Train Slot Cooperation in Multicarrier, International Rail-Based Intermodal Freight Transport

April Kuo, Elise Miller-Hooks, Kuilin Zhang, and Hani Mahmassani

Collaborative decision-making (CDM) strategies are proposed for the collaborative operation of international rail-based intermodal freight services by multiple carriers. The benefits of the proposed techniques are assessed using a carrier collaboration simulation—assignment framework on a real-world European intermodal network spanning 11 countries from Scandinavia to Greece through Bulgaria, Czech Republic, Hungary, Poland, Romania, and Slovakia. This is termed the REORIENT corridor. Three CDM strategies are presented in this work: (*a*) train slot cooperation, (*b*) train space leasing, and (*c*) train slot swapping. Results of numerical experiments indicate that these strategies are expected to result in significant improvements in terms of shipments that are attracted to the proposed services. The best-performing CDM strategy, train slot swapping, resulted in a more than 40% increase in terms of ton-kilometers attracted to proposed services. Such CDM strategies result in a win–win situation for all parties. In addition to attracting more demand, cost savings in terms of rolling stock and labor and reduced shipment delays can be achieved. The potential of such strategies for a real-world application is discussed.

This paper proposes collaborative decision-making (CDM) strategies for the collaborative operation of international rail-based intermodal (IM) services by multiple carriers. The benefits of the proposed techniques are assessed using a discrete-time carrier collaboration simulation-assignment framework on a real-world European IM network spanning 11 countries from the Baltic (Scandinavia) to the Mediterranean, Greece through Bulgaria, Czech Republic, Hungary, Poland, Romania, and Slovakia, termed the REORIENT corridor (depicted in Figure 1). Existing rail-based IM services are fragmented and are typically operated by publicly owned rail companies. In fact, Network Statements [see, for example, the Network Statement for Finland (*1*)] from REORIENT countries indicate that at least one carrier exists in every country with the exclusive business of national rail transport. Often, the rail infrastructure is state owned. Track access rights must be obtained for carriers of foreign countries to operate their trains internationally. Despite that European Commissions (EC) directives have both legally and functionally separated rail operations from infrastructure ownership and management, the government-owned national railways still maintain a symbiotic relationship with infrastructure providers. New entrants to rail business face considerable hurdles in terms of access to infrastructure and operations at border crossings. Moreover, passenger traffic has precedence over freight traffic. Thus, train timetables are created with priority for national carriers, leaving only residual track capacity for international freight traffic.

The EC's interoperability directives envision an environment in which new sufficiently capitalized entrants could enter and meet market needs through various types of specialized freight services. To enable this requires the ability to request and obtain slots (a slot, referred to as a train slot, is defined herein as the use of track capacity along a specific stretch of track for a given short period of time) in a timely manner. While the process is progressively becoming more transparent, rules for allocating slots remain riddled with inefficiency. In a low-traffic environment, slots may not be scarce resources, and some inefficiency in their allocation may be tolerated. However, there are indications that certain portions of the rail network under consideration are already exhibiting high levels of utilization, and slots will eventually come to be viewed as the valuable resources they are. Under the objectives of the EC which motivated this work, it is envisioned that considerable increases in rail freight traffic could be expected for new services coupled with various technological, administrative, and operational improvements (*2*). In such an environment, flexible means for utilizing slots become essential to attaining the desired service levels and associated efficiencies necessary to contain the cost of providing the service. Such flexible means fall under the general umbrella of CDM schemes, which constitute a class of approaches for the management of shared or public resources by a collection of private and public entities or agents with individual goals.

The available slots for operating international trains given national timetables can be patched together to form international train timetables and routes. These available slots (or bundles of slots) are sold for operation by various carriers. This mechanism of allocating slots can lead to inefficiencies that can be mitigated through cooperative agreements between carriers. Three strategies for cooperation (i.e., CDM schemes), designed to overcome these inefficiencies associated with operating across the countries of the REORIENT corridor, are proposed in this paper: (*a*) train slot cooperation, (*b*) train space leasing, and (*c*) train slot swapping techniques.

The three proposed CDM strategies take into account the carrier train timetables and the predetermined routes along which the trains will operate. Through the CDM schemes involving slot leasing,

A. Kuo and E. Miller-Hooks, Department of Civil and Environmental Engineering, University of Maryland, 1173 Glenn L. Martin Hall, College Park, MD 20742. K. Zhang and H. Mahmassani, Department of Civil and Environmental Engineering, Northwestern University, 600 Foster Street, Evanston, IL 60208. Corresponding author: A. Kuo, aprilkuo@umd.edu.

Transportation Research Record: Journal of the Transportation Research Board, No. 2043, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 31–40.
DOI: 10.3141/2043-04

FIGURE 1 REORIENT corridor.

swapping, and other mechanisms, these timetables can be improved—mutually benefiting all carriers. Thus, if different carriers, possibly from different countries, could cooperate with each other through the sharing of information and resources (e.g., slots or locomotive power), barriers to entry or to reliable service that may exist in such fragmented IM networks as the REORIENT corridor could be overcome.

