Place your logo here

Strategic planning in multimodal transportation: a systematic literature review

Wenhua Qu
Faculty of Aerospace Engineering, Delft, the Netherlands
w.qu@tudelft.nl

Abstract: *Multimodal transport offers an advanced platform for more efficient, reliable, flexible, and sustainable transport for freight transportation. However, combining different transportation modes in transport chains requires cautious planning of infrastructure constructions and collaboration of the involved service providers. This study presents a structured literature review for strategic planning of multimodal transport, covering literature that deals more than one transportation modes from the past two decades. The topics encompassed include the classic hub location problem, network design problem, as well as the competitions and collaborations of multimodal service providers. The reference in each category are evaluated with on problem characteristics, modelling formulations and their corresponding solution techniques. In the end, this review concludes with an outlook to main future research directions.*

Keywords: *Multimodal freight transportation, strategic planning, hub location problem, network design, competition and cooperation*

Conference Topic(s): *interconnected freight transport; logistics and supply networks; ports, airports and hubs;*

Physical Internet Roadmap *(Link): Select the most relevant area for your paper: ☐ PI Nodes, ☐ PI Networks, ☒ System of Logistics Networks, ☐ Access and Adoption, ☐ Governance.*

1 Introduction

Multimodal freight transportation refers to the combination of at least two modes of vehicles to move the freight from its origin to the required destination. Multimodal operators can take advantage by simultaneously exploiting the benefits of different transportation modes. The customers, including the shippers and logistic service providers, can benefit via comparing the possible service combinations and choosing the most suitable and economic one. In addition, the society as a whole can benefit from the mode shift from road towards greener modes, which can also lead to reduced pollutant emissions and accidents.

The multimodal transportation is one of the road-maps of the Physical Internet (PI) initiative (Alice roadmap to physical internet, 2023). From the view point of operators and customers, PI encourages " implementation of flexible contracts giving freedom for design and operation of multi-modal transport networks to avoid fixed specifications for routes, modes, inventory locations and timeslots" via the hyperconnected logistics network. Furthermore, PI supports the transition towards Zero Emissions Logistics via the mode shift.

Despite the potential economic and environmental benefits, multimodal transport still has yet to gain widespread acceptance and application. Unimodal road transportation remains dominant European inland transportation, 76.50% of freight was transported by road, whereas only 18.00% and 5.50% by rail and inland waterways(EUROSTAT, 2018). One reason for this is the complex nature of multimodal transport, involving more component parts and transshipments. This can leads to complicated process and concerns about flexibility and reliability.

Planning models can provide sufficient support to handle the complexity of the transportation to promote its acceptance and application. Generally, there are three levels of planning regarding to the planning horizons: strategic, tactical and operational planning. Of these three levels of planning, The strategic level involves long-term investment decisions on infrastructure planning, and hyperconnected network design. Its will have a considerable long lasting effect for the subsequent tactical and operational planning.

However, the strategic multimodal freight planning is a growing and evolving field. The well-known literature review of SteadieSeifi (2014) requires an update due to the significant amount of studies published in the past decade. Additionally, to the author's knowledge, there has been no literature review so far that expand the competition and collaboration among the stakeholders of the multimodal transport, despite the collaboration is encouraged by PI. This paper aims to fill these gaps by discussing strategic planning issues encountered in multimodal freight transportation, reviewing peer-reviewed papers published mostly between the year of 2015-2022, and some early but seminal papers.

The rest of the paper is constructed as follows Section 2 describes the research questions and methodological approach of the literature review. The collected studies are classified according to their main problem characteristics, which are described in section 3. In the end, section 4 gives a brief conclusion and a few possible future research directions.

2 Research questions and Methodology

This section describes the methodological approach of the literature review. In order to address the aforementioned gaps, this paper conducts a systematic survey of strategic multimodal freight transportation planning, mainly answering the following research questions(RQ).

RQ1: How can the research literature conducted on strategic multimodal freight transportation planning be systematically collected?

