Modeling and Solving the Intermodal Freight SErvice Network Timetabling problem (IFSENT)

Allan Larsen Michael B. Pedersen

The Centre for Traffic and Transport, Building 115,
The Technical University of Denmark,
DK-2800 Kgs. Lyngby – Denmark.
{ala,mbp}@ctt.dtu.dk

1 Intermodal Freight Transport

When reading the European Union's White Paper on transport policy for 2010, four main topics are pointed out as being of great importance. These are; 1) Shifting the modal balance, 2) Eliminating bottle necks, 3) Placing users at the heart of transport policy, and 4) Managing the globalization of transport. Topic 1) has attracted a lot of attention because of the ongoing discussions on whether rail transportation can regain market shares from the trucking industry in Europe. Compared to the US, where 40% of the total freight is accounted to rail haulage, only 8% of European freight is hauled by rail. Many point to the cause of this remarkable difference being the large amount of trans-continental freight moving from the Pacific ports to the Atlantic ports and the large flexibility on the US rail tracks due to the small amount of passenger transportation.

The discussion of modal shift sometimes seems somewhat misinterpreted. It seems impossible to encourage a shift from truck to rail, when most locations are not within proximity of rail services. It seems more correct to talk about modal integration, where trip chains consist of links operated by different modes. A classic example is the trip chain starting with a short haul truck link (drayage move) followed by a long-haul rail move and ending by another drayage move. The long-haul truck move is removed and thereby limits the contribution of congestion of the European highways. It is a commonly accepted fact that railways are not able to compete with trucks on short distances, although how short these distances are can be discussed, which indicates that for rail haulage to succeed it needs to integrate its operations with the trucking industry in order to compete on long haul transportation.

For an intermodal trip chain to compete with a direct unimodal service it must generally either be as fast or as cheap. In the trip chain example above two transfers should be made. These are time consuming, and hence the rail haulage must either be faster than the equivalent truck unimodal haulage or cheaper in order to attract time insensitive customers. Rail companies should be able to compete on the transport cost. The long haul train link generally consolidates loads from many trip chains and hence could profit from economies of scale. However, the average speed of freight trains in Europe is 18 km/h (app. 11 mph.). This is partly due to the subordination of freight trains to passenger trains, and partly due to the missing integration of the European rail systems. Hence, rail transport looses most of its competitive edge to inflexibility and slow transportation.

Generally any type of consolidated transport, both intermodal and unimodal requires dedicated management of the inevitable transfers in the network. It is imperative that effective trip chain integration is obtained in order for consolidated transport service networks to compete against direct transport. As mentioned above the trip link transfers can be time consuming and also add additional costs to the transport movement cost. Hence, efficient cost and time management of transfers should prove to affect the modal integration.

2 Definition of IFSENT

In this research we consider the possibilities of saving transfer time by optimizing the timetables of the trip links in a service network. The total transfer time can be split op into actual transfer time, i.e. the time it takes to perform the transfer between vehicles, and the waiting time. The waiting time can be accredited several sources, however the interesting one is the lack of synchronization between two links of a trip chain. This is also referred to as frequency delay. A typical example of poor synchronization is a link departing just prior to the arrival of another link. This often leads to either a missed transfer possibility or a very long frequency delay.

Poor synchronization of links in a service network can lead to unnecessary long travel times between any pair of Origin (O) and Destination (D) in the network, where a significant part of the total travel times can be accredited frequency delays. Hence if the timetables of the service network are synchronized either a better service may be offered between some O-D pairs (i.e.

either promise of shorter delivery times or a more robust service network less subject to major disruptions).

In this research we formulate an optimization model that designs timetables within a service network. We assume at first that the service network is given. That means we are going to decide on the number of departures for each service and their departure times, but not the connections between terminals.

3 Modeling the IFSENT

Since the IFSENT problem has to output timetables we need to include the time dimension into our model. We consider a network as shown in figure 1.

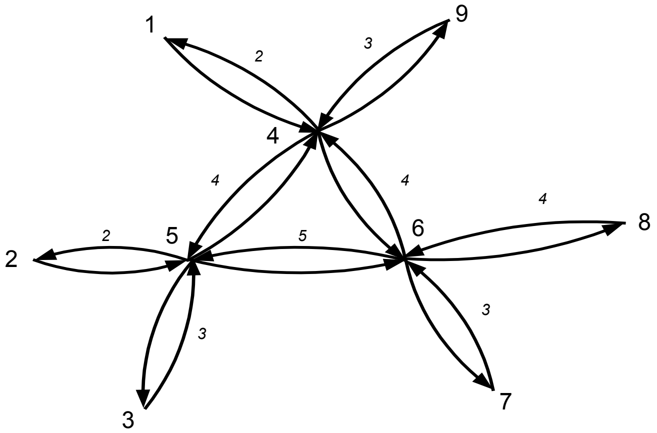

Figure 1. Example of a geographical lay-out of a service network.

