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Department of Logistics and Transport Management

Periodic Freight Train Paths in Network

Doctoral Thesis

Ph.D. Programme: Technology in Transportation and Telecommunications
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PROHLÁŠENÍ

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podpis

FOREWORD

The author of this thesis was educated in the context of passenger “Taktfahrplan”, but he found too much research in this field, so he got interested in “Takt” for freight railway.

European Commission (2011) declares support of sustainable means of transport, including freight railway and intermodal transport. Recent White Paper on European transport policy states “Rail, especially for freight, is sometimes seen as an unattractive mode. But examples in some Member States prove that it can offer quality service. The challenge is to ensure structural change to enable rail to compete effectively and take a significantly greater proportion of medium and long distance freight...”. Further, ambitious commitments of modal shift in future are set.

However, most problems of freight railway, mentioned by European Commission (2001) in previous White Paper, remain up to now – such as preference of passenger railway to the detriment of freight railway or idle of freight trains on borders due to lengthy haulage formalities, often waiting for free train path, and partially still necessary change of locomotive.

The author considers any ground-breaking solution of mentioned problems, e.g. construction of network of dedicated freight railway lines, very unlikely. Thus, solution, which is applicable now and there, as well as in conceptual planning, is further proposed. It accords the idea of European freight corridors: guaranteed capacity for freight trains – “under good conditions in terms of commercial speed and journey times” (European Commission 2010).

High-speed railway lines in Europe have great potential to relieve main lines with mixed traffic of the fastest trains, but they are not designed everywhere. Moreover, the problem of busy lines requires solution, which is usable immediately.

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LIST OF ABBREVIATIONS

AC	alternating current
ATO	Automatic Train Operation
BLS	Bern Lötschberg Simplon Bahn
CTU FTS	Czech Technical University in Prague, Faculty of Transportation Sciences
ČD	Czech Railways (České dráhy)
DB	Die Bahn (German Railways)
DC	direct current
e.g.	for example
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
FRU	Freight railway undertaking (freight train operating company)
FBS	Fahrplanbearbeitungssystem (timetabling software tool)
FTP	Freight train path
i.e.	that is
IM	(Railway) Infrastructure Manager
IPT	Integrated Periodic Timetable
MGB	Matterhorn Gotthard Bahn
MPM	maximum permissible brutto mass of load
No	number
PESP	Periodic Event Scheduling Problem
PFTP	Periodic freight train path
PRU	Passenger railway undertaking (passenger train operating company)
PuT	(Passenger) Public Transport – in this thesis mostly railway
RoLa	Rolling highway (from German „Rollende Landstrasse“) – railway transport of trucks on special wagons
RT	runtime (in tables)
RU	Railway undertaking (train operating company)
SBB	Schweizerische Bundesbahnen (Swiss Federal Railways)
SŽDC	Czech Railway Infrastructure Administration, state organization (in Czech: Správa železniční dopravní cesty)

INTRODUCTION

In European railway network, periodic timetables of passenger trains, in some cases even *Integrated Periodic Timetable (IPT)*, become more and more common – welcome by passengers, as well as by public transport planners. Such concepts, however, do not take needs of freight railway into consideration and in some cases even lower quality of freight train paths (freight trains have to stop more frequently to be overtaken by faster trains). Since the contribution of IPT for public passenger transport is indisputable, it is necessary to look for solution in the context of IPT.

Freight train paths remain mostly individual, with exceptions like Switzerland or Netherlands, where infrastructure managers implemented periodic freight train paths. They have lead to higher capacity available for freight trains. Yet, systematic approach for reduction of often stopping of freight trains on lines with dense mixed traffic, as well as for direct connection of freight train paths in nodes (if needed, among more than two lines) to avoid stopping, is still missing

Chapter 1 of this thesis presents the aim of this thesis – to develop a framework process for construction of network-bound periodic freight train paths, which will be designed as a network offer of capacity for freight trains (an analogue of IPT). Then, methodological approach is proposed.

Chapter 2 briefly presents principle of IPT, further summarizes timetabling problems of freight railway (especially in the context of IPT) and state of the art in the field of periodic freight train paths (PFTPs) and periodic timetables of freight trains.

Chapter 3 presents theoretical approach to network periodic offer of capacity for freight trains, intended as a freight-friendly analogue to IPT. Differences in parameters of really scheduled freight train and differences in runtimes of fictious freight trains with same mass, but different wagons, are briefly mentioned. Then, influence of freight trains on capacity utilisation is analysed. Further, method for depiction of flexible linking of a PFTP to two following directions is presented. A concept of freight IPT-node is derived. Finally, framework process for construction of flexibly-bound symmetric PFTPs is proposed, including proposals of facultative supportive measures (timetabling ones, including coordination with timetable of passenger transport, or technical or infrastructural measures).

In *Chapter 4*, results of theoretical implementation of the framework process in chosen part of Czech railway network and on planned new timetable, are presented and discussed.

Last chapters contain conclusion and recommendations for further research.

Keywords Integrated Periodic Timetable (IPT), periodic freight train paths, capacity utilisation, bottlenecks, speed bundling, train path conflicts

DEFINITIONS

Active overtaking	Overtaking of slower train by faster train, when the slower train does not have to stop.
Active crossing	A crossing on single-track line, when neither first nor second train have to stop.
At-grade intersection	A station, switch region or junction where two or more lines are connected together at the same level.
Block section	A section of track in a fixed block system which a train may enter only when it is not occupied by other vehicles. (Hansen, Pachl et al. 2008)
Buffer time	An extra time that is added to the minimum line headway to avoid the transmission of small delays. (Hansen, Pachl et al. 2008)
Brutto mass of load	Sum of mass of wagons and mass of load. The mass of locomotives is excluded.
Cab Signalling	A signalling system that display the movement authority on the driver‘s desk. (Hansen, Pachl et al. 2008)
Capacity utilisation	The time B taken to operate a compressed („squeezed“) timetable (so that all trains within chosen time are at the minimal possible headway apart) as a proportion of the actual time taken to operate the actual timetable A. So, capacity utilisation is equal to B/A. Adapted from Gibson, S., Cooper, G., Ball, B. (2002)
Compensation zone	A part of railway line with sufficient spare capacity.
Corridor	All possible journey routes (main route or alternative routes), according to market needs, between a defined source and target. (UIC 2004)
Distant signal	A fixed signal that provides an approach indication for the signal ahead but that cannot show a stop aspect. Adapted from Hansen, Pachl et al. (2008)
Disturbed train operation	An operating situation in which, due to conflict with another train, a train will encounter a signal showing a restrictive aspect and will therefore have to modify its speed. (Hansen, Pachl et al. 2008)
Disturbing train	A scheduled train (with own timetable), whose running excludes or disturbs running of other train. SŽDC (2011c).
Driving regimes	The driving modes that may be applied by the driver. There are four driving regres: *Acceleration*, *Cruising* (going at constant speed, realised by partial acceleration or braking), *Coasting*[1] (no traction or braking applied), *Braking*. (Hansen, Pachl et al. 2008)
Flyover	A station, switch region or junction where two or more lines cross at two or more different levels.
Headway	The space or time interval between two successive trains. (Hansen, Pachl et al. 2008)

[1] In Czech system of Automatic Train Opertaion (ATO) developed by Lieskovský and Myslivec (AŽD 2011, Lieskovský et al. 2009 and Lieskovský and Myslivec 2010), coasting is defined differently: no acceleration, but eventual braking to maintain chosen maximum speed while running downhill.

Integrated periodic timetable (IPT, Integrated Fixed-Interval Timetable, clockface timetable)	A timetable, where services run in PuT lines with 2^k-multiple of basic period (60 min as a rule), where k is integer. In every PuT line, services from opposite directions meet each other in the same time (symmetry time). IPT-node is a railway station where services of the same PuT line from opposite directions meet each other. If there is a node station, connections within services of more PuT lines can be ensured (in all directions).
Junction	Point of a network in which at least two lines converge and neither overtaking, crossing nor direction reversals are possible. (UIC 2004)
Line (capacity related)	A link between two large nodes and usually the sum of more than one line section. (UIC 2004)
Line section	The part of a line, in which the traffic mix and/or number of trains, the infrastructure and signalling conditions do not change fundamentally. It consists of one or more coherent sections, which are limited by two neighbouring stations or nodes. (UIC 2004)
Main signal	A fixed signal that authorises a running movement to enter a section of line. (Hansen, Pachl et al. 2008)
Minimal arrival headway	After minimal departure headway is calculated, minimal arrival headway is corresponding time between arrival (passing through) of the first train into following station or junction and arrival (passing through) of the second train into the same station or junction from the same line track from the same block section. (Formulated in accordance with SŽDC 2001)
Minimal departure headway	Shortest time between departure (passing through) of the first train from a station or junction and departure (passing through) of the second train from the same station or junction on the same line track into the same block section, while fulfilled of regular runtimes and required dwell times. Minimal departure is calculated to nearest station, which enables overtaking, or to junction, where run routes of both trains divide. (SŽDC 2001)
Minimal headway	Shortest time between running of two following trains with regard to their impossible or forbidden simultaneous running. Thus, it is the shortest time between arrival or departure, or passing through, of the first train, and departure, or passing through, of the second train. (SŽDC 2001)
Minimal platform headway	On lines with more tracks, in the case of railway stations with at-grade access to platforms, minimal platform headway is a minimal required interval between arrival (or departure) of passenger train stopping in the station, and passing of a train in opposite direction, if its track is closer to station building. This interval avoids risk for passengers caused by passing train. (SŽDC 2001)
Node	Point of a network in which at least two lines converge. Nodes can be stations or junctions. They can be differently-sized, depending on the number of converging lines and their tasks. (UIC 2004)
Operational concept (service concept, German: Betriebskonzept)	A concept of IPT-based public transport offer, which formulates layout of PuT lines, eventual interposition of them in common sections into half period, position of IPT-nodes and another connections between PuT lines, and resulting system travel times, synchronization times and other boundary conditions for timetabling. On the basis of operational concept, exact construction of timetable proceeds. This usually results in modification of the original concept. In long-time horizon, operational concept formulates requirements on targeted infrastructure improvements.
Periodic timetable (Clockface timetable)	A timetable where services operate in PuT lines, and each PuT line has a regular period.
PuT line (timetable related)	A group of services which serve particular sequence of stations and stops all day in regular period.

PuT segment	A PuT line (or group of them) in particular line section, with the same stopping pattern. On main lines there are usually fast (long-distance) and slow (regional) segments. In some cases, however, fast PuT line can partially serve as a slow segment and vice versa. This definition is adapted from segmentation of public transport by Weidmann (2008).
Regular runtime	Running time scheduled in timetable for particular train in particular section (between two stops, between two stations, junctions or another points on the railway line with track branching, or within one block section). It is mostly equal to sum of technical runtime and runtime reserve.
Relevant block section	Block section within the chosen line section, which determines the minimum headway along the entire chosen line section. (UIC 2004)
Route (capacity related)	Consecutive lines and nodes as a whole, between a defined source and target. (UIC 2004)
Run route (traffic related)	Tracks and turnouts that are locked and safely reserved exclusively for running of particular train or for shunting movement. After setting up of a run route or shunting route, it is possible to set a signal to show aspect which permits running or shunting.
Running track (main track)	Track which is used for regular train movements.
Service	Any passenger train which runs according to defined timetable.
Speed bundling	A scheduling principle where trains ought to run at harmonised speeds in order to make best use of the railway line capacity. (Hansen, Pachl et al. 2008)
Stations	Points of a network where overtaking, crossing or direction reversals are possible, including marshalling yards. (UIC 2004)
Stopping pattern	A sequence of stations and stops, where all services of particular PuT segment stop. Exception can be made by less significant stops, which are served alternatively (for instance, hourly service stops at even hours in stop A, but not in stop B, and at odd hours stops contrarily).
Synchronization time	Time diference between dwell time of a passenger train, which is required to ensure connection from another train, and minimal dwell time required for the train in this station otherwise. Adapted from Bär (2006)
System runtime	Regular runtime that is intentionally made longer (assuming running at lower speed than necessary) to achieve departure into particular station or junction in desired time window. This should avoid useless stop of freight train.
System travel time	An integer multiple of period or half period. Consists of sum of regular runtimes between two IPT-nodes, sum of dwell times and waiting times between them, and of proportional part of dwell, changing or waiting times in mentioned IPT-nodes (it depends, which time is limiting in particular case).
Technical runtime	Minimal running time that is feasible for particular train in particular section. Can be calculated for ideal weather conditions, ideal passenger behaviour etc.
Train diagram	A time-distance diagram that contains the train paths of all trains that run on a line. (Hansen, Pachl et al. 2008)
Train path	That part of the capacity of the railway infrastructure which is necessary to schedule or to run a train with a requested speed profile. (Hansen, Pachl et al. 2008)
Travel time	A sum of regular runtimes between two neighbouring stops, dwell times and waiting times between them.

Turnout An assembly of rails, movable points, and a frog, which effects the tangential branching of tracks and allows trains or vehicles to run over one track or another. (Hansen, Pachl et al. 2008)

Usable capacity "Usable capacity" shall exist if unused capacity can possibly be used for additional train paths, providing they meet the customer requirements (typical characteristics of the paths) for the area considered. (UIC 2004)

1 AIMS AND METHODOLOGY

1.1 Motivation

In European countries with polycentric structure of settlement, periodic or even Integrated Periodic timetables (IPT) tend to develop. The main cause of this trend is their attractiveness and ease of use for passengers. These timetables may represent a competitive alternative to individual transport: both from spatial (accessibility of many destinations thanks to connections) and temporal (usually, period of 60 min or less) point of view.

In some countries, tailor-made concepts of railway system development were implemented to reach optimal system travel times and capacity to improve efficiency of IPT. The probably best example is Swiss concept Rail 2000 (Bahn 2000). The synergy of IPT-based operational concept, production, rolling stock and infrastructure has lead to enormous growth of railway ridership, The growth, in some cases greater, than the planners awaited, has been proceeding up to now.

On the other hand, IPT and related improvements have had some negative consequences for freight railway transport. Passenger trains have consumed much railway capacity. Freight trains have to be often overtaken by faster passenger trains. This increases consumption of time and traction energy. Last but not least, more stops of freight trains mean more noise for inhabitants.

As IPT has lead to undeniable success for passenger railway, it cannot be cancelled for the sake of freight railway. At the same time, a new concept of freight timetable (or train paths), which allows freight railway to be competitive, has to be found.

Abundance of research for optimizing railway timetabling and operations has been done. However, every optimizing algorithm focuses only on one or few criterions. Thus, optimizing one feature of timetable can lead to deteriorate another one. Typical case is IPT, which is well optimized for the purposes of passenger transport offer, and in real timetabling process only slightly adjusted to gain required capacity for freight transport. The result is sufficient quantity, but mostly insufficient quality of freight train paths – too frequent overtaking by passenger trains. This leads to large energy consumption and long transport times, which are far from competitive with road transport, although many freight trains are nowadays able to run up to 100 - 120 km/h.

Czech Transport Sector Strategies (Ministerstvo dopravy 2012) declare in its principles aims in accordance with European transport policy (European Commission 2011). Further, recent growth in the field of combined transport in the Czech Republic is mentioned. As one of Specific aims, ensuring of sufficient capacity for freight railway is mentioned – *including peak times of passenger transport*.

1.2 Trends in freight railway transport in Europe and the Czech Republic

The demand for freight transport is very heterogeneous and the units are larger than in passenger transport. Even when using usual comparison “one passenger to one net ton”, typical shipment worth being transported by railway weighs more than 1-2 tons. The result is fewer trains with various origin/destination stations. Block trains loaded by bulk cargo play still important role in freight railway, but their overall share is still decreasing due to decline of heavy industry in Europe.

Freight trains can be divided into following groups:

- block trains
- intermodal trains
    - RoLa trains
    - container and other trains of combined transport (trailers, swap bodies etc.)
- wagonload trains

There are also other types of freight trains and service trains, eventually also trainset trains (passenger trainsets which do not transport passengers).

Nowadays, significance of international transport is growing, as well as regular offer (daily or on certain days of the week) in combined transport and offer of industry (e.g. automotive) in Just-in-time regime. Night leap is not anymore the only logistic solution suitable for railway.

With growing volumes of long-distance and agglomeration passenger railway transport, peaks tend to be stronger – especially morning peak (between approx. 7:00 and 9:00 am, so it is shorter than afternoon peak), *when usable capacity for freight trains falls considerably in key railway nodes in whole Europe, and thus in whole European railway network*.

The process of freight train path allocation in Europe and the Czech Republic, either in annual timetabling or in ad hoc regime (or by daily traffic management), is very unclear and clumsy because of tailor-made train paths for particular trains. This fact has negative impact on attractiveness, and thus on competitiveness, of freight railway. The unclearness of the allocation process makes non-discriminatory access to railway capacity more difficult. It can be anticipated that FRUs will require more flexible train path allocation and their better coordination with train paths of neighbouring IMs.

White paper on European transport policy (European Commission 2011) declares support of freight railway transport (eventually even at the expense of passenger transport), but does not contain any suggestion of systematic solution, which would increase quality and availability of long-distance freight train paths (together with maintenance of successful periodic timetable or IPT of passenger transport). Placing of all significant freight flows on separate (partially new) lines, as proposed by project of German Railways Netz 21 (Penner 2007), might be not economically feasible if freight flows are not high enough. Moreover, spatial requirements for such new lines are enormous. If new railway lines are constructed, they should offer new quality (for instance – high-speed railway lines). So, railways most often will have to cope with mixed traffic.

A trend of new, more powerful freight locomotives (electric: over 6 MW, diesel: over 3 MW) should be also pointed out. These locomotives enable more rapid acceleration than older ones. Electric locomotives are manufactured by few companies and differ very little in basic parameters (mass, power, maximum speed).

Freight wagons become faster and are equipped with better brakes – some container wagons can run loaded at the speed of 120 km/h. This technical development makes in some cases possible construction of parallel freight and long-distance train paths.

1.3 Research gap in the field of freight train paths

Science in railway timetabling and operation is prevailed by quantitative approach (mathematical modelling, network timetable optimization, traffic simulation and consequent analysis of stability, rescheduling etc.). The research focuses for instance on increase of stability (lowering of sum of delay minutes in network or earlier dampening of secondary delays), better capacity utilisation on given infrastructure by preserving of given stability, more efficient utilisation of rolling stock and staff, automation of traffic management etc.

The author of this thesis considers the idea of IPT last significant achievement in qualitative research (i.e. non-quantitative research) of railway networks.

On the other hand, freight timetables (and train paths) are by vast majority of researchers and experts considered as irregular (with the only exception – when there is a time window between periodic passenger trains only for one freight train per period). This perception reflects in proposed algorithms and developed software tools.

Except for bypasses of bottlenecks and dedicated freight lines, *there are not formulated infrastructure requirements of freight railway, derived from prospective timetable*. Because of irregular timetabling it is impossible to predict stations for regular overtaking or crossing, which makes the infrastructure projects more expensive, even if requirements of passenger transport are exactly determined from IPT-based operational concept.

IPT of course almost does not consider problem of train mass in sections with high gradients, and need for rear-end or head-end assistance for such sections.

1.4 Aims of the thesis

The aim of this thesis is to contribute to qualitative (in the sense of "non-quantitative") research in the field of railway capacity management, especially basic principles of timetabling of freight trains (or capacity allocation for them) in the context of IPT. A framework process for construction of network-bound periodic freight train paths (PFTPs) on the level of operational concept will be designed. Such framework process should neither affect IPT, nor restrict network capacity. Only small adaptations of present IPT or other penalising measures for passenger transport are allowed, assumed that achieved effect for freight transport is significantly larger. The thesis focuses mainly on railway lines and nodes with *mixed traffic*.

The framework process, proposed in this thesis, should be understood as a guideline for IM, which should be applied adequately to specific local conditions, rather than proposal of strict regulation.

Detailed aims are as follows

1. Contribution to clarification of relevance of PFTPs in railway network.
2. Formulation of framework process for IM for construction of qualitative (in terms of usage of maximum train speed and frequency of stops) and flexibly network-bound PFTPs in the context of IPT of passenger transport.
3. Formulation of rules for mutual coordination of passenger and freight periodic train paths, either as small improvements (for status quo) or as coordinated planning process (for future development of railway transport).
4. Verification of auxiliary technical and infrastructural measures – the appropriate ones will be integrated into the framework process.
5. Testing of the framework process on chosen part of Czech IPT.

The thesis should affirm or disprove following hypothesis:

PFTPs in network in the context of IPT (constructed according to proposed framework process) lead to lower number of overtakings of freight trains by passenger trains.

The thesis should contribute to answer following questions:

1. When and in which way do freight trains have direct impact on railway capacity utilisation?
2. When and in which way can this impact be reduced?
3. How much can be stopping of freight trains in bottlenecks reduced?

4. How much is targeted regulation of freight train running possible and appropriate (in terms of accurate runtime, accurate arrival time in bottleneck area etc.)?
5. In which conditions is it rightful to penalise passenger transport (e.g. by longer dwell time or adjustment of stopping pattern), if it results in increase of usable capacity for freight transport?

This thesis does not serve to any particular interest, but seeks to improve efficiency of railway system as a whole, building a bridge between advanced railway operation research and yet often clumsy process of freight train path allocation. *Assumed that IPT was a leap forward in passenger railway, the thesis seeks for some analogue for freight railway, keeping in mind that both concepts have to coexist together.*

1.5 Methodology

This thesis is elaborated at level of detail, which corresponds to *operational concept*. This is the level where orderers of public service[2] usually outline PuT lines, IPT nodes etc. Then, final timetable is negotiated and finally constructed by IM, together with public service orderers, PRUs charged by the order, other PRUs and FRUs. Exact timetable construction is, to the author's opinion, already being researched thoroughly by quantitative research.

Chosen level enables the author to focus on such phenomena and processes, which are common for all European railway networks with IPT, and influence railway capacity utilisation and quality of freight train paths – especially number of stops. This level is more general than the process of timetabling. For the sake of sustaining reasonable scope of this thesis, the research is not so detailed that it can result in exact timetable. More detailed view would inevitably meet obstacles, such as different regulations for timetabling process, different views on capacity calculation or estimation, different timetabling software, different standards for data interchange etc. in various countries.

This thesis deals with railway capacity from *qualitative (not quantitative)* point of view. Thus, neither precise algorithms nor numerical results are supposed to be essential output. If needed, typical empirical constants (e.g. maximum train speeds or minimal headways) can be used in examples. But the research is from the beginning outlined as indifferent to any constants. So the results can be used for railway lines with electronic as well as mechanical interlocking. Soft approach to the problem was chosen intentionally – due to large number of criterions to be optimized and because of reasons mentioned above.

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[2] In the Czech Republic, Ministry of Transport orders fast and some express trains, and regional authorities or charged subjects order regional trains. Due to its nature (see sub-chapter 2.1), IPT is usually not suitable to be operated commercially.

The three crucial objects of qualitative research of railway capacity in this thesis are

- *periodicity of freight train paths* (periodicity of passenger train paths is assumed)
- mutual *heterogeneity* within a period
- *symmetry of freight train paths* in both directions.

Periodicity is assumed as a basic point of view, but it should be kept in mind that no real network timetable is at 100% periodic.

(Partial) Periodic Event Scheduling Problem

Theory of periodic timetabling was mathematically formulated using *PESP (Periodic Event Scheduling Problem)*. For railway timetables, formulation of PESP was adapted by Nachtigall (1998). With aid of graph theory, *events* (i.e. time moments – e.g. arrival, departure) were represented by *vertices* and *activities* (e.g. running between stations or dwell time) as *edges*.

Periodic sequence of events was defined (for instance, sequence of minutes 0, 20, 35, 50, 75 changes by period of 60 min to 0, 15, 20, 35, 50 min, because 75 mod 60 = 15).

The nature of railway operation implies many constraints, either physical (technical runtime), or from safety reasons (minimal headways), or timetabling (synchronization times to enable connections).

One of the methods for computational solution of the problem is *constraint propagation* from particular vertex of reference (e.g. departure of particular train from particular station) to the rest of the solved network. The result is either a periodic set of admissible intervals or a proof of that it is impossible to solve the task. In this case, some (safety-irrelevant) constraints have to be *relaxed*. This exact method is further adjusted by various heuristic methods, to decrease execution time of computing the solution.

The mentioned formulation appeared to be advantageous for calculation of optimal timetable in given network (for particular initial conditions and optimization criterion). So, most timetable optimizations come out of this approach.

In this thesis, there is stressed only the above outlined understanding of periodic timetable (or IPT) in network. The reason is that author's approach is very similar, although soft. So, the calculations will be only approximate, as detailed optimization is not subject of this thesis.

Figure 1.1 illustrates constraint propagation on railway line. The time axis is vertical, distance axis is horizontal. Figure 1.1a comes out from admissible interval or time window (green stripe) for departure from station A and from admissible interval for arrival in station B. From both A and B, constraints propagate to other end of the line. *Their intersection, i.e. admissible area for train path from A to B, is marked dark blue*.

In Figure 1.1b, the situation is more complex due to admissible interval for passing through a station in between. The resulting admissible area for train path from A to B is then intersection of three sets.

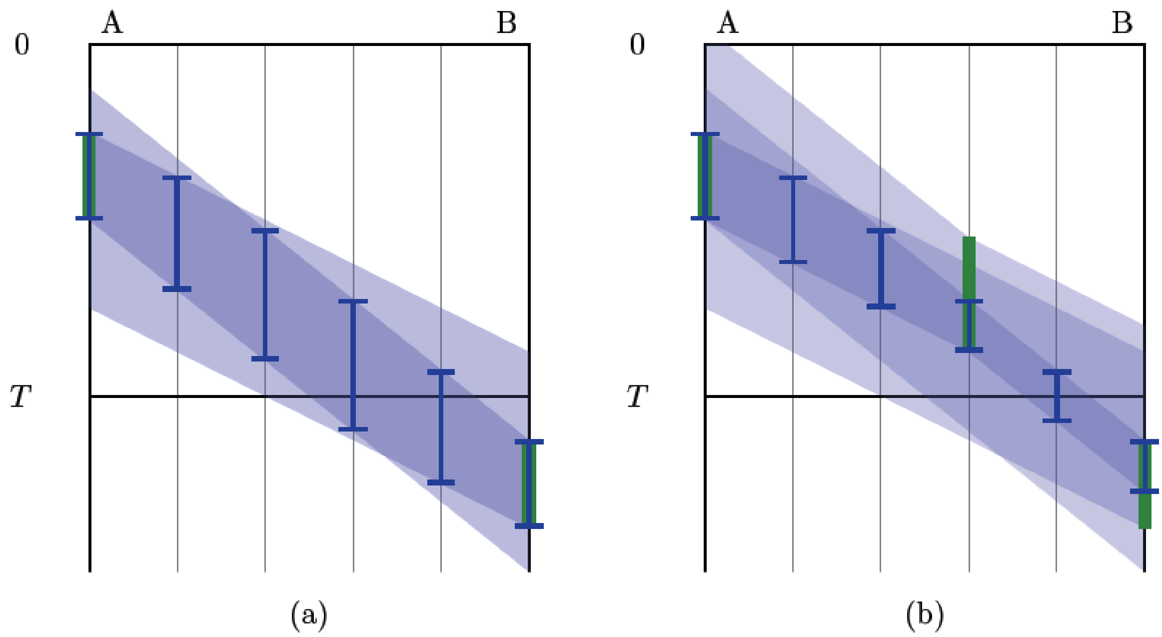

Figure 1.1 Illustration of slot propagation in line section with 2 (a) and 3 (b) stations with restricted time windows for running of a train (Caimi et al. 2009b).