RQ2: In which way is the multimodal planning is distinguished from single-mode transportation in terms of planning concerns, problems characteristics and model formulations?

RQ3: Which problems characteristics, models are already considered and which fields requires further research?

To address RQ1, we used the Scopus, one of the largest peer-reviewed databases for scientific publications. We performed four different search runs using various query strings for title, abstract and key words within the Scopus database.

(1): ("strategy planning" or " strategic planning") AND (transport* OR freight) AND (intermodal OR multimodal OR physical internet); (2):"hub location problems" AND (transport* OR freight) AND (intermodal OR multimodal OR physical internet) ; (3): "network design" AND (transport* OR freight) AND (intermodal OR multimodal OR physical internet) (4): "hubs" OR "consolidation" AND (transport* OR freight) AND (intermodal OR multimodal OR physical internet)

The abstracts of collected studies were screened to obtain relevant literature for future analyses (RQ2). The criteria for reserving papers for the next steps are as follows: (i) the main topic should be about the strategic planning, dealing with long term investment. (ii) the paper should explicitly deal with more than two transportation modes. Papers that claim multimodal/ intermodal/ syncrhomdal transport but assume homogenous vehicle set will not further studied. Additionally, both papers cited in the screened papers, and paper citing the screened papers are checked during the review process to ensure the broad coverage of review (RQ1). The classification and a detailed review of the chosen studies (RQ2) are presented in section 3. The answers to RQ3 is discussed in Chapter 5.

3 Results of the literature review

The studies on this topic can be divided into three groups: (i) multimodal hub location problems, (ii) multimodal network design problems, and (iii) competition and cooperation among the service providers. The ***hub location problem (HLP)*** deals with the location selection of a set of nodes to place hub facilities, whereas ***network design (ND)*** additionally makes decisions on the selection of the links to connect origins and destinations, possibly via hubs, as well as the routing of commodities through the network. ***Competition and cooperation*** discuss in which way the port operators improve their competitiveness to attract more customers. Cooperation, on the other hand, study the alliance of different operators such as their combined interest is maximized.

Table 1 summarizes the literature in this domain, indicating their investigated transportation mode, formulations, solving methodology and other concerning characteristics. It should be noted that in the literature HLP and ND are sometimes intertwined and a few studies fall into overlapping areas.

3.1 Hub location problems

In this subsection we briefly review the multimodal HLP regarding their involved modes, concentrated problems and the model formulations. For an extensive study on HLP without considering the multiple transporation modes, readers can refer to Alumur et al. (2021).

There are two main protocols for assigning demand (spoke) nodes to the installed hubs: single allocation (SA-HLP) and multiple allocation (MA-HLP). In the first category, all outbound or inbound flows of any node must travel directly from or to a certain specific hub. Whereas in multiple allocation network, flows of a given node can go directly from/to different hubs.

The goals of port authorities when planning the hub locations are two folded: (i) to **increase profits** as operator-oriented and (ii) to **improve service quality** as customer-oriented. The pursuit of profit at strategic level planning can be achieved mainly from *lowering operating cost* and *enhancing business volume*. The approaches to improve the service quality include but are not restrict to *shortening delivery time*, *providing smooth transhipment* among different modes at hubs and *maintaining reliable and robust hub services*.

3.1.1 Operators oriented planning

The *scale of economics* resulting from freight consolidation at hub terminals can bring down the operating cost. Racunica and Wynter (2005) incorporate the scale economies of (semi-) dedicated freight rail lines which could make use of shuttle trains between hubs. The authors adopt a *discount factor* on the inter-hub links, resulting a lower per unit price than that on extremal non-rail links. The inter-hub cost term was a concave increasing function of flow, which is accomplished through a non-linear formulation. Kurtulus (2022) uses piece-wise linear cost function to formulate the volume discount of consolidated rail transport. It is particularly worth noting that Kurtulus (2022) considers the repositioning of empty containers, whose considerable sizes accumulate into a significant portion of total transportation costs.

