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# **Planning Problems in Intermodal Freight Transport: Accomplishments and Prospects**

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*Abstract:* Intermodal freight transport has received an increased attention due to problems of road congestion, environmental concerns and traffic safety. A growing recognition of the strategic importance of speed and agility in the supply chain is forcing firms to reconsider traditional logistic services. As a consequence, research interest in intermodal freight transportation problems is growing. This paper provides an overview of planning decisions in intermodal freight transport and solution methods proposed in scientific literature. Planning problems are classified according to type of decision maker and decision level. General conclusions are given and subjects for further research are identified.

*Keywords:* intermodal freight transport, transportation planning, decision maker, time horizon

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## **1. INTRODUCTION**

Emerging freight transport trends, such as a geographical expansion of distribution networks and the increasing development of hub-and-spoke networks, demonstrate the importance and necessity of intermodal freight transport systems. A general description of current issues and challenges related to the large-scale implementation of intermodal freight transportation systems in the United States and Europe is given by Zografos and Regan [1] and by Vrenken et al. [2]. The objective of our paper is to provide an overview of the state-of-the-art research on planning problems in intermodal freight transport. Macharis and Bontekoning [3] discuss the opportunities for operations research in intermodal freight transport. The authors give a review of operational research models that are currently used in this emerging transportation research field and define the modelling problems which need to be addressed. Their overview covers papers until 2002. Because this is a very young field in transportation research, a significant number of papers on this topic have appeared in recent years. Therefore, we provide an update and focus on the planning issues in intermodal freight transport research. Following Crainic and Laporte [4], the presentation is organized according to the three classical planning levels: strategic, tactic and operational. Conclusions are drawn on the accomplishments and future perspectives in intermodal freight transport.

## **2. METHODOLOGY**

A scientific literature review is performed to update the survey of Macharis and Bontekoning [3]. A computerised search strategy was selected in order to detect recent publications in intermodal freight transport. As a preliminary step we searched the database of Dissertation Abstracts and the (Social) Sciences Citation Index (SCI). Next, a separate search

is performed of electronic journals concerning transportation which are not covered by those channels. In addition, we included research we already knew about from informal contacts with other researchers, as well as our own research. Finally, studies are retrieved by tracking the research cited in literature obtained earlier (ancestry approach).

Planning problems in intermodal freight transport can be related to four types of decision makers, based on the four main activities in intermodal freight transport. First, *drayage operators* organize the planning and scheduling of trucks between terminals and shippers and receivers. Second, *terminal operators* manage transshipment operations from road to rail or barge, or from rail to rail or barge to barge. Third, *network operators* are responsible for the infrastructure planning and organisation of rail or barge transport. Finally, *intermodal operators* can be considered as users of the intermodal infrastructure and services and select the most appropriate route for shipments through the whole intermodal network.

Each type of decision maker is faced with planning problems with different time horizons. Long term, strategic planning involves the highest level of management and requires large capital investments over long time horizons. Decisions at this planning level affect the design of the physical infrastructure network. Medium term, tactical planning aims to ensure, over a medium term horizon, an efficient and rational allocation of existing resources in order to improve the performance of the whole system. Short term, operational planning is performed by local management in a highly dynamic environment where the time factor plays an important role. The dynamic aspect of operations is further compounded by the stochasticity inherent in the system. Real-life operational management is characterized by uncertainty.

The combination of both classes provides a classification matrix with twelve categories of intermodal operations problems, as depicted in Table 1. The classification is not exhaustive and some decision problems can be faced by several decision makers and can be relevant for the same decision maker at different time horizons. However, the decision problems have been placed in the classification matrix of Table 1 where they are most prominent. Table 1 provides a structured overview of planning problems in intermodal transport involving a single decision level and a single decision maker. Section 3 discusses studies on strategic planning problems. Papers on a tactical decision level are presented in section 4. Section 5 deals with scientific research on intermodal transport at the operational decision level. Two separate tables have also been constructed. Table 2 compiles scientific research in intermodal transport involving multiple decision makers. Table 3 presents studies that explicitly take into account multiple decision levels. These integrating studies are discussed in section 6. The number of studies that require decisions from more than one decision maker or that cover various time horizons are very limited. This important conclusion has been formulated already by Macharis and Bontekoning [3]. We find that little improvement has been realised in recent years. However, intermodal transport, by definition, involves several decision makers who need to work in collaboration in order for the system to run smoothly. An increased level of coordination is necessary to improve the intermodal transport flow. If intermodal transport is to be developed it will require more decision-making support tools to assist the many actors and stakeholders involved in intermodal operations. A very good attempt at outlining these tools can be found in Van Duin and Van Ham [5] in which a three-level modelling approach is followed in order to take account of the different goals of the different stakeholders.

