. Shipping lines sometimes are involved in the inland transport by cooperation with inland terminals [62]. Inland transport operators are also crucial; for example, barge container carriers in fact control about half of Rhine terminals [63]. Kotowska et al. [64] point out that, to improve the quality of hinterland connections, the seaport authorities usually cooperate with inland ports, acquire shares in inland ports, or invest in inland terminals operating as dry ports. The Rotterdam Port Authority possesses, for example, the Wanssum Intermodal Terminal, located in the southeast of the Netherlands, and Alphen aan den Rijn, located 60 km away from Rotterdam.

Despite the diversity in stakeholders involved, policymakers should play a leading role in the strategic planning of hinterland ITT. While investing in a new terminal or expanding an existing terminal, the policymaker should make decisions on a more comprehensive perspective. For example, in the development of two inland intermodal terminals connected to Botany port in Sydney, several impediments from different actors can be identified. The truck companies are strongly against any actions that could reduce the road transport share, and the seaport's proposal for solving port congestion was charging the truck companies a higher fee in peak hours [45]. Roso et al. [65] point out that a win-win cooperation is possible. If an inland intermodal terminal is properly implemented, the money saved at the seaports can be used to subsidize the rail shuttle service. The road

transport share may be reduced but the road transport operators could have a lower operation time at the terminals. Ng et al. [66] point out that the institutional framework and multiple governmental agencies negatively affect the integration of dry port and seaport in Brazil. Bask et al. [67] analyze the development of two seaport-dry port systems and identify financial support from policymakers in both cases.

Several research gaps can be found in the coordination between actors: firstly, the conflicting interests between different policymakers are rarely studied. For example, Jeong et al. [2] study the European railway network and indicate that the national governments have little interests in investment that could promote international transport because the benefits may only be achieved outside the country. Therefore, the investment and benefit analysis should be further studied from policymakers' perspective. Secondly, although the cooperation between transport and terminal operators is critical in providing hinterland ITT service, few studies investigate how to balance their interests. Van Riessen et al. [58] investigate the European Gateway Services provided by Europe Container Terminals (ECT), who runs three terminals in the port of Rotterdam. In that case, the ECT works as an intermodal network planner, transporting containers between the port and hinterland terminals. However, the service could involve multiple operators; for example, Rodrigue and Notteboom [68] point out that some railway operators provide direct shuttle service on the spoke of a competitor's established hub-and-spoke network, and Iannone [46] indicates that some seaport terminals and freight forwarders are reluctant to cooperate with inland terminals to prevent losing their core activities. Therefore, the relationship and cooperation between operators should be further studied.

5.3. Methodologies Used in ITT Operation Planning. Mathematical modeling, case study, and simulation have been used in hinterland ITT planning. Mathematical modeling is widely used in infrastructure network planning and service network planning to identify the optimal network with the lowest investment and operation cost. For example, Iannone and Thore [40] optimize the container import flow in the Campania region in Southern Italy. The authors formulate the transport process using a MIP model aiming at minimizing the transport cost, inventory cost, terminal operation cost, and customs operations cost. Limbourg and Jourquin [35] propose an integer programming model to find optimal locations for European transfer terminals embedded in a hub-and-spoke network. Alfandari et al. [69] formulate the barge rotation problem with a MIP model to determine which terminal to visit and which container to transport. To reflect the different actors preference in choosing services in the network, Vasconcelos et al. [70] use a Logit choice model to determine the proportion that a specific service is chosen. Meng and Wang [71] introduce user equilibrium constraints in their model. Moreover, fuzzy variables are used to characterize the uncertainties in the system, such as transport and operation time ([72], Wang et al., 2018).

Case studies and conceptual studies are used to demonstrate the experience obtained in the network development

process and service network planning. For example, Hanaoka and Regmi [38] analyze the development of the intermodal transport system with dry ports in five Asian countries. The authors discuss the modality of the transport systems and ownership of the dry ports and summarize the lessons learned from each case. Similarly, Jeevan et al. [47] analyze the influential factors of dry port operations in Malaysia based on the data obtained from online-survey. Trip and Bontekoning [49] discuss the possibility to organize freight consolidation in Valburg terminal. A bundling plan is made based on the transport volume, operational capacity, and railway timetable to demonstrate that the consolidation is possible.

In the methodology aspect, two research gaps can be identified: firstly, powerful algorithms are needed. The size of the ITT network keeps growing with the development of the inland terminals, and at the same time, the integration in transport and logistics problems are becoming more important [73]. The collaboration of different operators, dynamics in the demand, operation time, and cost should also be considered in the ITT planning. This trend can be already seen in software, such as Nodus (proposed by [74]), which could solve large-scale transport problem multiple modes and handling operation [75]. Further extensions could cover more factors in the ITT system. Meanwhile, some factors in the planning problem, such as the cost discount for scale economies in freight consolidation [1], cannot be accurately formulated by linear functions. In Liu et al. [76], the authors minimize the intermodal transport system cost considering scale economies with a nonlinear and discontinues objective function. The problem is solved by a hybrid heuristics with a small network. Therefore, methodologies and algorithms that could precisely formulate the system and handle large-scale network should be further studied.