Another approach to enhance profit is to *uplift the market share*. Some shippers with *price sensitive demands* generally send their commodities in the cheapest way, while some with *elastic demands* usually do not choose long term contract but intermittently switch to other carriers. *Attracting and retaining customers* can be achieved via proper price policy of the hub

Table1 literature of strategic planning of multimodal freight transportation

reference	Transportation modes	allocation	Centralized or decentralized control	formulation	Additional considerations
1. Hub location Problem					
Merakli and Yaman (2016)	intermodal	multiple	centralized	linear MIP	polyhedral demand uncertainty
Kurtulus (2022)	rail, road, sea	single	centralized	piece wise linear MIP	empty container relocation and volume discount
Zhang et al. (2022)	ground, air	multiple	centralized	non-linear MIP	incomplete connectivity and deliver time restrictions
Mohammadi et al. (2019)	multimodal	single	centralized	non-linear MIP	Effect of uncertainties and congestion
Alumur et al.(2012a)	ground, air	multiple	centralized	linear MIP	time-definite delivery
Teye et al. (2018)	rail, road	single	centralized	convex, non-linear MIP	shippers use the ports or not
2. Network design problem					
Alumur et al. (2012b)	ground, air	single	centralized	linear MIP	small package delivery considering cost and service levels simultaneously
Meng and Wang (2011)	sea,rail,roa d	single	decentralized	non-linear MIP	user equilibrium
Wang and Meng (2017)	sea,rail,road	single	decentralized	non-linear MIP	re-design an existing intermodal freight transportation network
Wang et al. (2018)	rail, road	single	centralized	linear MIP	uncertain demand, cost and time
Serper and Alumur (2016)	ground, air	single	centralized	linear MIP	multiple vehicle types
Yang et al. (2016)	intermodal	single	centralized	non-linear MIP	mixed uncertainties of cost and time
Real et al.(2021)	heterogeneous vehicles	multiple	centralized	linear MIP	flow-dependent transportation cost
3. Competition and cooperation					
Xu et al. (2018)	intermodal	multiple	decentralized	game-theory	port competition, shippers' route choice behaviours and stakeholders' environmental concerns
Zhang et al. (2018)	intermodal	multiple	decentralized	MIP	port competition & shippers route choice
Jiang et al. (2020)	multimodal	multiple	decentralized	non-linear MIP	port competition and shippers' choice
Mahmoodjanloo et al. (2020)	multimodal	single	decentralized	non-linear MIP	hub location, assignment and pricing decisions based on elastic demand
Tamannaei et al. (2021)	Rail road	single	decentralized	game-theory	duopoly competition and government intervention
Gong and Li (2022)	intermodal rail, sea	multiple	decentralized	game theory	social welfare maximization considering the competition and cooperation
Wei and Lee (2021)	rail, sea	single	decentralized	hybrid method	a coordinated horizontal alliance system, cross border logistics

services. Mahmoodjanloo et al. (2020) study how to attract customers as an entrant company by deciding a convenient location (as the main problem of the bi-level model) and subsequently setting proper price for its transportation services (sub-problem). In areas far away from sea ports, inland railway terminals or airports act as promising and sustainable solutions to attract customers from pure road transportation. According to Kurtulus (2022), the success of an intermodal rail terminal hinges on its location. We add a side note here that the role of a rail terminal has evolved as the development of multimodal transport. They have taken on new roles as extensions of the seaport, which has little room for physical expansion to accommodate the ever-growing freight demand, into the hinterland. Therefore they are named as dry ports, inland ports, inland terminal, and inland container depot, etc.

We note here there are abundant studies on single mode HLP concerning profit (O'Kelly and Bryan (1998), Alibeyg et al. (2016)) and service quality (Elhedhli and Wu (2010), Yang et al. (2016)). However, these studies are not discussed in this work as the aim herein is to focus on multimodal transport.