This network does not contain any information on timetables, but only a relation between the 9 terminals and a travel time between them. We choose to expand this network it into a time-space network as shown in figure 2 by duplicating each terminal for as many time periods as included in the time-space network and adding the link relations over time between the terminals. Time-space networks have been used for service network design models before. Kim et. al. [1999] formulate a service network design model for an express package delivery problem using time-space networks.

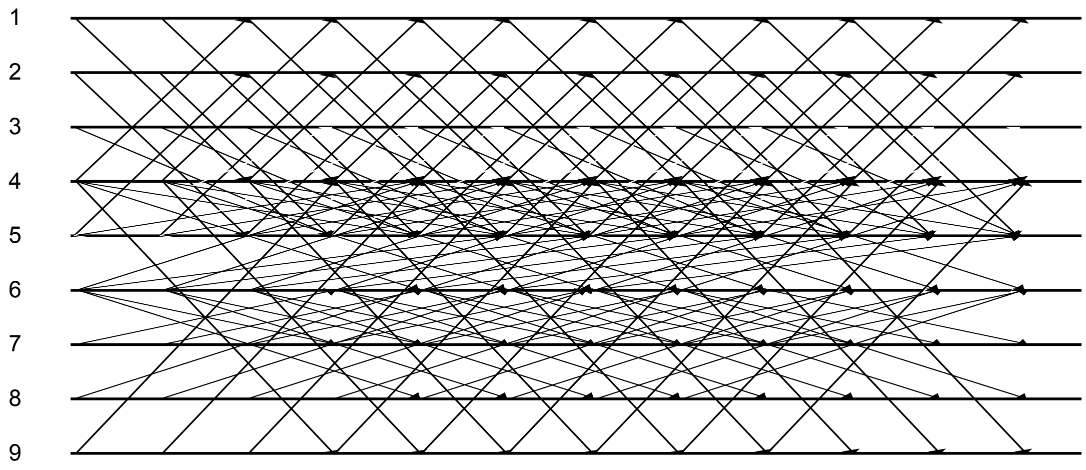

Figure 2. Time-space expansion of the service network in figure 1.

As can be seen in figure 2, the number of nodes and arcs in the network has increased significantly. Special care must be taken when formulating these time-space networks in order to avoid intractable problems (which likely occurs for even reasonably small problems).
Each arc in figure 2 represents a possibility to make a vehicle move in time from one terminal to another. The problem now is to decide which arcs to use and hereby to produce a timetable for each service. We model the choice of arcs by assigning a variable, $y_{i,j}$, to each arc, where $i, j \in N$, where N is the set of nodes, and $(i, j) \in A$, where A is the set of arcs in the time-space network. The $y_{i,j}$ variables take on the value 1 if the arc is used and 0 if not. The usage of an arc is associated with a fixed cost $f_{i,j}$ which captures the cost of operating a vehicle between the two terminals at the given time. In order to control the amount of flow we introduce decision variables, $x^p_{i,j}$, which represent the flow between nodes $i, j \in N$ of demand type p. The set P defines instances of pairs of nodes $p=(o,d)$, $o, d \in N$, so that supply from origin node o can meet the demand at destination node d. Note that the origins and destinations are related to both space and time. For each link $(i, j) \in A$, we have $|P|$ number of flow-variables, one for each combination of origin and destination.

We consider two objectives for the IFSENT. One is, given a freight OD-matrix, to minimize the weighted sum of the total network waiting time. This objective does not consider cost minimization and will therefore produce timetables with very high service at outrageous cost unless budget restrictions are introduced. However, using this objective with budget constraints will result in very short travel times along the main freight corridors at a risk of leaving small freight flows with a very low service level. Another objective is a cost minimization objective, where we minimize the sum of the costs of using the chosen links ($y_{i,j}$=1) in the network and eventually some variable cost connected to the flow variables ($x^p_{i,j}$). Solving the IFSENT using a cost minimization objective would result in the least cost timetable without any consideration for service quality. The service quality may be added as constraints stating the maximum time allowed for a transport between an OD-pair.