Industry structure in Europe continues to evolve, with various possible business models emerging in different parts and segments of the market. The result will be a mix of multinational carriers operating services across borders, as well as evolved national undertakings with integrated services, and other possible combinations. In all of these cases, the problem of slot allocation and management will play a critical role in the efficient and competitive use of the infrastructure.

CDM strategies proposed in this paper are assessed through a discrete-time carrier collaboration simulation model that replicates services, carrier operations, and shipper response to the revised (more efficient) timetables. The platform makes it possible to model variability in such aspects as delays at the classification yards; time required for IM transfer at terminals, ports, and border crossings; and required travel times. The increase in rail-based IM market share that results from the introduction of more efficient CDM-based timetables is estimated in the simulation platform. This can be compared with the market share anticipated from noncollaboratively derived timetables.

BACKGROUND REVIEW ON CDM

CDM involves teamwork through communication, cooperation, and coordination among each of the agents in the team (*3*). Whereas earlier forms of CDM were envisioned and performed through debate and negotiation among a group of people, modern incarnations rely extensively on sophisticated collaboration support systems that allow most activities and interaction to occur virtually through well-defined frameworks and protocols. Conflicts of interest are inevitable and support for achieving consensus and compromise is required. For problems in which agents compete, but where there is an opportunity to cooperate, an improved solution for each agent might be achieved by incorporating CDM. CDM has been applied in many works addressing, for example, air traffic flow management, supply-chain systems, submarine command and control, engineering design projects, and homeland security problems (*4–8*).

Among these works, the works in air traffic flow management are the most relevant, especially the aircraft arrival and departure slot arrangement, which, like track capacity allocation in rail-based IM freight transport in the REORIENT corridor, is a capacity allocation problem (*4, 9, 10*). The goal of the aircraft arrival/departure slot arrangement is to minimize delays incurred at congested airports. Through a procedure built by CDM, arrival or departure slots are assigned to an appropriate aircraft to minimize the total delay of airlines, thus arranging slots more efficiently. Airlines can benefit from cooperating with each other even though they are inherently competitive.

REORIENT CORRIDOR

A 5-day planning horizon is considered (i.e., Monday through Friday) in this simulation analysis. The resulting periodic schedule is assumed to be used repetitively (i.e., repeating every Monday). The input required for the simulation-based analysis includes: the REORIENT corridor network topology, the attributes of the network (rail link length, number of tracks, terminal and classification yard locations, travel speeds), zone-to-zone (origin–destination, O-D) freight demand data, service routes, and a train timetable for operating the service routes.

The network representation of the REORIENT corridor created for, and employed in, this work consists of 5,577 rail links, 5,753 rail nodes (i.e., terminals, classification yards, stations, and border crossing points), 4,713 road links, 5,753 road nodes, 54 sea links, and 21 port nodes. The rail link lengths range from 0.009 to 20 km. Approximately 20% of the links are single track and 80% are double track. The maximum speed on the tracks over the network is between 60 km/h and 80 km/h and depends on the track segment. The available terminals where shipments can be loaded or unloaded are primarily located in Sweden, Poland, Austria, Hungary, Romania, and Greece.

Zone-to-zone (O-D) freight demand data are used in this paper. Approximately 3.2 million freight shipments traversed some portion of the REORIENT network in 2006 (*11*). These shipments are categorized into 22 commodity types. Each type can further manifest as either containerized or bulk units. Shipments are continuously generated from Monday to Thursday with 65% of the shipments generated split evenly between Monday and Thursday and the remaining 35% of shipments split between Tuesday and Wednesday. Thus, the node-to-node shipments are generated from a known, fixed, and deterministic demand generation distribution model embedded in the simulation platform (*12*).

Four southbound service design options, developed in consultation with rail carriers from the region and founded on market-based research, have been proposed for the REORIENT corridor. For the purposes of this analysis, these services are permitted to carry both bulk and unitized flows. The routes associated with these service designs are shown in Figure 2.

T1. Halsberg, Sweden–Trelleborg, Sweden–Swinoujście, Poland–Vienna, Austria/Bratislava, Slovakia–Budapest, Hungary

T2. Trelleborg–Swinoujście–Bratislava/Vienna

T3. Gdańsk, Poland/Gdynia, Poland–Bratislava/Vienna–Budapest–Belgrade, Yugoslavia–Thessaloníki, Greece

T4. Bratislava–Budapest–Bucharest, Romania–Constanta, Romania

Fifteen loading or unloading terminals are specified for access to these routes, including Sofia, Bulgaria; Arad, Romania; Bucharest; Budapest; Thessaloníki; Gdańsk; Poznan, Poland; Vienna; Swinoujście; Constanta; and Bratislava. Mutually beneficial multicarrier train timetables were developed with the proposed CDM strategies for the operation of these four routes. Operations along these routes will also affect the temporal and spatial patterns of flows traversing other portions of the REORIENT network.

FIGURE 2 Four expert-generated service routes.