Caimi et al. (2009b) adapted PESP to practical needs of periodic timetabling – changes of demand volume during the day. They introduce formal mathematical notation of partial periodicity, when particular periodic services (and train paths) are introduced only in peaks, another for instance on workdays from 7:00 to 19:00 etc. Figure 1.2 depicts four phases of partial periodic timetable generation

- operational concept (service concept) as a result of offer planning including boundary conditions, runtimes, minimal intervals and further timetabling constraints
- its projection into one period (60 min)
- calculation of timetable for one period by solving of PESP
- and finally roll-out of the result into classical timetable

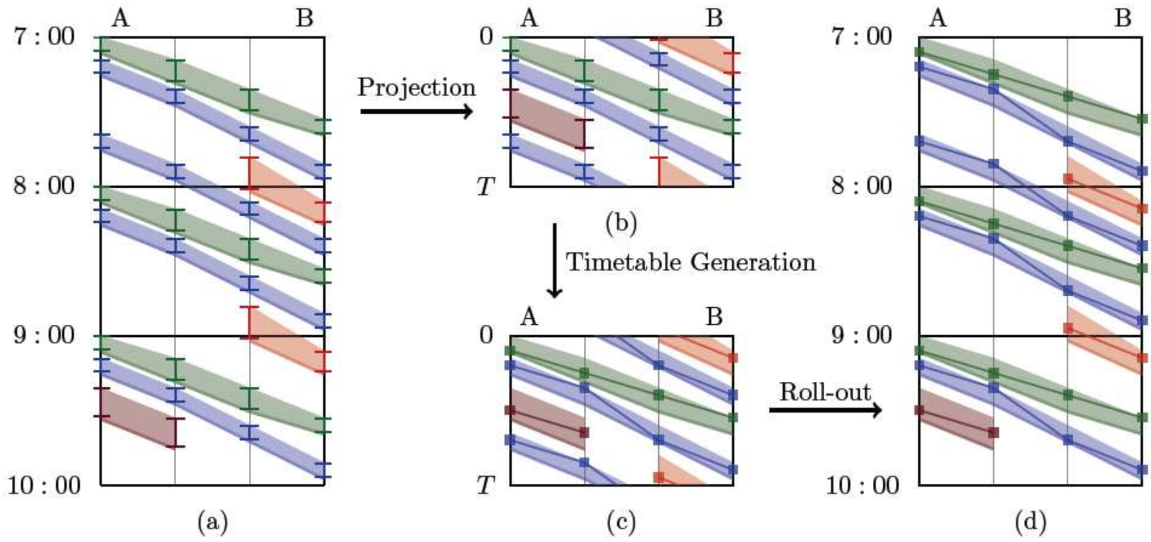

Figure 1.2 Illustration of partial periodic timetable generation process. (Caimi et al. 2009b).

For alternative periodic train paths (e.g. peak passenger vs. freight) the concept of partial periodicity introduced above is used. This means that some train paths can be constructed as alternative (peak passenger vs. freight) or facultative (on demand).

Level of detail

For presented aims of the thesis, macroscopic level (number of trains of particular category per time unit) is too gross. On the other hand, microscopic level (blocking time theory - see UIC (2004)) is too detailed, as quantitative research is not purpose of this thesis.

The chosen level of detail distinguishes

- parallel or heterogeneous train paths
- sequence of trains (double- and more-track lines), or order of trains (single-track lines), i.e. every single case of overtaking or crossing
- (partial) "bending" of train path, i.e. slower planned running than technically possible due to restricted capacity
- number of tracks on every section of railway line – in a station, only tracks for overtaking or turn-around are considered
- compliance of passenger of freight train paths with unified (zero) symmetry, which is one of basic elements of IPT (see sub-chapter 2.1)

The research is done in periodic time window for two reasons:

1) to adopt periodic view on capacity
2) to decrease complexity of the solved problem

As a basic period of services of passenger railway, *one hour* is assumed. Period of two hours or more is very little attractive for passengers, and thus used only exceptionally. In agglomeration areas, a 30 min period of offer of passenger railway is mostly used. Generally, period of depicted time window is determined by period of least frequent PuT line or segment on given line.

Timetabling constraints due to at-grade platforms on double-track lines are depicted.

On network level, bottleneck areas are distinguished. The framework process, developed in this thesis, uses the idea of division of railway network, presented by Caimi et al. (2009a), into condensation zones (bottleneck areas, where as little time reserves as possible are required, because of better capacity utilisation) and compensation zones (where higher time reserves are required to compensate small delays from condensation zones).

In *bottleneck areas*, endeavour is made to design periodic freight train paths with as little stops as possible (in case of need, with slight adjustment of passenger train paths). In this thesis, bottlenecks are understood as condensation zones.

In this thesis, following two types of railway lines are particularly understood as bottlenecks. The first type is main double-track line with mixed suburban and long-distance traffic. The second type is single-track line with more than one PuT segment of passenger transport. Another type of bottleneck is section with high gradient, which requires use of rear-end or head-end assistance.

In *compensation zones* (i.e. outside bottlenecks), a freight train path usually connects two strict time slots on their boundaries. If the overtaking of freight train by passenger trains is necessary, it should be designed preferably in compensation zone, because of sufficiency of capacity there. Extension of runtime is also possible (with the consequence of coasting or running at lower speed) rather than stop, when time distance between available slots on the border with condensation zones is too high for regular runtime.

Depiction

For illustration and approximate construction of PFTPs, an adapted "Czechoslovak" arrangement of train diagram is used: horizontal time axis and vertical axis. Contrary to classical train diagram, *vertical axis represents distance only in a symbolic way, because runtimes of various train groups are compared, but not calculated*. Minute scale is added if needed – for depiction of approximate headways. Single-track line sections are marked by grey background.

The exceptions from this rule are adopted train diagrams and output from FBS timetabling software, where numbers instead of minute scale are used. Passenger trains are marked black, freight train paths are marked blue, or with other colour to be distinguished (e.g. local freight train paths).

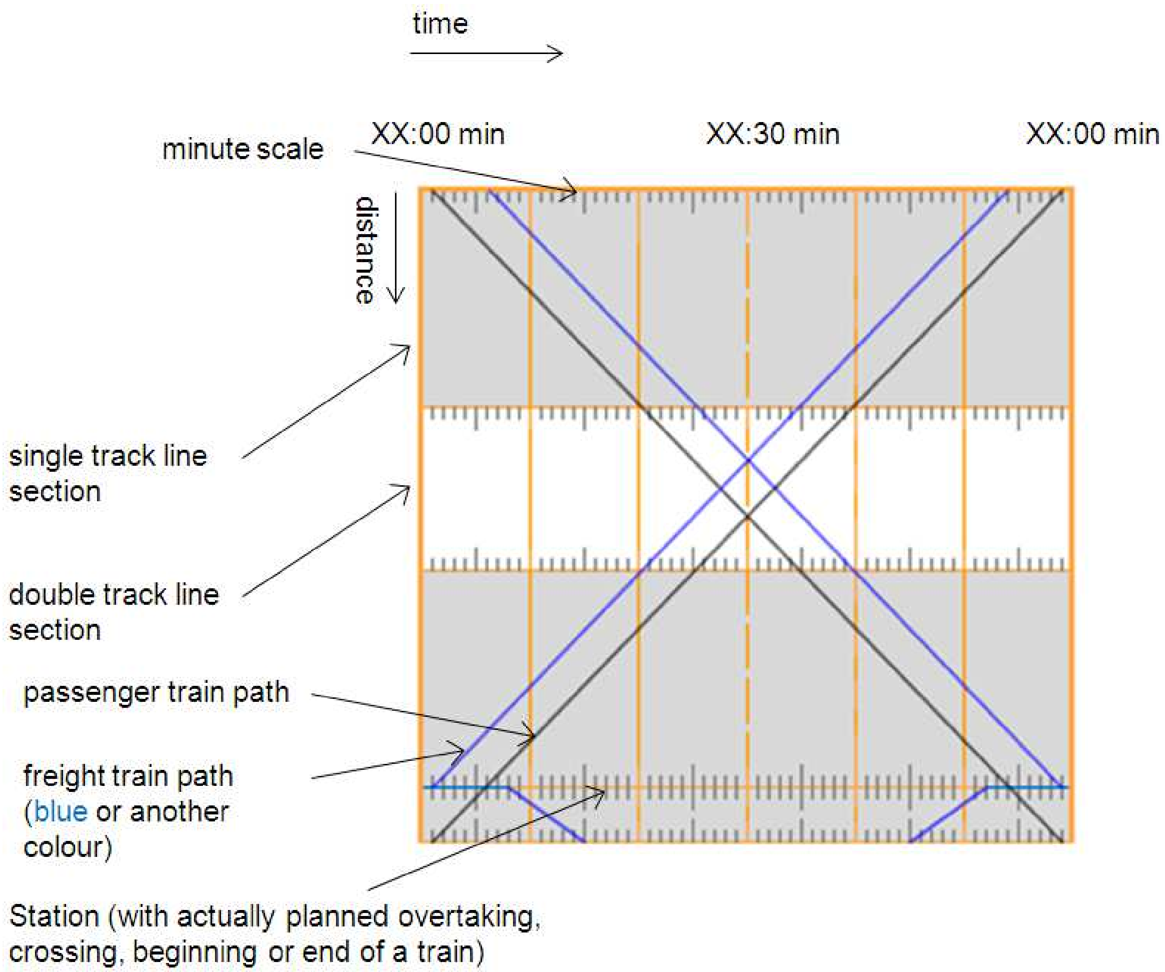

Figure 1.3 Usual depiction rules of a fictious or real, but simplified train diagram in this thesis.

The PFTPs, resulting from implementation of the framework process, are depicted in the form of *netgraph* (network graphics or interval graphic, in German: Netzgrafik).

Netgraph can be called an extended plan of PuT lines. Following information is represented there:

- *Spatial aspects of public transport offer:* PuT lines, node stations, served stations and number of stops in between
- *Temporal aspects of public transport offer:* period of each PuT line, interposition of more PuT lines (which operate in common section) into half period, periodic arrival and departure times of services of PuT lines in node station and important intermediate stations
- *Qualitative aspects of public transport offer:* distinguishing of long-distance traffic and regional PuT lines, and other attributes of particular PuT lines if necessary (category of a train, RU), number of changes per relation

(adapted from IRFP (2013))

This is usual form of illustrating of (Integrated) periodic timetable, especially for the purpose of planning operational concept.

In this thesis, netgraph is used to depict flexibly bound PFTPs. Each line stands for PFTP with 1-hour-period in both directions (with, at least partial, zero symmetry). Because of right-hand operation on Czech railway network, times of departure and arrival are marked on the right of each line in particular direction. Departure (or more often passing) times are marked after particular station. Arrival times are marked before the station, but only in the case of stop. Connection of two PFTPs into one (or contrary) shall be understood as alternative. Connections marked with arrow work only in particular direction.

2 STATE OF THE ART

2.1 Principle of IPT in railway passenger transport

IPT is a special case of periodic timetable, which ensures connections between various PuT lines in whole network. For this effect, following requirements must be fulfilled.

Unified period (interval) of services

All services included in IPT operate in *PuT lines*. All PuT lines operate in constant period which is equal to 2^k-multiple of basic period (60 min as a rule), where k is integer.

Unified symmetry axis

In every PuT line, services from opposite directions meet each other in the same time (*symmetry* time). This time repeats after half period. Should services of two PuT lines enable mutual connections with equal changing time, these two PuT lines must have equal symmetry time.

In European long-distance railway, symmetry time slightly before the top of the hour is common. This is called *zero symmetry axis*. In practice, symmetry times in minute 57 to 01 are used. In suburban railway, symmetry time in minutes 00, 15, 30 and 45 are used.

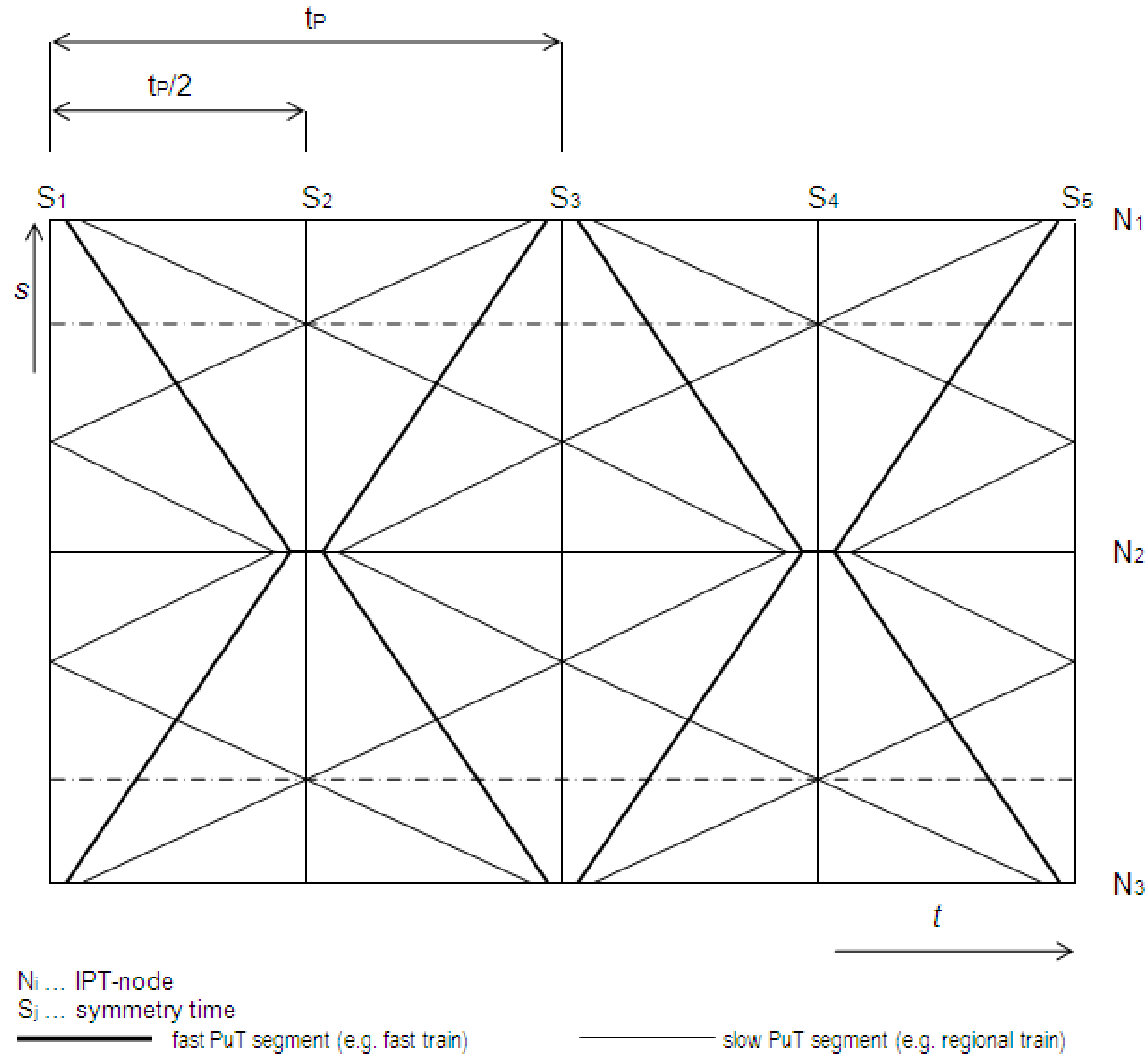

Figure 2.1 Ilustration of train diagram based on IPT, with marked basic period t_P, IPT-nodes N and periodically repeating symmetry times (symmetry axes) S. Adapted from Baudyš (2006).

IPT-nodes

IPT-node is a railway station where services of the same PuT line from opposite directions meet each other (always in symmetry time as mentioned above). If there is a junction station, connections with services from other PuT lines can be ensured (in all directions). The planners of public transport offer endeavour to make IPT-nodes in central stations of big cities or in other significant junctions (in terms of number of changing passengers).

Arc equation

To keep “rendezvous“ in every IPT-node, trains have to depart from each IPT-node shortly after symmetry time and arrive in next IPT-node shortly before symmetry time. From the fact that symmetry time repeats each half period, the arc equation follows

$$t_{T,A\leftrightarrow B} = \frac{n}{2} \cdot t_P \ , \tag{1}$$

where

$t_{T,A\leftrightarrow B}$	is travel time between IPT-nodes A and B, including both half of dwell time in node A and half of dwell time in node B[3]
n	is natural number
t_P	is basic period (interval)

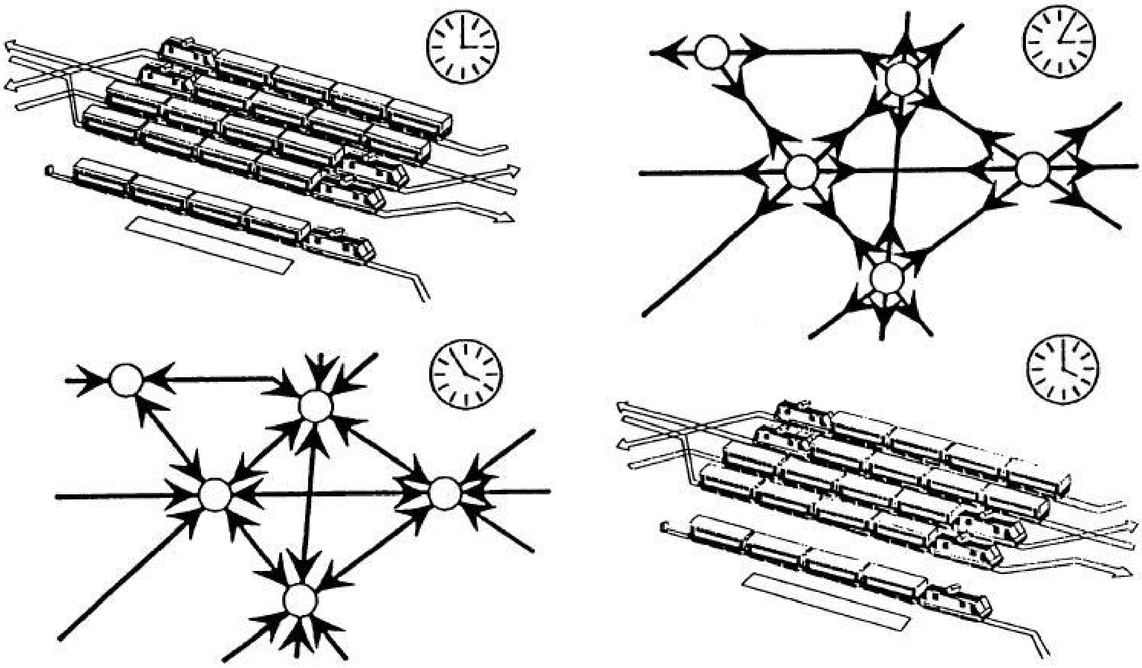

Figure 2.2 Principle of IPT depicted by phases of symmetry time in IPT-node, departure of trains, arrival of trains and next symmetry time in IPT-node after one period (same minute) (Lichtenegger 1990).

Cycle equation

As mentioned above, symmetry time repeats each half period. So, for one hour period, if symmetry in minute 00 was chosen, another symmetry time would occur in minute 30. Because “rendezvous“ in every IPT-node repeats after period, in some IPT-nodes it occurs always around minute 00 and in another IPT-nodes always around minute 30[4]. To ensure connections within whole network (which is main advantage of IPT), it is necessary to achieve *system travel time* along every cycle (in the sense of graph theory)

[3] or 0,5·(dwell time + synchronization time)

[4] If chosen another symmetry time, rendezvous can occur e.g. in minutes 15 and 45, or 25 and 55.

equal to integer multiple of the period to achieve arrival to the same symmetry time (either again to minute 00 or again to minute 30). The cycle equation is expressed as follows:

$$\forall(A,m): t_{T,A\rightarrow A,m} = n \cdot t_P \tag{2}$$

where

A	is an IPT-node
$t_{T,A\rightarrow A,m}$	is travel time along m-th cycle from node A into node A, including at least 2 another IPT-nodes and dwell time in A
m, n	are natural numbers

Attractiveness of IPT

The contribution of IPT for attractivieness of public transport is indisputable. It is proven by practice in Netherlands, Switzerland, and from partial implementation in Germany, the Czech Republic and Hungary. Thus, solutions for freight railway should be sought in the context of IPT.

In Figure 2.3, effect of demand, which was pulled by increasing offer, is represented. Not only increasing number of trains, but also the advantages of IPT (which was in operation on Swiss railway network for all represented years) influenced increasing interest of passengers for railway transport.

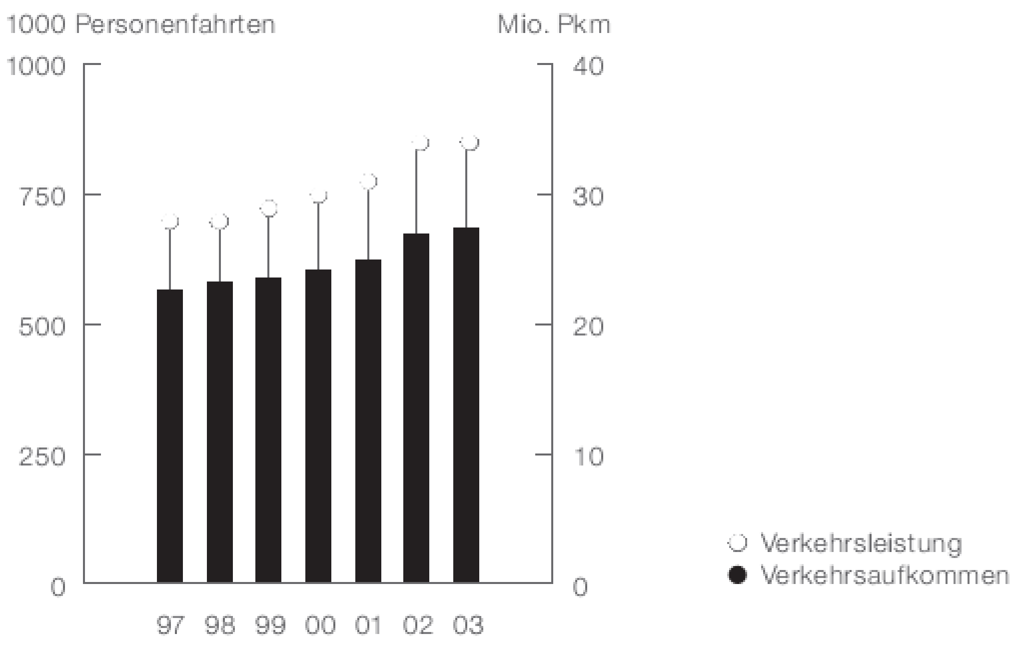

Figure 2.3 Overview of daily average number of seat-kilometres offered by SBB (white rings, in millions), compared to daily average number of journeys by train (black columns, in thousands) between 1997 and 2003 (SBB 2003).

Table 2.1 represents success of implementation of IPT on Czech long-distance railway network. Increase of number of long-distance services ordered by public sector, and operated in the framework of IPT has pulled demand of passengers.

Route	Increase of No of services Mar. 2005 to Mar. 2003 [%]	Increase of No of journeys/month
Liberec – Pardubice	20,2	1 100
Praha – Tanvald	49,5	1 900
Nymburk – Česká Lípa	43,9	600
Liberec – Ústí n. L.	48,4	4 800
Cheb – Ústí n. L.	59,1	10 000
Plzeň – Jihlava	11,3	3 000
Zdice – Protivín	20,5	1 000

Table 2.1 Relative increase of number of long-distance services and absolute increase of number of journeys per month in chosen directions between March 2003 and March 2005. (Janoš 2006).

However, there are some differences in Czech and Swiss implementation of IPT. In the Czech Republic, no analogue to Rail 2000 (Bahn 2000) has been implemented, or at least planned by competent authorities. Further, the basic period of services is as high as 120 min, with numerous exceptions and “holes” in periodic operation outside peak times. The probably more serious killer of attractiveness are often changes of particular services from year to year, which is partially caused by uncertain budget for subsidies.

2.2 Railway capacity

“*Capacity as such does not exist.* Railway infrastructure capacity depends on the way it is utilised. The basic parameters underpinning capacity are the infrastructure characteristics themselves and these include the signalling system, the transport schedule and the imposed punctuality level. On a given infrastructure, capacity is based on the interdependencies existing between:

- the *number of trains* (per time interval, e.g. trains per hour). When train intensity increases, less capacity is left for quality, as expressed in the parameters described below;
- the *average speed* . The braking distance increases proportionally more than the average speed;
- the *stability*. Margins and buffers have to be added to the running time of trains and between train paths to ensure that minor delays are suppressed instead of amplifying and so causing (longer) delays to other trains;
- the *heterogeneity*. When the differences in running time between different train types worked on the same track are great, similarly the capacity consumption of the same number of trains will increase proportionately.