Which one of the two objectives to choose depends on the type of the network. The first approach is appropriate for intermodal public transport networks. These networks often have to offer the best possible service (i.e. shortest possible travel times) given some budget constraints (e.g. government subsidization). The second objective resembles the cost structure of a freight transport network. E.g. in intermodal express package networks such as UPS, FEDEX etc. delivery promises are given for e.g. 24 hours and 48 hours. Similar products are provided by several LTL operators that offer e.g. a five day delivery from a terminal in Denmark to a terminal in Spain. The guaranteed delivery times can then be added as maximum travel time constraints (service constraints).

There are many constraints that can be added to the IFSENT. However, in our basic formulation we will add only flow conservation constraints and link capacity constraints. Hence our formulation is exactly the same as the arc-formulation of the network design problem as presented in Crainic and Laporte [1997]:

$$Min \quad \sum_{i,j} f_{i,j} \cdot y_{i,j} + \sum_{i,j} \sum_{P} c_{i,j} \cdot x^p_{i,j} \qquad (1)$$

$$s.t.$$

$$\sum_{j} x^p_{j,i} - \sum_{j} x^p_{i,j} = d^p_i \quad \forall i \in N \; and \; p \in P \qquad (2)$$

$$\sum_{P} x^p_{i,j} \leq u_{i,j} \cdot y_{i,j} \quad \forall (i,j) \in L \qquad (3)$$

$$y_{i,j} = \begin{cases} 1 \; if \; link \; (i,j) \; is \; used \\ 0 \; if \; not \end{cases} \qquad (4)$$

$$x^p_{i,j} \geq 0 \; \forall (i,j) \in L \; and \; p \in P \qquad (5)$$

The objective function (1) minimizes the total system cost consisting of the arc usage cost $f_{i,j}$ and some variable cost on the flow. The variable cost could consist of a depreciation factor on the value of the freight, inventory cost if holding freight over time periods in a terminal or even cost of using another carriers link if the freight is outsourced. Constraints (2) are flow balance constraints whereas constraints (3) are link capacity constraints. Constraints (4) and (5) are binary and non-negativity constraints respectively.

In the original formulation of the network design model the set *P* represents the set of commodities to flow in the network. However, we consider only a single commodity (e.g. parcels or containers) and use the multi-commodity aspect of the model to model node pair specific demand. Since a node pair represents two terminals at different points in time we can set the OD-demand according to the promised level of service (e.g. 15 time periods from delivery at origin terminal to pick-up at destination terminal) and hereby automatically include the maximum travel time constraints in the definition of the set *P*.

The presented model is still very general and can not capture all operational constraints in designing service network timetables. Especially fleet balancing constraints need to be included in the model. Other constraints may be restricting split deliveries. Which additional constraints to add will depend on the application.

4 Solving the IFSENT

We have tested different configurations of the arc-based model with different sets of constraints using variable size network cases and trying to solve the instances to optimality. We use the commercial MIP solver XpressMP to solve the instances. The results give an indication of the network sizes that can be solved to optimality. We show that only for small networks with about 5-15 terminals and 20-30 time-periods can be solved using standard MIP software. The simple arc formulation proves to be intractable and alternatives such as path or tree formulations must be considered. However, also the alternative formulations have severe limitations on the solvable network size.

Real-life applications consist of at least 50 terminals. Furthermore, more than 50 time periods must be used in order to have reasonable representation of the time horizon. Hence we have developed a heuristic that are able to solve real-life instances of the IFSENT. The method used is inspired by Ghamlouche et al. [2003] who proposed a cycle-based neighborhood structure to be used with meta-heuristics. The neighborhood structure was applied on multi-commodity network design problems. Another interesting heuristic approach is presented in Fischetti and Lodi [2003]. Here a standard LP solver (Cplex 7.0) is used as a 'black box' in order to solve problem subspaces within an external branching procedure. The authors report that high-quality results can be obtained faster than when applying Cplex directly. Given the difficulty of finding good bounds for network design problems this method will be interesting to investigate further for the INSENT.

5 Future work with IFSENT

When operating a regional and national freight transport service the value of being able to respond / react to real-time variations to the demand behavior is of paramount importance. (or potential upgrade of one service to an alternative one with higher capacity) if the resources allow this.

During operational disturbances such as bad weather, technical problems and staff sickness often disrupt the schedules. Therefore, we believe that the freight business will gain immensely from having a simulation tool that can be used for analyses of the impact of disruptions and robustness of the current timetable / service network design.

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