Table 1. Papers involving a single decision level and a single decision maker

Decision maker	Time horizon		
	Strategic	Tactical	Operational
Drayage operator	<p><b>Co-operation between drayage companies</b> Spasovic (1990) Walker (1992) Morlok and Spasovic (1994) Morlok et al. (1995)</p> <p><b>Truck and chassis fleet size</b> -</p>	<p><b>Allocation of shippers and receiver locations to a terminal</b> Taylor et al. (2002)</p> <p><b>Pricing strategies</b> Spasovic and Morlok (1993)</p>	<p><b>Vehicle routing</b> Wang and Regan (2002) Imai et al. (2007)</p> <p><b>Redistribution of trailer chassis and load units</b> Justice (1996)</p>
Terminal operator	<p><b>Terminal design</b> Ferreira and Sigut (1995) Meyer (1998) Rizzoli et al. (2002) Ballis and Golias (2004) Bontekoning (2006) Vis (2006)</p>	<p><b>Capacity levels of equipment and labour</b> Kemper and Fischer (2000) Kozan (2000) Kulick and Sawyer (2001) Huynh (2005)</p> <p><b>Redesign of operational routines and layout structures</b> Voges et al. (1994) Marín Martínez et al. (2004)</p>	<p><b>Resource allocation</b> -</p> <p><b>Scheduling of jobs</b> Alicke (2002) Corry and Kozan (2006) Gambardella et al. (2001)</p>
Network operator	<p><b>Infrastructure network configuration</b> Crainic et al. (1990) Loureiro (1994) Southworth and Peterson (2000) Klodzinski and Al-Deek (2004) Tan et al. (2004) Groothedde et al. (2005) Parola and Sciomachen (2005)</p> <p><b>Location of terminals</b> Meinert et al. (1998) Rutten (1998) Arnold and Thomas (1999) Groothedde and Tavasszy (1999) Macharis and Verbeke (1999) Arnold et al. (2004) Macharis (2004) Racunica and Wynter (2005) Kaproš et al. (2005)</p>	<p><b>Configuration consolidation network</b> Janic et al. (1999) Newman and Yano (2000a) Newman and Yano (2000b)</p> <p><b>Production model</b> Nozick and Morlok (1997) Choong et al. (2002) Lin and Chen (2004) Li and Tayur (2005)</p> <p><b>Pricing strategy</b> Tsai et al. (1994) Yan et al. (1995) Li and Tayur (2005)</p>	<p><b>Load order of trains</b> Feo and González-Velarde (1995) Powell and Carvalho (1998)</p> <p><b>Redistribution of railcars, barges and load units</b> Chih and van Dyke (1987) Chih et al. (1990)</p>
Intermodal operator	n.a.	n.a.	<p><b>Routing and repositioning</b> Min (1991) Barnhart and Ratliff (1993) Boardman et al. (1997) Ziliaskopoulos and Wardell (2000) Erera et al. (2005)</p>

### **3. STRATEGIC PLANNING**

Crainic and Laporte [4] mention location models, network design models and regional multimodal planning models suitable for strategic planning in intermodal transport. Location models help to determine the optimal location of a new intermodal terminal. Network design models are concerned with the configuration of the infrastructure network. Regional multimodal planning models consider the entire transportation system in a certain region, the products that use it, as well as the interaction between passenger travel and freight flows. The impact of infrastructure modifications, evolution of demand or government and industry policies is verified. Other planning problems at a strategic decision level identified by Macharis and Bontekoning [3] include cooperation between drayage companies, determination of truck and chassis fleet size and terminal design. The strategic planning problems of each decision maker and solution methods proposed in scientific literature are discussed in the following sections.

#### **3.1 Drayage Operator**

At a strategic decision level a drayage operator could decide to cooperate with other drayage companies, with the objective to improve cost efficiency without affecting the timeliness of operations. Spasovic [6], Morlok and Spasovic [7] and Morlok et al. [8] investigate whether a central planning of pickups and deliveries of multiple drayage companies serving one intermodal terminal can reduce drayage costs. The problem is formulated as a large-scale integer linear program, taking time windows and service constraints into account. The authors conclude that substantial cost savings can be realised through cooperation between drayage companies. Trips are combined in a more efficient

manner, leading to a reduction of empty hauls. The central planning problem of multiple drayage companies is also addressed by Walker [9]. He discusses a cost-minimising vehicle-scheduling algorithm to generate an efficient set of tours consistent with the shippers' pickup and delivery times, travel times and realistic limits on the length of a working day.

### **3.2 Terminal Operator**

A strategic planning problem of terminal operators is the design of the terminal. Decisions regarding design include the type and number of equipment used and type and capacity of load unit storage facilities, the way in which operations are carried out at the terminal and how the equipment is used, and the layout of the terminal. Simulation models have been developed by various researchers.

Simulation models for rail/road intermodal terminals have been constructed by Ferreira and Sigut [10], Ballis and Golias [11] and Rizzoli et al. [12]. Ferreira and Sigut [10] compare the performance of conventional rail/road intermodal terminals and RoadRailer terminals. The RoadRailer terminal design uses trailers with the capability of being hauled on road as well as on rail. These bi-modal trailers are not carried on railway wagons. They are provided with a detachable bogie or a single rail axle permanently attached to the trailer. Both concepts are evaluated by means of discrete event simulation. Speed of operation is chosen as performance criterion, expressed as mean loading finish time. The authors conclude that for a comparable cycle of manipulations, containers are handled faster than RoadRailer trailers. The comparison does not take into account the full set of costs incurred when operating both types of terminals. Initial capital costs, in terms of track and vehicle equipment, are significantly higher in the case of conventional container terminals. Ballis and Golias [11]