The relation between these parameters is clearly shown in the "capacity balance", as illustrated in Figure 2.4 below. In this qualitative model, an axis for each parameter is drawn from a unique origin. A chord links the points on the axes, corresponding to the value of each parameter. The length of the chord represents *the* capacity. Capacity utilisation is defined by the positions of the chord on the four axes. Increasing capacity means increasing the length of the chord. " (UIC 2004)

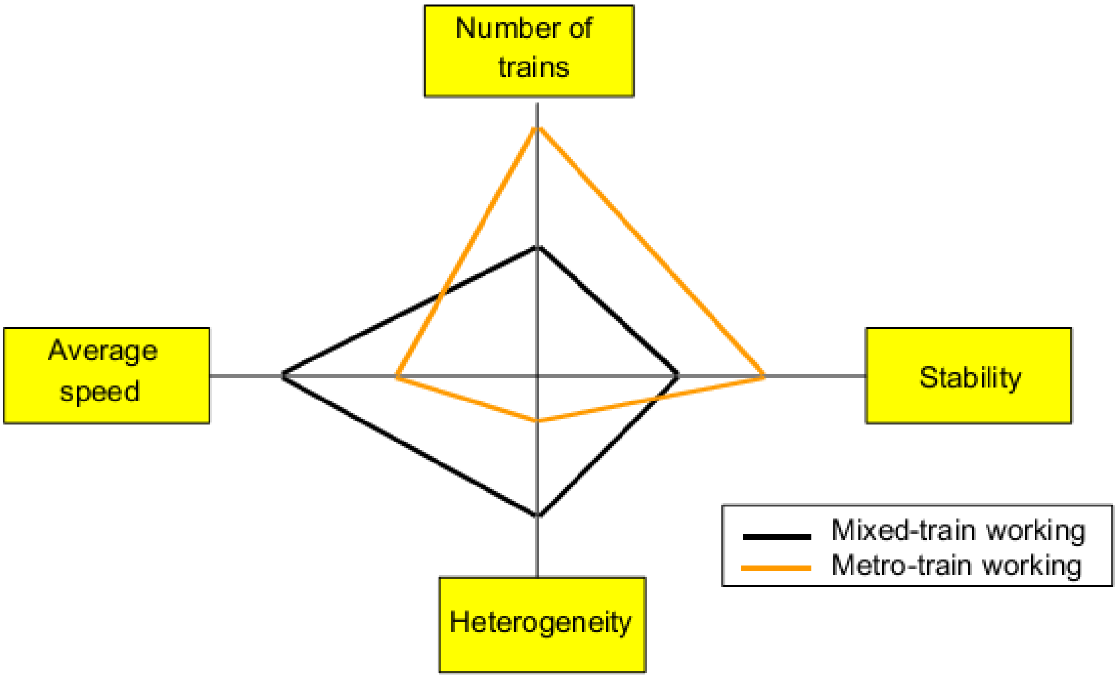

Figure 2.4 Capacity chord – mixed and metro traffic (UIC 04).

In this thesis, stability and average speed of passenger trains are assumed as given, if not modified due to coordination with freight trains. Number of trains, or more exactly, train paths, is also assumed as regular (actual use of freight train path by freight train is not relevant here).

In UIC (2004) there are mentioned four different views of capacity – from the position of the market, infrastructure planning, timetabling and operations. All types of actors deal with *mix of traffic and speed*. In case of periodic (regular interval) timetables or even IPT, special requests such as system travel times are added to the view of timetable planning.

Assumed that IPT is a part of a certain public transport system, it can be seen as a result of consensus (or at least compromise) between public sector, communities, RUs, IM(s) and direct requests from passengers.

In this thesis, market needs are assumed as given, with preference of integrated, open offer of passenger trains (and therefore subsidized by public sector). Passenger trains are assumed to operate in periodic timetable with zero symmetry.

2.3 Capacity of a line

If buffer times and time reserves are assumed as great enough to provide system stability against primal delays of several minutes (and then these times can be considered as constants independent on mix of traffic), and IPT is considered, then maximum number of trains per hour depends on heterogeneity of section runtimes – within freight trains, as well as freight trains vs. the most frequent PuT segment. For instance, 15-min-period of suburban trains vs. one fast train per hour, or bundle of three fast trains per hour vs. hourly regional service. Speed bundling (of trains with same or similar speed) leads to better capacity utilisation than alternation of fast and slow train. On the other hand, suburban service is based on low periods, and fast and freight trains often must use the same railway line (mixed traffic).

Cases of speed bundling of trains with various speeds within periodic timetable are drawn in a well arranged way for example by Krýže – Figure 2.5.

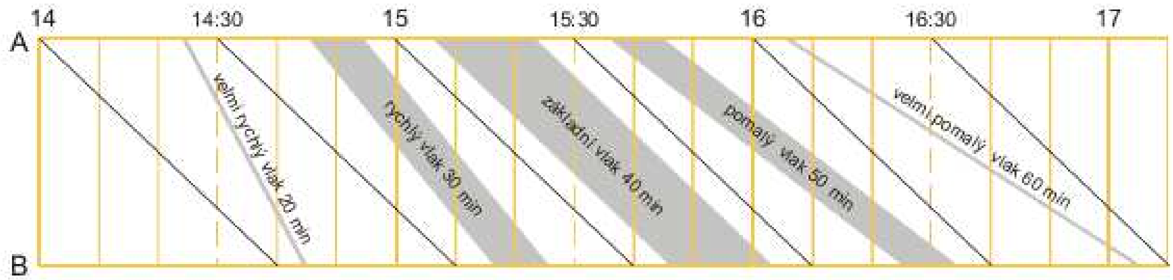

Figure 2.5 Usable capacity (sizes of time window) for trains with different speeds in the context of periodic timetable on double-track line. Usable capacity for both “very slow“ and “very fast“ trains is very little. Slower or faster train cannot run through this section without overtaking (Krýže 2005).

On double-track line, capacity is restricted by turn of trainsets and by minimal platform headways, if there is only at-grade access to platforms in the stations.

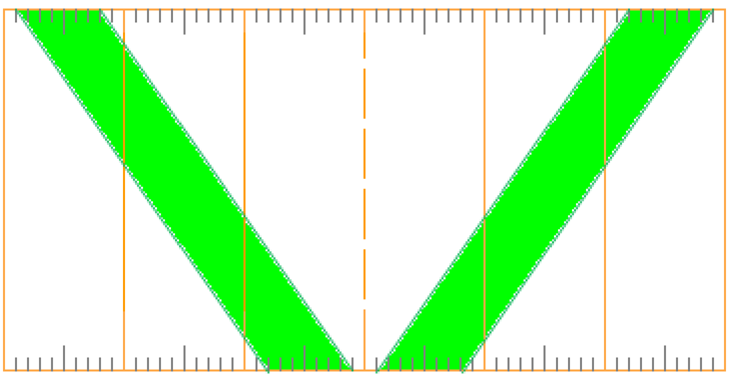

Figure 2.6 Time windows for periodic train paths in the opposite direction on single-track line, if zero symmetry should be preserved.

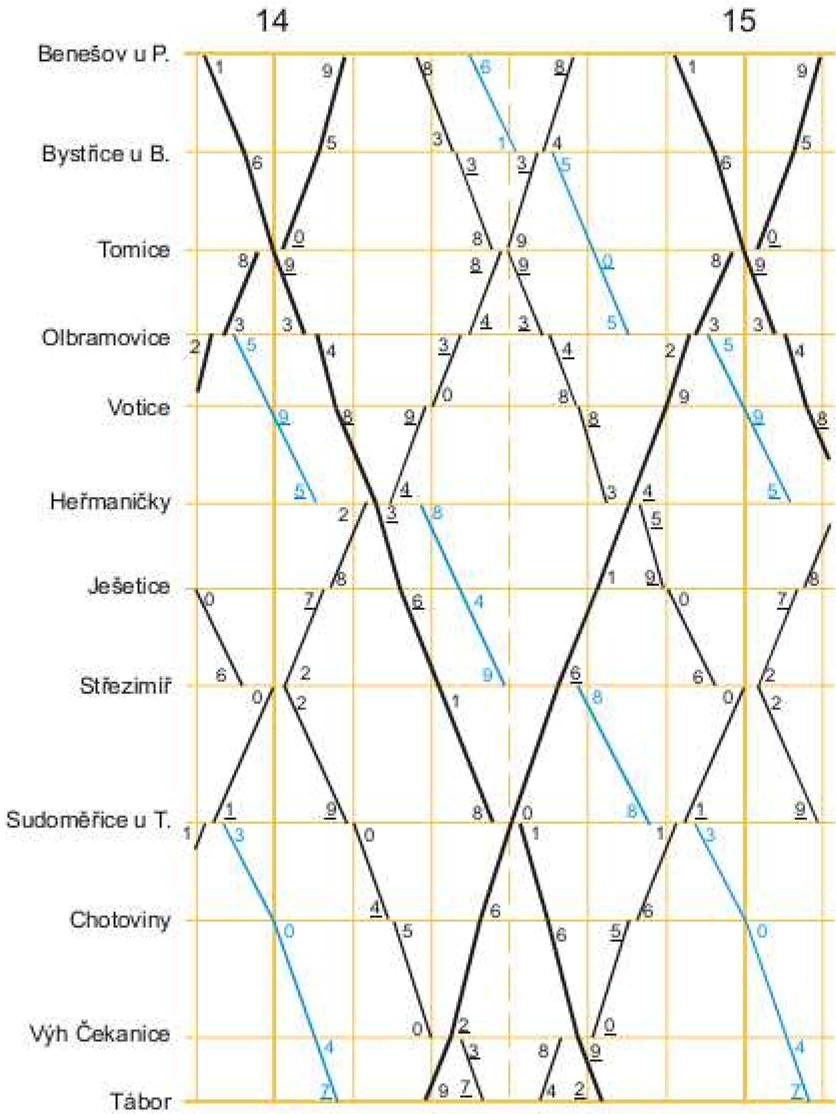

Figure 2.7 PFTPs on single-track line. Contrary to periodic passenger timetable, these PFTPs cannot be scheduled into zero symmetry with PFTPs in opposite direction, because they are designed to pass through outside stations exactly at zero minute. (Krýže 2005).

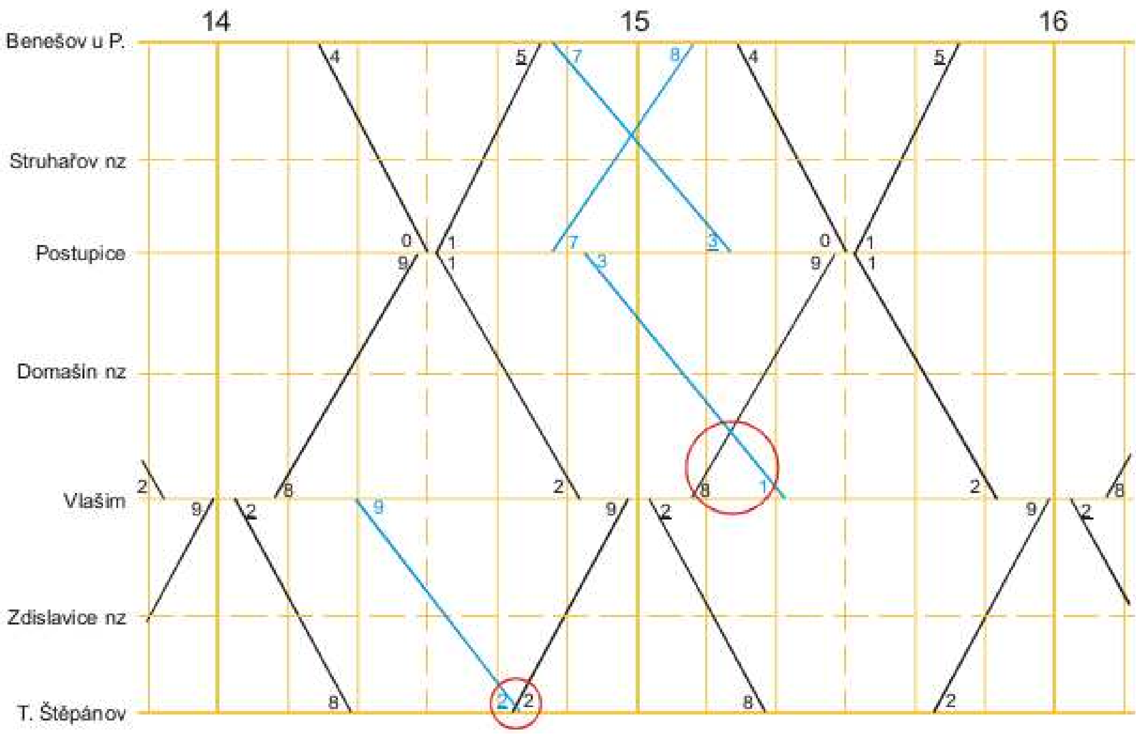

Figure 2.8 Lack of usable capacity for freight trains on a local single-track line with periodic timetable of passenger transport. There are no block posts between stations. The freight train paths between Benešov u P. and Postupice are alternative. (Krýže 2005)

Opava (2010) developed formulas for calculation of recommended freight train masses for various gradients, if freight trains should accelerate sufficiently to enable stable operation. Typical Czech freight electric locomotive (class 163) was considered. The resulting gross train mass was mostly lower than 500 t, which is about half or third of typical mass of Czech freight train. For more powerful modern locomotives, results would be similar because of maximum technically possible tractive force.

2.4 Problems of timetabling of freight trains in periodic passenger operation

Lindner and von Redern (1989) pointed out a system conflict between IPT and freight transport, which often takes place on main double-track lines. In ideal case (from the IPT viewpoint), regional train departs from IPT-node just few minutes after fast train, to arrive in further IPT-node few minutes before arrival of next fast train. Because changing times even in larger node stations mostly do not exceed 5 min, it is impossible for freight train to run between fast and regional train. So, freight train has to stop somewhere to be overtaken by passenger train. In Figure 2.9, two IPT-nodes with connection between fast and regional trains are presented.

If fast PuT segment operates in longer period than regional trains, Krýže (2005) proposes an interposition of freight and fast passenger train paths.

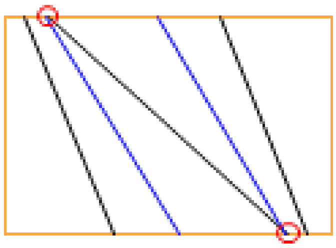

Figure 2.9 Capacity consumption of IPT-connection.

Figure 2.10 represents problem of dense passenger operations together with considerably slower freight train. This has to stop often to be overtaken by passenger trains. Long braking and long acceleration after stop (which follows from generally greater mass of freight train than passenger train) further increases heterogeneity of passenger and freight train paths, and thus leads to lower capacity utilisation.

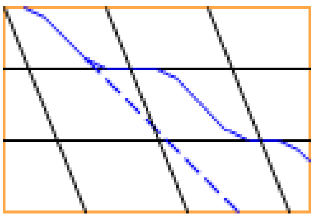

Figure 2.10 Dense passenger operations vs. freight train.

2.5 Periodic freight train paths in theory

Lindner and von Redern (1989) found that it was necessary to let periodic time windows ("canals") free for freight trains. These should be wide enough for required number of freight train paths per hour. *These time windows should be preferably connected in nodes* (if needed, among more than two lines to enable use by freight trains with various origin/destination stations). In the case of insufficient capacity, the authors proposed to *review the structure of passenger transport offer*. Of course, requirements of freight transport should not lead to breakup of important elements of network offer of passenger transport.

In closing of their paper, the authors mentioned an important postulate, which has remained actual up to now. *Strictly speaking, the process mentioned above does not result in periodic freight products (train systems), but in periodic freight train paths, which can be used by freight trains also only partially.*

The authors admit certain variability within given time window, which is caused by difference in section runtime between passenger and freight trains – e.g. 1-2 freight train paths for the speed of 90 km/h instead of 2-3 freight train paths for the speed of 100 km/h.

Finally, justification of this newly-emerged linkage in timetabling (PFTPs), which cannot be given reasons neither by operation planning nor by product structure of FRUs, was discussed. On the other hand, PFTPs provide qualitative offer of capacity for freight trains during the day.

Stähli (1990) considered two types of freight trains from the periodicity point of view. The first type were local freight service trains with frequent stops, but a frequency of only one pair a day. According to experience, train paths for such trains can be constructed after periodic train paths. The second type were through freight trains or long-distance freight trains. Their train paths should be already planned as periodic, in coordination with passenger timetable – using netgraph (see sub-chapter 1.5). Stähli did not see important only systematization of timetable, but also better capacity utilisation.

Opitz (2009) maximised number of PFTPs in the framework of network-optimized IPT, using Ford-Fulkerson algorithm and feasibility check by PESP-Solver. For freight trains' modelling he used one trainset and "template train atoms" differing in stopping or passing process. These atoms were combined together to model a PFTP. There were no requirements for freight train paths' quality (except summarization of waiting minutes weighted by net load – but this does not lead directly to lower number of overtakings), as capacity utilisation problem was solved on the example of Rhine bottleneck corridor Weinheim – Basel. Nevertheless, most main railway corridors in Europe suffer rather from lack of demand after freight transport (which relates to unattractive transport times, caused i.a. by low-quality freight train paths).

Wichser (2004) described *a sharpening conflict in requirements for railway capacity allocation between PRUs and FRUs,* which has been outlined above. Periods of long-distance or regional PuT lines in Switzerland are commonly 30-60 min. By suburban trains, a period of 15 min can also occur. On the east-west corridor, for instance on railway line Biel – Yverdon-les-Bains, long-distance trains of two PuT lines (each with 60 min period) must run 3 min behind each other, to provide that freight trains need not to be overtaken too often (as Figure 2.11 illustrates). Freight transport planners struggle for status quo, but public transport planners would rather implement an interposition into 30 min period in the mentioned section. However, such period would lead to unbearable decrease of freight train path quality, which is at present already lowered by frequent overtakings.

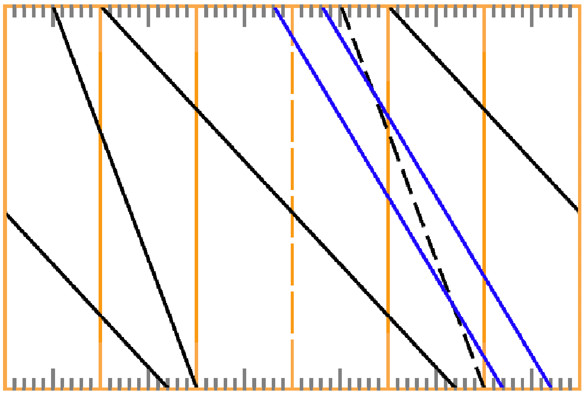

Figure 2.11 Illustration of a conflict between PRUs' and FRUs' requirements for railway capacity allocation.

Wichser further formulated requirements for quality of PFTPs. He claimed that in the future they should be *planned together with periodic passenger train paths*. Present and future (horizon 2010 - 2020) bottlenecks of Swiss railway network from viewpoint of freight railway were determined.

In the next part, Wichser described market requirements for freight railway. He stressed importance of involvement in logistic chain, need for shortening of transport times and for train paths, which are available in the short term – for better traffic management. He *required the same priority for both passenger and freight trains* and search for *global optimum* by solutions for disturbances.

Despite higher speeds of freight trains nowadays, Wichser pointed out growing difference in speeds of passenger and freight trains after putting new Alpine base tunnels into operation, which will lead to lowering of capacity utilisation on Gotthard and Lötschberg corridors. So he found desirable not to increase speed of passenger trains, if it is not forced by system travel time.

Wichser also emphasised need of connection of freight train paths between subsequent lines, so that freight train can pass through without stop. Such connections should be provided particularly on borders between national railways (IMs) or between significant nodes of freight railway (marshalling yards or terminals of combined transport).

Finally, Wichser warned against lowering of period of (sub)urban railway from 30 min to 15 min on lines, where this could lower capacity of significant freight corridors.

Čapek (2004) developed in cooperation with SBB Infrastruktur (and in the frame of PULS 90 project) a software tool called FlexFahrplan, whose aim was to plan timeslots for freight trains more rapidly and with better capacity utilisation. Thus, an algorithm for speed bundling of FTPs with passenger (or another already allocated) train paths was developed as a part of this tool.

2.6 Capacity of a node station or junction

There does not exist any unambiguous definition for capacity of railway node station or junction. It is determined either statically using analytical methods, or dynamically using software simulation of railway traffic, which examines timetable stability. There is again necessary to know the planned timetable in advance – including lengths of trainsets and occupation of station tracks. *Generally, the more simultaneous conflict-free run routes relevant for given timetable are enabled by switch regions, the higher capacity of the node station (or junction).*

2.7 Network capacity

Capacity of railway network is limited by its bottlenecks – elements (either line sections or nodes), whose capacity is used at its maximum (so that higher utilisation would threaten system stability). Thus, capacity of subsequent elements cannot be utilised more.

In Czech railway network, especially its central elements are bottlenecks (Binko 2007). Binko in his work also pointed out capacity conflict between long-distance and regional trains. After modernization of main lines, runtimes of long-distance trains were shortened in some sections. Resulting higher heterogeneity has lead to necessity of overtakings of regional trains by long-distance trains.

Swiss railway network is the busiest one in Europe due to developed IPT of passenger transport (period of 30 min is very frequently used) and transalpine (north - south) freight transit. Dense offer of passenger services has been leading to growth of demand above planners‘ estimations. Despite of some successfully implemented innovation (e.g. ETCS Level 2), experts have to seek new ways how to utilise current infrastructure even more efficiently. The reason is that there is very little space and finance for new infrastructure. Luethi (2009) describes project PULS 90 of Swiss Federal Railways, which is based on the idea of division of network into *condensation and compensation zones*.

In condensation zones, or bottlenecks, buffer times and time reserves are lowered. These are increased around, in condensation zones – of course without negative impact on capacity utilisation. Stability in condensation zones is secured by *real time rescheduling*, based on special algorithm, which calculates minimal sum of feasible target delays within given area. If the first train is delayed, so that it disturbs operation of the second train (this event is predicted by monitoring and calculation), the rescheduling system sends a message to locomotive driver of the second train. Content of this message, sent in sufficient advance, is a speed which the second train has to slow down to, to meet permissive signal aspect (not „Stop“). The acceleration from stop would delay the second train more than slowing down to lower speed.

According to interview with Lüthi, a co-researcher of the project, freight trains can be rescheduled with accuracy of 30 seconds (for a comparison, Intercity trains achieve accuracy of 7,5 seconds).

2.8 Periodic freight train paths in practice

On Swiss railway network, IPT has been working for few tens of years. Swiss railway network is, to author's knowledge, the only one, where PFTPs in mixed traffic with IPT are used. Part of these train paths are allocated to FRUs during annual timetabling process. The rest remains in offer as catalogue freight train paths (contrary to Czech practice*, whole remaining usable capacity is filled by catalogue freight train paths*). Figure 2.12 depicts cut-out from train path catalogue for Gotthard railway line (Basel – Bellinzona – Chiasso/Luino) for timetable 2009/10. It is worth to notice that these train paths are not always periodic precisely to minute (e.g. „green“ group in Chiasso).

Fahrplanzeiten / Strecken																Teilstr. / Anschlusszeiten				
SH / ZVB / RBL		Basel RB		Arth-Goldau			Erstfeld			Bell SPAO			Chiasso/Luino			LI	GALL	NOV	CHI	Mil GP
ab	von	ab	von	an	BW	ab	an	BW	ab	an	BW	ab	ChSm	ChSU	LI	ab	an	an	ab	an
52381F	RBLA	1451	BRBD	1631	b	1634	1701	bcd	1713	1904	bd	1911		2018					2113	2157
		1504	BRBD	1656	b	1659	1727	bd	1739	1928	bd	1935		2039					2137	2221
		1508	BRBD				1739	bcd	1751	1941	bd	1948		2053					2155	X
		1536	BRBD				1746	bcd	1758						2053	2207	2335			
		1547	BRBD	1724	abc	1742	1819	bd	1828	2012	abc	2038			2132					
52383F	RBLA	1551	BRBD	1731	b	1734	1801	bcd	1813	2004	bd	2011		2118					2213	2257
		1604	BRBD	1756	b	1759	1827	bd	1839	2028	bd	2035		2138					2237	2321
		1608	BRBD				1839	bcd	1851	2040	bd	2047		2146					2255	2339
		1629	BRBD				1846	bcd	1858						2210	2243	2330			
		1647	BRBD	1824	abc	1842	1919	bd	1929	2113	abc	2141			2242	2253	2357			
52385F	RBLA	1651	BRBD	1831	b	1834	1901	bcd	1913	2104	bd	2111		2224					2313	2357
		1706	BRBD	1856	b	1859	1927	bd	1939	2128	bd	2135		2239					2343	0027
		1710	BRBD				1939	bcd	1951	2141	bd	2148		2247					0001	0045
		1729	BRBD				1946	bcd	1958						2253					
		1747	BRBD	1924	abc	1942	2019	bd	2028	2215	abc	2240			2332	0021	0104			

Figure 2.12 Catalogue of train paths for Gotthard railway line and 2009/10 timetable (particular groups of train paths, that repeat, at least approximately, in a 60 min period, are distinguished with colours by the author) (Trasse Schweiz AG 2009).

Swiss freight timetabling is very specific because of Switzerland's geography. The main volume of freight transport is represented by two north-south transit corridors. Domestic freight transport flows are strongest in east-west axis. Thus, the Swiss solution with low number of connections between PFTPs cannot be exactly transferred in other European countries. Freight timetabling in Switzerland is also strongly consolidated by concept Bahn 2000, which was focused mainly on targeted investments in favour of passenger railway.

The other case of practical usage of PFTPs, known to the author, has occured on dedicated freight line (Betuweroute), which serves Dutch container seaports (Keyrail 2011).

RailNetEurope (2012), the association of European IMs and Allocation Bodies, promotes freight corridors with internationally allocated train paths, partially periodic. However, PFTPs for these corridors do not always respond national timetables.

2.9 Periodic freight timetables in theory

Periodic timetables are mostly considered as unfamiliar for freight trains. Unlike passenger transport, demand after freight transport is very heterogeneous. Moreover, it pays for both shipper and FRU to transport large quantities of goods less frequently. In 1989, Lindner and von Redern (1989) formulated rules for construction of freight train paths within periodic timetable of passenger trains.

At first, the authors evaluated *advantages and disadvantages of periodic timetable for freight trains*. Advantages of periodic freight timetables were mentioned - clarity of offer for customers, speed bundling, steadier exploitation of marshalling yards and border controls, and shuttle trains operations. On the other hand, disadvantages are lower utilisation in times with little demand, too little quantity of goods for regular freight lines and necessity of compromise solutions between periodic freight timetable and peak (particularly suburban) passenger trains. *The conclusion was that rather periodic freight train paths, used eventually only partially, made sense.*

The authors further stressed limitedness of demand by end of working time of industrial companies (loading, departure), and subsequently before beginning of working time (arrival, unloading) – a well-known principle of night leap. However, present logistic solutions are more flexible (e.g. Just-in-time).

Müller (1999) investigated an IPT-based concept (Cargo-Takt-System) for wagonload transport in Germany, with use of conventional or innovative rolling stock (automatic coupling, autonomous drive etc.). Marshalling yards were proposed to correspond to IPT-nodes in passenger transport. The result of Müller’s research was a calculation that has shown no significant time- or cost-saving potential for such concept with use of conventional freight wagons.