3.1.2 Customers oriented planning

Delivery time is a key concern in the e-commerce logistics, with 'next day delivery' or 'delivery within 24h' promises posing challenge for logistics companies to balance among the delivery time, operating costs and mode shifting. Alumur et al. (2012b) explore the combination of air cargo with ground transportation in Turkish market. Zhang et al. (2022) address delivery-time restrictions in the air-ground HLP, considering both single (SA-HLP) and multiple (MA-HLP) allocation scenarios. They find that the operation cost in SA-HLP is far higher than that of MA-HLP due to increased travel time between O-D pairs and restricted path choice with higher travel cost to meet the delivery time requirements.

Consolidating flows makes planning more vulnerable to uncertainties and disruptions, which can cause substantial recovery time and thus a lower service level. The uncertainties or disruptions can rise exogenously, such as the uncertain demand Meraklı and Yaman (2016) and endogenously, for example, random travel time, random transportation cost, or unreliable routes (Mohammadi et al. (2019). The HLP therefore considers *reliability* and *robustness* in the strategic level to hedge in advance against various uncertainties.

Reliability concerns computing, estimating, or maximizing the probability that a network remains connected in the face of random failures. Stochastic technique, which *assumes foreseen probabilistic information and corresponding parameters*, is a common way to deal with future uncertainty. Mohammadi et al. (2019) consider stochastically degraded capacity of hubs and links to minimize both the total cost and the transportation time. There are also uncertainties that with *no information about their probability distributions*. Wang et al. (2018) rely on fuzzy optimization techniques to handle the uncertain information in the network design problem. Teye et al. (2018) use the entropy function to maximise all possible states. The goal is to select the most likely state consistent with all the information available about the containerised transport system.

On the other hand, *robust optimization* does not make assumptions about the probability distributions but assumes that the data belongs to an uncertainty set. A robust solution is one whose worst case performance over all possible realizations in the uncertainty set is the best. Meraklı and Yaman (2016) adopt two polyhedral uncertainty sets from the telecommunications literature, namely hose and hybrid models, to represent the uncertainty in the demand data.

A particular application associated with the multimodal HLP but not involved in a single-mode HLP, is the *mode-change transhipment lines at hubs*. A transhipment line represents a collection of infrastructure facilities such as yard cranes, vehicles and straddle carriers, needed to accomplish container mode changes (Meng and Wang (2011)). Transhipment will cause additional cost and time. Meng and Wang (2011) use a trans-log cost function to estimate transhipment costs in a context where *multiple* types of containers need to be transported.

Hub congestion problems arise with the growing freight demand, which can reduce serve level. Contreras et al. (2012), Elhedhli and Wu (2010) and Alkaabneh et al. (2019) study the SA-HLP with capacity and congestion considerations. These works use a convex fractional function of flow, which is asymptotic to the hub capacity. If flow is close to the capacity limit, the asymptotic behaviour of the cost function implies a more severe impact of congestion. Similarly, Cagri Ozgun Kibiroglu et al. (2019) address congestion using a rational function flow. Teye et al. (2018) assume that the maximum quantity of cargo that each port must not exceed the hub's handling capacity, which however may not reflect the real-world scenarios. Meng and Wang (2011) and Wang and Meng (2017) employ the BPR (US Bureau of Public Roads)-form time function developed to convert the congestion affect to longer travel time on the arc of a multimodal hub network design problem. To the authors' knowledge, there is room for further research on congestions and the corresponding influences in multimodal HLPs.

3.2 Network design problems

Multimodal network design (ND) problem not only deals with the hub locations (main task of the HLP), but also establishes the connectivity between hubs, determines capacities of hubs, determines which transportation modes to serve at hubs, allocates non-hub nodes to hubs, and decides the number of vehicles of each mode to operate on the hub network to route the freight between origin-destination pairs. For example, the multimodal ND studies encompass the connectivity among hubs. HLPs usually assume a fully or complete inter hub connectivity, which is not true in the real application (Zhang et al. (2022), Real et al. (2021)). Readers can check (Basallo-Triana et al. 2021) for a literature review on the single mode ND problems. The subsection concentrates on the literature within the last decade implicitly mentioning multimodal transportation in the ND problem.

