Discrete optimization in rail transport
An extended abstract

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1 Introduction

Fewer than twenty years after the invention of the steam engine in 1785, the first steam driven locomotives were constructed. During the first decades of the nineteenth century, rail traffic increased drastically, especially in coal mining, and for freight transportation. However, the railroad companies quickly started public passenger transportation. In the 1830’s, most European railroads were already being built in order to transport passengers.

For the efficient use of the new technology in this early age of railroad systems, it was soon necessary to develop detailed plans for the schedules of the public transportation services. The planning process started with the definition of the routes and lines of the railroad network. To attract customers, regularly serviced routes connecting stations had to be guaranteed. Assignment and dispatch of locomotives, railroad carriages, and personnel became more and more involved. These problems of the early ages of rail traffic continue to be relevant for modern railroad systems.

These days, the number of passengers transported on modern railroads is increasing [16]. New train systems lead to a new age of passenger transport. Because of these improved services, passengers can travel fast and comfortably to the desired destinations. Due to the increasing mobility and due to congested roads, public railroad networks are still expanding. In Europe, there are plans to improve the international railroad infrastructure [31]. Future train systems promise speeds up to 500 km/h [30].

On the other side, public freight transport on the rails is decreasing¹. Trucks provide much more flexibility for the transportation management, and the current pricing is much in favour of road transportation. Raising such prizes by political decisions is a highly sensitive topic, but due to ecological and economical arguments on larger scales the situation may change in the long run. By now, the development of improved combined traffic systems did not result in a significant shift of market shares from road to railroad systems. However, for private enterprises with large amount of heavy internal freight transport, rail traffic provides an economically reasonable means of transportation.

Nowadays, since computers are integrated in the planning process, sufficient data for discrete optimization models are available for the optimization of international, national, and local rail transport, at least in principle. For a growing number of railroad applications these models can be solved combining modern optimization techniques and the increasing power of computers. In public research programs,

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¹A significant example for this process is the decision of the German mail company Deutsche Post AG to stop rail transport and to start transport by truck.
e.g. in many traffic oriented interdisciplinary national and European projects, the financial support is pooled which is necessary to transfer this knowledge and technology to transportation companies.

Methodology and Overview

Here, we provide references to recent developments and the use of mathematical programming methods in rail transport planning within the last 5–10 years. We will focus on some new aspects of the planning process, primarily in public passenger transport, and on recent results which lead to more comprehensive planning and optimization of railroad network systems (see also [7]). We mention some of the most challenging problems in rail transport which now can be modeled and solved by discrete optimization techniques, in particular, the computation of the line plans, train schedules, and schedules of rolling stock. Many other issues occurring in rail transport, like pricing, seat allocation, and in fact most issues particular to freight transport are omitted in view of the scope and size of this short overview. Two more detailed recent surveys of discrete optimization techniques in public passenger transport are Bussieck, Winter, and Zimmermann [10] and Caprara, Fischetti, Toth, and Vigo [13].

2 Planning Rail Traffic in Passenger Transport

Improvements in the process of planning traffic, e.g. the development and evaluation of operation plans based on analytic models, are stimulated by the increasing success of railroad passenger transport. In densely populated countries like the Netherlands, Switzerland, or Belgium and for long distance railroad services in other countries, e.g. in Germany, a regular interval oriented, periodic or cyclic train schedule forms the backbone [19] of the railroad transport system. Such train schedules based on a system of lines with fixed frequencies were introduced at the beginning of the twentieth century in urban public transport. The train schedule serves as the most important interface to the passengers using the railroad transport system. It defines the cornerstone for all subsequent planning tasks. Because of the complexity of the railroad transport system, the process of planning traffic is hierarchically organized, and several stages have to be passed before the train schedule can be created.

Network Planning

The design of a railroad network from scratch is impossible in a historically grown infrastructure, but due to high speed trains, new stations, capacity extension and reduction the railroad network is changing. In particular, possible decisions have to be evaluated, recommended or rejected. In fact, such decisions are mainly based on political reasoning.

Public transport companies offer several railroad subsystems to meet the requirement of their customers. Typically, fast long-distance trains (Intercity), trains connecting district towns (Interregio), and regional commuter trains operate in the railroad network. The set of stations where a train of such a subsystem should stop has to be determined. This decision is based on technical constraints as well as on an economical analysis.

Models for railroad passenger transport have to include passenger demand data. A convenient and useful representation of these data is the origin-destination matrix (OD-matrix). How to find a reasonable estimation of the OD-matrix from counting passengers on the edges of a railroad network or from spot tests with passenger interviews is one of the first problems [20, 29].
Line Planning

Lines are the fundamentals of periodically scheduled systems. A line is a route in the railroad network connecting two terminal stations. The frequency of a line is the number of trains that serve this route in a fixed time interval (e.g. in one hour). The line optimization problem consists in choosing a set of operating lines and its frequencies to serve the passenger demand and to optimize some given objective. Particular focus lies on minimizing the inconvenience for passengers in the transportation system by calculating line plans with a maximum number of direct travelers [9, 34]. However, the process of privatization of state-owned railroads enforces the efficient utilization of resources. For that objective, cost-optimal line planning is modelled [15, 16]. The overall cost of a transportation service is primarily based on the dispatch of rolling stock and personnel. Besides the routes and the frequencies, in the cost-optimal line planning approach, one has to find the optimal number of coaches per train, based on trivial estimates of the circulation of rolling stock. For a detailed discussion of line planning we refer to Bussieck [8].