present a modelling approach focusing on the comparative evaluation of conventional and advanced rail/road terminal equipment. The modelling tool set consists of a micro-model to compare alternative terminal designs and a macro-model to analyze the attractiveness of the intermodal transport chain. The micro-model incorporates an expert system, a simulation model and a cost calculation module. The expert system assists users to form technically sound terminal designs. The simulation model is used to determine train and truck service times, which are then compared to predetermined service criteria. For each accepted terminal design a cost-versus-volume curve is calculated. Truck waiting time costs are taken into account. The micro-model reveals that each design is effective for a certain cargo volume range and is restricted by capacity limitations. The effects of an efficient terminal operation in conjunction with advanced rail operating forms is further investigated in the macro-model. The discrete event simulation model of Rizzoli et al. [12] can be used to simulate the processes in a single terminal or in a rail network, connecting several rail/road terminals through rail corridors. The objective of the model is to assess the impact of various technologies and management policies to enhance terminal performance and to understand how an increase in intermodal traffic affects terminal performance.

Two studies discuss the simulation of rail/rail intermodal terminals. Meyer [13] faces the design problem of a rail/rail terminal in a hub-and-spoke system for the exchange of a maximum of six trains at a time. In addition, the terminal should be able to handle a limited volume of rail/road exchanges. Dynamic computer simulation with Petri-net applications was developed to determine required capacity for cranes and internal transport systems, and the most efficient arrival pattern of trains. Bontekoning [14] develops a simulation model to perform a systematic comparison between various hub exchange facilities in an intermodal rail network. Her main objective is to identify favourable operational conditions for an

innovative intermodal terminal concept (Bontekoning and Kreutzberger [15]), which can replace shunting yards.

Vis [16] discusses the strategic decision of choosing the type of material handling equipment for storage and retrieval of containers in and from the yard at sea terminals. Simulation is used to compare the use of manned straddle carriers with automated stacking cranes. The total travel time required to handle a fixed number of requests serves as performance measure. A sensitivity analysis of the input parameters is executed in order to formulate advice on the choice for a certain type of material handling equipment in relation with the layout of the stack.

### **3.3 Network Operator**

At a strategic decision level a network operator has to plan the infrastructure of the intermodal network. This implies decisions regarding investments in links and nodes. Network models have been proposed by various authors. Crainic et al. [17] extend uni-modal network models by adding links connecting the various modes in order to derive an intermodal network model. The development of geographic information system (GIS) technology yields new opportunities for the modelling of large multi-modal freight networks as Southworth and Peterson [18] show. Loureiro [19] presents a multi-commodity multi-modal network model to be used as a planning tool for determining investment priorities for intercity freight networks. The main component of the model incorporates a non-linear bi-level multi-modal network design formulation. Its aim is to minimise the transportation costs incurred by shippers and the environmental impacts caused by the use of less efficient modes of transportation for moving freight. Investment options to be considered by the model may

involve the addition of new physical links to the network, the improvement of existing links (i.e. an increase of capacity), and the location of intermodal transfer facilities at specified nodes of the network. Groothedde et al. [20] propose a collaborative hub network for the distribution of fast moving consumer goods. The available transport modes are inland navigation and road transport by trucks. Inland navigation is used for inter-hub transportation in order to achieve economies of scale. Pre- and end-haulage is performed by truck. Parallel to this hub network, direct trucking is used to maintain responsiveness and flexibility. Predictable demand should be sent through the hub network before the order is placed. Peak demand can be accommodated by direct trucking. The hub network design problem is formulated as a cost model and solved with an improvement heuristic. The heuristic starts with a feasible and cost-efficient solution and seeks to improve it by adding barge capacity or hubs to the network. Simulation models may also be applied to plan the infrastructure network configuration. Tan et al. [21] discuss a modelling methodology for building discrete-event simulation models for a state-wide intermodal freight transportation network. Their model simulates the movements of trucks, trains, barges and ships as well as transshipment of freight between different modes. The objective of their modelling effort is to demonstrate interactions between transport modes under various intermodal policy changes and to support transport planning on a regional and state-wide level.

Two research papers focus on the impact of transport growth on the hinterland network. Parola and Sciomachen [22] analyze the impact of a possible future growth in sea traffic on land infrastructure in the north-western Italian port system. The central question is how to achieve a modal split equilibrium between transport by rail and transport by road. Discrete event simulation is used to model a set of maritime terminals, their interconnections and land infrastructures. The simulation model is validated by means of the present

configuration. Three future scenarios of land infrastructure are evaluated, assuming a constant growth in sea traffic in the time period 2002-2012. The authors examine the degree of saturation of railway lines and the level of congestion at truck gates. Klodzinski and Al-Deek [23] develop a methodology for estimating the impact of an intermodal facility on a local road network. First, an artificial neural network model is used to generate truck trips from vessel freight data. Second, the generated truck volumes serve as an input for a microscopic network simulation model. By doing so critical links in the road network can be identified. This methodology may also be used to evaluate local port networks to manage traffic efficiently during heavy congestion or to investigate the impact of forecasted port growth on a road network.