COLLABORATIVE STRATEGIES

The three CDM strategies proposed in this paper—the train slot cooperation, train space leasing, and train slot swapping techniques—rely on various mechanisms for collaboration among carriers. The means of collaboration considered include joint operation of train slots, exchange of train slots between carriers, and leasing of train capacity. These three CDM strategies are described next.

Train Slot Cooperation

In the train slot cooperation approach, two or more carriers can join forces to jointly operate a train slot. Carriers operate over separate portions of the train slot's route (e.g., nearly all carriers operating within the REORIENT corridor operate only within a specific country), such that operation along the entire route is carried out through the cooperation of multiple carriers. Thus, through collaboration with other carriers, carriers can transport shipments with origins or destinations that are not covered by the carrier's own service routes.

This method of joint operation of a train line is particularly relevant in the REORIENT corridor, where track access rights may not be granted to foreign carriers in one or more of the countries on a particular route. Even if track access rights could be obtained, operation across borders is often cumbersome and costly, requiring alternative or specialized equipment (as differences in, for example, power or track gauge often exist), training, and knowledge (e.g., of local language). In such instances, the shipment will be transferred from one carrier's train to another's at the border of two countries. Certain operations may be required at borders, where one of the border countries does not provide track access rights to rail carriers from the other border country or where partnership agreements for joint operation have been enacted. However, the time required for such operations may be reduced if two carriers, each of which is permitted or better suited to operate within its own country, were to collaborate on the shipment through information sharing.

Figure 3*a* illustrates such operations at a border. Carriers A and B operate in bordering countries. Assume that neither carrier is given track access rights to operate in the other's country. Carriers A and B

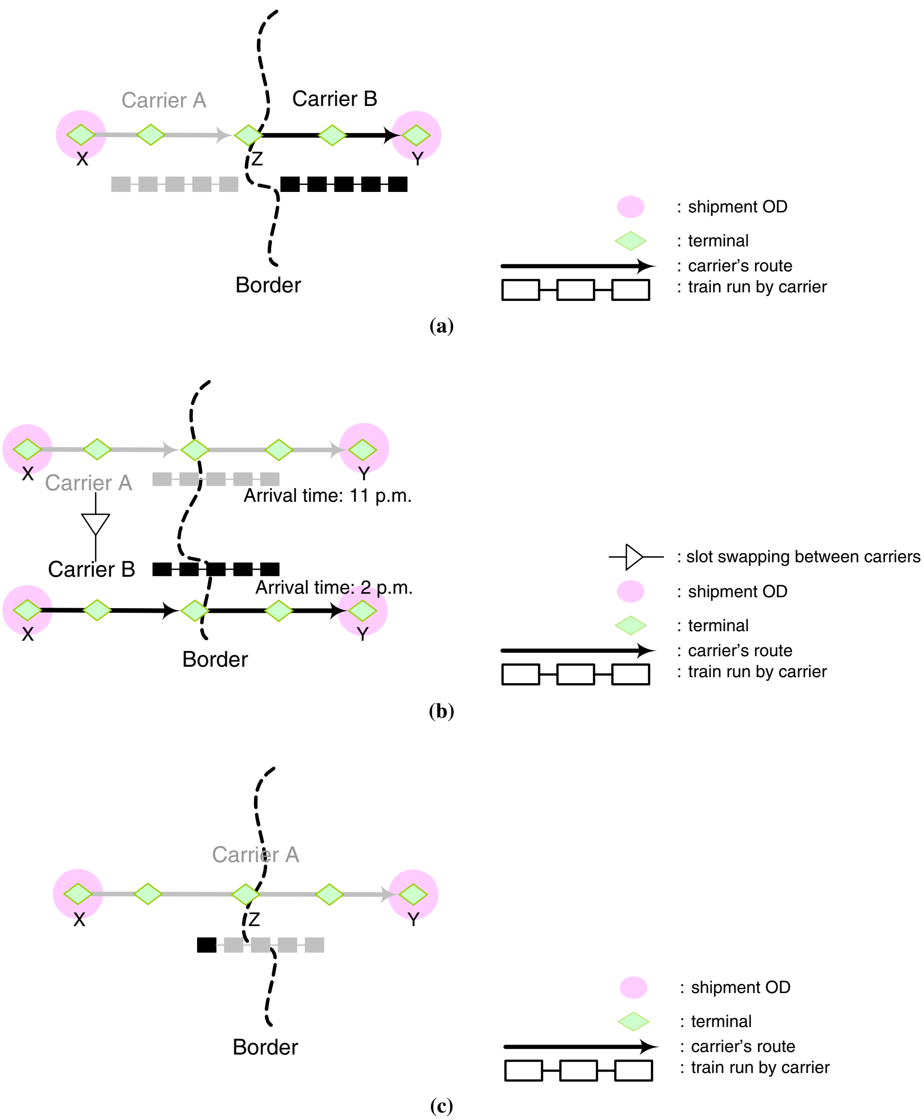

FIGURE 3 CDM strategies: (*a*) train slot cooperation, (*b*) train slot swapping, and (*c*) train space leasing.

co-transport a shipment from origin *X* to destination *Y*. The shipment is transported by Carrier A from origin *X* to terminal *Z,* which is located at the border between the two countries. The shipment is then unloaded from Carrier A's train and reloaded to Carrier B's train. Alternatively, the shipment can be transported directly from origin to destination if the carriers are willing to share their rolling stock. It is also possible that they might choose to simply switch locomotives such that the locomotive running the train is owned by the carrier that is operating the train. This requires appropriately gauged railcars. Transport by Carrier B of the shipment continues until destination *Y* is reached.