3.2.1 Operators oriented planning

From the profit maximization viewpoint, the network designers deal with operating costs, including not only fixed costs of establishing hubs with different capacities, but also the cost to set the connections, purchasing and vehicle operating costs, transportation costs and material handling costs (O'Kelly et al. (2015), Real et al. (2021) Wang and Meng (2017), Serper and Alumur (2016)). Real et al. (2021) argue that the scale of economics is suitable for the interhub operating, but is too oversimplified to be applied on hub arcs. The authors calculate the arc transportation costs via the fixed cost of using a vehicle and distance-dependent cost. This is to avoid miscalculations of the total network cost, as well as erroneous decisions of hub locations and non-hub allocations. Wang and Meng (2017) examine the costs of building up or enlarging a link among already existing hubs to decide the expansion of the hub-and-spoke network.

3.2.2 Customers oriented planning

Multimodal ND considers the *mode choice* of customers not only within the hubs but also in the connections among hubs. The concept of mode choice in the ND literature was first introduced literature by O'Kelly and Lao (1991). The authors consider two hubs, one master and one mini hub, at fixed locations, and analyse the allocation decisions for air and ground transportation modes. A series studies, Alumur et al. (2012b) and Serper and Alumur (2016) consider the mode choice for the small parcels delivery in the Turkeish market. The delivery firm operates its own fleet on the network connections and makes crucial decisions about which links to operate its air crafts and trucks. Serper and Alumur (2016) consider which transportation modes to serve at hubs and the number of vehicles of each type on the links in the intermodal network planning. Teye et al. (2018) include the multiple shippers' choices whether or not to use the multimodal transport or road-only transport at the first step of network planning. Real et al. (2021) study the itineraries for the selected vehicles for an incomplete multimodal ND problems.

Multimodal ND can promote the mode shift from a systematic level. Kurtulus and Ismail Bilge Cetin (2020) investigate the potential for mode shift in short-distance inland container transport by considering behavioural aspects of inland container transportation mode choice. Their study based on Turkey's rail-road intermodal indicate that the transportation cost has the biggest impact on shippers' mode choice and the modal shift is more sensitive to the road transport costs than to intermodal rail cost. Both studies by Kurtulus and İsmail Bilge Cetin (2020) and Kurtulus (2022) reveal the importance of providing enough capacity of the railway links for achieving low emissions in Turkish transportation system. Zhang et al. (2021) evaluate the environmental benefits of modal shift from trucks in Shenzhen, China. However the Kurtulus (2022) argues that modal shift should not be seen as a miracle solution for emissions reduction but as a first step before the adaptation of high energy-efficient rail transportation technologies.

3.3 Competition and cooperation

This subsection explores the topic of competition and cooperation among the multimodal service providers at the strategic level. Multimodal transport involves the competitions among a wide range of stakeholders and requires the cooperation of service providers involved. Competition among ports is defined as the pursuit of customer capture (Marianov et al. (1999)), in the form of hub locations and pricing strategies, during strategy planning. Horizontal cooperation is defined by the European Union (2001) as concerted practices between companies operating at the same level(s) in the market.

3.3.1 Competition

A common type of competition at the strategic level can be observed between two dry ports serving overlapping hinterland areas, which naturally have a contest relationship (Zhang et al. (2018), Jiang et al. (2020)). These competitions are usually studied via game theory using either *Nash equilibrium* (Zhang et al. (2018), Xu et al. (2018), Tamannaei et al. (2021)) or *Stackelberg equilibrium* (Jiang et al. (2020)) models. In the Nash game, each player is assumed to know the equilibrium strategies of other players, and no one has anything to gain by changing only one's own strategy. Stackelberg models investigate the decisions of two planners in which the leader firm moves first and then the follower firms move sequentially.

Competition between two ports can have different goals, to have the maximizing profit (Zhang et al. (2018)) or capturing the maximum flows (Jiang et al. (2020)). Competition strategies may involve setting convenient hub locations (Mahmoodjanloo et al. (2020)), facility locations (Zhang et al. (2018)) and pricing strategy (Jiang et al. (2020), Mahmoodjanloo et al. (2020)).