Locations for intermodal terminals may be determined by means of network models. Arnold and Thomas [24] minimise total transport costs in order to find optimal locations for intermodal rail/road terminals in Belgium by means of an integer programming model. Groothedde and Tavasszy [25] minimise generalised and external costs in order to find the optimal location of intermodal rail/road terminals. Simulated annealing is used to find near-optimal locations of terminals. Arnold et al. [26] propose an alternative formulation closely linked to multi-commodity fixed-charge network design problems. The resulting linear integer program is solved heuristically. The model is illustrated for the location of rail/road terminals in the Iberian Peninsula. In this application, the impact of variations in the supply of transport on modal shares of containerised freight transport is explored. Macharis [27] develops a GIS model to analyse the potential market area of new terminals and to analyse their effect on the market area of the existing ones. Rutten [28] investigates the interrelationship between terminal locations, number of terminals, shuttle train length and system performance in an intermodal rail network. The author discusses the TERMINET model, which comprises a

traffic conversion method and a freight flow consolidation method. First, freight flows are converted from tonnes to numbers of load-units. Second, freight volumes are assigned to routes and consolidated with the objective to find terminal locations that will attract sufficient freight to run daily trains to and from the terminal. The model is applied to the design of an inland road and rail terminal network in the Netherlands. Racunica and Wynter [29] discuss the optimal location of intermodal hubs in a hub-and-spoke network with (semi-) dedicated freight rail lines. The problem is formulated as a frequency service network design model with frequencies of service as derived output. A concave cost function is applied in order to capture cost reductions obtained by consolidation at hub nodes. The resulting model is a non-linear, mixed-integer program. Next, the concave increasing cost terms are approximated by a piecewise linear function in order to obtain a linear program. This linear program is solved by two variable-reduction heuristics, which solve a sequence of relaxed subproblems. Finally the solution method is tested on a case study of the Alpine freight network.

Second, simulation may be used to define terminal locations. Meinert et al. [30] investigate the location of a new rail terminal in a specific region in which three rail terminals are already located. The authors specifically consider the impact of the location of the new terminal on drayage length and time. In order to accomplish this, a discrete event simulation tool is developed which provides the ability to address individual rail terminal design considerations such as handling capacity required, regional design considerations related to terminal location and trucking distances, and demand distribution over time. A significant feature of this simulator is that, rather than modelling only the operation of the terminal, it also models the drayage to and from regional destinations.

Third, multi-criteria analysis can be applied to select the most appropriate location out of a number of potential sites for an intermodal terminal. Macharis and Verbeke [31] examine four potential sites for new barge terminals in Belgium by means of a multi-actor, multi-criteria analysis. Their criteria represent the aims of the actors who are involved, namely the users of the terminal, the operators/investors and the community as a whole. The evaluation of the terminal projects was carried out with the GDSS-PROMETHEE-method (Preference Ranking Organization METHod for Enrichment Evaluations, Macharis et al. [32]). A multi-criteria analysis is also proposed by Kapros et al. [33] to evaluate intermodal terminal projects. The central idea in their methodology is the trade-off between public interest and business interest. Criteria are weighted using the Rembrandt method and location alternatives are ranked using a linear additive aggregation function.

#### **4. TACTICAL PLANNING**

According to Crainic and Laporte [4], the service network design problem is a key tactical problem in intermodal transport. The service network design problem concerns the selection of routes on which services are offered and the determination of the characteristics of each service, particularly their frequency. For each origin-destination pair a routing has to be specified. A decision needs to be made about the type of consolidation network, general operating rules for each terminal and work allocation among terminals. Empty balancing looks for an optimal repositioning of empty vehicles to meet forecast needs of the next planning period. Crew and motive power scheduling regards the allocation and repositioning of resources required by the selected transportation plan. The following tactical planning problems can be defined for each decision maker.

## **4.1 Drayage Operator**

A tactical decision of drayage operators is the assignment of freight locations to intermodal terminal service areas. Taylor et al. [34] compare two alternative heuristic methods that seek to reduce total empty and circuitous (out of route) miles incurred during intermodal drayage movements. The first heuristic uses the minimization of circuitous miles as criterion to assign freight to an intermodal terminal. The second heuristic minimizes the sum of total circuitry, empty miles associated with the geographical separation of pickups and deliveries and empty miles due to operational fluctuations in inbound and outbound freight demand within a small service area. Both heuristics are tested in a large experimental design. Conclusions are formulated on the appropriateness of each heuristic in particular situations.

Spasovic and Morlok [35] use their strategic planning model for the highway portion of rail-truck intermodal transport, described in section 3.1, to develop pricing guidelines for drayage service. The model generates marginal costs of moving loads in the drayage operation. The marginal costs are used to evaluate the efficiency of drayage rates charged by truckers in the current operation as well as rates used in a proposed operation with centralized planning of tractor and trailer movements. The need for railroad management to become aware of the characteristics of drayage operations and the system-wide impacts of drayage movements on the profitability of intermodal transport are indicated.

## **4.2 Terminal Operator**

A terminal operator has to decide on the required capacity levels of equipment and labour. Kemper and Fischer [36] model the transfer of containers in an intermodal rail/road

terminal with a single crane. Their objective is to determine quality of service in terms of waiting times and utilisation of resources, especially with regard to the dimensions of the waiting areas for incoming trucks. Stochastic Petri-nets are used as modelling language and results are obtained numerically by computation of the steady state distribution of an associated Markov chain.