Penner (2007) presented the concept 200X of Railion Deutschland (German national FRU). This concept should simplify wagonload transport by service of less points in network and train formation in few large marshalling yards. This means cancellation of direct connections between not neighbouring marshalling yards, which should lead to periodic timetable of „through trains“ between neighbouring marshalling yards.

German project LogoTakt (2009) seeks to develop technologies, processes and necessary tools that enable putting of whole multimodal logistic chain into periodic operation. Thus, system robustness should be ensured.

Široký and Cempírek (2009) developed a model periodic timetable for trains of combined transport within Central Europe and busy European sea ports. They used genetic algorithms to minimize sum of waiting time due to transshipment of containers weighted by their numbers. Periods of 6, 12, and 24 hours were used, but specific train paths were not constructed.

2.10 Periodic timetables in freight railway transport

Accompanied combined transport

At present, periodic timetables in freight transport are most often used in accompanied combined transport. The first reason is time windows, determinated by passenger transport. The second reason is regularity and thus attractiveness of such offer for road transport companies or car owners.

Accompanied combined transport can be divided by transport unit into RoLa and car transport. The purpose can be either objective favourableness of such transport (Eurotunnel, high mountains in the way) or public interest (environmental protection, quality of life for inhabitants). In some cases, both reasons can be present. If the demand is sufficient, period of such offer can be similar to passenger trains. For instance, trains for car transport in Switzerland operate in the period of 30 min (e.g. BLS 2009: Kandersteg – Goppenstein), or 30-60 min (e.g. Matterhorn Gotthard Bahn 2009: Realp – Oberwald).

Unaccompanied combined transport

In the field of container transport, daily operation of some trains with constant departure time can be observed (METRANS 2012). To author's knowledge, no periodic timetables of trains of unaccompanied combined transport are valid up to now.

3 FORMULATION OF FRAMEWORK PROCESS FOR CONSTRUCTION OF PERIODIC FREIGHT TRAIN PATHS IN NETWORK

3.1 Parameters of freight trains, scheduled through main Czech freight corridors

To gain knowledge about suitability of PFTPs for Czech railway network, following parameters of scheduled freight trains from SŽDC (2009b) were analysed.

- length
- brutto mass of load
- maximum allowed speed of a train

Local freight service trains (Mn), locomotive (Lv) and another service trains for internal use of IM or RUs (Služ) were excluded from the analysis, as well as postal freight express trains, whose parameters were similar to parameters of fast passenger trains.

For the analysis, four stations on main Czech railway corridors were chosen (see Annex A):

- Polom on the line 305B/270 Bohumín – Přerov (between Suchdol nad Odrou and Hranice na Moravě)
- Tlumačov on the line 305F/330 Přerov – Nedakonice (between Hulín and Otrokovice)
- Úvaly on the line 501A/011 Česká Třebová – Praha-Libeň (between Poříčany and Praha-Libeň)
- Vlkov u Tišnova on the line Brno hl. n. – Kutná Hora hl. n. (between Tišnov and Křižanov)

Days of operation of the trains varied significantly – daily, some days in week, optional operation etc.

Polom	≤ 1600 t	1601 - 2000 t	> 2000 t
100 km/h	93	13	7
90 km/h	37	53	12
< 90 km/h	14	1	2

Table 3.1 Numbers of freight trains after sorting according to brutto mass of load and maximum allowed speed – scheduled through Polom. 13 trains are longer than 600 m. (SŽDC 2009b)

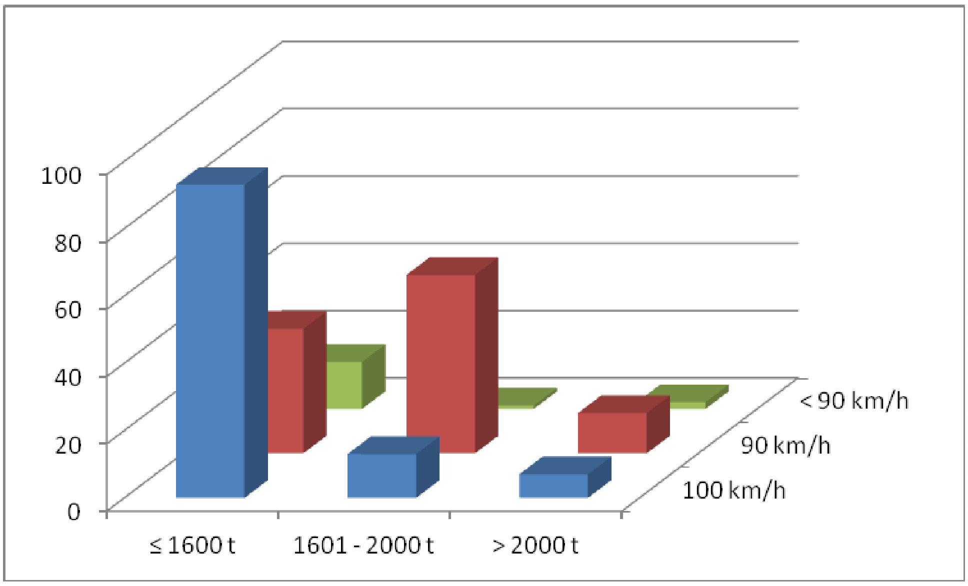

Figure 3.1 Numbers of freight trains, scheduled through station Polom – overall 232 trains. 84% of them can run at 90 or 100 km/h and their brutto mass of load does not exceed 2000 t. Data: SŽDC (2009b)

Tlumačov	≤ 1600 t	1601 - 2000 t	> 2000 t
100 km/h	69	11	5
90 km/h	20	20	9
< 90 km/h	3	0	1

Table 3.2 Numbers of freight trains after sorting according to brutto mass of load and maximum allowed speed – scheduled through Tlumačov. 15 trains are longer than 600 m. Data: SŽDC (2009b)

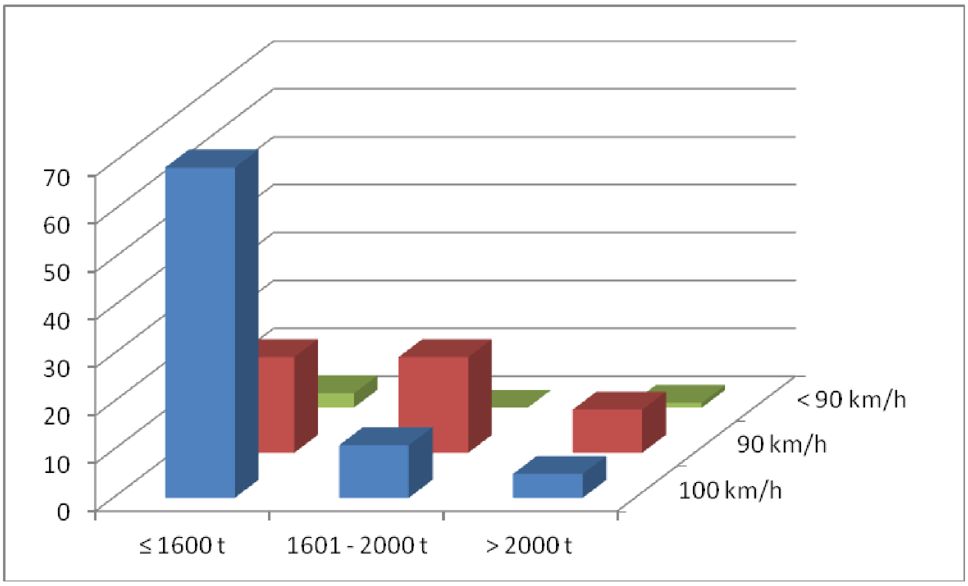

Figure 3.2 Numbers of freight trains, scheduled through station Tlumačov – overall 138 trains. 87% of them can run at 90 or 100 km/h and their brutto mass of load does not exceed 2000 t. Data: SŽDC (2009b)

Úvaly	≤ 1600 t	1601 - 2000 t	> 2000 t
100 km/h	37	7	1
90 km/h	34	16	4
< 90 km/h	2	0	0

Table 3.3 Numbers of freight trains after sorting according to brutto mass of load and maximum allowed speed – scheduled through Úvaly. 10 trains are longer than 600 m. Data: SŽDC (2009b)

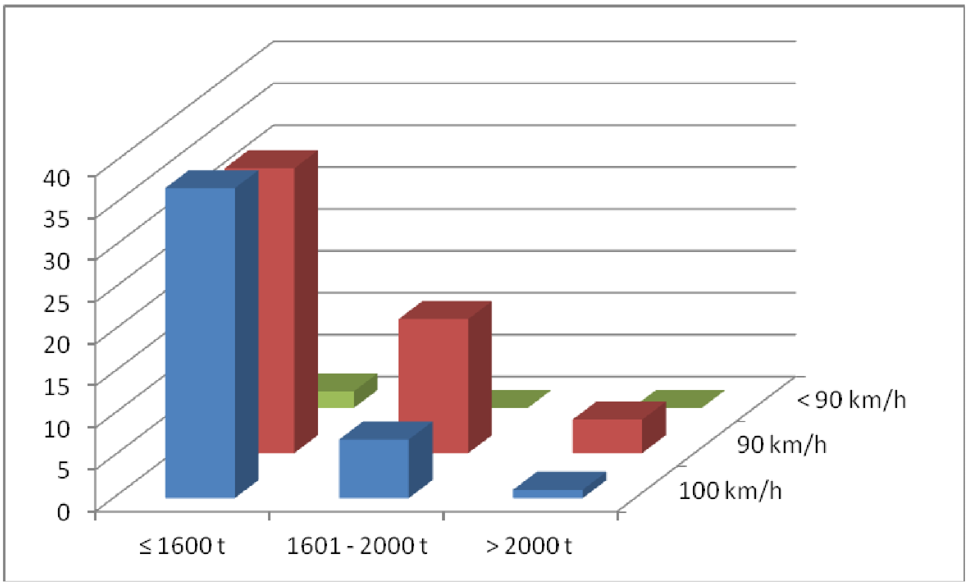

Figure 3.3 Numbers of freight trains, scheduled through station Úvaly – overall 101 trains. 93% of them can run at 90 or 100 km/h and their brutto mass of load does not exceed 2000 t. Data: SŽDC (2009b)

Vlkov u Tišnova	≤ 1600 t	1601 - 2000 t	> 2000 t
100 km/h	50	0	0
90 km/h	35	11	4
< 90 km/h	0	0	0

Table 3.4 Numbers of freight trains after sorting according to brutto mass of load and maximum allowed speed – scheduled through Vlkov u Tišnova. 20 trains are longer than 600 m. Data: SŽDC (2009b)

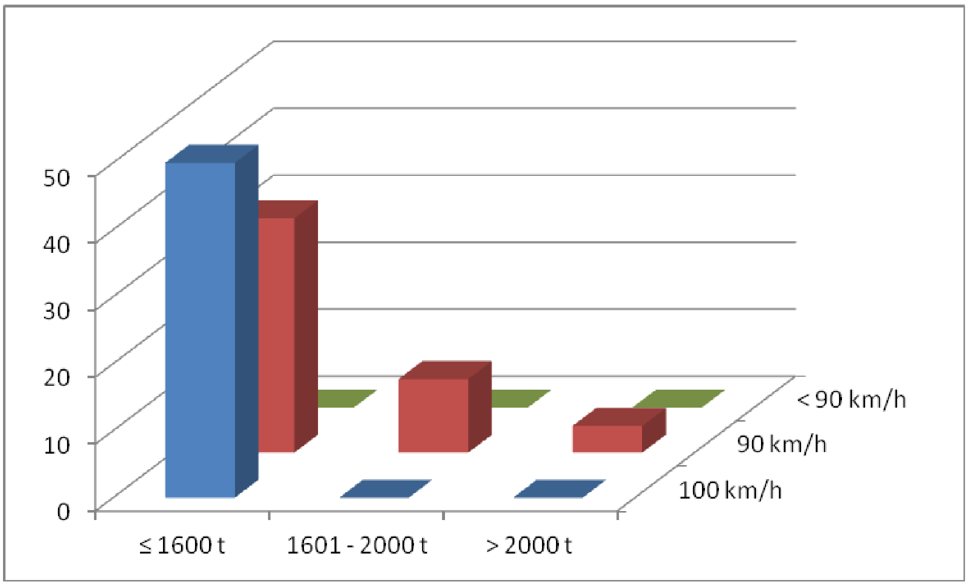

Figure 3.4 Numbers of freight trains, scheduled through station Vlkov u Tišnova – overall 100 trains. 96% of them can run at 90 or 100 km/h and their brutto mass of load does not exceed 2000 t. Data: SŽDC (2009b)

Results of the analysis confirmed suitability of freight trains, running on main Czech freight corridors, for PFTPs: 84% to 96% of analysed freight trains can run at 90 or 100 km/h and their brutto mass of load does not exceed 2000 t. Only 6% to 20% of them are longer than 600 m. For more accurate results, trains should be weighted according to number of days in year, when they really run.

3.2 Suitability of PFTPs for trains with same mass and locomotive, but different wagons

Runtimes of freight trains with same mass and locomotive, but different wagons, should be examined, because of different rolling resistance for different types of wagons (two-axle or four-axle) and different axle load. If these runtimes differ in tens of minutes within approximately 100 km, and if there is adequate demand, both slower and faster PFTPs can be constructed.

The pilot attempt was done with freight trains loaded with coal, containers, cars and mixed load (wagonload traffic). For every train, typical Czech electric locomotive class 163 and German freight wagons comparable with Czech ones were used. The mass of load (wagons + cargo) was equal to lower critical MPM of both directions. Only for car train, length instead of load mass was critical. The train paths were constructed in timetabling software Fahrplanbearbeitungssystem (FBS) on main line section Česká Třebová – Kolín, with stops only in both end stations.

Figure 3.5 represents a train diagram of fictious freight trains on Czech main line section Česká Třebová – Kolín, which busy both passenger and freight traffic. There are four train pairs – each one with different wagons. The time axis in the train diagram is vertical, the distance axis is horizontal.

Results show that, except for the lighter car train, there are only few minutes differences in runtimes between trains, within distance of approx. 100 km.

Posibilitiy of running of "special" freight trains – either unusually slow or heavy – through PFTPs must be examined. For instance, by using bundle of more PFTPs or in off-peak hours instead of peak passenger train.

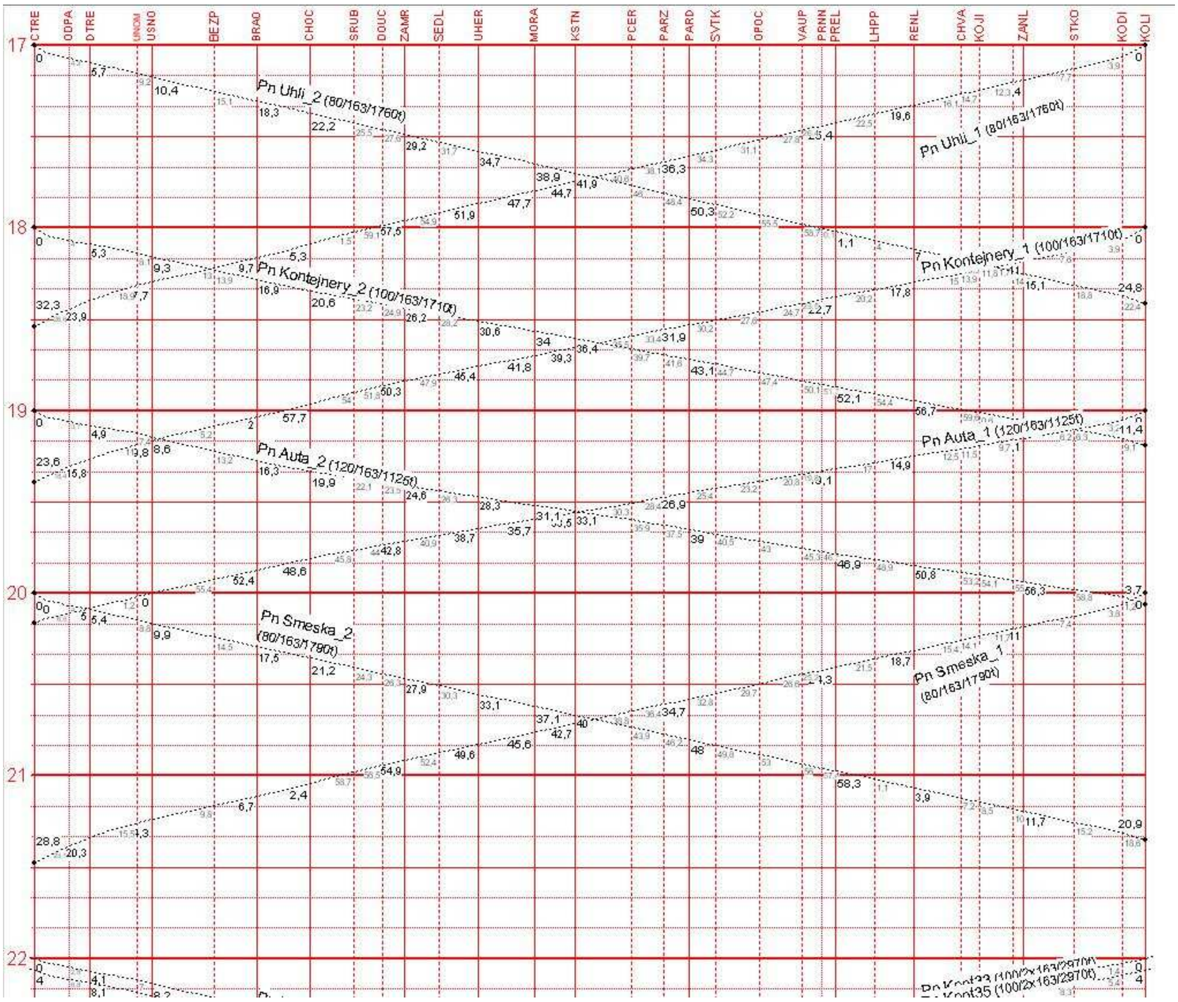

Figure 3.5 Examination of suitability of periodic train paths for freight trains with same mass and locomotive, but different load, on main line section Česká Třebová – Kolín. From above, there is train pair with coal, containers, cars and wagonloads. In brackets there are maximum allowed speed/locomotive class/gross mass of load in tons.

3.3 Theoretical approach: analogue to IPT

Looking at IPT in passenger transport, we can ask a question whether some analogue to IPT could be useful for freight railway. This analogue should be applicable in the context of IPT, because of its doubtless contribution to passenger transport quality. Freight transport demand is mostly too heterogeneous, so it cannot be satisfied by lines with regular period and mutual connections in nodes.

The resulting offer of periodic freight train paths should contain certain

- *regularity* (in terms of all-day available capacity in the context of IPT)
- *flexibility* (in terms of flexible connections between various directions in node or possibility to use only part of a freight train path)
- *train path quality* (fewer overtakings).

Contrary of the passenger transport, freight trains mostly need not to stop in significant nodes of railway network, but in certain freight terminals or marshalling yards aside from them. *Passing of freight train through node can save both capacity of bottleneck area and traction energy.*

The idea of offer of network-bound periodic freight train paths is illustrated on Figure 3.6. Each line represents a periodic freight train path in both directions, in unified period and with zero symmetry (if possible) to ensure symmetric connection of freight train paths in nodes. Boxes stand for node stations (opposite sides represent two switch regions of the station).

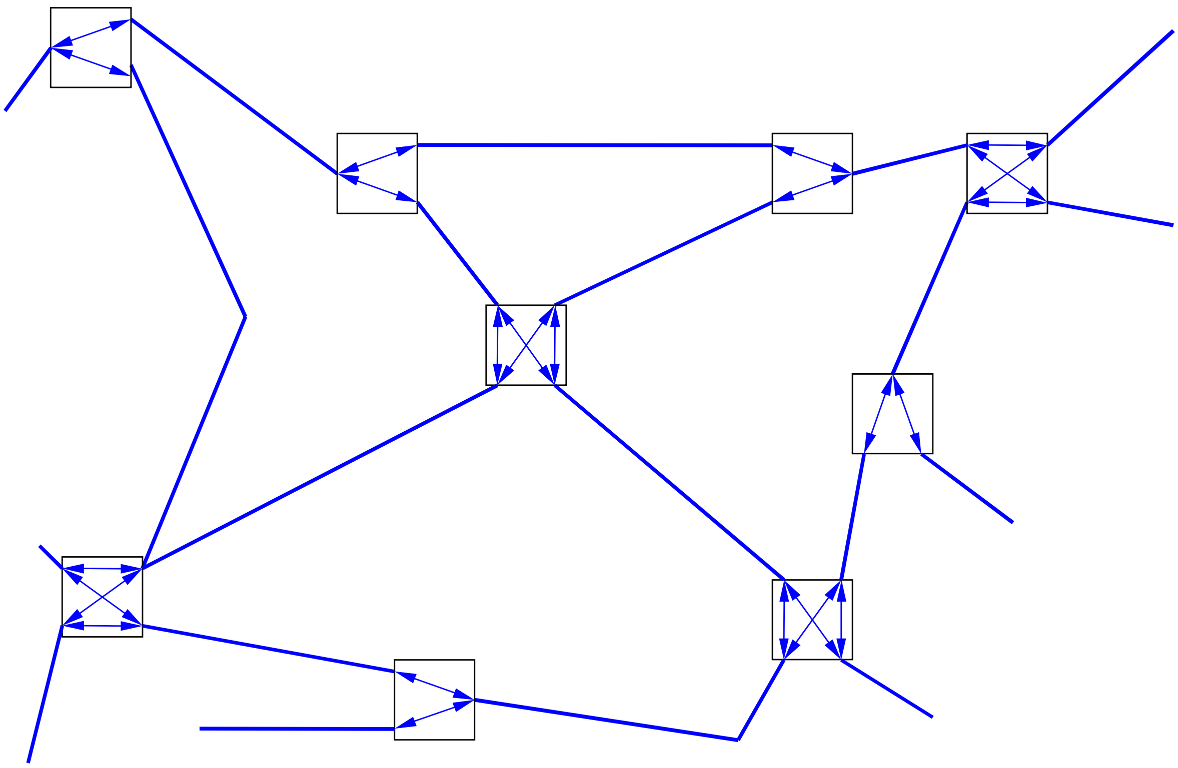

Figure 3.6 Illustration of network offer of periodic freight train paths.

IPT of passenger trains is understood as offer of periodic train paths (practically identical with timetable), which can be mutually coordinated between more RUs (for instance, in Switzerland). IPT is not comercially profitable, but attractive for passengers, so such services must be subsidized by public sector. Public sector, or charged subject (e.g. coordination body of integrated transport system) plans the offer of passenger services and coordinates it with buses and city public transport. The demand is represented by passengers, who use offered trains in part of their journey, and change them in node stations.

In freight railway, RUs offer to shippers particular time of loading and unloading of cargo. To fulfil this offer, RUs have to request capacity, i.e. train paths, by IMs. This means, contrary to IPT, there are two interfaces between offer and demand in freight railway (Figure 3.7).

As already mentioned above, tailor-made capacity allocation for freight trains is inflexible and unclear. Proposed network offer of PFTPs can be the alternative.

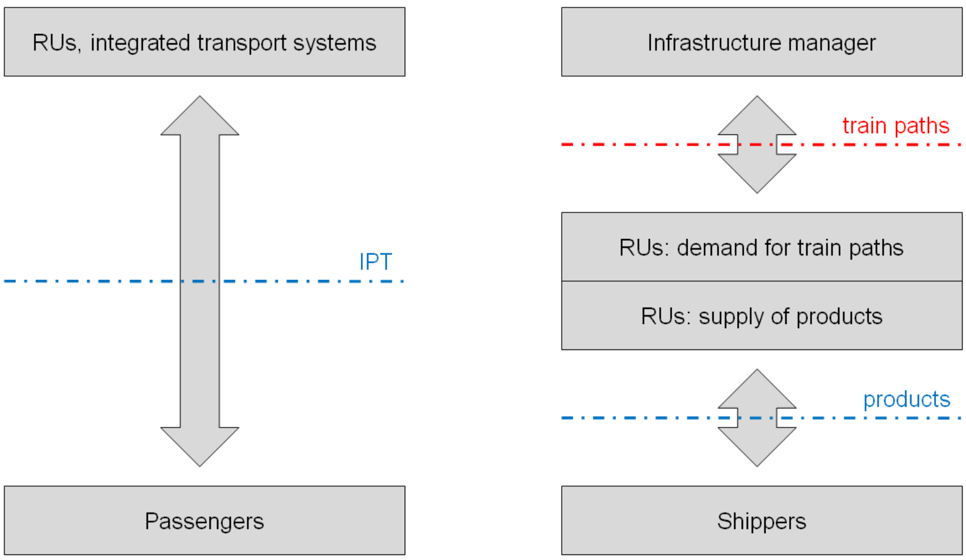

Figure 3.7 Interface between offer and demand in the case of IPT (passenger services ordered by public sector) and liberalised freight railway.

Common elements and differences between IPT in passenger transport and proposed offer of network-bound PFTPs are listed in Table 3.5.

Questions of period and PuT lines for freight trains were discussed above. PuT lines of freight trains are usually useless, with very few exceptions.

The period ensures regular offer of capacity, as well as efficient capacity utilisation within IPT. Zero symmetry ensures equal quality of the offer of capacity in both directions. So, if there is ensured passing through node station for freight trains in one ditection, the same passing through works for opposite direction as well.

System travel time in IPT ensures that passenger trains can reach both neighbouring IPT-nodes (and thus mutual connections to all involved PuT lines). *System* *runtime* for freight trains is slightly different. In ideal case, it would be equal to system travel time. But, in practice, freight trains have to be overtaken by passenger trains. So, primary purpose of system runtime is to avoid unnecessary stops of freight trains – either by speed bundling with slow PuT segment, or to reach particular time window to pass through node station or junction without stop. If lengthening of runtime up to particular system runtime is required, "coasting valley" can be used (see Figure 3.8).