The competitions can be classified into three types in terms of time sequence: *static competition*, *dynamic competition*, and *competition with foresight* . If the existing rivals (i.e., incumbents) do not react to the entrance of a new competitor, this is a static competition. In this situation the entrant(s) consider(s) hub location and price, taking into account the effect of their rivals (Mahmoodjanloo et al. (2020), Jiang et al. (2020)). In dynamic competition, competitors simultaneously determine their competitive factors. Zhang et al. (2018) study the competition between dry port Dalian port and Yingkou port in China, analysing their locations and pricing strategy to maximize profits from the view point of the port operators. In competition with foresight, a competitor will react to an entrant's decisions sequentially. In Mahmoodjanloo et al. (2020), the incumbent port adjusts facility location and price to react to an entrant.

The game theory competition models can also explore how competition is influenced by *outside force*, such as the shippers' preferences or the government policy intervention. The shippers' discrete choice behaviour is mainly embedded with nominal logit models (Xu et al. (2018), Jiang et al. (2020)). Xu et al. (2018) study the competition with consideration of shippers' choice especially with environment concern on emission reduction. Jiang et al. (2020) study the joint choice of shippers on port, transportation mode and dry port, using data collected by revealed preference and stated preference techniques. Mahmoodjanloo et al. (2020) consider the effect of customer loyalty and elastic demand. Tamannaei et al. (2021) investigate the role of government intervention (taxes on fuel usage based on environmental, economic, and social concerns) in different sustainability dimensions of a competitive freight transportation market.

3.3.2 Cooperation

The profit-driven competition among the shippers can lead to information isolation, non-coordination and inconsistency operations among the operators, which are not beneficial to the multimodal transport as one service portfolio. There are recent projects such as synchromodality, physical internet or (single mode) vehicle platooning, which aim to remove the barriers and promote the cooperation among different members within the system. Most of the literature concentrate the flexible and cooperation from the tactical and operational level planning. Here we review the limited literature on the coordinated strategic planning.

Wei and Lee (2021) establish a coordinated horizontal alliance system for inland ports with China railway Express platforms. The case study reveals that the agreed-upon policies and activities agreement in the alliance governance mechanism, the joint planning and scheduling of routes, and shifts of the railway Express in the alliance operation mechanism can effectively promote the global cooperation. However, Gong and Li (2022) find that the cooperation of China-Europe Railway Express company and the international liner shipping company yield a lower total social welfare compared to that under competition. Not two entities always produce a higher return together than on their own, which is the ground for cooperation. A real world practice, the integration of Ningbo Port and Zhoushan Port, takes place to mitigate excessive port competition and avoid misallocation of resources. This port integration, which occurred from 2006 to 2016, was under strong government leverage. Readers can check Dong et al. (2018) to for further details about quantitative measures the effects of regional port integration.

4 Conclusion and a few future research directions

This presented literature review examines studies on multimodal transport planning mainly from 2015 to 2022. It updates the literature review ever since SteadieSeifi et al. (2014). In addition, it discusses the competition and collaboration among the service providers, of which the collaboration is important but has not been thoroughly reviewed in this field. The overarching topics (hub location problems, network design problems, competition and collaboration) are discussed in detail in terms of the involved transportation modes, problem characteristics and model formulations.

An outlook for few possible future research directions (RQ3) can be given. Firstly, it is worth noting that there are more studies about competitions than collaborations for the strategical planning of multimodal freight transportation, as can also be seen from Table 1 and subsection 3.3. The ongoing multimodal freight renovations such as Physical Internet, Synchromodality and other similar projects, provide clear information that participants can benefit more from the collaborations. The progressing technologies, such as digitization and data sharing, support the cooperation and make cooperation more conductible. The collaborations therefore will be a promising direction.