Suppose a carrier is able to obtain track access rights in all countries en route, but the carrier has only enough cargo to fill a train a portion of the time. The latter implementation of the train slot cooperation method would allow two or more carriers to jointly use the train slot over time.

Train Slot Swapping

The train slot swapping approach allows two carriers, each of which owns a train slot, to exchange capacity rights for the slots. This can facilitate cooperation when one carrier has excess capacity in a slot and the other has newly arising need for transport along the other carrier's route. Alternatively, when two carriers have excess capacity in their train slots, each carrier might be able to improve its level of service by swapping train slots for given trains or given days of the week. Such swaps can also help the carriers to maintain delivery time windows promised to the shippers.

In Figure 3*b,* the train slots with the same O-D pair, shown in gray and black, are owned by Carriers A and B, respectively. The arrival time at destination *Y* is 11:00 p.m. on Carrier A's slot and 2:00 p.m. on Carrier B's slot. Suppose a delivery must be made by Carrier A between 1:00 p.m. and 6:00 p.m. Carrier A, however, will not make the deadline if it uses its own slot. Thus, Carrier A may exchange its own slot with Carrier B for the black slot that is not currently in use, thereby avoiding some penalties imposed by the shipper for late arrival. Carrier B may then choose to use the newly received train slot or may even choose to swap or lease it.

Train Space Leasing

Presume for a moment that slots are sold in bundles of time and must be purchased for every day of the week if purchased for a single day. It may be the case that a single carrier that owns a particular train slot cannot fill an entire train every single day of the week. The train space leasing approach proposed herein allows the carrier to lease a portion of the train capacity to other carriers. It is assumed that no carrier is willing to sell all of a train's capacity. That is, it is assumed that it would be more lucrative to swap train slots than to operate a train carrying only shipments from other carriers. A fixed percentage of the train's capacity will, therefore, be reserved for the train slot's owner. More than one carrier can lease a train's excess capacity. Through such an approach, the carrier who owns the slot can increase its revenue by opening the residual train capacity to other carriers. Figure 3*c* illustrates this cooperation method. In the figure, a train slot that is operated from origin *X* to destination *Y* is owned by Carrier A. Suppose a container must be delivered from origin *X* to destination *Y* by Carrier B. If the residual capacity (a single train car shown in black) of a train operating in this train slot can be leased to Carrier B, both carriers can benefit. That is, Carrier A gains additional revenue by charging Carrier B and Carrier B gains by renting space on Carrier A's train without having to operate a train.

SIMULATION-BASED FRAMEWORK

Analysis of the complex interactions over space and time associated with the movement of freight between O-D pairs over IM freight networks with rail services involving the cooperation of multiple carriers involves many difficult problems. As a result, it is very difficult to describe the problem using a quantitative optimization-based model. Therefore, a carrier collaboration simulation-assignment framework was developed to analyze and evaluate the proposed carrier CDM strategies that result in various IM rail freight services contemplated in the REORIENT corridor. The carrier collaboration simulation-assignment framework is shown in Figure 4. The simulation platform is employed to evaluate services (i.e., timetables) that are generated by optimization-based scheduling algorithms [described in Kuo et al. (*13;* A. Kuo, E. Miller-Hooks, and H. Mahmassani, Multiline train scheduling for inelastic and elastic demand, unpublished paper, 2008)] exploiting the chosen CDM strategy.

This carrier collaboration simulation-assignment platform extends an existing network modeling platform developed to analyze and evaluate proposed operational improvements and various IM rail freight services contemplated in the REORIENT corridor. Specific details of the simulation environment and other core network modeling and analysis capabilities developed to evaluate the effectiveness

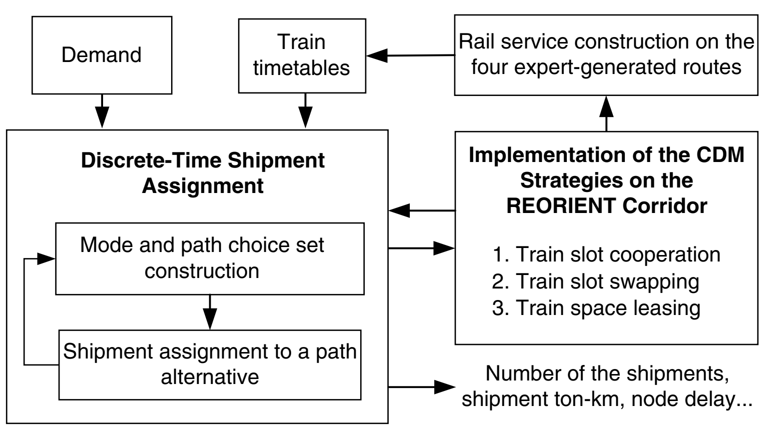

FIGURE 4 Carrier CDM simulation-based analysis.