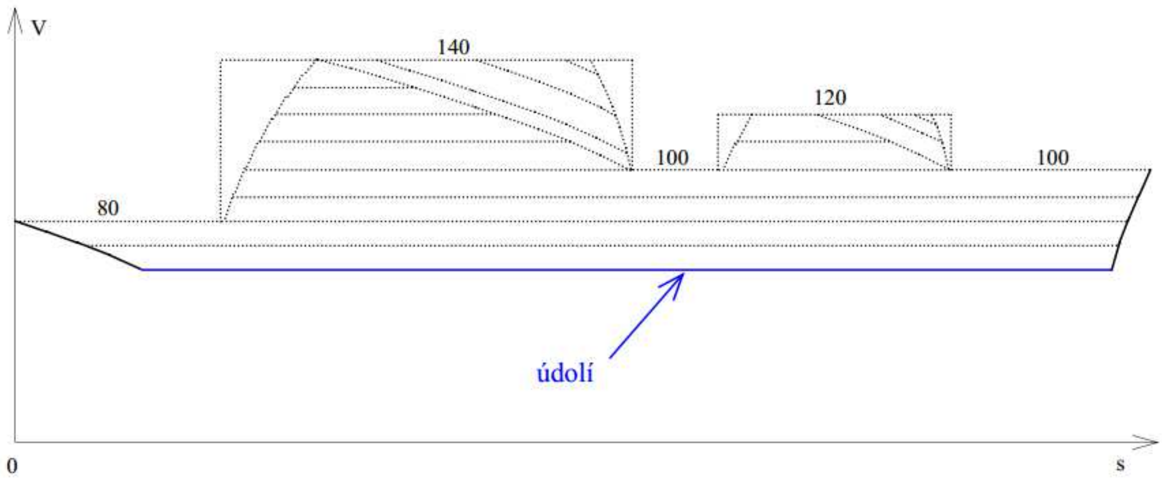

Figure 3.8 Utilisation of "coasting valley" (marked by blue colour) for few minutes lengthening of runtime. (Vicherek 2011)

Figure 2.8 displays often neglected (even in timetabling software) difference between calculated regular runtime of freight train and needed system runtime determined by two time windows. This problem often occurs on freight bypass lines in node areas, which connect two main lines with dense mixed traffic.

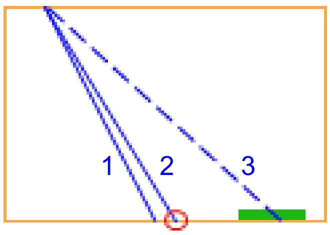

Figure 3.9 Illustrations of various runtimes of a freight train: technical (1), regular (2) vs. system (3) runtime.

On the other hand, system runtime can represent maximum allowed runtime for a freight train between certain overtaking stations, to fit in a PFTP.

Connections in passenger transport mean sufficient dwell and changing times to enable the passengers change between two trains. This happens usually in node station. The changing passengers are interested in adequate changing time (with reserve included). The passengers, who proceed further in the same train, are interested in as little dwell time as possible. An ideal IPT-node represents a tradeoff between these interests. However, to enable mutual connections between two trains, both trains have to dwell in the station longer than in the case of connection only from the first to the second train. The difference between resulting dwell time of a train and dwell time, which would be sufficient otherwise, is called synchronization time. The time, which represents a “freight” analogue to synchronization time, can be defined as *system runtime* – in the case wher passenger change between trains, freight trains “change” between train paths. The interest of both FRUs and IMs is to carry out this change without stop.

Just as system travel times represent constraints for passenger trains – their speed, acceleration or stopping pattern, system runtimes represent similar constraints for PFTPs, and therefore for freight trains which can use it. To fit in certain maximum runtimes through line sections, freight trains must fulfil certain ratio of locomotive power to MPM, and certain maximum speed, as well as some minimal braked weight percentage.

Element	**Passenger**	**Freight**
	PuT lines	network-bound PFTPs
period	yes	yes
zero symmetry	yes	yes
	system travel time	system runtime
multiples of period	yes	not necessary
connections (customer’s view)	dwell + change	preferably passing through
connections (offer planning)	synchronization time	system runtime

Table 3.5 IPT vs. offer of network-bound PFTPs.

3.4 Construction of priority and local PFTPs on a double-track line

Figures 3.10a-f represent the soft process of estimation of usable capacity for PFTPs in one direction of double-track line with periodic timetable of passenger trains and following construction of two segment of PFTPs – priority (or express) and local one. There is a fictious timetable on a fictious double-track line with 30-min-period of long-distance and suburban trains and 60-min-period of regional trains. There is assumed only one minimal runtime of all freight trains in each section and unified minimal departure/arrival headway of 3 minutes. Only one direction is depicted, passenger train paths and PFTPs in opposite direction are is in this case considered as symmetric by zero minute with the timetable below.

The line is divided into sections with constant number and sequence of trains per hour. For each section, usable capacity is determined. Then, usable capacity for passing of a freight train through whole line without stop is determined. This is used for construction of priority PFTPs. On each end, these PFTPs are equipped with alternative connections into more neighbouring directions (it is assumed in this example that conflict-free passing through node is always possible). The problem of passing through node station is analysed further. In the end, local PFTPs (with more overtakings) are constructed, using remaining usable capacity.

The explicit marking of usable capacity is not necessary in practice, if the situation is transparent enough.

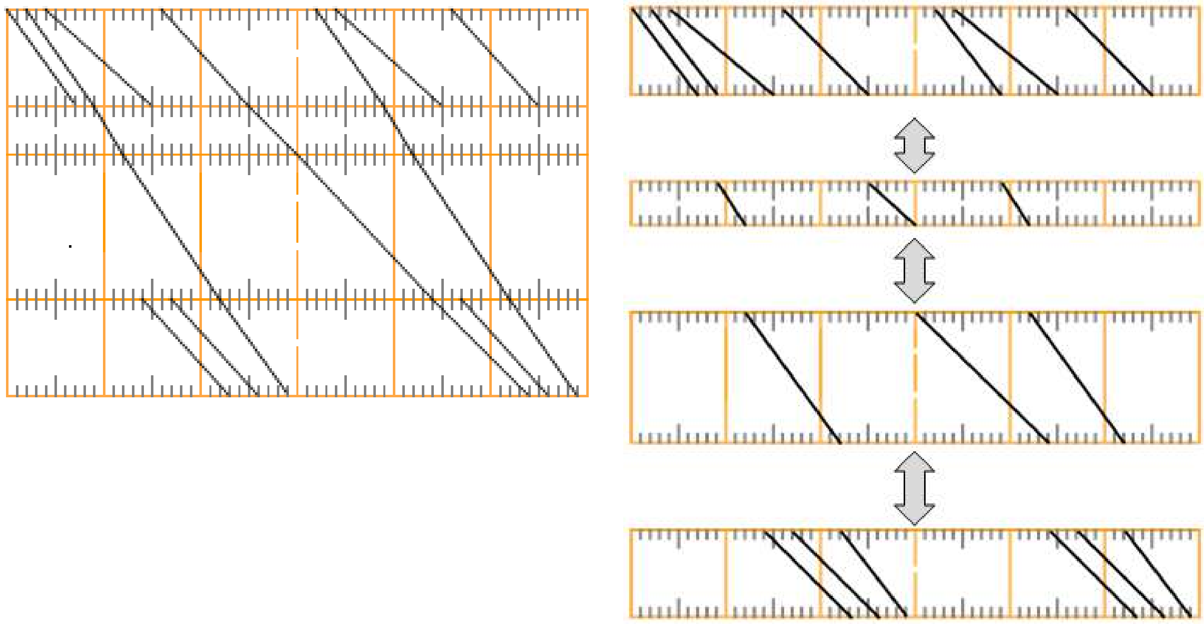

Figure 3.10ab Example of periodic passenger timetable in one direction (double-track line) and its division into sections with constant number and sequence of trains. The first and last sections are apparently bottlenecks of the line.

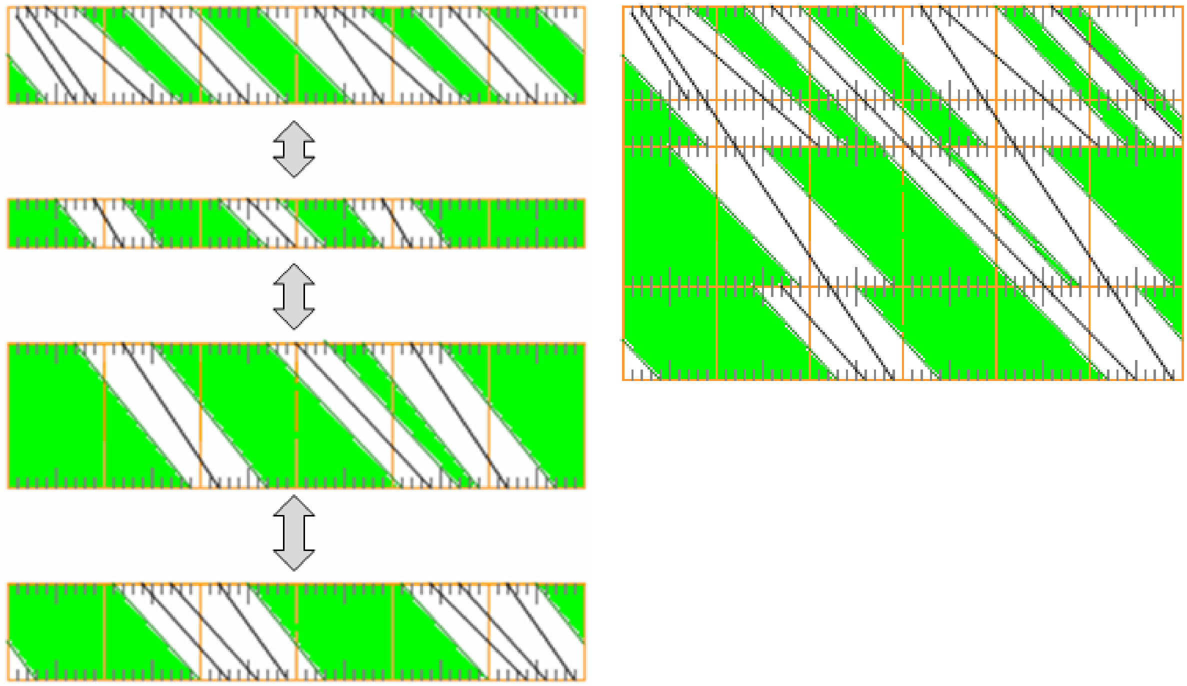

Figure 3.10cd Marking of usable capacity for freight trains in single sections and whole line – the usable capacity is delimited by passenger train paths, by mimimal departure headways for passing through of a freight train and by minimal regular runtimes of freight trains

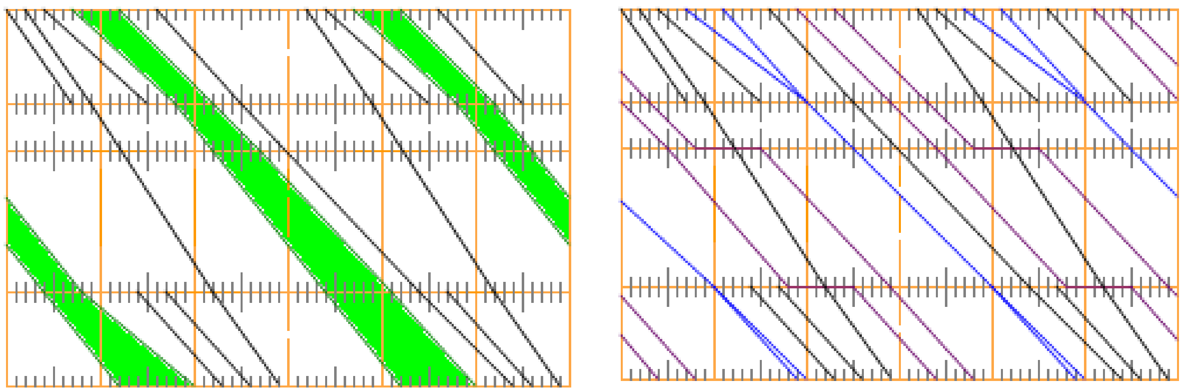

Figure 3.10ef Marking of capacity for passing of a freight train through whole line without stop and construction of priority PFTPs (with alternative connection from/into more directions) and local PFTPs.

3.5 Where to stop for overtaking – a soft decision process

It is evident that any stop of freight train in bottleneck area leads to lower capacity utilisation. So, overtakings should be preferably planned outside bottlenecks – in compensation zones.

Following attributes of overtaking stations have influence on quality of overtaking:

- gradient on following line section (acceleration up the hill lengthens runtime of a freight train significantly and increases consumption of traction energy)
- maximum allowed arrival speed[5] on overtaking track (usually depends on arrival turnouts)
- gradient on previous line section (braking downhill increases wear of brakes)
- maximum allowed departure speed from overtaking track (usually depends on arrival turnouts)
- usable length of the longest overtaking track in particular direction

In author's opinion, it is very difficult (if not impossible) to set exact order of priorities of the attributes listed above. Each line, each passenger timetable and each set of freight trains make together unique combination of specific conditions. So, a choice of the most suitable station for overtaking is always a *soft decision process*.

Following example should explain reasons for this opinion.

Let us set order of priority of the attributes of overtaking station as follows:

1. gradient on following line section
2. gradient on previous line section
3. usable length of the longest overtaking track in particular direction
4. maximum allowed departure speed on overtaking track
5. maximum allowed arrival speed from overtaking track

Let us have electrified double-track line in flat terrain, where there operate freight trains of maximum length 400 m. In each station, there is maximum arrival or departure speed 60 km/h for all overtaking tracks. The usable length of overtaking tracks varies from 420 to 530 m. The only exception is one station with arrival and departure speed 40 km/h for overtaking tracks, which are 600 m long (usable length).

According to chosen order of priorities, the only station with maximum arrival and departure speed of 40 km/h should be chosen, because of longest overtaking track there. However, common sense would advice to choose another station – in this case, usable length is not critical, and freight train can accelerate more rapidly, which leads to more efficient capacity utilisation.

Thus, it was decided not to specify any order of priorities, so the following framework process can remain applicable in various situations.

[5] from infrastructure point of view

3.6 Influence of requirement for unified (zero) symmetry

The impact of requirement for unified (zero) symmetry on PFTPs can be divided as follows:

Stations on single-track lines are often not located ideally for crossing exactly around symmetry time. So, freight trains have to dwell longer. This phenomenon is similar to practical implementation of IPT on single-track lines.

On the other hand, if overtaking of freight train by passenger train happens in symmetry time, it means the same event also for opposite direction. This requires a station with at least four free tracks.

For double-track line, in each direction, another station for overtaking can be chosen for various reasons (as stated above).

Generally, keeping of zero symmetry is not so important “inside” the line, where no connections between PFTPs occur, as in both ends of certain line – in node stations, junctions etc. So, *inner and outer symmetry of PFTPs should be distinguished*.

3.7 Influence of gradients on freight train path symmetry

In passenger transport, gradients can cause more signifiant diference in runtimes between different directions only by heavier trains pulled by low-powered (mostly diesel) locomotives. On the other hand, higher gradients make runtimes of freight trains for each directions very different, because of higher ratio of train mass to locomotive power (and thus to tractive force). In freight timetabling process, for each direction and each section with different gradient, traction calculation is necessary to determinate particular runtime. This calculation is made for locomotive (or multiple locomotives) of particular class.

The result of such calculations is *maximum permissible brutto mass of load of the train (MPM)*. This mass must not be exceeded, otherwise running of particular train pulled by given locomotive(s) on given section cannot be guaranteed. In sections with higher gradients, MPM can fall to half of MPM in flat land. In such sections, *MPM for passing through the section without stopping* and *MPM for acceleration anywhere in the section* are often distinguished. The second mass is significantly smaller than the first one. Moreover, MPM for passing through the section without stopping often requires some minimal running speed, which must be kept continuously, e.g. 40 km/h. MPMs further differ for particular types of rolling (train) resistence according to types of wagons in the train (e.g. with bogie or without, loaded or empty etc.).

Railway freight carriage in line sections with high gradient is in practice supported by additional locomotive or two – either head-end assistance, or rear-end assistance. There are minimal times required for coupling or uncoupling of these locomotive(s), which have no equivalent in the opposite direction. Thus, to keep unified (zero) symmetry of

PFTPs, such times must be compensated by artificial increase in regular runtime[6]. Another increase is necessary for compensation of longer time for acceleration up the hill and for runtime up the hill itself.

If there is high gradient up the hill and then downhill on a certain line (looking in one chosen direction), the symmetry of PFTPs is deviated on the top of the hill. This can complicate (but also simplify, according to position of station) crossing between opposite PFTPs on a single-track line. Figure 3.11 represents a fictious double-track line with peak (i.e. point with locally highest altitude) in the middle. There are two stations, suitable for overtaking of freight trains, around the peak. If the PFTPs were rigidly zero-symmetric all the line long, then the freight trains in one direction would have to accelerate up the hill after stop for overtaking, which would lead to higher consumption of traction energy. Figure 3.12 represents deviation from unified symmetry axis.

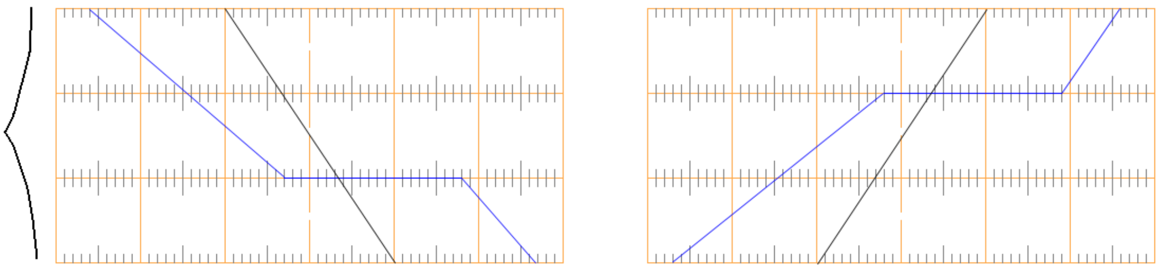

Figure 3.11 Local asymmetry, but global zero symmetry of PFTPs on fictious double-track line with peak in the middle. Altitude profile of the line is marked left.

[6] if local assymetry of PFTPs would have influence on sustaining of globally unified symmetry.

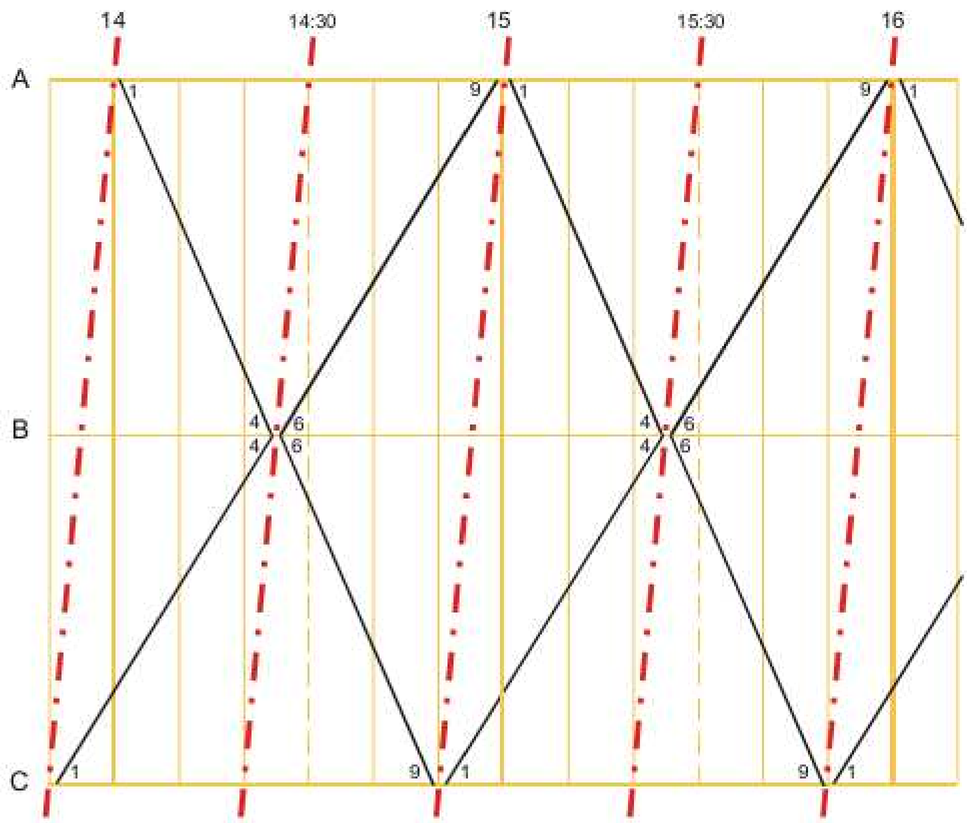

Figure 3.12 Influence of assymetric runtimes on symmetry time; symmetry time (axis) is marked by dot-and-dash. While there is zero symmetry in station A, in station C there is symmetry time in minute 50 (Krýže 2005).

3.8 Construction of PFTPs through node stations

In most node stations, there are at-grade intersections of railway lines. So, running of one train can block running of more other trains in another directions. In present, freight train paths are often constructed only for arrival into (or departure from) node station. This leads to lower capacity utilisation. In most cases, freight trains do not need to stop in node station, if they proceed into further destination. To avoid stops in node station, system runtimes (artificially lengthened runtimes) in compensation zones can be used.

Because of at-grade intersections, it is necessary to develop a method for transparent displaying of conflict run routes within period. The „IPT-clock“, used for displaying of connections between passenger trains, is not suitable for displaying of passing of freight trains through node without stop. For analysis of present state or for construction of PFTPs (eventually with slight adjustment of passenger train paths), a *node diagram* is proposed. Its example is depicted in Figure 3.13.

Node diagram is designed for periodic time window, here – one hour. In the middle, there is a conflict axis with minute scale. On this axis, there are necessarily marked those PFTPs, which represent conflict run routes (i.e. those run routes, which exclude at least one another run route from another direction). The conflict axis should represent a switch region of a junction or the middle of a station. In the case of larger station, there may be more conflict axes, which may represent more switch regions. Neighbouring line sections are represented by simplified train diagrams. There is always a periodic time window (here one hour) with minute scale. The time may begin in minute 00 or 30 – the more appropriate alternative for particular situation should be chosen. Length of neighbouring sections is generally represented only in a symbolic way, because only technical runtimes (supposed as already calculated) influence construction of PFTPs. The distance has direct influence only in the case that neighbouring section is very short (e.g. one 1 km long block section – this results very often in necessity of stop of some trains).

In some cases, e.g. node station with at-grade intersection of two double-track lines, the node station is critical for capacity utilisation. So, neighbouring sections are compensation zones. Instead of stopping in node station and waiting for free time window to proceed, a freight train can wait in the section, running considerably slower using "coasting valley" (e.g. 40 km/h) than technically allowed, to meet the time window and pass through node station without stop.

If this measure is feasible in all neighbouring sections, and sustaining of zero symmetry is possible, a *freight IPT-node* can occur. Contrary to passenger transport, all trains pass through without stop, and connections are secured between train paths, not between trains. The example of freight IPT-node is drawn on Figure 3.14 (for the same type of station as mentioned above).

Apparently, in some cases it is necesary to run considerably slower to achieve conflict-free passing through node station. In the case of high gradient in some neighbouring section, this slower running can have negative impact on MPM. If there is a single-track neighbouring section, slower running has negative impact on capacity utilisation of the section. Thus, freight IPT-node should be implemented only if a local worsening of capacity utilisation does not matter in particular case. In any case, passing through the node saves traction energy and lowers noise impact on inhabitants caused by braking. Classical timetabling would result in comparable travel times because of larger surcharges for acceleration and braking of freight train and waiting times for free time window.

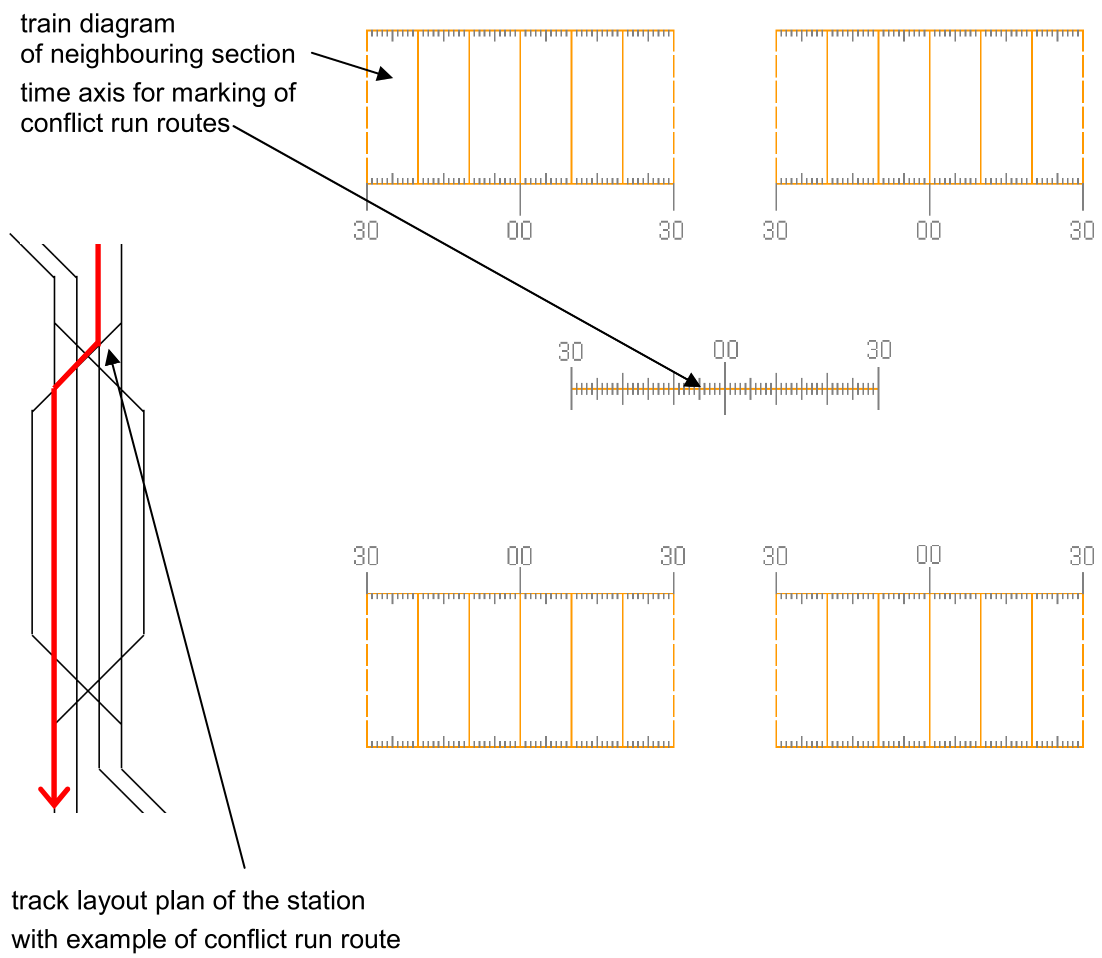

Figure 3.13 Parts of node diagram.

