بسم الله الرحمن الرحیم

برنامه ریزی حرکت قطارها

فصل ۱۵: برنامه ریزی خطوط مسافری

Line Planning Problem

مدرس: دکتر مسعود یقینی

پائیز ۱۳۸۹

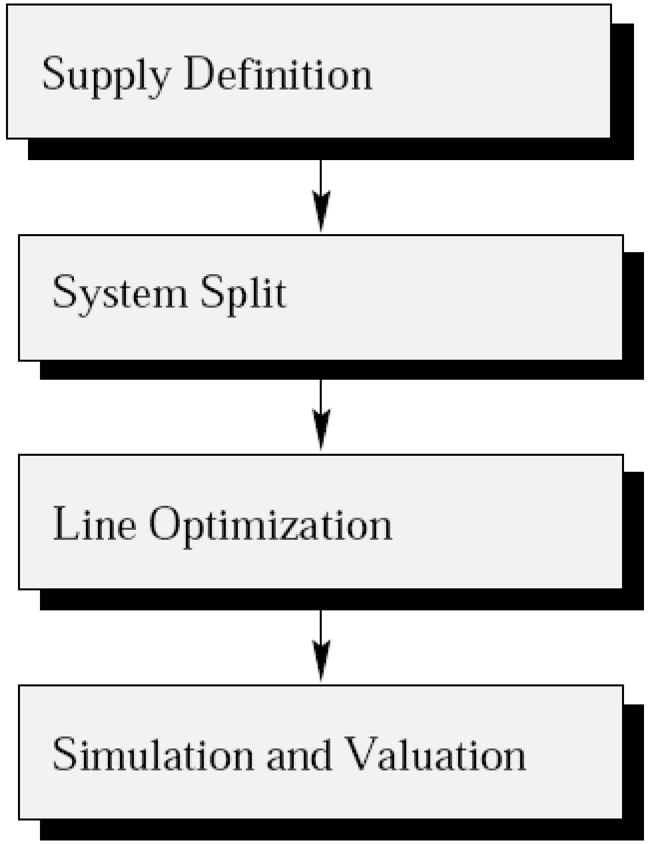
Outline

- Introduction
- Supply Networks
- System Split
- Line Optimization
- Simulation and Valuation

Introduction

Introduction

- A framework for line planning:



Introduction

- ***Supply definition***
  - Public transportation is split into several ***services*** to meet the requirements of their customers.
  - The aim of the supply definition is the decomposition of the global transportation network into several **supply networks** or ***supply* systems**.
  - Railroad companies offer different services includes: ***Inter-City, Inter-Region, Local trains***
  - The problem of finding a line plan can be independently performed on the different supply networks.

Introduction

- ***System Split***
  - The determination of a line plan should serve the ***transportation demand*** with an efficient usage of resources at a high level of quality.
  - Let T is a $n \times n$ origin-destination demand matrix, n denotes the number of stations in the transportation network
  - *Let* $T^{a,b}$ presents the number of passenger traveling from station a to station b.
  - A procedure that distributes the passengers (demands) among the different supply networks is the main idea of this ***system split***

Introduction

- ***Line Optimization***
  - The ***line optimization problem*** consists of finding a set of operating lines, given by ***routes*** and ***frequencies***, subject to certain operational constraints that optimizes a given objective.
  - Several different objective functions are proposed:
    - Minimizing the operational cost with respect to a given level of service and quality.
    - Maximizing the level of service for fixed operational cost
    - A reasonable approach to improve the level of service is to minimize the ***total travel time*** of all passengers.

Introduction

- ***Line Optimization*** *(cont.)*
  - At the line optimization stage there is no train schedule, hence the exact waiting time while changing lines is unknown.
  - Changing lines itself is a major inconvenience, hence the line plan which provides a minimum number of ***changes***,
  - Line plan provides a maximum number of travelers on direct connections (***direct travelers***).

Introduction

- ***Simulation and Valuation***
  - In a final analysis the line plans of the several supply networks will be combined.
  - The behavior of the passengers will be simulated and the interaction of the line plans will be valued by calculating different reference numbers.

Supply Networks

Definition of Supply Networks

- In the past
  - Railroad companies offered ***single connections*** with fast trains and some local trains to meet the requirements of their customers.
- Nowadays
  - The core of a refined service is derived from ***line-based connections*** for long- and medium distance travelers as well as for local transportation.
- German railroad have the following subdivisions:
  - ***InterCityExpress or InterCity***
  - ***InterRegio***
  - ***Regional Express or AggloRegio services***

Definition of Supply Networks

- ***InterCityExpress/InterCity (ICE/IC)***
  - Trains of the ICE/IC system connect principal centers of a country.
  - One of the remarkable features of these trains is the comfortable equipment with dining car, phone, and other board services.
  - The average distance of adjacent stations is about 60 kilometers.
  - The average transit speed is about 150 kilometers per hour and up to 250 kilometers per hour.