Furthermore, strategic level planning for coordinating multimodal long-haulage and last -mile delivery is limited. Last mile delivery, as the subsequent procedure of long haulage, is also undergoing changes such as crowd-shipping, dial a ship, and the involvement of unmanned aerial vehicles (UAVs). Each of these variants has its own pros and cons, and it is necessary to study how each adapts as the subsequent chain in the rear of long haulage transportation from the strategic level such as the warehouse choices, the service zones defining.

Last but not least, the polycentric characteristic of multimodal transportation is rarely discussed in the strategic planning. The polycentric framework naturally lies in the multimodal transportation due to geographical distribution, organizational structure, financial settlement and other reasons. Strategic planning cannot design an alliance and synergy if it ignores the rooted poly-centrality.

References

- Alibeyg, A., Contreras, I., Fern ́andez, E., 2016. Hub network design problems with profits. Trans. Res. Part E: Logist 96, 40-59
- Alkaabneh, F., Diabat, A., Elhedhli, S., 2019. A lagrangian heuristic and grasp for the hub-andspoke network system with economies-of-scale and congestion. Trans. Res. Part C: Emerging Technologies 102, 249-273
- Alumur, S.A., Campbell, J.F., Contreras, I., Kara, B.Y., Marianov, V., O'Kelly, M.E., 2021. Perspectives on modeling hub location problems. Eur. J. Oper. Res. 291, 1-17
- Alumur, S.A., Kara, B.Y., Karasan, O.E., 2012a. Multimodal hub location and hub network design. Omega 40, 927–939. Special Issue on Forecasting in Management Science.
- Alumur, S.A., Yaman, H., Kara, B.Y., 2012b. Hierarchical multimodal hub location problem with time-definite deliveries. Trans. Res. Part E: Logist 48, 1107–1120
- Basallo-Triana, M.J., Vidal-Holgu ́ın, C.J., Bravo-Bastidas, J.J., 2021. Planning and design of intermodal hub networks: A literature review. Computers & Operations Research 136, 105-469
- Cagrı Ozgun Kibiro ̆glu, Serarslan, M.N., ̇Ilker Topcu, Y., 2019. Particle swarm optimization for uncapacitated multiteiple allocation hub location problem under congestion. Expert Systems with Applications 119, 1–19
- Contreras, I., Cordeau, J.F., Laporte, G., 2012. Exact solution of large-scale hub location problems with multiple capacity levels. Transportation Science 46, 439–459
- Dong, G., Zheng, S., Lee, P.T.W., 2018. The effects of regional port integration: The case 6 of ningbo-zhoushan port. Trans. Res. Part E: Logist 120, 1–15.
- Elhedhli, S., Wu, H., 2010. A lagrangean heuristic for hub-and-spoke system design with capacity selection and congestion. INFORMS Journal on Computing 22, 282–296
- Gong, X., Li, Z.C., 2022. Determination of subsidy and emission control coverage under competition and cooperation of china-europe railway express and liner shipping. Transport Policy 125, 323–335
- Jiang, X., Fan, H., Luo, M., Xu, Z., 2020. Strategic port competition in multimodal network development considering shippers' choice. Transport Policy 90, 68–89.
- Kurtulus, E., ̇Ismail Bilge C ̧ etin, 2020. Analysis of modal shift potential towards intermodal transportation in short-distance inland container transport. Transport Policy 89, 24–37
- Kurtulus, E., 2022. Optimizing inland container logistics and dry port location-allocation from an environmental perspective. Research in Transportation Business & Management , 100839
- Mahmoodjanloo, M., Tavakkoli-Moghaddam, R., Baboli, A., Jamiri, A., 2020. A multi-modal competitive hub location pricing problem with customer loyalty and elastic demand. Computers & Operations Research 123, 105048.