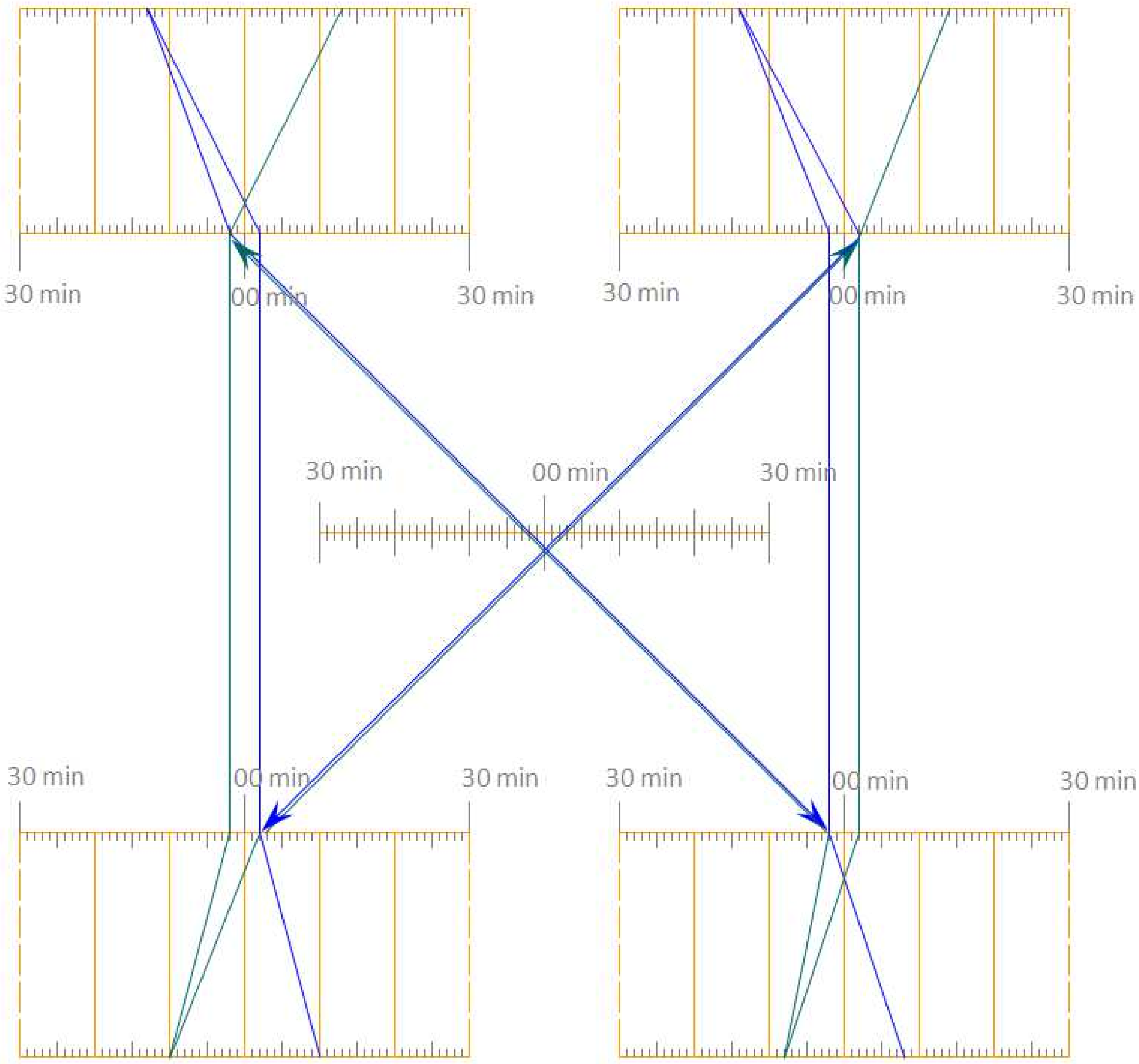

Figure 3.14 An ideal freight IPT-node depicted by node diagram. Type of station is the same as in Figure 3.13. Direction north → south is marked with blue colour, direction south → north with turquoise colour.

3.9 Framework process for construction of network-bound PFTPs

The framework process is soft, and thus should be understood rather as a guideline for IM than strict regulation. The result of its implementation should be sequence of train paths and program of operation in nodes and other significant stations (e.g. overtaking) – mixed operational concept for both passenger and freight trains. The train path construction itself should be done by IM – however, to give feasible results, the framework process must adopt empirical headways and other necessary constants.

For the case that simple construction of PFTPs for given infrastructure and IPT cannot fulfil requirements of FRUs, additional measures are proposed as a part of the framework process. These measures are introduced further in more detailed way.

Some parts of the framework process should be understood as iterative – the most typical case is construction of PFTPs on lines and through nodes.

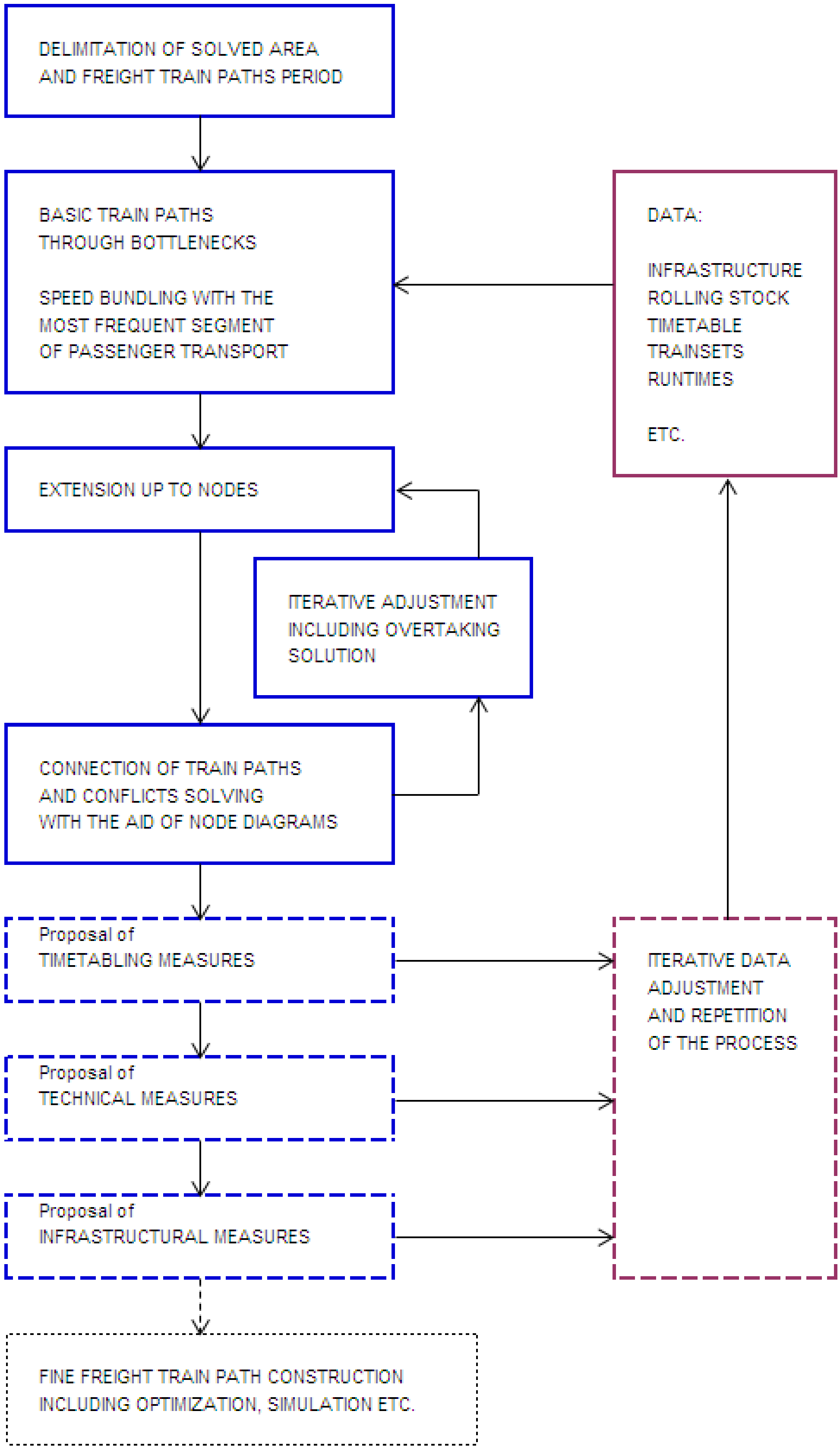

Figure 3.15 Framework process for construction of network-bound periodic freight train paths.

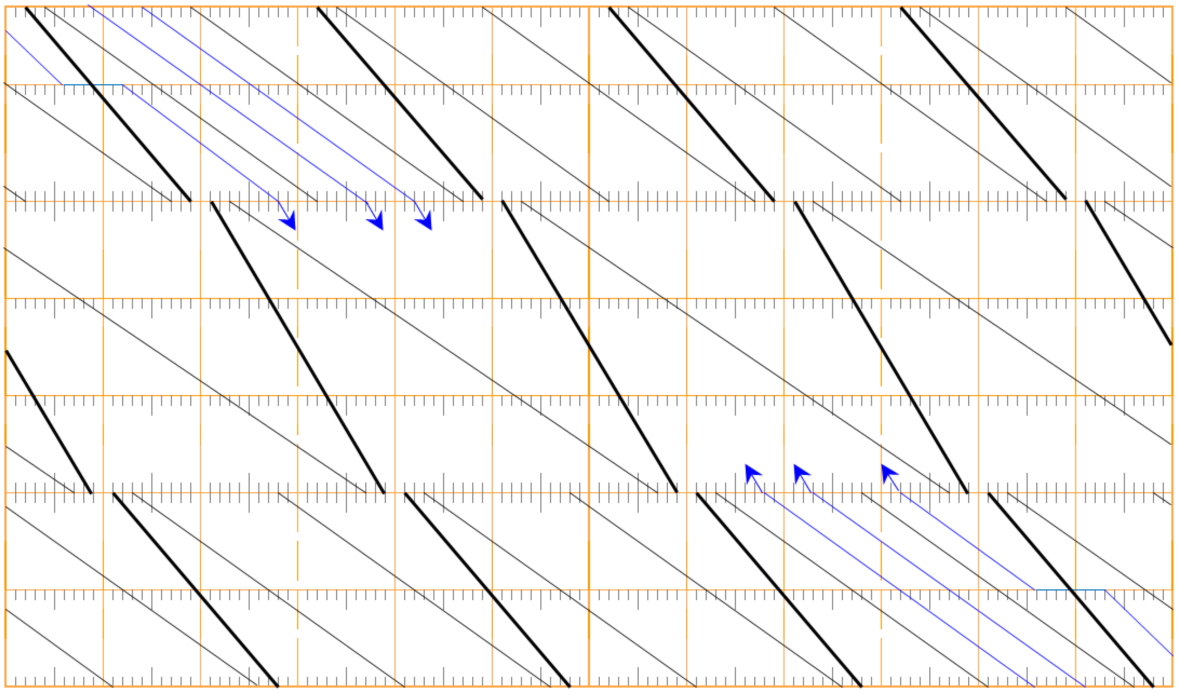

Figure 3.16a Construction of basic PFTPs through bottlenecks (within 30 min period).

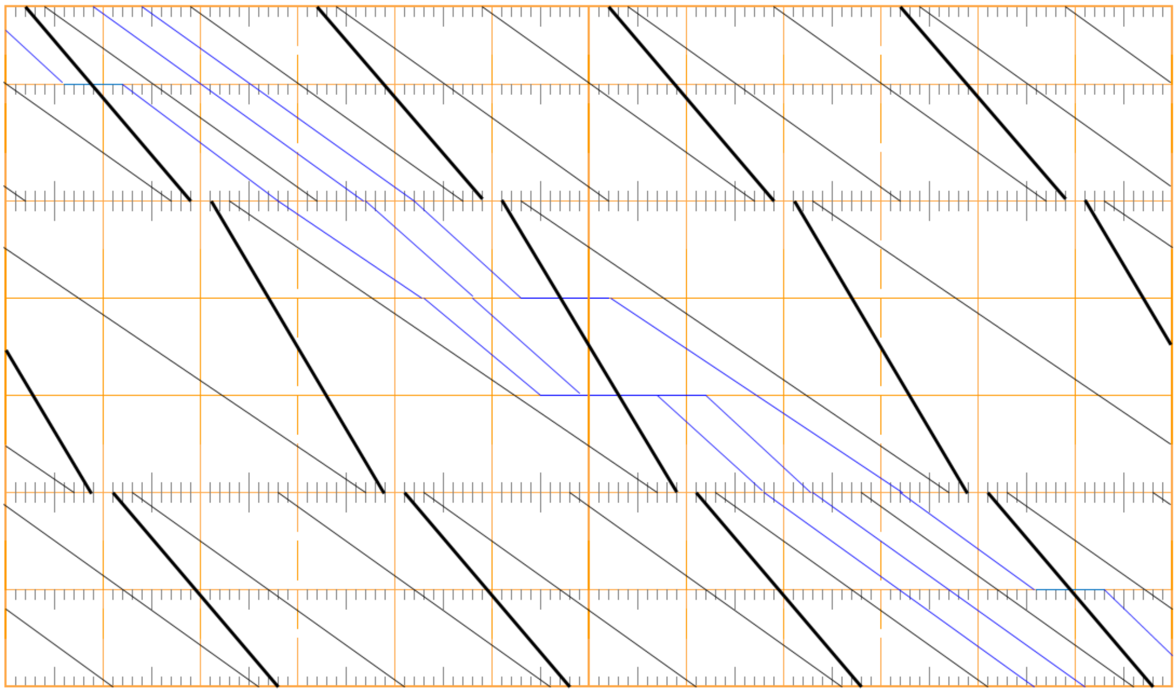

Figure 3.16b Connection of PFTPs within line section.

As outlined in Figure 3.16a and Figure 3.16b, construction of PFTPs *proceeds always outside* from freight IPT-nodes or from another connections of PFTPs into/from various directions (either forward or backwards in time). PFTPs, constructed forward and backwards, meet each other in some station, where a stop is scheduled (usually connected with overtaking by faster passenger train). This way of construction ensures a building set for PFTPs, which can be theoretically used for any network with sufficient usable capacity for PFTPs.

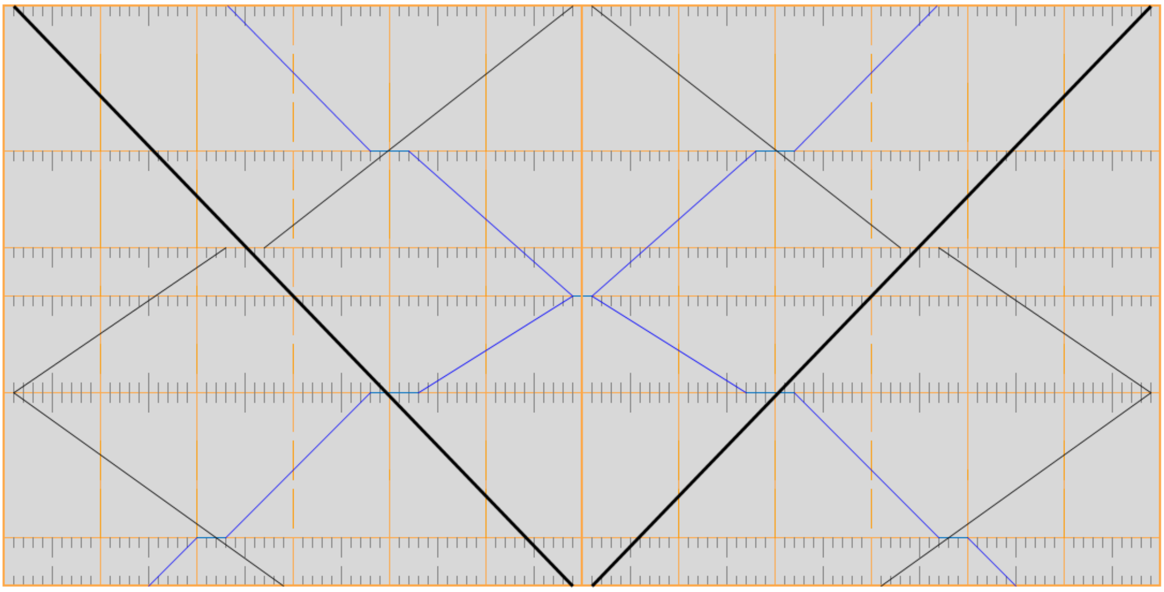

Figure 3.17 Construction of PFTPs on single-track line with two segments of passenger transport (each with 120 min period).

3.10 Timetabling measures

Artificial slowing down of freight train in particular line section can be necessary because of timetabling reasons (system runtime) or capacity reasons (speed bundling with most frequent PuT segment of passenger transport).

In practical operation, all involved staff (locomotive drivers, station masters and/or dispatchers) must be familiarized with such measures and trained to implement them properly. It is desirable to highlight planned slower freight train running into all forms of timetable for the staff – both with recommended running speed and minute of planned entry into bottleneck area. Each locomotive driver has his/her own driving style, so more alternatives how to achieve required system runtime, should be enabled. In compensation zones, if there is enough time to run slower, it is desirable to run in energy saving regime, i.e. using coasting. On the other hand, the staff must be aware when the freight train has to accelerate as rapidly as possible, due to tight system runtime.

For sections with high gradients, most freight trains need aditional locomotive in more. To utilise capacity better, these locomotives should be coupled and uncoupled in compensation zones – even at a cost of longer running. Faster running of freight train downhill against running up the hill can result in higher unused capacity downhill than up the hill. This difference can be used for return of rear-end or head-end assistance back.

Coordination of PFTPs with offer of passenger transport

The need of such coordination depends on total demand for capacity of given infrastructure, but also on mix of traffic (sequence of faster and slower trains).

PFTPs can be mostly moved by few minutes, but passenger train paths are determined by connections in nodes (often in both ends). In case of significant excess of freight demand against passenger demand and insufficient capacity, passenger transport has to be penalised by some of following measures

- lengthening of changing (waiting) time in station to enable running through of freight train – see Krýže (2005) and Figure 3.9
- adjustment of stopping pattern (reduction or increase in number of stops in particular section) because of speed bundling or broadening of time window for freight trains (Figure 3.18)
- lowering of number of PuT segments because of broadening of time window for freight trains or crossing on single-track line – Figure 3.19

If other measures (e.g. infrastructural – see further) are inapproptiate or in too long time horizon, some above mentioned penalising measures are inevitable. If some stops of passenger trains are cancelled at all, an alternative service by bus must be secured.

In Czech Republic, probably the thorniest example is single-track railway line 541A/071 Nymburk – Mladá Boleslav. There are two PuT segments, both operated in 2-hour-period. Car factory in Mladá Boleslav is supplied mostly by this railway line, so there are serious conflicts in demand for capacity between passenger and freight transport. This resulted besides other things in effort of car factory for permission to ensure its supply by the use of megatrailers. This measure would have negative impact on more inhabitants than eventual cancelling of service of few stops (e.g. the town Dobrovice, which is approximately 2,5 km distant from railway). Hourly service of fast trains instead of present operational concept would satisfy needs of more passengers, and interposition with hourly PFTPs can be easily made. In the present, two new stations are built on this railway line, and in the future, doubling of the line is supposed.

Because of sensibility of penalisation of passenger transport, *it is strongly recommended to do it in advance, in the form of lowering of level of future improvement*. For instance, PuT line of regional trains operates at present in 120-min-period. For next operational concept, 30-min-period for this line was proposed. Because of busy freight traffic on the same line, where this regional PuT line operates, operational concept is revisited, so that proposed new period is only 60 min. In the case of large passenger flows in peaks, longer trainsets can be put into operation.

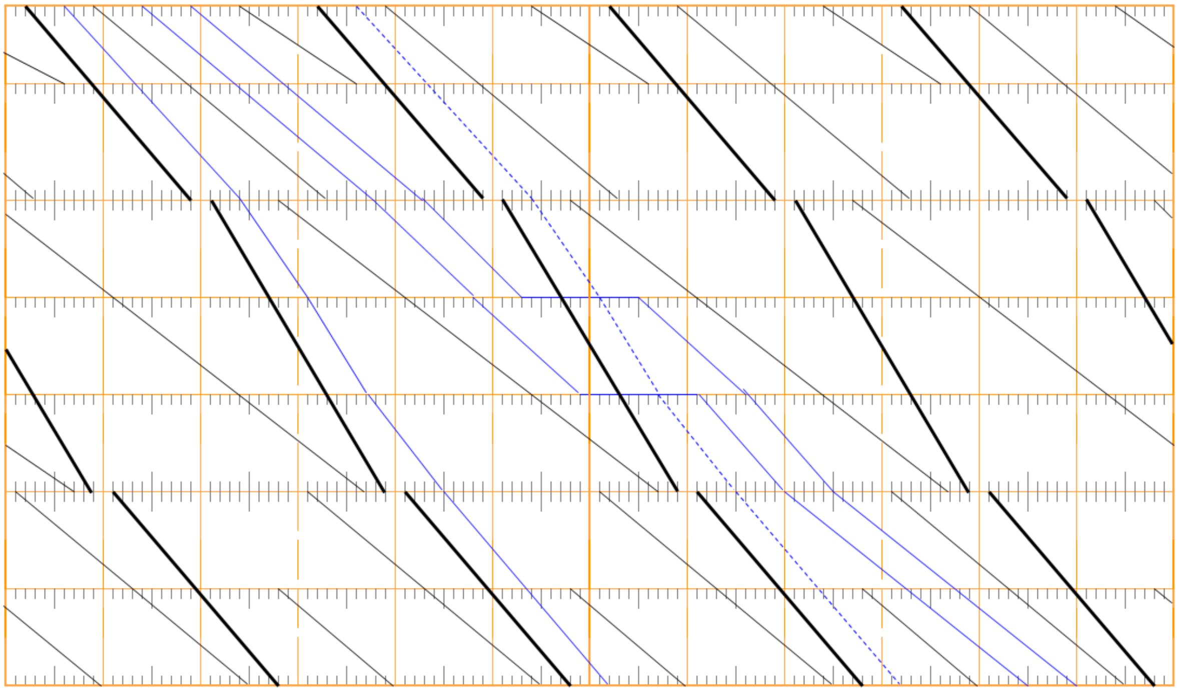

Figure 3.18 Coordination with passenger transport: thanks to adjustment of regional trains, qualitative PFTPs for express freight trains (marked by dashed line) can be constructed.

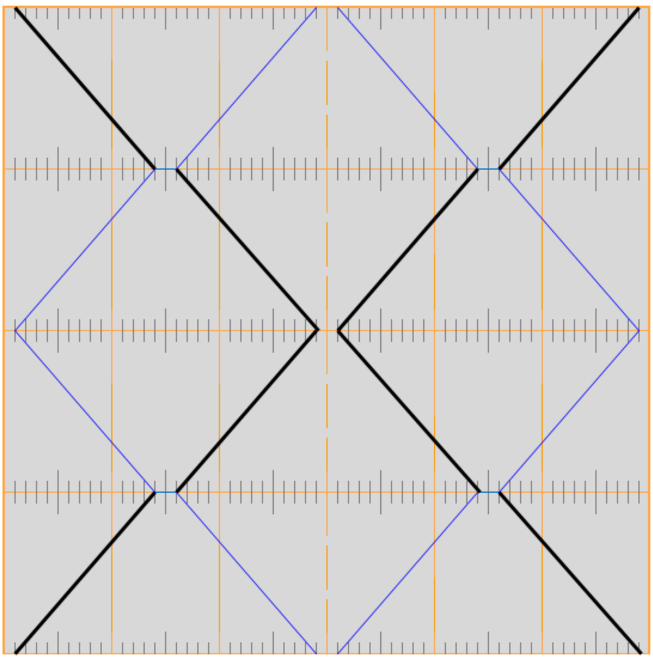

Figure 3.19 Interposition of passenger and freight train paths on a single-track line – thanks to reconfiguration of passenger transport offer into one PuT segment.

3.11 Technical measutes

As Luethi et al. (2009) pointed in conclusion of their paper, simulations show that reliability of railway system can increase, if train running is very precisely planned and controlled, e.g. running through particular point in exact time at given speed (entry into bottleneck area – see above). In the Czech Republic, there is system of Automatic Train Operation (ATO) developed by Lieskovský and Myslivec (AŽD 2011, Lieskovský et al. 2009 and Lieskovský and Myslivec 2010), which enables precise driving of a train (± 1 km/h, ± 10 s) and cooperates with signalling system. This system has been successfully implemented by regional (mostly suburban) trains. Nowadays, ATO is being tested on seldom stopping trains – mostly fast trains. By seldom stopping trains, a new problem occurred: how to fit into exact time window (to overtake, but not disturb operation of suburban train), but this problem has been solved., ATO was once tested also on a freight train. Such system has large potential to improve railway traffic and capacity utilisation – preferably combined with real-time rescheduling system, which orders locomotive driver to run slower, but without waiting before stop signal (by disturbed train operation).

Vicherek (2011) implemented a rescheduling algorithm in his own simulation software, which he used for simulation of the traffic on line section Hranice na Moravě – Prosenice (line 305/270), on the basis of a realized timetable of chosen day in the timetable period 2009/10. Results of the simulation have shown that contribution of rescheduling was for simulated line, trains and timetable relatively small, but runtimes of freight trains fell significantly – thanks to the system Automatic Setting of Run Routes (implemented in the simulation) and running of freight trains at defined speed. Thus, the largest savings in traction energy were recorded by freight trains.

Vicherek stressed not only importance of cooperation of rescheduling with Automatic Setting of Run Routes, but in the future also with ATO. Cooperation with ATO would lead to faster reaction of a train to any change, and would enable the driver to concentrate more on safety-relevant inputs.

Such combination of ATO and rescheduling would also improve real-time information about exact train position and enable more accurate prediction of traffic situation. Rao (2013) intends to develop an algorithm for integration of ATO and real-time rescheduling. Because of state of the art and likely trade secret, this is only facultative part of the proposed framework process.

3.12 Infrastructural measures

In case of insufficient capacity or train path quality, and stable short- and mid-term demand for freight train paths at the same time, proposal of targeted infrastructure improvement is appropriate.