In Kozan [37] a network model is presented to analyze container progress in a multimodal container terminal. As objective the author minimizes total throughput time, which is the sum of handling and travelling times of containers from the time the ship arrives at the port until the time they are leaving the terminal and in reversed order. The mathematical model can be applied as decision support tool for equipment investments. Long-term data collection should be carried out before implementing the model. Simulation models are also frequently designed to support tactical decisions at an intermodal terminal. Kulick and Sawyer [38] develop a simulation model to support the analysis of labour deployment and other resource capacities at a major intermodal terminal. The model is used to explore areas where container throughput can be improved. Huynh [39] proposes statistical and simulation models to explain the relationship between the availability of yard cranes and truck turn time. Truck turn time is defined as the time it takes a truck to complete a transaction at an intermodal terminal.

A second tactical planning problem of terminal operators is the redesign of operational routines and layout structures. Voges et al. [40] analyse operating procedures for an existing terminal. Three questions are studied. How should the dispatcher at the gate and the crane drivers make their decisions on how to continue the process? If a certain crane strategy would result in favourable waiting times for trucks, are the crane drivers able to follow it without computer support? When would it be useful to abandon the strategy and to work intuitively? Average waiting time of trucks serves as performance criterion. A combination of Human



Integrated Simulation (HIS) and computer simulation based on a Petri-net model has been applied. This combined approach takes both objective influences and human factors into account. In this game approach human beings play the role of operators at the terminal. A study of operational routines for the transshipment process at intermodal terminals is also given by Marín Martínez et al. [41]. The authors investigate a set of operation modes for a gantry crane at a rail-rail terminal. A discrete event simulation model is built of a Spanish border terminal. Four operation modes are evaluated in a number of scenarios, varying crane characteristics, container sizes and degree of coordination of train scheduling. The authors prefer to recommend rules of operation instead of generating the optimal solution for each particular combination of trains because rules may be easier to implement in practice.

### **4.3 Network Operator**

First, a network operator has to decide which consolidation network to use. Four basic types of consolidation networks are a point-to-point network, a line network, a hub-and spoke network and a trunk-collection-and-distribution network. Janic et al. [42] evaluate rail-based innovative bundling networks operated in the European freight transport system. Their objective is to identify promising or preferable network configurations which can increase the competitiveness of intermodal transport. Indicators for network performance have been defined and quantified for selected bundling networks. The evaluation of consolidation networks is performed by means of the Simple Additive Weighting (SAW) multi-criteria method. Newman and Yano [43] [44] compare a variety of decentralized planning approaches with a centralized approach for scheduling trains in an intermodal network. The authors simultaneously determine an explicit direct and indirect (i.e. via a hub) train schedule and corresponding container routing decisions. The problem is formulated as an integer program

and decomposed into a number of subproblems. Their decentralized scheduling approaches lead to near-optimal solutions within significantly less computational time than the centralized approach.

A second tactical decision of a network operator is the type of production model, i.e. how to operate the trains or barges. This involves decisions about frequency of service, train length, allocation of equipment to routes and capacity planning of equipment. Nozick and Morlok [45] study a medium-term operations planning problem in an intermodal rail-truck system. The authors develop a modelling framework to plan various elements of rail-truck intermodal operations simultaneously. The problem is formulated as an integer program and solved heuristically. The model encompasses all elements of the operation, including road haulage, terminals and rail haulage. However, attention is focused on the portion of service that is usually within the control of a railroad company, i.e. rail haulage and terminal operations. Moreover, train schedules and the configuration of the network are assumed to be fixed. Choong, Cole and Kutanoglu [46] present a model for empty container management in intermodal transportation networks. The authors analyse the effect of planning horizon length on mode selection. They formulate that a longer planning horizon leads to higher utilization of slower modes of transportation. Empty containers can be transported by barge at a very low cost. Within barge capacity limits, empty containers can be piggy-backed onto existing barge tows of loaded containers. However, a trade-off has to be made between the low transportation cost and the relatively slow speed of barge transport. The problem is formulated as an integer programming model that minimizes total cost of empty container management. Based on a case study of the Mississippi River basin, the authors conclude that a longer planning horizon, used on a rolling basis, can give better empty container distribution plans for the earlier periods. However, advantages might be small for a system that has a

sufficient number of container pools. The authors do not integrate loaded and empty container flow decisions in a single model. Lin and Cheng [47] study a network design problem of a door-to-door express service. An air-ground intermodal carrier provides a delivery service in a hierarchical hub-and-spoke network. The network consists of multiple clusters. Local cluster centres are connected to their own hub through a secondary route. Each hub is connected to other hubs through a primary route. Large trucks or aircrafts are used on primary routes, smaller trucks or aircrafts on secondary routes. The problem is to determine fleet size, routes and schedules for both primary and secondary trucks or aircrafts simultaneously, with the objective to minimize the sum of fixed and operating costs while meeting the desired service level. The authors formulate the problem as an integer program in a route-space directed network. The binary program is solved through an implicit enumeration algorithm that contains an embedded least time path sub-problem.