of service scenarios and operational strategies in the REORIENT corridor are given in Arcot et al. (*14*) and Mahmassani et al. (*15*). This modeling approach integrates a mode choice modeling process within a network flow assignment framework. For a given specification of services and operational strategies, this platform and its extension, which explicitly recognizes multiple-carrier operations, provide detailed information on flows by mode and service between the various origins and destinations in the study area. An overview of the carrier collaboration simulation-assignment platform extension is given in Figure 4, followed by a more detailed description of its main components.

Implementation of CDM Strategies on REORIENT Network

The three proposed CDM strategies were used in creating mutually beneficial train timetables for the four expert-generated routes (Figure 5*a*). Each implementation results in a suggested timetable. In the train slot cooperation implementation (Figure 5*b*), the access rights to the expert-generated routes (i.e., ability to operate along the routes) are assumed to belong to one carrier. Thus, in this implementation, four carriers (one associated with each of the four service routes) can collaborate with one another. That is, a shipment is permitted to be transported by any of the four carriers.

In the train slot swapping implementation (Figure 5*c*), there are two carriers (Carriers A and B) operating train slots on the service routes. The train schedules for Carriers A and B were created by alternating slot assignments to carriers over time, resulting in an equitable distribution of train slots. In this scenario, to allow shorter delivery times, a shipment originally transported by Carrier A (or B) can be transferred to another train slot owned by Carrier B (or A) at any of the intermediate terminals.

In the train space leasing implementation (Figure 5*d*), as in the implementation of the train slot swapping strategy, there are two carriers (Carriers A and B) operating train slots on the service routes. Unlike in the former implementation, where shipments carried by either carrier can switch carriers, in this implementation, such swapping is restricted. Carrier A can transport its shipments in a slot owned by Carrier B, but the reverse is not permitted. This replicates the renting of space by a carrier on another carrier's trains.

Rail Service Construction on the Four Expert-Generated Routes

Once a strategy is adopted, train timetables are created. Given the suggested routes, frequencies, and the residual network capacity (i.e., remaining capacity after passenger and national traffic are assigned), train timetables are constructed for each carrier using a model that employs a binary multicommodity network flow program in generating a timetable for each carrier. Model formulation and proposed solution approach designed for its solution are given in Kuo et al. (*13*) and Arcot et al. (*14*). The model seeks to minimize an additive function of the delays from scheduled arrival times at the destinations and total operational cost along the corridor. Operational costs considered include the service charges that arise from swapping of locomotives, infrastructure charges, and track access charges. The decision maker's preference with respect to delay and cost minimization can be reflected by including appropriate weights on the

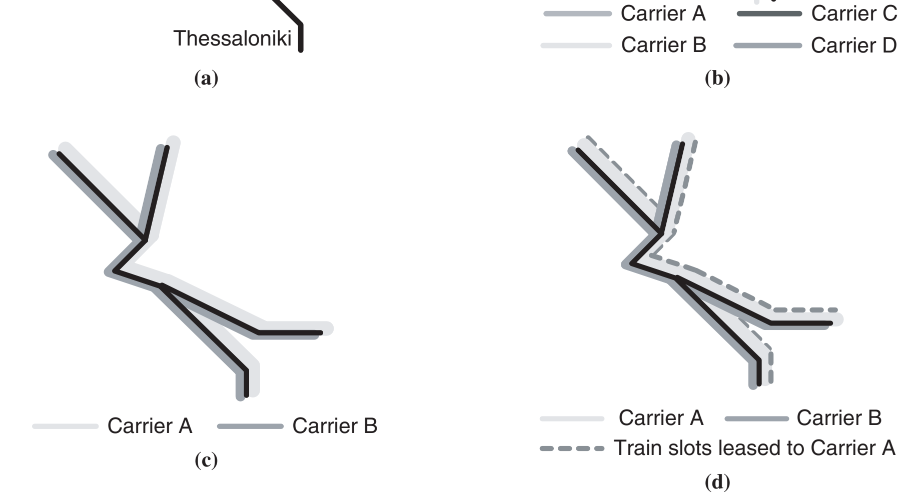

FIGURE 5 Collaborative decision-making strategies on the expert-generated routes: (*a*) four expert-generated routes, (*b*) four carriers in train slot cooperation, (*c*) two carriers in train slot swapping, and (*d*) two carriers in train space leasing.

delay and cost components of the objective function. In addition to constraints that ensure that enough train frequency exists to ship the demand along the routes between origins and destinations, the model contains other constraints related to the track capacity usage that must be imposed while constructing the train timetable. Such constraints include train siding, train overtaking, and track capacity usage constraints.