Train Schedule Generation

The generation of train schedules is divided into two parts. The first part consists in finding a regular periodic train schedule based on a proposed line plan and corresponding fixed frequencies of the lines. The arrival and departure times of the trains have to satisfy certain regulations, e.g. the safety conditions defined by the company [27, 28]. An objective for this construction is to minimize the total transit time of the passengers, i.e. the time spent by the customer in the system, including traveling time and waiting time [24]. Similar to the line planning problem, cost aspects also become more and more important for train schedule generation. Particular cost models take the circulation of locomotives and coaches into account [12]. The second part, the domain of the experienced human planner, consists in adjusting the proposed regular train schedule to meet an abundance of local requirements (rush hours, splitting of lines, etc.) and peculiarities [14, 35]. We consider train schedule generation in an ongoing project [11].

Schedules: Rolling Stock and Personnel

All itineraries have to be served by a train consisting of a locomotive (or railcar) and some carriages. Difficulties in scheduling the rolling stock include the restricted assignment of the material, the maintenance, and the location of the depots. All trains have to be equipped with a crew including engine-driver and accompanying staff. At this planning stage, the cost can be computed, and hence the objective is to minimize the cost subject to all cumulated conditions and requirements [18, 26].

Real-time Traffic

After all the strategic and tactical planning, one has to ensure the realization of the schedules. For example, external influences will result in delayed trains. Minor irregularities in the execution of a schedule may imply severe disturbances, and it may well be necessary to recompute some schedules online. The inherent difficulty of discrete optimization problems with severe real-time constraints is a quite recent research subject [4, 5]. For a more detailed survey, we refer to Winter and Zimmermann [33].
Hierarchy of Planning

The planning tasks were described above within a hierarchy of subtasks, i.e. the generation of OD-matrices was followed by line planning, line planning was followed by train schedule generation, and train schedule generation was followed by scheduling of rolling stock and personnel. This top-down approach has certain advantages. The complete problem decomposes into subproblems of manageable size which can be solved by using currently available methods and hardware. In addition to the technical advantages, this decomposition supports the various planning time intervals which arise from another classical subdivision consisting of strategic, tactical, and operational procedures [1]. Operational decisions reflect the day-by-day activities and the disturbances when executing the schedules. Tactical planning addresses resource allocation for the period from one to five years ahead. Most of the problems in railroad transport systems occur at the tactical level. Strategic planning focuses on resource acquisition for the period from five to fifteen years ahead. Network planning problems may be viewed as the main strategic issues, but, in order to evaluate possible strategic alternatives, the subsequent stages including at least line planning and train schedule generation have to be considered.

The disadvantages of the hierarchical planning are obvious, since the optimal output of a subtask which serves as the input of a subsequent task, will not result, in general, in an overall optimal solution.

3 Planning Issues in Freight Transport

Although selected planning processes are tangent or overlapping, planning freight transport is completely different to planning passenger transport. Models from passenger transport are of limited use, since they are based on quite different assumptions, e.g. freight trains are dispatched on demand rather than according to a train schedule. Even the usually shared railroad network has to be planned according to the respective needs. Apart from the relatively small amount of freight trains directly connecting the origin with the destination of a railcar, trains have to be split and cars have to be regrouped according to their final destination at intermediate marshalling yards. In order to avoid the time consuming, and since expensive reclassification, i.e. sorting and regrouping of trains in each yard, rail cars are assigned to blocks. A block is attributed with its own OD pair and cars are not regrouped on the corresponding leg. For a more detailed discussion and models of blocking we refer to [6, 25]. Not only cars have to be assigned to blocks but also blocks have to be assigned to trains. This so-called makeup-policy is already discussed in [2]. Of course, decisions at this stage and the planning of the circulation of empty cars will mutually influence each other [3].

Here, we cannot consider freight transport in more detail. However, we will refer to some exemplarily planning task not appearing in this form in passenger transport which we consider in an ongoing project [22].

Locomotive Scheduling

Briefly, locomotive scheduling is the assignment of engines to trains. Only few attention has been given in the literature to this issue, and if any, only trains subject to a train schedule were considered [17, 18, 32]. For a recent approach to huge problem instances we refer to [21].

However, there need not exist a train schedule in rail freight traffic. Private or industrial freight railroad companies are charged with the internal goods transportation for e.g. steel mills, container terminals or in chemical industry. Only a small fraction of the trains is scheduled on a regular basis, instead, locomotives have
to serve transportation requests that arrive on demand which is known only a few hours before the request’s due time. Such a request is given by origin and destination tracks, a time window, the size of the load, and a set of admissible locomotives. The objective is to construct for a given planning period of, say, one working shift, a schedule for each locomotive, such that each request is served within its time window by exactly one feasible engine that never exceeds its tractive power. For most applications it is reasonable to consider minimization of total time or distance traveled by the locomotives [23].

References