Finally, pricing strategy decisions have to be considered at the tactical planning level. Li and Tayur [48] develop a tactical planning model for intermodal rail transport that jointly considers operations planning and pricing decisions. In the operations-planning subproblem, freight routing, train routing and train assignment are considered simultaneously. Train routes, frequency of service and number of locomotives and flatcars used on each route need to be determined. The combined problem is formulated as a nonlinear programming model. It is solved to optimality through a decomposition that exploits the structure of the subproblems. The model is developed for the intermodal transport of trailers, but may be easily extended to intermodal transport of containers. Two other papers on pricing strategy decisions are given by Yan et al. [49] and Tsai et al. [50]. Yan et al. [49] develop a framework for estimating the opportunity costs for all services in trailer-on-flatcar operations. These opportunity costs are to be taken into account when setting the price level of intermodal transport. The framework

is based on a network model, formulated as a linear network flow problem with side constraints. A mathematical program is formulated to address this problem incorporating an efficient algorithm for approximating better the reduced costs. The algorithm combines the use of Lagrangian relaxation with a minimum cost algorithm and a shortest path algorithm. Tsai et al. [50] construct two models to determine an optimal price level and service level for intermodal transport in competition with truck transport. The authors consider the whole intermodal chain, contrary to Yan et al. [49] who only consider rail haul. The models take into account not only carriers' pricing behaviour (supply side) but also shippers' mode choice behaviour (demand side). Solutions to find an equilibrium are pursued by a mathematical programming approach. The objective is to optimise intermodal profit within some constraints, which include shippers' mode choice behaviour, non-negativity of carrier price and cargo amounts and intermodal volume constraints.

## **5. OPERATIONAL PLANNING**

Important operational decisions are the scheduling of services, empty vehicle distribution and repositioning, crew scheduling and allocation of resources. The main issues are similar to those at the tactical decision level. However, while tactical planning is concerned with 'where' and 'how' issues (selecting services of given types and traffic routes between spatial locations), operational planning is interested in 'when' issues (when to start a given service, when a vehicle arrives at a destination or at an intermediary terminal, etc.).(Crainic and Laporte [4])

### **5.1 Drayage Operator**

The distribution of containers by truck may be considered as a pickup and delivery problem (PDP), which is a special case of the vehicle routing problem. Full containers need to be picked up at their origin and brought to the terminal or delivered from an intermodal terminal to their destination. In a recent study Imai et al. [51] propose a heuristic procedure based upon a Lagrangian relaxation in order to schedule pickups and deliveries of full container load to and from a single intermodal terminal. Wang and Regan [52] propose a hybrid approach to solve a PDP containing one or more intermodal facilities. The authors apply time window discretization in combination with a branch and bound method.

Justice [53] addresses the issue of chassis logistics in intermodal freight transport. A drayage company has to provide sufficient chassis at terminals in order to meet demand. A planning model is developed to determine when, where, how many and by what means chassis are redistributed. The problem is mathematically formulated as a bi-directional time based network transportation problem. Own software has been developed to calculate solutions using five sub-problems: find planning horizon, determine train arrivals and departures, obtain chassis supply and demand, obtain unit costs with each supply-demand pair, optimise for minimum cost solution through simplex based iterations. It is assumed that supply and demand of chassis at a terminal in a given time period are known.

## **5.2 Terminal Operator**

A tactical planning problem of terminal operators is the scheduling of jobs in a terminal. Corry and Kozan [54] develop a load planning model to dynamically assign containers to slots on a train at an intermodal terminal. The objectives are to minimize excess handling time and optimize the mass distribution of the train. Because truck arrival times are

not known in advance, the model needs to be applied over a rolling horizon. The simplifying assumption is made that all containers have equal length. A simulation model is developed to assess the performance of the dynamic assignment model under two different operating environments, a simplified case and a more realistic scenario. Significant reduction of excess handling time could be achieved with a relatively small concession in mass distribution. Gambardella et al. [55] split loading and unloading operations in an intermodal terminal into a resource allocation problem and a scheduling problem. The two problems are formulated and solved hierarchically. First, quay cranes and yard cranes are assigned over a number of work shifts. The resource allocation problem is formulated as a mixed-integer linear program and solved using a branch-and-bound algorithm. Then a scheduling problem is formulated to compute loading and unloading lists of containers for each allocated crane. The scheduling problem is tackled using a tabu search algorithm. The authors validate their approach by performing a discrete event simulation of the terminal. A new intermodal terminal concept called 'mega hub' is investigated by Alicke [56]. In a mega hub the connection of containers to wagons is not fixed, therefore no time consuming shunting is necessary. Load units are transhipped between several block trains during a short stop at the intermodal terminal. Trains operate according to time-tables and arrive in bundles of six trains in which transhipment takes place. Rotter [57] provides an overview of the operating concept of a mega hub and summarises potential benefits and necessary requirements. Alicke [56] models the terminal as a multi-stage transhipment problem, in which the optimal transhipment sequence of containers between trains needs to be determined. An optimization model based on Constraint Satisfaction is formulated and various heuristics are developed. The objective is to minimize the maximum lateness of all trains. Practical constraints like the distinction between direct and indirect transhipment as well as overlapping crane areas are included. The model may be used to calculate an initial schedule or to reschedule in case of delay of a train.