Shipment Assignment

A shipment is defined as the smallest unit of cargo (i.e., a container or carload) that will be transported from shipment origin to destination. The shipment will be transported along a sequence of arcs that are serviced by available modes with feasible IM transfers (referred to herein as a path alternative). Each path alternative is operated by a carrier. Link costs and travel times are assumed to be additive, as are node (i.e., terminal or intersection) costs and transfer delays. When faced with a joint mode and route choice set, a shipper will choose a path that minimizes the shipper's generalized cost of transporting a shipment from shipment origin at the time that the shipper takes responsibility for the shipment to its destination.

A dynamic freight assignment problem, addressed within the carrier collaboration simulation-assignment framework in an IM network, where carriers collaborate with one another in the transport of shipments is solved by determining the number of shipments for each alternative and the resulting temporal-spatial loading of shipments and conveyances. The framework features three main components: (*a*) freight traffic simulation, (*b*) a shipper behavioral model, and (*c*) path processing along with shipment assignments as permitted by acceptable CDM strategies. The freight traffic simulator depicts freight flow propagation in the IM network. This facilitates the evaluation of network performance for the given set of modal and route decisions made by individual shippers. The shipper behavioral component models a shipper's mode and route selection decision in a stochastic utility maximization framework with multiple evaluation criteria. The third component is intended to generate realistic route choice sets based on the chosen CDM strategy and to perform stochastic network loading required to solve the shipment assignment problem. Different CDM strategies will lead to the generation of different realistic route choice sets within the network. Very large service transfer penalties are imposed on the terminal nodes to prevent shipments from transferring to train slots operated by carriers that do not collaborate. For additional details on the first two components of this assignment framework, see Arcot et al. (*14*) and Mahmassani et al. (*15*).

Evaluation Criteria for CDM Strategy

Several evaluation criteria are proposed to assess the performance of the overall system under different service design options in the CDM scenarios. From the system's perspective, the objective is to attract more shipments to use the services and to transport these shipments in a more efficient way. That is, under the implementation of a CDM strategy, it is expected that more of the shipments will choose the proposed services than had chosen these services over truck under non-CDM operations because of improvements in distance or time required to reach the final destination. The performance is evaluated based on the number of the shipments attracted by the freight transport system and shipment tons and ton-kilometers.

PRELIMINARY FINDINGS FROM EXPERIMENTAL RESULTS

The train timetables for the proposed service routes generated by the optimization model described in Kuo et al. (*13;* A. Kuo, E. Miller-Hooks, and H. Mahmassani, Multiline train scheduling for inelastic and elastic demand, unpublished paper, 2008) employing each of the selected collaborative strategies were evaluated with the aid of the carrier collaboration simulation-assignment platform. Flows along the services in terms of tons and ton-kilometers were generated through the assignment mechanism of the simulation framework. Changes in flow can be used to assess changes in market share that result from the introduction of improved services that follow from the implementation of collaborative strategies for operating the rail system. Such comparisons can be made for the proposed services by considering results obtained from running the simulation model. Results of the runs are shown in Figure 6, along with accompanying Table 1. Specifically, in the figure, the improvements due to the introduction of the three CDM strategies described in this paper are assessed by subtracting the amount of flow in tons or ton-kilometers attracted to the services for which no collaboration among carriers is permitted from the amount of flow attracted to the services for which a given CDM strategy is adopted. Related numerical results are given in Table 1, where this difference is shown for each of the four proposed service routes by adopted CDM strategy. Additionally, this difference is divided by the flows produced where no collaboration is permitted and is shown as a percentage, indicating the percent increase in flows resulting from the introduction of each specific CDM strategy.

Findings

Train Slot Cooperation

The experimental results show that the total improvement due to the introduction of carrier collaboration in the form of train slot cooperation among four carriers, as measured in tons or ton-kilometers transported by newly proposed rail-based IM services, is on the order of 2% and 5%, respectively. That is, increases of 25,000 tons and 15,000,000 ton-km were predicted along the newly proposed services as a consequence of permitting train slot cooperation between various carriers. This increase was noted primarily for the T3 and T4 services. Not much change is indicated for T1 and T2 services. This can be explained by the significant overlap in T1 and T2 services, permitting shippers to choose the best of the two routes for their purposes and existing slack in their current timetables. With greater usage of T1 and T2 services, greater benefit could be gained from collaboration.

Train Slot Swapping

Significant gains (on the order of 24% and 40% in terms of tons or ton-kilometers, respectively) are predicted where the carriers jointly operate train slots on the service routes (i.e., where train slot swapping is permitted). This strategy appears to outperform other proposed CDM strategies, resulting in the greatest increase in market share for the IM rail freight services. This superior performance may be due to certain characteristics of the proposed services and O-D demand within the region. For example, most shipments travel relatively short distances on the IM network (on the order of three zone lengths).