The first type of measures is proposal for construction of new turnouts, tracks for overtaking, turnouts for higher speed in branch, lengthening of stations on single-track lines for enabling of active crossing (if there is only one PuT segment and interposition with PFTPs into half period is possible) or for allowing stop of longer trains, or doubling of line sections (Figure 3.20) etc.

Second type of measures focuses on division of block sections, so that they enable lowering of minimal headways.

In the Czech Republic, automatic block is possible only for blocks with minimal length 1000 m. This constraint leads to low capacity utilisation in centres of agglomerations, where maximum allowed speeds are often up to 60, respectively 100 km/h (which respond to minimal allowed braking distance 400, respectively 700 m). These braking distances are allowed between main signal and distant signal. Practical headway by relay and electronic interlocking system is approximately 3 minutes.

ERTMS/ETCS brings new possibilities to utilise capacity in a more efficient way. Block sections are divided with eurobalises. For every train, individual braking curve (and corresponding braking distance) is calculated. Braking distance can extend over more block sections. Thus, lower minimal headways can be achieved. Shorter block sections are very helpful in the area of frequent acceleration of trains (e.g. after stops of suburban train, after node station or after station of regular overtaking of freight trains).

In Switzerland, new railway line for the speed of 200 km/h (Mattstetten - Rothrist) allows mimimal headway of less than 2 minutes (scheduled headway is 2 minutes). However, the trains have to accelerate on separate tracks, because of older interlocking systems used in Zurich and Berne node area.

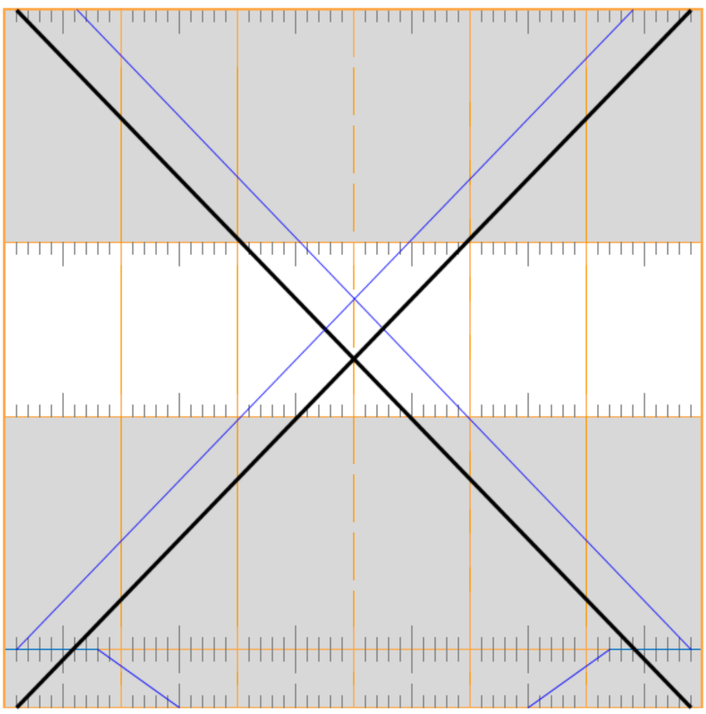

Figure 3.20 Example of an infrastructure measure: construction of double-track section and speed bundling of passenger and freight trains.

3.13 Overview of additional measures, which can support the framework process

Timetabling measures

- artificial slowing down of a freight train
- coupling and uncoupling of rear-end or head-end assistance in compensation zones
- lengthening of dwell time of passenger trains
- adjustment of stopping pattern of passenger trains
- lowering of number of PuT segments on particular line

Technical measures

- ATO
- real-time rescheduling

Infrastructural measures

- turnouts for higher speed in branch
- new turnouts
- lengthening of overtaking tracks
- lengthening of station tracks on a single-track line
- partial doubling of single-track line
- ETCS

4 IMPLEMENTATION

4.1 Purpose of the studies

The framework process introduced above is presented in two studies, where PFTPs were designed on main railway lines emptying into Prague node area, in the context of passenger timetables 2008/2009 and 2009/2010. The resulting PFTPs were flexibly connected together in freight node station Praha-Malešice.

The purpose of Studies 1 and 2 is to implement the framework process derived above, within real SŽDC timetable (of passenger trains), and to discuss number of scheduled stops and symmetry in resulting PFTPs.

The timetable of passenger trains ordered by public sector, valid at that time, was adapted to purely periodic, with at least 60-min-period of all PuT lines. Either daily or peak operation of PuT lines was considered. Passenger trains running outside periodic service and fully commercially operated trains were not considered.

The purpose of Study 3 is to implement an additional timetabling measure – adjustment of the PuT segment of regional trains to achieve less stops for PFTPs.

4.2 Introduction of solved area

Figure 4.1 outlines main track layout plan of the node area with all flyovers marked. Electrified tracks are marked green. Following lines[7] were involved in the studies:

- 501A/011 from Praha-Libeň to Kolín (marshalling yard, crossing of main passenger and main freight corridor)
- 519A/221 from Praha-Hostivař to Benešov u Prahy (last station with traction system 3000 V DC, and beginning of single-track line at that time)
- 521A+B/171 from Praha-Vršovice čekací koleje to Beroun (marshalling yard, last station with traction system 3000 V DC)
- 525F (freight bypass) from Praha-Hostivař to Praha-Libeň
- 525G (freight bypass) from Praha-Vršovice čekací koleje to Praha-Běchovice
- 526A + 527A/090 from Praha-Libeň to Děčín (Czech border station on main line to Dresden)

[7] the lines are numbered according to two systems: tables of train parameters/passenger timetable

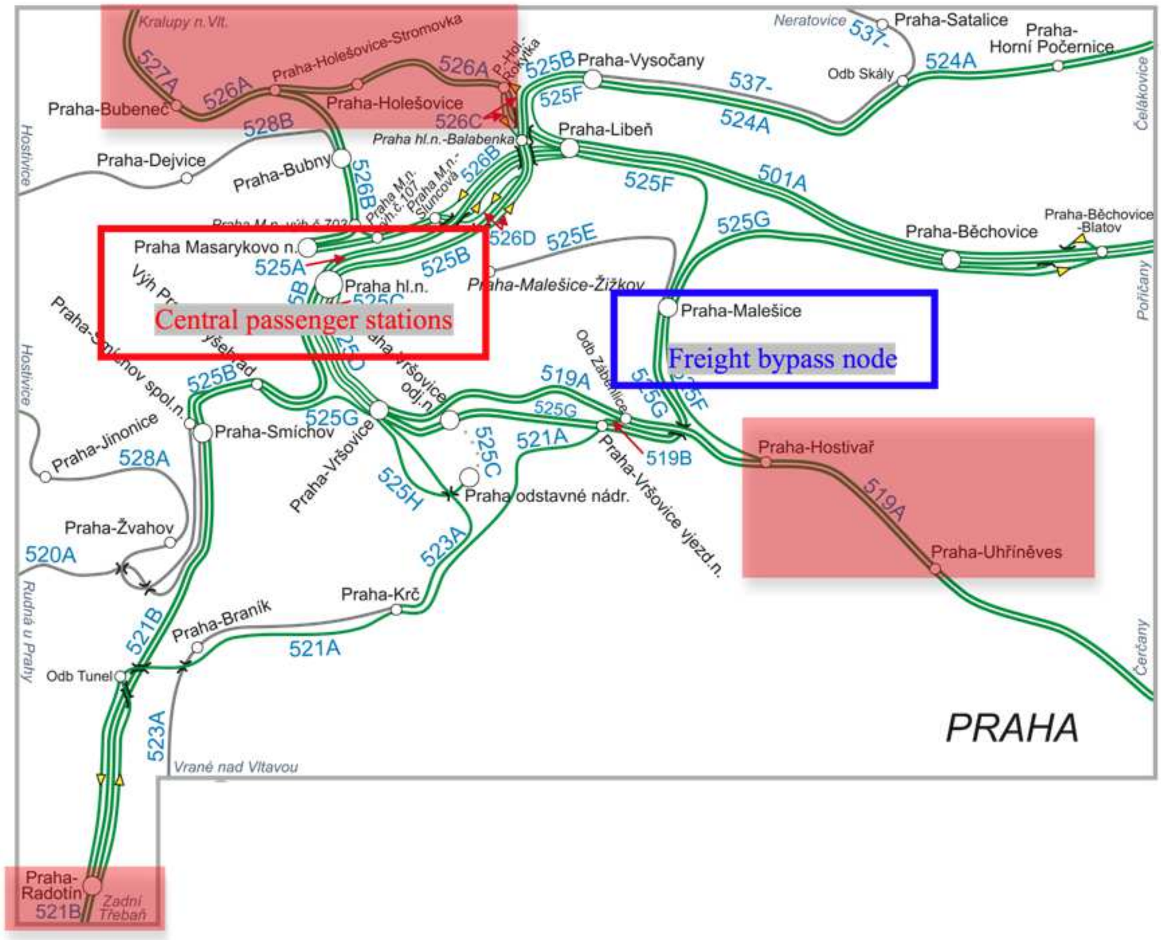

Figure 4.1 Prague node area – main track layout plan (Drábek 2011). The author marked bottlenecks (pink colour) and significant stations. The number of trains per hour was comparatively low (Table 4.1), but, on the other hand, some stations and block posts were equipped with mechanical interlocking and two stations on double-track lines have at-grade access to platforms (Praha-Bubeneč, Praha-Hostivař). Map source: SŽDC (2008).

Freight bypass lines around Praha-Malešice are understood as inner compensation zones, although single-track line 525F presents a significant constraint for train path construction.

4.3 Rules for construction of PFTPs

PFTPs were constructed only on conceptual level of detail. Values from the timetable valid that time – SŽDC (2008) for Study 1 and SŽDC (2009) for Study 2 were adopted under following simplifying conditions:

- 2 min supplement for acceleration or braking of a freight train to stop (not included in the netgraph and train diagrams, but considered by every scheduled stop)
- minimal departure (or arrival) headway between two trains running on the same track and in the same direction, which is critical for given section, is 3 min

(exceptionally 2 min), in the section Praha-Radotín – Beroun 5 min (exceptionally 4 min) because of obsolete system of block posts

- minimal platform headway is 3 min
- if using of rear-end or head-end assistance is common on particular line, it is a prerequisite for using PFTPs (especially by more heavy freight trains – over approximately 1400 t)

All runtimes are stated in minutes, exceptionally with accuracy of half minute.

Detailed rules for determination of minimal runtimes for PFTPs for Study 1 are stated in Annex B.

Detailed rules for determination of minimal runtimes for PFTPs for Study 1 are stated n Annex G.

4.4 Methodology of comparison of number of freight train stops

Another purpose of both studies is to affirm or disprove hypothesis formulated in sub-chapter 1.4. To fulfil this purpose, *a comparison of scheduled number of stops of freight trains in each study and corresponding SŽDC timetable* had to be worked out.

For the sake of objectivity of such comparison, all irrelevant stops were excluded from the comparison.

Irrelevant stops of freight trains are

- in original or destination station of the train
- if the train proceeds further to (or arrives from) another line, not included in the study
- stops for coupling or uncoupling of head-end or rear-end assistance
- any stops caused by requirements of FRUs (e.g. coupling or uncoupling of wagons)

On the other hand, relevant stops of freight train are also stops, which had the only reason in construction of freight train path (scheduled stop instead of scheduled slow running).

Following types of freight trains were excluded from the comparison:

- disturbing trains (marked red in SŽDC train diagrams)
- local freight service trains (abbreviation Mn)
- locomotive trains (abbreviation Lv)

- trainset trains (abbreviation Sv)
- freight trains for service of sidings (abbreviation Vleč)
- service trains for internal use of IM or RUs (abbreviation Služ etc.)

The time scope for the comparison was the assumed time scope of passenger traffic: from 4:00 to 24:00. For the SŽDC timetables, those trains were included, which entered particular lines between 4:00 and 24:00 from following stations:

Line 501A/011

- Kolín marshalling yard (Kolín seř. n.)
- Praha-Běchovice

Line 519A/221

- Benešov u Prahy
- Praha-Uhříněves
- Praha-Hostivař

Line 521A/171

- Praha-Vršovice čekací koleje
- Praha-Radotín
- Beroun marshalling yard (Beroun seř. n.)

Line 526A + 527A/090

- Praha-Libeň
- Praha-Bubeneč
- Ústí nad Labem jih
- node area Ústí nad Labem západ (*only for Study 2*)
- Děčín freight station (Děčín hl. n. nákl. n. – *only for Study 2*)

Line 525F

- Praha-Hostivař
- Praha-Libeň

Line 525G

- Praha-Běchovice
- Praha-Malešice
- Praha-Vršovice čekací koleje

The stations above were chosen, because they represent border of SŽDC train diagrams, or because significant number of freight trains begins, ends, enters or leaves solved area in these stations.

The spatial scope of the comparison was equal to area solved by particular study. If there were designed PFTPs through end stations of the solved area further, the stops were also counted in the end stations. If the designed PFTPs ended by stop in the end stations, no stops in the end stations were counted.

Because of different number of FTPs in SŽDC timetables and PFTPs in the studies, *total number of stops divided by number of FTPs was chosen as quantity for the comparison*.

Thus, a question occurred, how to count FTPs in a comparable way.

4.5 Methodology of counting of FTPs

For the choice of FTPs, equal criteria as for counting of freight train stops were valid. FTPs without common line section (e.g. Praha-Libeň – Ústí nad Labem Jih and Ústí nad Labem hl. n. – Děčín freight station) were counted as only one FTP. On long lines, FTPs in more sections were counted, to gain maximum number of FTPs on given line. These sections were:

Line 501A/011

- Kolín marshalling yard (Kolín seř. n.) – Poříčany
- Poříčany – Praha-Běchovice

Line 519A/221

- Benešov u Prahy – Praha-Uhříněves
- Praha-Uhříněves – Praha-Hostivař

Line 521A/171

- Praha Vršovice čekací koleje – Praha-Radotín
- Praha-Radotín – Beroun marshalling yard (Beroun seř. n.)

Line 527A/090

- Praha-Bubeneč – Roztoky u Prahy
- Kralupy nad Vltavou – Hněvice marshalling yard (Hněvice seř. n.)
- Lovosice jih – Ústí nad Labem jih
- Ústí nad Labem hl. n. – Děčín freight station (Děčín hl. n. nákl. n. – *only for Study 2*)

The lines, which are object of both studies, can be redefined as northern and southern lines, according to emptying into node station Praha-Malešice.

Then, northern lines are

L1: Praha-Malešice – Praha-Běchovice – Kolín marshalling yard

L2: Praha-Malešice – Praha-Libeň – Děčín freight station/ Ústí nad Labem západ

and southern lines are

L3: Praha-Malešice – Praha-Hostivař – Praha-Uhříněves – Benešov u Prahy

L4: Praha-Malešice – Praha-Vršovice čekací koleje – Beroun marshalling yard

On each of four lines mentioned above, maximum number of FTPs in the direction south → north ($\max_{SN,Ln}$) and maximum number of FTPs in the direction north → south ($\max_{NS,Ln}$) were chosen. n stands for number of redefined line.

Then, total daily number of FTPs, which are relevant for the comparison, for the SŽDC timetable from the year i was calculated as follows

$$n_{FTPS,\check{S}ZDC,i} = \max[(\max_{SN,L1} + \max_{SN,L2}),(\max_{SN,L3} + \max_{SN,L4})] + \max[(\max_{NS,L1} + \max_{NS,L2}),(\max_{NS,L3} + \max_{NS,L4})] \tag{3}$$

PFTPs in the studies were calculated as follows. All-day PFTPs were multiplied by 20. The PFTPs, which were available only outside peak hours, were multiplied by particular number of hours. The total daily number of PFTPs in the studies ($n_{PFTPs,Study,k}$, where k stands for the number of study) was also calculated by formula (3).

The part of economic benefit of PFTPs, which can be easily quantified, is a difference in number of scheduled train stops per one FTP between SŽDC timetable of the year i and PFTPs designed in Study k.

$$B_{Study,k} = n_{Stops,FTPs,\check{S}ZDC,i} - n_{Stops,PFTPs,Study,k} \cdot \frac{n_{FTPs,\check{S}ZDC,i}}{n_{PFTPs,Study,k}} \tag{4}$$

Relative economic benefit of PFTPs in Study k can be calculated as follows

$$b_{Study,k} = 1 - \frac{\dfrac{n_{Stops,PFTPs,Study,k}}{n_{PFTPs,Study,k}}}{\dfrac{n_{Stops,FTPs,\check{S}ZDC,i}}{n_{FTPs,\check{S}ZDC,i}}} \tag{5}$$

4.6 Study 1: Passenger timetable 2008/09

Demand analysis (directions of freight trains)

On the basis of freight timetables (SŽDC 2008) for solved lines, daily numbers of freight trains for each line and direction were calculated – including optional freight train paths, excluding post expresses, local freight service trains and disturbing trains. These numbers are shown in origin-destination matrix in Table 4.1.

from \ to	**Libeň**	**Běchovice**	**Hostivař**	**Vrš. ček. k.**
Praha-Libeň		16/5	27/18	18/1
Praha-Běchovice	13/4		8/1	20/6
Praha-Hostivař	29/15	10/2		
Praha-Vršovice. čekací koleje	20/1	18/4		

Table 4.1 Daily demand of freight trains for train paths - overall/international trains.

The need of PFTPs for particular lines and directions was determined as follows: Initially, numbers from matrix above (overall) were multiplied by 0,7. This ratio resulted from iterative determination of minimal runtimes for PFTPs on the basis of really scheduled runtimes of freight trains (see Annex B). This calculation resulted in daily numbers of freight trains which fit into designed PFTPs (Table 4.2). They were divided by number of hours of operation of passenger trains (assumed 20). The other freight trains – mostly local freight service or other „special" trains – can run within remaining usable capacity on given line.

Directions	Trains suitable for PFTPs / d	PFTPs / h
Praha – Ústí n. L.	44	2
Ústí n. L. - Praha	43	2
Praha - Kolín	38	2
Kolín - Praha	31	2
Praha - Benešov	25	1
Benešov - Praha	28	2
Praha - Beroun	27	2
Beroun - Praha	27	2

Table 4.2 Need of PFTPs per hour for particular sections and directions.

Construction of time windows for PFTPs on particular lines

The framework process for network-bound PFTPs was used with many cases of system runtimes. In the sections next to Praha-Malešice station, time windows were spread as much as possible (but with regard to zero symmetry) to enable at least partial freight IPT-node. In single-track sections Praha-Libeň – Praha-Malešice – Praha-Hostivař, conflicts between sections were eliminated, with crossing in Praha-Malešice as a result.

At the end of solved area, passing through node station into next station was ensured, or conflict-free arrival into/departure from node station (Benešov u Prahy) at least.

Linking of time windows in Praha-Malešice node

In the first step, attempt to link time windows in all relevant directions (Table 4.1) was done, so that freight trains can pass through without stopping, and conflicts between them are avoided. This attempt succeeded only partially.

In further iterative steps, PFTPs were moved (within time windows) and linked together. The basic principle was design of freight IPT-node in Malešice station. Time reserves of several minutes in runtimes in neighbouring sections were implemented. The resulting partial freight IPT-node is illustrated in Figure 4.2.

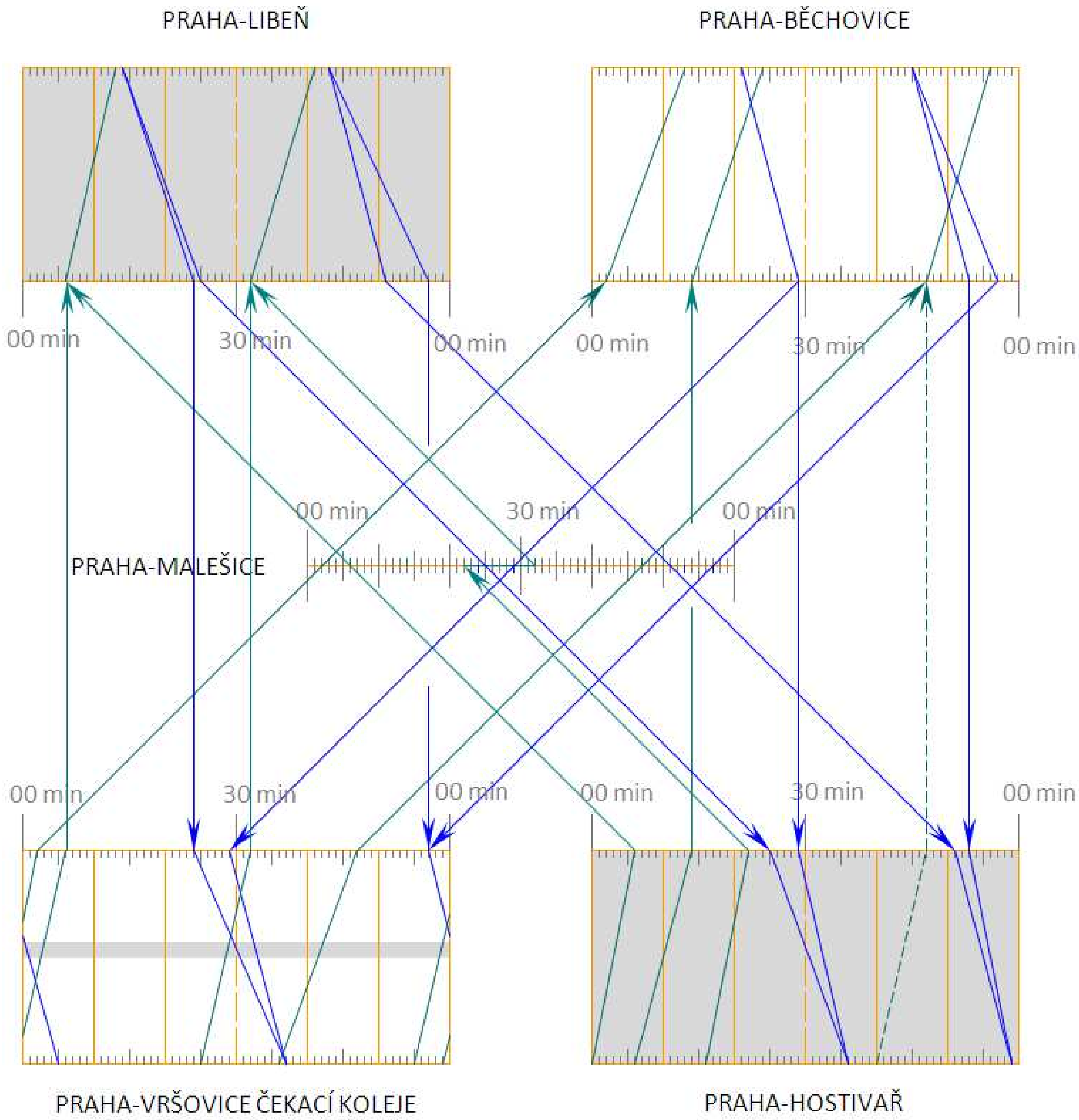

Figure 4.2 Node diagram of station Praha-Malešice and neighbouring sections. Accented line stands for PFTP available only outside passenger peaks. Passenger train paths are not depicted. Direction north → south is marked with blue colour, direction south → north with turquoise colour.

The resulting PFTPs are illustrated on netgraph (Figure 4.3).

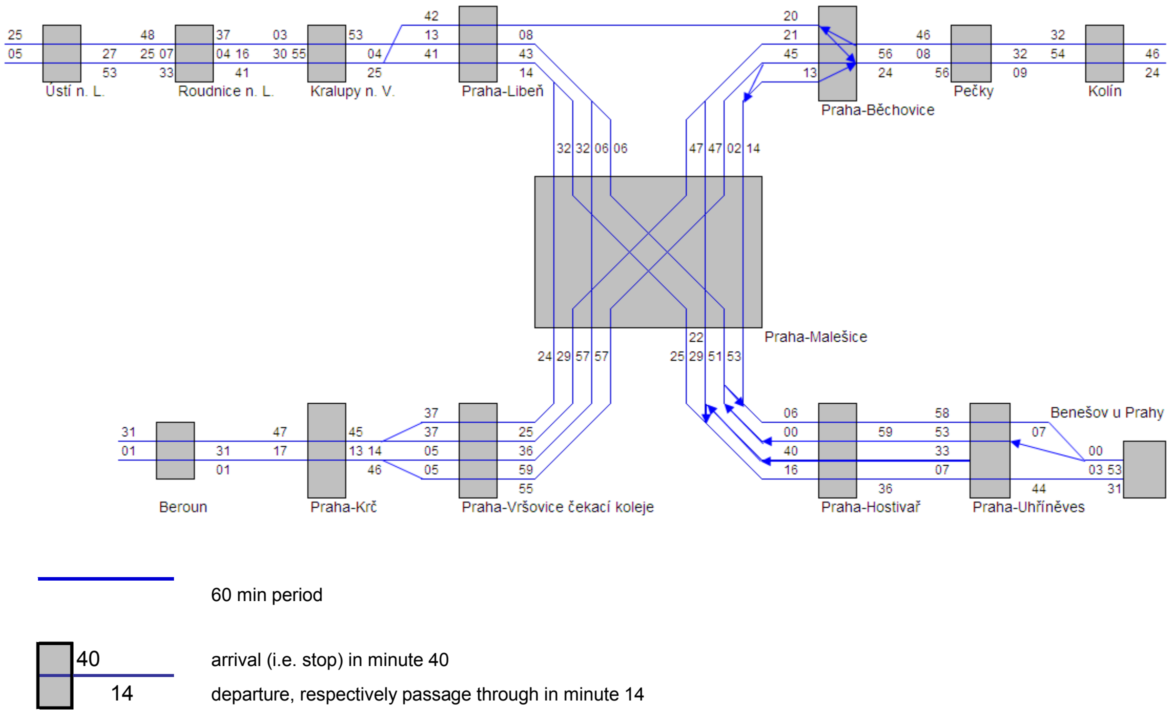

Figure 4.3 Netgraph of PFTPs through Prague node area and adjacent lines (right-hand operation). Arrows stand for PFTPs in one direction only.