### 5.3 Network Operator

Network operators have to take daily decisions on the load order of trains and barges. Feo and González-Velarde [58] study the problem of optimally assigning highway trailers to railcar hitches ('piggyback' transport) in intermodal transportation. The problem is defined as a set covering problem and formulated as an integer linear program. Two methods are proposed to minimize a weighted sum of railcars used to ship a given set of outbound trailers. First a general purpose branch-and-bound code is applied, second a Greedy Randomized Adaptive Search Procedure (GRASP) is developed to approach optimal solutions. The heuristic incorporates a selection of the most difficult to use railcars available together with the most difficult to assign trailers. In doing this, the least compatible and most problematic equipment is considered first. Feo and González-Velarde [58] only consider the local trailer assignment problem at a single yard, at a single point in time. Powell and Carvalho [59] want to introduce network level information to improve decisions made at a local level. The previous model ignores the importance the choice of destination has in the aim to fully utilise the equipment. For example, if the container is going to a destination that pools a large number of trailers, flatcars are favoured that can carry trailers. Network information such as this can influence the decisions made by the local terminal. Powell and Carvalho [59] propose a dynamic model for optimizing the assignment of trailers and containers to a flatcar. The problem is formulated as a logistics queuing network which can handle a wide range of equipment types and complex operating rules. The repositioning of railroad-owned equipment is integrated in this problem formulation.

A second operational planning problem of network operators is the redistribution of railcars, barges and load units. In Chih et al. [60] a decision support system called RAILS is set up to optimally manage intermodal double-stack trains. This assignment problem is complex as there are height constraints and choices between different modes. The system is to be used on a daily basis to ensure the correct size of each train and to generate rail car repositioning instructions. The planning horizon is two weeks and takes the local and global system needs into consideration. The problem is formulated as a non-linear multi-commodity integer network flow problem. As the problem is NP hard, a heuristic method is developed in order to be able to solve the network optimisation problem within a reasonable time. The heuristic breaks the solution procedures into several components and uses well developed traffic assignment and capacitated network transshipment optimisation algorithms to solve the problem. In Chih and Van Dyke [61] a similar approach is followed for the distribution of the fleet's empty trailers and/or containers.

#### **5.4 Intermodal Operator**

At an operational level an intermodal operator has to determine the optimal routing of shipments. Barnhart and Ratliff [62] discuss methods for determining minimum cost intermodal routings to help shippers minimize total transportation costs. Their models are focused on the rail/road combinations compared to uni-modal road transport. Two types of decision settings are identified depending on who owns the equipment and who is providing the service. When rail costs are expressed per trailer, minimum cost routings are achieved with a shortest path procedure. For rail costs expressed per flatcar, optimal routings are determined with a matching algorithm and a b-matching algorithm. The latter models are also



able to incorporate non-monetary constraints such as schedule requirements and flatcar configuration restrictions in case different types of flatcars and trailers exist.

A decision support system is constructed by Boardman et al. [63] to assist shippers in selecting the least cost combination of transportation modes (truck, rail, air, barge) between a given origin and a corresponding destination. As an indicator of cost average transportation rates for each transportation mode are used. This is a simplification of reality as there would normally be a cost difference between long haul truck and short haul drayage costs. Least-cost paths in the network are calculated by means of the K-shortest path double-sweep method. The software is interfaced to a commercial geographic information system software package to assist the user in visualizing the region being analyzed.

Ziliaskopoulos and Wardell [64] discuss a shortest path algorithm for intermodal transportation networks. The authors introduce the concept of time dependency of optimal paths in their routing model. The time horizon is divided into discrete intervals. Also delays at switching points, fixed time schedules of transport modes and movement delays or movement prohibitions are taken into account. The algorithm computes optimal routes from all origins, departure times and modes to a destination node and exit mode, accounting for the time-dependent nature of the arc travel times and switching delays, without explicitly expanding the network. The computational complexity of the algorithm is independent of the number of modes. Computational time increases almost linearly with the number of nodes in the network and the number of time intervals.

Min [65] focuses on the multi-objective nature of the modal choice decision. A chance-constrained goal programming (GP) model is constructed that best combines different

modes of transportation and best maintains a continuous flow of products during intermodal transfer. The GP model is a multiple objective technique for determining solutions. The comparison between transportation modes is based on costs, market coverage, average length of haul, equipment capacity, speed, availability, reliability and damage risk. The most service-cost-effective transportation mode is sought for each segment in the international distribution channel.

An integrated model for routing loaded tank containers and repositioning empty tank containers in an intermodal network is defined by Erera et al. [66]. The problem is formulated as a deterministic network flow model over a time-expanded network. A computational study verifies that integrated container management can substantially reduce empty repositioning costs. The results also indicate that it is worthwhile to make repositioning decisions daily as opposed to weekly. Imposing a lower bound on the repositioning quantity has relatively little impact on total costs.

## **6. INTEGRATING APPLICATIONS**

### **6.1 Multiple Decision Makers**

Van Duin and Van Ham [5] construct a three-stage modelling approach for the location and design of intermodal terminals. The authors incorporate the perspectives and objectives of shippers, terminal operators, agents, consignees and carriers. For each stage, an appropriate model is developed. In a first stage, a linear programming model determines the optimal locations for intermodal terminals. This model takes account of the existing terminals in the Netherlands and can then be used in order to find some new prospective area. In the

next stage a definite location in the prospective area is found by means of a financial analysis. Here the location of large potential customers is one of the most decisive factors. In the last stage a discrete event simulation model of the terminal offers the opportunity to simulate the operations of the terminal. This model can be used to make decisions on the amount of cranes, amount of employees, etc.