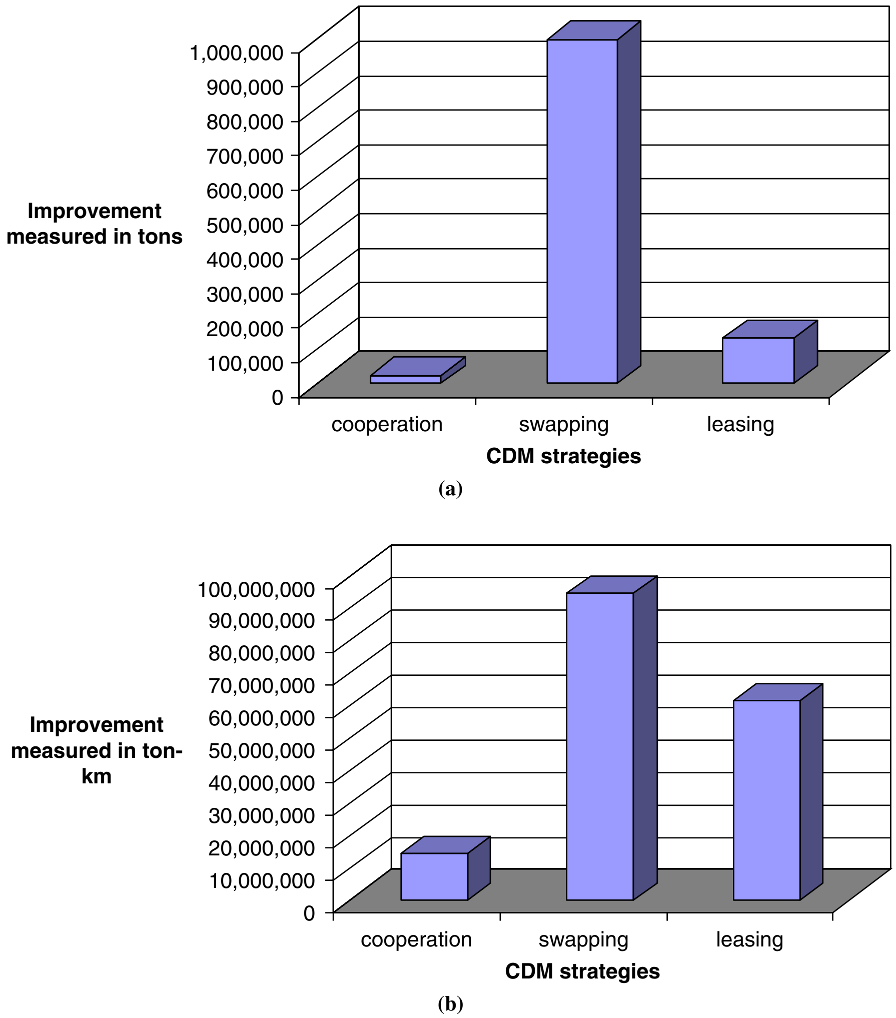

FIGURE 6 Results of running the simulation model: (*a*) improvement in tons by CDM strategies compared with noncollaboration and (*b*) ton-kilometers produced by scenarios with and without train slot cooperation.

With short travel distances, the probability of transferring between services is likely to be small. It is expected that if average travel distances were to increase, the relative performance of the train slot cooperation strategy would improve.

Note that the improvements due to the train slot swapping strategy are found primarily along the T2, T3, and T4 routes. This appears to be the result of the fact that most shipments are carried by T2 instead of T1; thus, better connections will exist for transferring to T3 or T4 from T2. In addition, the majority of shipments employ routes in the Czech Republic, Austria, Slovakia, and Hungary, where several services are offered. Transfers to other service routes and border crossings are required in these regions even for short travel distances. Because service schedules (timetables) offered with train slot swapping have greater frequencies than those offered with train slot cooperation, train slot swapping outperforms train slot cooperation. Note that the train slot cooperation strategy is tested assuming the operation of four carriers along four service routes, while the train slot swapping strategy is tested assuming the oper-

TABLE 1 Improvement on CDM Strategies Compared with Noncollaboration

	Train Slot Cooperation		Train Slot Swapping		Train Space Leasing	
Route	Tons (%)	Ton-km (%)	Tons (%)	Ton-km (%)	Tons (%)	Ton-km (%)
T1	785 (0.64)	99,605 (0.36)	124,241 (4.46)	593,107 (2.18)	2,302 (1.88)	616,168 (2.27)
T2	412 (0.24)	1,424,630 (3.77)	172,114 (25.7)	14,040,913 (55.78)	14,921 (9.49)	7,944,896 (25.41)
T3	13,108 (4.32)	6,804,861 (5.91)	316,887 (12.09)	33,384,719 (37.67)	27,552 (9.52)	22,698,017 (22.86)
T4	9,470 (2.53)	6,048,579 (4.55)	384,146 (43.09)	46,336,764 (50.05)	85,644 (28.69)	30,132,865 (29.69)
Total	23,775 (2.44)	14,377,675 (4.59)	997,388 (23.59)	94,355,502 (40.41)	130,419 (15.04)	61,391,946 (23.03)

ation of only two carriers. Despite this, such conclusions can be drawn, because collaboration among four, as opposed to two, carriers can lead to greater opportunities for collaboration and is, therefore, advantageous.