- Marianov, V., Serra, D., ReVelle, C., 1999. Location of hubs in a competitive environment. Eur. J. Oper. Res. 114, 363371
- Meng, Q., Wang, X., 2011. Intermodal hub-and-spoke network design: Incorporating multiple stakeholders and multi-type containers. Trans. Res. Part B: Methodological 45, 724-742
- Meraklı, M., Yaman, H., 2016. Robust intermodal hub location under polyhedral demand uncertainty. Trans. Res. Part B: Methodological 86, 66-85.
- Mohammadi, M., Jula, P., Tavakkoli-Moghaddam, R., 2019. Reliable single-allocation hub location problem with disruptions. Trans. Res. Part E: Logist 123, 90-120.
- O'Kelly, M., Bryan, D., 1998. Hub location with flow economies of scale. Trans. Res. Part B: Methodological 32, 605-616
- O'Kelly, M.E., Campbell, J.F., de Camargo, R.S., de Miranda Jr, G., 2015. Multiple allocation hub location model with fixed arc costs. Geographical Analysis 47, 73-96
- O'Kelly, M.E., Lao, Y., 1991. Mode choice in a hub-and-spoke network: A zero-one linear programming approach. Geographical Analysis 23, 283-297
- Racunica, I., Wynter, L., 2005. Optimal location of intermodal freight hubs. Trans. Res. Part B: Methodological 39, 453-477.
- Real, L.B., Contreras, I., Cordeau, J.F., de Camargo, R.S., de Miranda, G., 2021. Multimodal hub network design with flexible routes. Trans. Res. Part E: Logist 146, 102-188.
- Road map to the physical internet, 2023. https://www.etp-logistics.eu/wp-content/uploads/2022/11/Roadmap-to-Physical-Intenet-Executive-Version_Final-web.pdf
- Serper, E.Z., Alumur, S.A., 2016. The design of capacitated intermodal hub networks with different vehicle types. Trans. Res. Part B: Methodological 86, 51-65.
- SteadieSeifi, M., Dellaert, N.P., Nuijten, W., Van Woensel, T., Raoufi, R., 2014. Multimodal freight transportation planning: A literature review. Eur. J. Oper. Res. 233(1), 1-15.
- Tamannaei, M., Zarei, H., Rasti-Barzoki, M., 2021. A game theoretic approach to sustainable freight transportation: Competition between road and intermodal road-rail systems with government intervention.Trans. Res. Part E: Methodological 153, 272-295
- Teye, C., Bell, M.G., Bliemer, M.C., 2018. Locating urban and regional container terminals in a competitive environment: An entropy maximising approach. . Trans. Res. Part B: Methodological 117, 971-985
- Wang, R., Yang, K., Yang, L., Gao, Z., 2018. Modeling and optimization of a road–rail intermodal transport system under uncertain information. Engineering Applications of Artificial Intelligence 72, 423-436
- Wang, X., Meng, Q., 2017. Discrete intermodal freight transportation network design with route choice behavior of intermodal operators. Trans. Res. Part B: Methodological 95, 76-104
- Wei, H., Lee, P.T.W., 2021. Designing a coordinated horizontal alliance system for china's inland ports with china railway express platforms along the silk road economic belt. Trans. Res. Part E: Logist 147, 102-238
- Xu, X., Zhang, Q., Wang, W., Peng, Y., Song, X., Jiang, Y., 2018. Modelling port competition for intermodal network design with environmental concerns. Journal of Cleaner Production\cite 202, 720-735.
- Yang, K., Yang, L., Gao, Z., 2016. Planning and optimization of intermodal hub-and-spoke network under mixed uncertainty. Trans. Res. Part E: Logist 95, 248-266.
- Zhang, H., Yang, K., Gao, Y., Yang, L., 2022. Accelerating benders decomposition for stochastic incomplete multimodal hub location problem in many-to-many transportation and distribu tion systems. International Journal of Production Economics 248, 108-493
- Zhang, J., Zhang, S., Wang, Y., Bao, S., Yang, D., Xu, H., Wu, R., Wang, R., Yan, M., Wu, Y., Hao, J., 2021. Air quality improvement via modal shift: Assessment of rail-water port integrated system planning in shenzhen, china. Science of The Total Environment 791, 148-158
- Zhang, Q., Wang, W., Peng, Y., Zhang, J., Guo, Z., 2018. A game-theoretical model of port competition on intermodal network and pricing strategy. Trans. Res. Part E: Logist, 114, 19–39.