Definition of Supply Networks

- ***InterRegio (IR)***
  - IR trains connect principal centers as well as district towns with an average transit speed of 90 kilometers per hour.
  - The average distance of adjacent stations is about 60 kilometers.

- ***Regional Express Train/AggloRegio (AR)***
  - Lines in such a system are designed for local transportation, act as feeder service for long-distance connections

Definition of Supply Networks

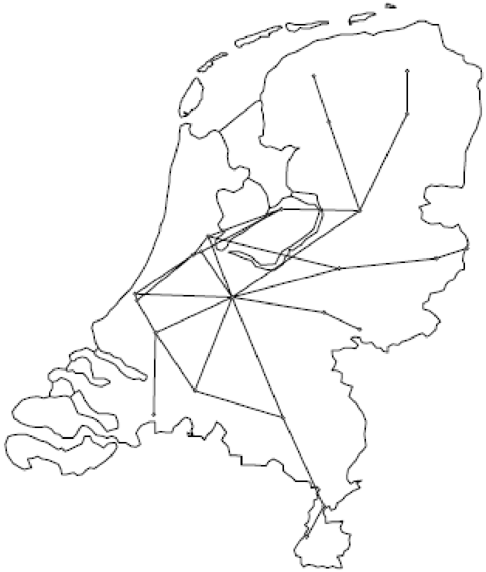
- ***Supply Networks***
  - The different supplies, offered by the railroad company, suggest a logical partition of the physical track network in so called ***supply networks***.
- ***The Graph:***
  - a finite graph $G_X = (V_X, E_X)$ is modeled the ***supply networks*** and the ***global railroad network***
  - where X represents the particular system (e.g. $X \in \{IC, IR, AR\}$).
  - V_X : the set of nodes that represents the stations of the supply network
  - E_X : the set of edges, that represents the connecting routes of adjacent stations.

Definition of Supply Networks

- An edge $e \in E_X$ in general may consists of a sequence of tracks and stations.
- G_X may be directed (e.g. networks with one-way tracks) or undirected.
- For simplicity, we assume an undirected supply network, but all remaining models and methods can be easily extended to the directed case.

Definition of Supply Networks

- Supply networks of the Dutch railroad



InterCity

InterRegio

AggloRegio

Definition of Supply Networks

- The decision, if trains of the IC, IR, or AR system stop at a particular station *v* is based on the infrastructure of this station as well as on the volume of traffic at *v*.
- Usually, for railroad networks we have a hierarchical arrangement of the supply networks, like

$$V_{\mathrm{IC}} \subset V_{\mathrm{IR}} \subset V_{\mathrm{AR}}$$

- The supply networks are more or less disjoint.

Definition of Supply Networks

- Certain attributes of the edges $e \in E_X$ in a supply network $G_X = (V_X, E_X)$, e.g. the ***ride time*** in minutes, are sensible within the supply networks only,
  - e.g. the ride time substantially varies for same edges in different supply networks (different average speed in IC, IR, and AR systems).
- A line exactly belongs to one system, therefore the determination of a line plan for the global railroad network can be divided into line planning for each supply network in principle.

Definition of Supply Networks

- Some important and required information, namely the volume of traffic, is unavailable for the supply networks.

System Split

System Split

- ***System Split***
  - The procedure that splits the origin-destination matrix of the complete transportation network into origin-destination matrices for the supply networks, called ***system split***

System Split

- An example:
  - Assume there are some passengers at a small station $a \in V_{AR}$ which want to travel to another small and far away station $b \in V_{AR}$.
  - No fast train (ICE/IC or IR) stops at these stations, hence there is a slight hope only for a direct connecting train, and if it exists, it will be very slow.
  - We assume that the travelers take an AR train to the next station c, where an ICE/IC or IR train stops, use this fast train to reach a station d near station b and finally get on an AR train to station b.

System Split

- An example: (cont.)
  - In general, a reasonable journey in the transportation network may start with a sequence of ***system changes*** to superior trains and may terminate with a sequence of changes to inferior trains.
  - For the example mentioned above with systems ICE/IC, IR, and AR we obtain the following combinations.

AR

AR — IR—AR

AR — IR — ICE/IC — IR —AR

AR — IR — ICE/IC — AR

AR — ICE/IC — IR — AR

AR — ICE/IC — AR

System Split

- An example: (cont.)
  - The first combination represents ***travel paths*** that use AR trains only.
  - The travel paths of the second combination start with some AR trains followed by IR connections and finish with one or more AR trains.
  - With the additional assumption that travelers use the ***shortest path*** with respect to the ride time inside a system we can calculate the travel route for each combination.
  - Let D_X be a $|V_X| \times |V_X|$ ***shortest path matrix*** of the graph $G_X = (V_X, E_X)$ with edge length f^{RT} (ride time).
  - $D_X^{a,b}$ with $a, b \in V_X$ represents the length of a shortest path connecting a and b in G_X.