Secondly, empirical analysis methodologies are needed to quantitatively discuss the cost and benefit of any investment and activities for policymakers. Existing research mainly focuses on maximizing single decision maker. The empirical analysis is needed to demonstrate the benefits to regional, national governments and international organizations.

6. Conclusion

This paper reviews ITT in the port area and in the hinterland. Based on the 77 papers, we can find that the number of studies on port ITT planning is relatively small but increases in the last years. Meanwhile, the academic community pays special attention to the ITT network in Rotterdam port as half of the port ITT research focuses on this area. The hinterland ITT, especially the European network, has been more intensively studied.

The port ITT research aims at developing an efficient transport network with the lowest ITT costs. Five major ways to reduce the port ITT costs can be identified in the existing research: (1) properly designing of the terminal layout; (2) choosing an efficient ITT fleet; (3) improving the information system; (4) better assignment of the deep-sea vessels to terminals; (5) and optimizing the routing of ITT vehicles. On the other hand, the hinterland ITT studies focus on relieving port congestions and providing better connections

in terms of service coverage, frequency, and price. Compared with the port ITT studies, more strategical problems, such as the network layout, the terminal's location, and function, have been discussed in the hinterland ITT system. Moreover, considerable efforts have been taken to optimize the barge transport between the seaport and several inland waterway terminals.

The responsibilities of port ITT stakeholders are relatively clear in the existing research: the terminal operator could run an ITT service on a self-owned network; the transport operator could transport ITT containers if these operations are profitable, and the port authority is also assumed to act as a third party ITT provider. However, the situation is more complicated in the hinterland. The existing research shows that the multiple policymakers, such as location government, national government, and international organizations, are involved in the hinterland ITT. These policymakers play a significant role as they not only determine the network layout and subsidize the infrastructure construction, but also get involved in the transport and terminals operations.

As for the methodologies used in the research, mathematical modeling and simulation tools are widely used in both port and hinterland ITT studies to find the optimal freight flow, vehicle route, and terminal scheduling. Queueing theory and game theory have been used in port ITT studies to investigate the relationship between different subsystems and actors. Control theories are also studied in the dispatching of the port ITT vehicles. Conceptual and case studies are more often used in hinterland ITT to summarize the development trend and lessons can be learned in different cases. User equilibrium theory and logit model have been used to reflect different actors behavior in the hinterland ITT.

This study identified research gaps in port and hinterland ITT; see Table 3. In terms of the strategical planning, multi-mode ITT system is rarely investigated in the port ITT system; studies discussing the port ITT transport demand and its relation with network and terminal design are rare, while a considerable number of research papers and projects can be found focusing on the hinterland ITT. Moreover, how to optimize the port ITT operations with different types of information systems should be further investigated. External effects of ITT system have been studied in the port and hinterland; however, more comprehensive analysis based on a multi-modality system is needed for the hinterland ITT.

On the tactical and operational level, the scheduling of the rail service and the integrated planning of transport and terminal operations should be further studied in both port and hinterland ITT. Moreover, as the hinterland ITT may involve more terminal, transport operators and more complicated networks, the coordination between multiple operators and the fleet scheduling considering freight consolidation should be further studied.

The coordination between terminal and transport operators should be further studied in both port and hinterland ITT, and a trusted party or cooperation framework is needed to balance various benefits. In particular, the multiple policymakers' interests in the hinterland ITT system should be further investigated. Moreover, future research should help

TABLE 3: Research gaps in port and hinterland ITT studies.

	Port ITT		Hinterland ITT	
	Strategical	*Tactical and Operational*	*Strategical*	*Tactical and Operational*
Planning Problems	(i) Infrastructure investment and potential ITT cost should be studied in an integrated way. (ii) Port ITT demand is rarely studied. (iii) Integrated multi-modality systems should be further investigated. (iv) Dynamics of the information systems should be considered in ITT planning.	(i) Organization of rail ITT system is rarely studied. (ii) The ITT operations should be formulated taking into account upstream and downstream transport and terminal handling operations.	(i) External effects should be investigated and formulated based on a multi-modality ITT system.	(i) Integration between multiple terminals and vehicles has received less attention. (ii) Freight consolidation and vehicle scheduling are rarely studied with a multi-modality fleet. (iii) Seaport-dry port rail service is rarely studied.
Stakeholders	(i) Stakeholders and ways to coordinate terminal operator and multiple transport operators should be further studied. (ii) Stakeholders' share of responsibility revenue is rarely investigated.		(i) Conflicting interests between different policymakers are rarely studied. (ii) Stakeholders and ways to coordinate terminal operator and transport operator should be further studied.	
Methodologies	(i) Quantitative methodologies are needed to reflect different actors' financial interests. (ii) ITT operations should be more precisely formulated.		(i) Quantitative methodologies are needed to reflect different actors' financial interests. (ii) Powerful algorithms are needed to handle the large-scale planning problems and nonlinear factors.	

to identify the costs and benefits of organizing the ITT in the port area.

In the methodology perspective, quantitative methodologies are needed to reflect different actors' financial interests as the existing research mainly uses conceptual and case studies in the analysis. Some simplifications and assumptions in mathematical modeling in port ITT, such as handling operation time and disturbance, should be further studied and more precisely formulated. Moreover, powerful algorithms are needed to deal with the increasing problem size and handle the nonlinear factors in the problem.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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