A strategic analysis involving all four decision makers has been performed by Gambardella et al. [67]. The authors model the complete logistic chain in a complex network of intermodal terminals in order to understand how intermodal transport can be put in competition with road transport. The model consists of two subsystems: an Intermodal Transport Planner and a simulation system, including a road, rail and terminal simulation module. The planning of intermodal transport is performed by means of an agent-based model of the intermodal transport chain. A discrete event simulation system is designed to verify the feasibility of these transport plans and to measure their performance.

Evers and De Feijter [68] investigate strategic decisions of both terminal operators and network operators. An explorative study is carried out on the choice between centralized versus decentralized service of inland barges and short sea vessels in a seaport area. The authors propose to equip the central service station with an automated quay stack. Both scenarios are simulated for the Maasvlakte harbour area of Rotterdam. In this case study a centralized service appears to be preferable.

Bostel and Dejax [69] integrate operational planning decisions of terminal operators and network operators. The operational problem of optimizing container loading on trains in rail/rail transshipment is addressed. The authors seek to determine the initial loading place of

containers in beginning terminals as well as their reloading place after transshipment at a rail/rail terminal, with the objective to minimize transfer operations and therefore the use of handling equipment. The problem is formulated as a minimum cost multi-commodity network flow problem with binary variables. The following two cases are analysed: first optimisation of container transfers with imposed initial loading and second joint optimisation of initial loading and reloading. Both cases are considered in the situation of unlimited storage capacity and in the situation of limited storage capacity. Because of the complexity of the problem, the authors developed a heuristic solution methodology. Experiments on large-scale real datasets show that joint optimization of initial loading and transfer of containers increases the productivity of bottleneck equipment.

In Table 2 the papers, described in this section, are positioned in the decision maker/time horizon matrix.

Table 2. Multiple decision makers

Decision maker	Time horizon			
	Strategic		Tactical	Operational
Drayage operator				
Terminal operator	Van Duin and Van Ham (1998)	Gambardella, Rizzoli and Funk (2002)	Evers and De Feijter (2004)	Bostel and Dejax (1998)
Network operator				
Intermodal operator				

## 6.2 Multiple Decision Levels

A general summary of decisions facing a terminal operator can be found in Vis and de Koster [70]. For each process taking place at a container terminal, the authors discuss types of material handling equipment used and related decision problems at all three decision levels.

Quantitative models proposed in literature to solve these problems are presented. Most models address a single type of material handling equipment. The authors conclude that joint optimization of several material handling equipment is a topic for future research. Furthermore, it is necessary to extend models from simple cases to more realistic situations.

A second study integrates strategic and tactical planning decisions of a network operator. Jourquin et al. [71] combine a network model with GIS software to support strategic decisions of a network operator. A virtual network is constructed in which all successive operations involved in multi-modal transport are broken down in a systematic way and a detailed analysis of all costs is included. The generalised costs are minimised according to the shortest path algorithm. By simulation with different parameter values, the software can provide performance measures such as tons per km, total distance, total cost, duration and capacity utilisation of nodes and links. At a tactical level the model is used to derive the impact of different types of consolidation networks on the distribution of flows over the available infrastructure and modalities.

Table 3 shows the position of both papers.

Table 3. Multiple decision levels

Decision maker	Time horizon		
	Strategic	Tactical	Operational
Drayage operator			
Terminal operator	Vis and de Koster (2003)		
Network operator	Jourquin et al. (1999)		
Intermodal operator			

## 7. CONCLUSIONS AND PROSPECTS

Intermodal transport has grown into a dynamic transportation research field. Many new intermodal research projects have emerged. An investigation has been made into planning issues in intermodal transport. Intermodal planning problems are more complex due to the inclusion of multiple transport modes, multiple decision makers and multiple types of load units. Two strategic planning problems, terminal design and infrastructure network configuration, have received an increased attention in recent years. Yet the number of scientific publications on other intermodal planning problems, especially at the operational decision level, remains limited or non-existent. Topics such as the allocation of resources to jobs in an intermodal terminal or the determination of truck and chassis fleet size in intermodal drayage operations still need to be tackled. The following themes are interesting for future research:

- Drayage operations constitute a relatively large portion of total costs of intermodal transport. The development of efficient drayage operations can encourage its attractiveness. However, few research has been conducted on intermodal drayage operations.
- A tactical planning problem that requires more research attention is the design of the intermodal service network and in particular the determination of an optimal consolidation strategy. Additional insight should be gained into which bundling concepts can contribute to the improvement of intermodal transport operations.
- Research efforts are also needed into the further development of solution methods and the comparison of proposed operations research techniques. Metaheuristics can offer an interesting perspective in view of the increased complexity of intermodal planning problems.

- The main attention until now is given to intermodal transport by rail. In regions with an extensive waterway network, such as Western Europe, intermodal transport including inland navigation is also important. Future research is necessary to improve operations in intermodal barge transport.
- A final research field for the future is the cooperation between actors in the intermodal transport chain. Not many studies take multiple decision makers into account. However, an increased level of coordination is required to improve the performance of intermodal freight transport. Also more integration can be achieved between planning problems at different decision levels.

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