System Split

- So, we can compute the travel route for each combination. For example

$$\min\{D_{\mathrm{AR}}^{a,v_1} + D_{\mathrm{IR}}^{v_1,v_2} + D_{\mathrm{ICE/IC}}^{v_2,v_3} + D_{\mathrm{AR}}^{v_3,b} \mid v_1 \in V_{\mathrm{AR}} \cap V_{\mathrm{IR}},\ v_2 \in V_{\mathrm{IR}} \cap V_{\mathrm{ICE/IC}},\ v_3 \in V_{\mathrm{ICE/IC}} \cap V_{\mathrm{AR}}\}$$

- where a, b, v_1, v_2, v_3 are pairwise different, provides the length and the path itself of the travel route R for the combination AR — IR — ICE/IC — AR of the station pair a, b.

System Split

- From the passengers point of view the different reasonable combinations and the resulting travel path are more or less attractive concerning several attributes.
- The sophisticated valuation of the travel path is based on the **ride time**, **price**, **level of comfort**, and **the number of system changes**.
- Note that a system change always forces a change of lines.

System Split

- The passengers commuting between *a* and *b* do not form an integrated whole but can be classified by their trip purpose, e.g. **business trips**, **private** or **vacation trips**.
- The valuation produces different results for different trip purposes and provides an assignment of the volume of traffic to the different travel routes.

System Split

- Let us assume that t passengers of the origin-destination pair a, b use route r with

$$r = a \xrightarrow{\text{AR}} v_1 \xrightarrow{\text{IR}} v_2 \xrightarrow{\text{ICE/IC}} v_3 \xrightarrow{\text{AR}} b.$$

- The t passengers contribute to the origin-destination:
  - pairs a, v_1 and v_3, b in the AR origin-destination matrix T_{AR}.
  - pair v_1, v_2 in the IR origin-destination matrix T_{IR}
  - pair v_2, v_3 in the ICE/IC origin-destination matrix $T_{\text{ICE/IC}}$.

System Split

- An aggregation over all possible routes and all origin-destination pairs leads to an origin-destination matrix for each supply network.
- Additionally, the distribution of passengers along the transportation network provides for each edge $e \in E_X$ the traffic load $ld(e)$, i.e. the number of passengers using a particular edge e.

Line Optimization

Line Optimization

- The decomposition of the complete transportation network into supply networks permits a separate line optimization.
- In this section some approaches to the line optimization problem are summarized

Line Optimization

- PATZ
  - represented a model for the line optimization problem that determines a line plan with small *penalty*.
  - The penalty of line *l* is calculated with respect to the number of empty seats and the number of passengers in *l* changing to another line to reach their destination.
  - The algorithm starts with a line plan containing a line for each origin-destination pair.
  - Lines will be successively eliminated from the line plan in a greedy fashion with respect to the penalty.
  - The capacity for passengers of the eliminated line will be assigned to other lines.

Line Optimization

- WEGEL
  - introduced the widespread notion of line frequency requirements.
  - For every edge *e* of the transportation network the line frequency requirement *lfr*(*e*) represents the required number of trains in a line plan to serve the traffic load *ld*(*e*) (number of passengers) on edge e.
  - A fixed line/vehicle capacity *C* permits the computation of the required number of lines for edge *e* by lfr(e) / [ld(e) / C].
  - The method of WEGEL computes line plans that maximize the number of direct travelers subject to the line frequency requirement for each edge *e*.

Line Optimization

- DIENST
  - introduced a branch-and-bound procedure that computes a basic line plan with a maximal number of direct travelers.
  - Afterwards, some lines are added to the basic line plan with respect to the remaining line frequency requirement in order to reduce the number of changes between lines.

Simulation and Valuation

Simulation and Valuation

- In the final step of the framework the line plans of the different supply networks individually generated by a line optimization procedure will be composed.
- This composition together with the initial origin-destination matrix is analyzed by simulating the passengers' behavior when traveling from their origin to their destination.
- The simulation is based on a more realistic model of passengers' behavior than the optimization models.

Simulation and Valuation

- The simulation terminates with a bunch of reference numbers like
  - number of direct travelers,
  - number of changes,
  - capacity utilization,
  - total travel time.
- An experienced human planner may take advantage of these numbers.

Simulation and Valuation

- The adjustment of some parameters of the system split or the line optimization procedure can be used to model several operational and political constraints which cannot be included in a mathematical model.
- In order to provide an interactive and flexible decision support system for supply planning in public transportation, each step of the framework described above must be efficiently performed.
- From the computational point of view the line optimization represents the bottleneck.
- Hence a fast algorithm which produces provable good solutions is of valuable interest.

پایان