Train Space Leasing

Considerable increase (on the order of 15% in tons and 23% in ton-kilometers) in flows along the proposed services is predicted where the train space leasing strategy is applied. While large, this increase is significantly smaller than the increase predicted for the train slot swapping strategy. This may be because only one carrier is permitted to lease some subset of train slots from other carriers. If additional swapping options were permitted (e.g., a greater percentage of a carrier's train slots could be swapped or multiple carriers were permitted to swap their train slots), improvement in the performance of this strategy would be expected.

CONCLUSIONS

Three CDM strategies are proposed (train slot cooperation, train space leasing, and train slot swapping) for operating a multicarrier rail-based IM freight transport system. The strategies were assessed through a carrier collaboration simulation-assignment framework to manage collaboratively competing demands for the use of the infrastructure. Experiments were run to assess the potential impact of employing such strategies within proposed services along the REORIENT corridor, a real-world international, rail-based IM freight transport network. Results of these experiments indicate that the proposed strategies are expected to result in significant improvements in terms of shipments that are attracted to the proposed services. The best-performing CDM strategy (the train slot swapping strategy) led to a more than 40% increase in terms of ton-kilometers attracted to the services.

Like other CDM strategies, the proposed strategies result in a win–win situation for all parties. In addition to attracting more demand, cost savings in terms of rolling stock and labor and reduced shipment delays can be achieved. To realize the potential benefits through implementation of these strategies in actual rail operations, operational information of competing carriers must be shared among members of the alliance. An authority jointly selected by members of the alliance would work on behalf of the alliance. The shared information is provided to facilitate the assignment of resources to carriers with transportation needs.

Information required to implement the first of the three proposed strategies, train slot cooperation, may include existing itineraries of trains operated on the network and knowledge of the desired shipments that cannot be transported on a member's scheduled trains. Information that is needed to implement the train slot swapping strategy, the second proposed CDM strategy, includes train slots that carriers are willing to swap for train slots of competing carriers, desired train slots belonging to competing carriers, and knowledge of competing carriers' new transportation needs. Information that is required to employ the train space leasing strategy, the third collaborative strategy, includes excess train capacity of trains operated by carriers in the alliance and the details of shipments for which carriers seek transport. Rules for allocating available resources, such as available train capacity and train slots that can be swapped, to the carriers of the alliance for each carrier must be constructed and agreed upon.

Likely objectives of the alliance in creating rules for implementing the CDM strategies are to maximize total revenue (through efficient use of track capacity) and to ensure equality in allocating or re-allocating resources and in revenue distribution. Mechanisms that might be employed to create a collaborative environment in which the incentives for competing carriers to operate despite the need for sharing proprietary information about their business are as follows:

1. The number of train slots traded in by a carrier must be equal to those assigned from the authority. For all carriers in the alliance, the value to a carrier of the train slots traded to other carriers must equal, or nearly equal, the value of train slots received from other carriers for a given time period.
2. Carrier A, which leases space on a competing Carrier B's train, will give priority to Carrier B when that carrier seeks to lease space on one of Carrier A's trains. Alternatively, Carrier A can pay Carrier B to lease space with no further obligation.
3. Two carriers will only agree to the joint operation of a train slot if it is beneficial to both. Such benefit can be derived through payment received from the shippers directly or by one carrier to another.
4. Any train slot purchased jointly by two or more carriers will be shared by the carriers in proportion to the fee that the carrier pays.

Such rules for implementing the proposed CDM strategies will promote fair and efficient resource sharing among multiple competing carriers, where no carrier will be worse off as a result of the collaboration. The revenue resulting from delivering shipments must be equitably distributed among the carriers that operate the trains or own the shipment delivery contracts. One approach that could support a fair distribution of revenue among the carriers would be to ensure that the carrier operating the train on which a competing carrier's shipment is transported is compensated for more than the marginal cost of including the shipment on the train.

More sophisticated collaborative mechanisms can be proposed and assessed. For example, three or more carriers might jointly operate separate portions of a route, where they might swap train slots. There may be a limit on the number of swaps that is permitted between any pair of carriers. Train capacity can be leased to more than one carrier. Additionally, these experiments included only those scenarios in which collaboration is permitted among all carriers on any route. However, it may be the case that only a portion of the carriers may enter into collaboration agreements along a given route. Assessment of the potential of these and other more advanced CDM strategies would require further investigation.

ACKNOWLEDGMENTS

This paper is based on work supported by the REORIENT project, a Coordinated Action project supported by the European Commission's 6th Framework research program. The authors are grateful to several graduate research assistants who contributed considerably to the development of the platform and its application to the REORIENT network. The authors have benefited from the collective contribution of the REORIENT consortium partners, especially Demis, bv (Delft, the Netherlands) for data collection, and the Institute for Transport Economics (TOI, Oslo, Norway) for various aspects of the work, especially the contributions of Johanna Ludvigsen. The work presented in this paper remains the sole responsibility of the authors.

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The Railroad Operating Technologies Committee sponsored publication of this paper.