Comparison of numbers of scheduled stops

Number of relevant FTPs in SŽDC (2008), daily number of PFTPs in Study 2,[8] as well as numbers of relevant stops of freight trains in both cases were determined as follows (for details, see Annex D).

$$n_{FTPs,SŽDC,2008} = \max\left[\left(\max_{SN,L1} + \max_{SN,L2}\right),\left(\max_{SN,L3} + \max_{SN,L4}\right)\right] + \max\left[\left(\max_{NS,L1} + \max_{NS,L2}\right),\left(\max_{NS,L3} + \max_{NS,L4}\right)\right]$$

$$n_{FTPs,SŽDC,2008} = \max[(33+45),(23+29)] + \max[(28+41),(25+27)]$$

$$n_{FTPs,SŽDC,2008} = \max(78,52) + \max(69,52)$$

$$n_{FTPs,SŽDC,2008} = 78 + 69$$

$$n_{FTPs,SŽDC,2008} = 147$$

$$n_{Stops,FTPs,SŽDC,2008} = 10+20+45+18+30+34+33+48+33+9+26$$

$$n_{Stops,FTPs,SŽDC,2008} = 306$$

[8] The additional off-peak PFTPs from Praha-Uhříněves to Praha Malešice were not included, as they are scheduled in very short section.

$$n_{FTPs,Study,1} = \max[(\max_{SN,L1} + \max_{SN,L2}),(\max_{SN,L3} + \max_{SN,L4})] + \max[(\max_{NS,L1} + \max_{NS,L2}),(\max_{NS,L3} + \max_{NS,L4})]$$
$$n_{FTPs,Study,1} = \max[(40+40),(40+40)] + \max[(40+40),(40+40)]$$
$$n_{FTPs,Study,1} = \max(80,80) + \max(80,80)$$
$$n_{FTPs,Study,1} = 80 + 80$$
$$n_{FTPs,Study,1} = 160$$

$$n_{Stops,PFTPs,Study,1} = 20 + 60 + 40 + 40 + 60$$
$$n_{Stops,PFTPs,Study,1} = 220$$

Absolute economic benefit of Study1 – number of avoided stops:

$$B_{Study,1} = n_{Stops,FTPs,SŽDC,2008} - n_{Stops,PFTPs,Study,1} \cdot \frac{n_{FTPs,SŽDC,2008}}{n_{PFTPs,Study,1}}$$
$$B_{Study,1} = 306 - 220 \cdot \frac{147}{160}$$
$$B_{Study,1} = 306 - 202$$
$$B_{Study,1} = 104$$

Relative economic benefit of Study 1:

$$b_{Study,1} = 1 - \frac{\dfrac{n_{Stops,PFTPs,Study,1}}{n_{PFTPs,Study,1}}}{\dfrac{n_{Stops,FTPs,SŽDC,2008}}{n_{FTPs,SŽDC,2008}}}$$
$$b_{Study,1} = 1 - \frac{\dfrac{220}{160}}{\dfrac{306}{147}}$$
$$b_{Study,1} = 1 - 0{,}66$$
$$b_{Study,1} = 0{,}34$$

The resulting PFTPs contain only *eleven* cases of stopping for overtaking or crossing, within two pairs of PFTPs per hour.

By using of PFTPs constructed according to the proposed framework process, *104 stops of freight trains were avoided, which represents 34% of scheduled stops from SŽDC (2008).*

4.7 Study 2: Passenger timetable 2009/10

Line	Fast	Suburban	Suburban peak
501A/011	5	2	0
519A/221	1	2	2
521A+B/171	2	2	4
526A+527A/090	2	2	2

Table 4.3 Maximum numbers of passenger trains per hour and direction on solved lines. Peak trains are additional.

Passenger timetable used

As a basic context for freight train path construction, Czech passenger railway timetable 2009/10 (SŽDC 2009a) was used. Peak suburban trains were involved, if they were part of periodic service (e.g. completion to 30 min period instead of 60 min or additional peak line).

Demand analysis

Besides freight train paths from SŽDC 2009a (distinguishing regular and optional ones), parameters of real freight trains (maximum speed, length and brutto mass of load) were also used to gain knowledge about real freight operations on solved lines. From such data, initial requirements for periodic freight train paths were derived.

Since runtime calculations are not part of the framework process, regular passing runtimes of freight trains were used, divided in fast (typically container trains) and slow (typically loaded block trains). Trains with empty wagons were not considered, as they run faster than loaded trains. For more details, see Annexes E - G.

Train path construction

To show that the concept mentioned above should be feasible also in present state of Czech railway, no additional measures were considered. (For analysis of minimal departure headways and buffer times of bottlenecks, see Annex H.)

Results - PFTPs

Based on demand analysis, two freight train paths systems were designed – for fast and for slow freight trains. Green marked train paths are preferably established for fast freight trains (due to connections), but also compatible for slow freight trains. Their marking and final critical parameters are presented in the Table 4.4. Brutto mass of load is mentioned for train with one locomotive class 163/363.

PFTP	**Max. speed** [km/h]	**Gross weight** [t]	**Length** [m]
Fast	100	1600 (519A and 521A+B: 1470)	610
Slow	90	2000 (519A and 521A+B: 1470)	600
Combined, preferably fast	90	2000 (519A and 521A+B: 1470)	610

Table 4.4 Critical freight train parameters for PFTP types.

On the line 501A, middle track was frequently used for active overtaking of freight trains.

On the line 519A, due to low demand, slow and fast train path systems were merged. An additional train path was designed to container terminal in Praha-Uhříněves.

On the line 521A+B, almost exact 30 min period has emerged from constraints caused by passenger transport (both PFTPs had to be bundled with suburban trains). The most critical element of the case study is active crossing of freight trains in the station Praha-Vršovice čekací koleje (800 m long station tracks).

On the line 527A, fast train paths were terminated in Děčín, while the slow ones in Ústí nad Labem – a gateway to mining and industrial area of Northern Bohemia. To avoid stopping, fast freight trains were designed to be active overtaken by Eurocity trains between Dolní Beřkovice and Hněvice.

The resulting PFTPs paths are outlined in netgraph (Figure 4.4). Arrival minutes (close before stations) are marked only in the case of necessary stop. Of course, freight trains can also stop in another stations in between, if overtaking tracks are long enough there.

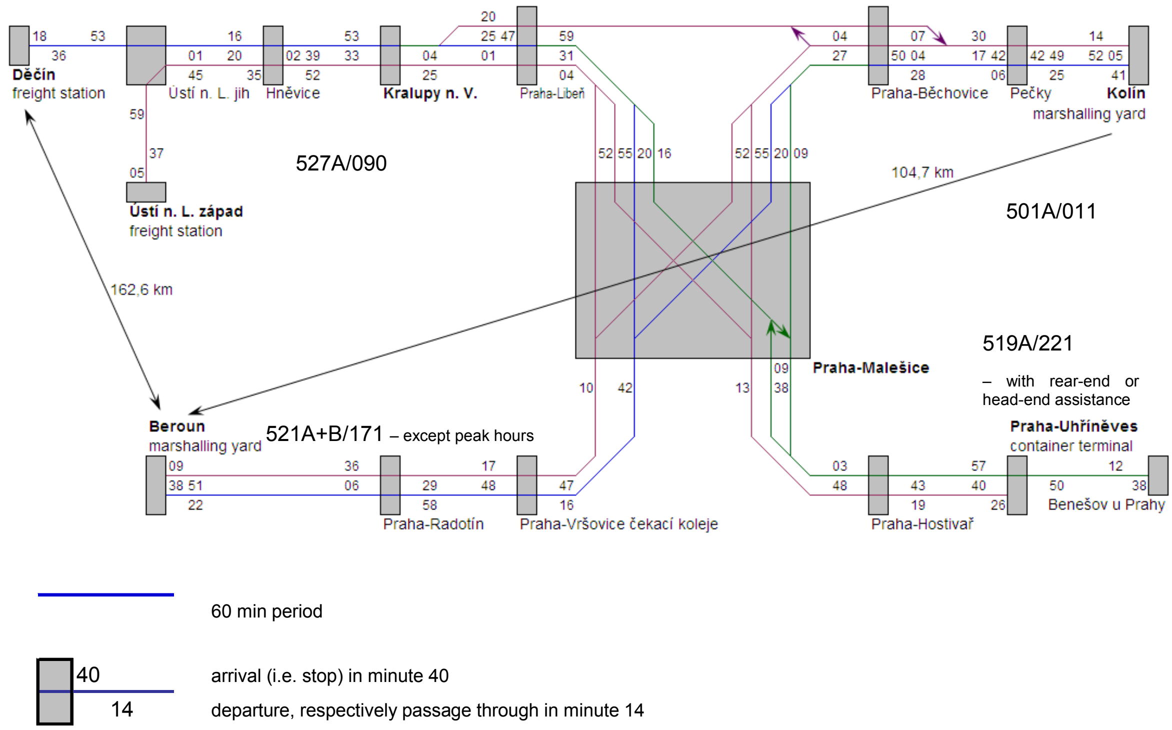

Figure 4.4 Netgraph of PFTPs in Prague node and on neighbouring lines.

Passing through node station Praha-Malešice

The solution of passing through Praha-Malešice (with only one stop from direction Praha-Hostivař) is drawn up in node diagram (Figure 4.5). Vertical interrupted connecting lines mean that such passing does not conflict to any running in opposite direction, unless there is single-track line (the station is too short for active crossing.

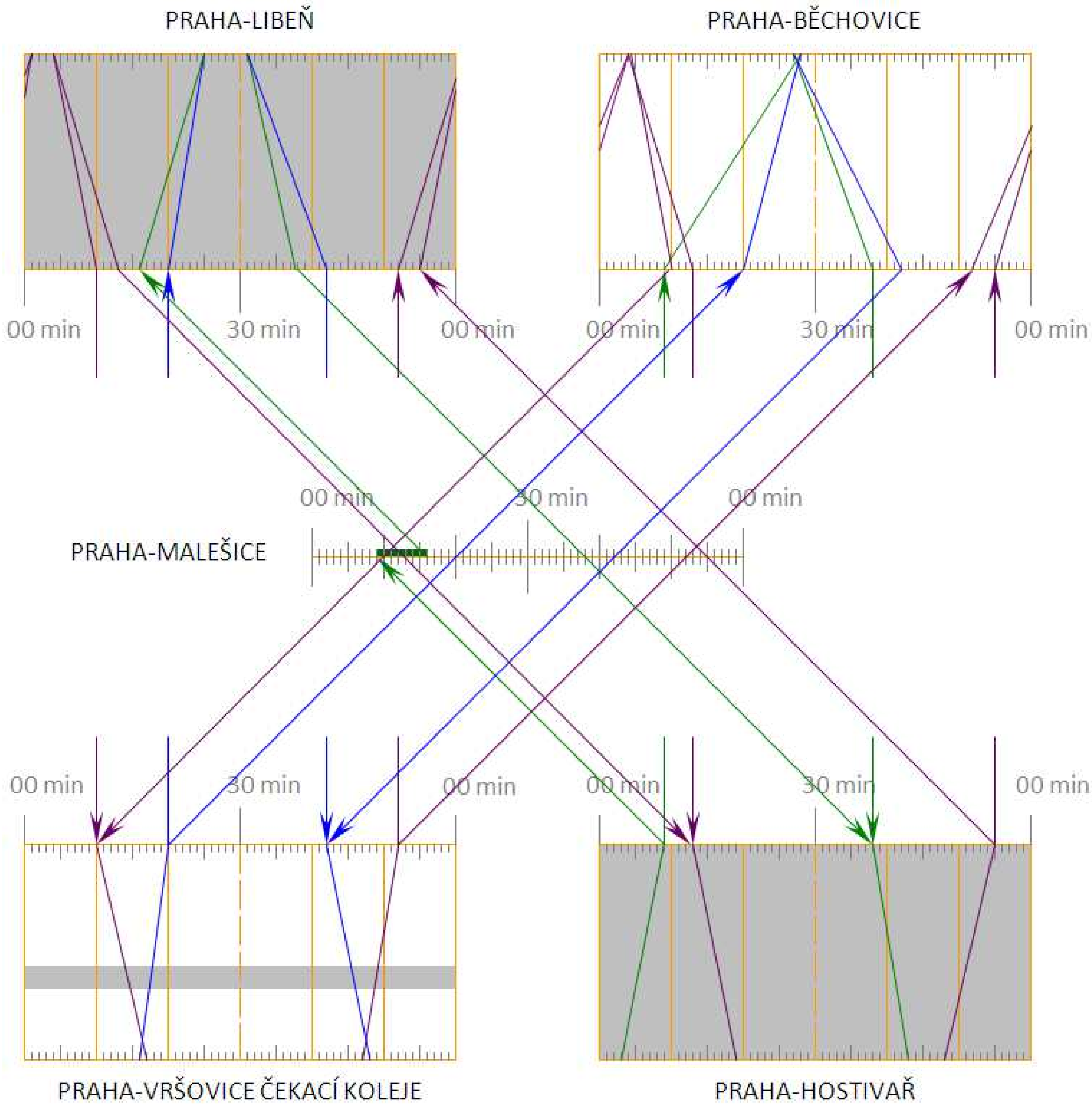

Figure 4.5 Node diagram of station Praha-Malešice and neighbouring sections.

Comparison of numbers of scheduled stops

Number of relevant FTPs in SŽDC (2009a), daily number of PFTPs in Study 2, as well as numbers of relevant stops of freight trains in both cases were determined as follows (for details, see Annex J).

$$n_{FTPs,SŽDC,2009} = \max[(\max_{SN,L1} + \max_{SN,L2}),(\max_{SN,L3} + \max_{SN,L4})] + \max[(\max_{NS,L1} + \max_{NS,L2}),(\max_{NS,L3} + \max_{NS,L4})]$$
$$n_{FTPs,SŽDC,2009} = \max[(33+47),(24+25)] + \max[(32+51),(29+24)]$$
$$n_{FTPs,SŽDC,2009} = \max(80,49) + \max(83,53)$$
$$n_{FTPs,SŽDC,2009} = 80 + 83$$
$$n_{FTPs,SŽDC,2009} = 163$$

$$n_{Stops,FTPs,SŽDC,2009} = 11 + 32 + 48 + 11 + 32 + 19 + 23 + 63 + 45 + 14 + 52$$
$$n_{Stops,FTPs,SŽDC,2009} = 350$$

$$n_{FTPs,Study,2} = \max[(\max_{SN,L1} + \max_{SN,L2}),(\max_{SN,L3} + \max_{SN,L4})] + \max[(\max_{NS,L1} + \max_{NS,L2}),(\max_{NS,L3} + \max_{NS,L4})]$$
$$n_{FTPs,Study,2} = \max[(40 + 40),(40 + 40)] + \max[(40 + 40),(40 + 40)]$$
$$n_{FTPs,Study,2} = \max(80,80) + \max(80,80)$$
$$n_{FTPs,Study,2} = 80 + 80$$
$$n_{FTPs,Study,2} = 160$$

$$n_{Stops,PFTPs,Study,2} = 20 + 20 + 40 + 40 + 20 + 20$$
$$n_{Stops,PFTPs,Study,2} = 160$$

Absolute economic benefit of Study1 – number of avoided stops:

$$B_{Study,2} = n_{Stops,FTPs,SŽDC,2009} - n_{Stops,PFTPs,Study,2} \cdot \frac{n_{FTPs,SŽDC,2009}}{n_{PFTPs,Study,2}}$$
$$B_{Study,2} = 350 - 160 \cdot \frac{163}{160}$$
$$B_{Study,2} = 350 - 163$$
$$B_{Study,2} = 187$$

Relative economic benefit of Study 2:

$$b_{Study,2} = 1 - \frac{\frac{n_{Stops,PFTPs,Study,2}}{n_{PFTPs,Study,2}}}{\frac{n_{Stops,FTPs,SŽDC,2009}}{n_{FTPs,SŽDC,2009}}}$$
$$b_{Study,2} = 1 - \frac{\frac{160}{160}}{\frac{350}{163}}$$
$$b_{Study,2} = 1 - 0,47$$
$$b_{Study,2} = 0,53$$

The resulting PFTPs contain only *eight* cases of stopping for overtaking or crossing, within two pairs of PFTPs per hour.

By using of PFTPs constructed according to the proposed framework process, *187 stops of freight trains were avoided, which represents 53% of scheduled stops from SŽDC (2009a).*

4.8 Evaluation and discussion of results of Study 1 and 2

Almost no freight train has to stop in Prague due to capacity reasons. The number of PFTPs per hour is approximately comparable to average number of freight train paths on lines with most intensive freight traffic, but PFTPs are constructed in hypohetical hourly timetable of all long-distance PuT lines (in actual facts, many of them operate in 120 min period).

Because of different runtimes in both directions (both for passenger and freight trains), it was impossible to preserve zero symmetry everywhere.

Requirements for passing through nodes preferably without stopping and alternative (flexible) connection of PFTPs have lead to extension of runtimes up to several tens of minutes against actual freight train paths in at that time valid timetable. The capacity uilisation of single-track section Praha-Libeň – Praha-Malešice – Praha-Hostivař was lowered (because of pair of PFTPs of opposite direction every 30 min instead of speed bundling). However, this section as (at that time) freight only did not inhibit network capacity.

On the line 521B/171 between Řevnice and Praha-Radotín, additional passenger services in morning peak leave no usable capacity for PFTPs. If there were only peak trains with standard stopping pattern, speed bundling would probably enable enough capacity for PFTPs (see train diagram of this line in Annex I). However, comparatively low demand for FTPs in (see Annex J) can be satisfied by remaining PFTPs outside peak times – with night time as reserve for larger demand than scheduled. The only problem is few hours during day, when FRUs cannot meet customers’ requirements.

On the line 519A/221, using of rear-end or head-end assistance is inevitable for every train whose brutto mass of load is greater than approximately 1400 t (with usual electric locomotive class), if the FRU wants to fit in a designed PFTP. Otherwise, running outside peaks of passenger transport is recommended.

Many stops of freight trains, which occurred in SŽDC timetables, were “replaced” by very slow running of freight train, using “coasting valley” to lengthen runtime up to required system runtime. Of course, every such slowering and following acceleration costs appreciable value of brake wear, noise and traction energy. But these values are always less than corresponding values by stop of the train. Moreover, braking without stop and following acceleration is much simpler for the locomotive driver. *So, every single case of stop “replaced” by slower running is an indisputable economic (and environmental) benefit.*

Constructed PFTPs cannot be understood as finished concept. For actual timetabling, runtimes for model freight trains should be calculated more precisely, including time reserves to obtain sufficient stability. Before real implementation, verification of timetable stability by timetable simulation in bottlenecks (followed by necessary freight train path adjustments) is strongly recommended.

Parameters of freight train paths turned out to be derived from capacity utilisation (maximum runtime that can avoid stop of freight train for the purpose of overtaking by passenger train) and infrastructure (effective lengths of available overtaking tracks).

As no supportive measure was proposed, the resulting system of PFTPs, though technically feasible, requires on-time communication between well-instructed station masters and dispatchers and locomotive drivers, as well as accurate and responsible fulfilling of their duty. Necessity of proper maintenance of rolling stock, infrastructure and communication systems is self-evident.

4.9 Study 3: Prospective passenger IPT in the mainline section Pardubice - Kolín

Population and designed passenger timetable

The chosen section is a part of traditional Czech main railway route between Olomouc and Prague, which has been in operation since 1845. There are cities of Pardubice (a centre of region) and Kolín, with small town of Přelouč in between. Due to traditional railway service and industry in Chvaletice, the other municipalities with railway service have grown to range from 400 to 3,000 inhabitants (ČSÚ 2010).

The double-track line serves to express trains, fast trains, long-distance freight trains, coal trains for Chvaletice power station and regional trains. According to research project (Kopecký et al. 2009), in future there are supposed to be 5 express, 2 fast PuT lines with 60-min-period and 1 regional PuT line with 30-min-period. The PuT lines are presented in netgraph (Figure 4.6), as well as in train diagram for one direction (Figure 4.7). Bold vertical lines border 60-min-period, the others 10 min. There are abbreviations of stations and stops in the left column.

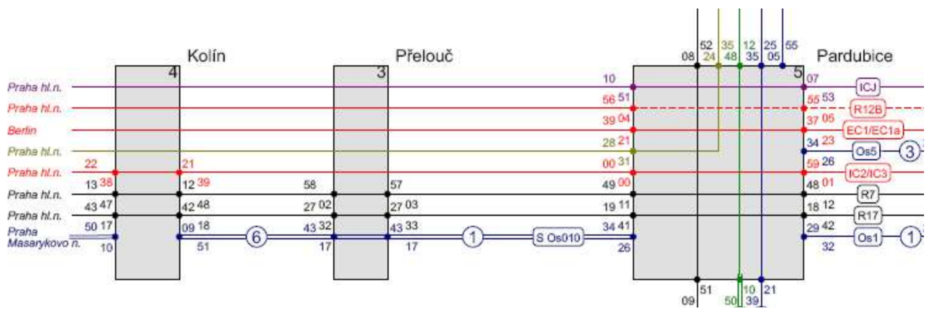

Figure 4.6 Part of netgraph of prospective operatioinal concept of passenger transport between Kolín and Pardubice (Kopecký et al. 2009). Numbers in circles stand for numbers of intermediate stops.

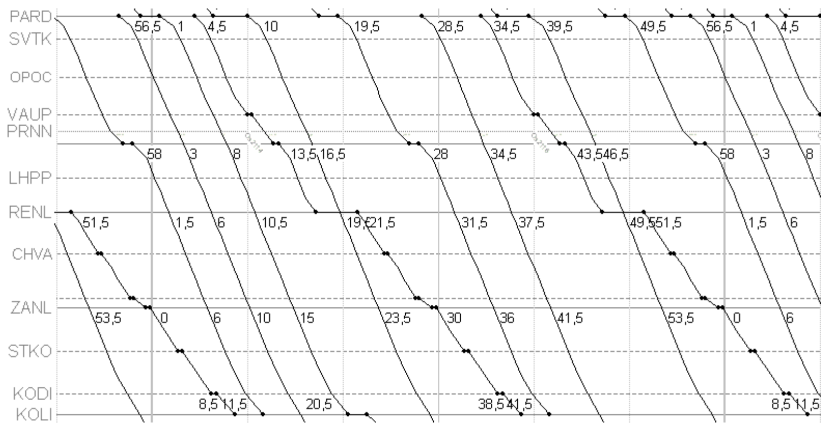

Figure 4.7 Part of train diagram Pardubice – Kolín (one direction). Passenger timetable is planned without regard to freight transport (Kopecký et al. 2009, Drábek and Záruba 2010b).

Proposed solution

Apparently, section runtime of express trains is approximately 20 min. Runtime for transiting freight train with the mass of load of 1360 t, highest allowed speed of 100 km/h and locomotive class 163 is 27 min. Due to parallel systems of IPT-nodes, express and fast train paths are almost equally spread within hour. The remaining usable capacity is consumed by regional trains.

The proposed solution is following (in 1-hour time window):

1) Cancel (temporarily) regional PuT line

2) Shift fast train paths closer to nearest express train paths, if possible (see following sections till Prague Main Station)

3) Construct freight train paths with at most 1 stop

4) Give back passenger train path (60-min-period is enough for the population around regional train stops)

This solution is, however, insufficient, because the regional train is going to be overtaken twice, with over 15 min retard. The only possibility is a very unpopular step – *to cancel some least significant stops. The criteria for choice of cancelled stops are low population and possibility of transport service by bus, with only few minutes enhancement of travel time.*

On the basis of these criteria, there were chosen villages Valy (400 inhabitants), Lhota (100 inhabitants) and Řečany (1300 inhabitants). Stops Svítkov, Opočínek and Kojice were supposed not to be served even in the project (Kopecký et al. 2009). Figure 4.8 represents resulting timetable.

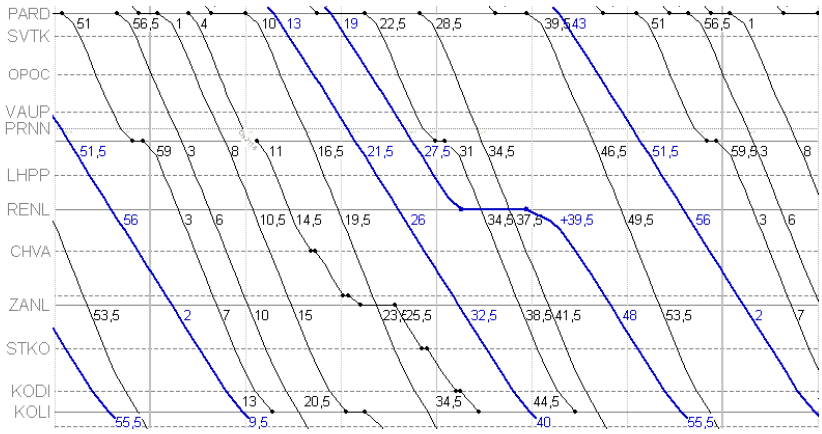

Figure 4.8 Part of train diagram Pardubice – Kolín (one direction). Suggestion for coordinated solution for passenger and freight train paths (blue) (Kopecký et al. 2009, Drábek and Záruba 2010b).

Discussion

The problem of deterioration of current public transport offer is delicate – even in the case of few hundreds of inhabitants. However, in the case of mere reduction of planned service extension, this dilemma could be avoided. The multipartite dialogue is necessary – between RUs, IMs, public transport coordinators, local authorities and, last but not least, touched inhabitants. The more relevant information the actors share, the more hope there is for consensual solution.

The chosen example was one of the most controversial ones – in most cases there is sufficient a few minutes train path shift with no significant influence on quality of passenger service. However, some traditional regional train stops on main lines have no sense anymore, because adjacent villages could be served more comfortably by bus, and their cancelling can help freight railway transport.

CONCLUSION

The framework process proposed in this thesis was tested in two implementation studies in Prague node area.

The hypothesis expressed in the beginning of the thesis was affirmed in both implementation studies in Prague node area. The number of overtakings increased locally, e.g. on the line Kolín – Praha in the Study 2, but globally it decreased to very low numbers – compared to frequency of PFTPS (2 pairs per hour).

In the Study 1, 104 stops of freight trains were avoided, which represents 34% of scheduled stops from SŽDC (2008).

In the Study 2, 187 stops of freight trains were avoided, which represents 53% of scheduled stops from SŽDC (2009a).

Proposed running of freight train through Prague node mostly without stopping there, and in some cases running more than 100 km without stopping in Prague at all is seldom realized in present daily operation. Because of consideration of all passenger PuT lines as with period 1 hour (because of possible further expansion of service to 60 min period) or less, and comparable number of train paths per hour to freight timetable at that time, higher capacity utilisation with proposed PFTPs can be declared. Results of both studies show that better results can be achieved if passenger train paths can be moved few minutes earlier (or later). This approach was tested and discussed in the third implementation study.

It is obvious that construction of PFTPs, if constructed in the space left by passenger trains, often face a dilemma: ether tight timetable with no time reserves in particular section, or one more stop for overtaking, which can disable freight train to pass through node station into suitable time window in subsequent sections. Timetable proposals presented in the studies above are likely to fail in timetable simulations as unstable. Moving of passenger train paths few minutes earlier (or later) can lead not only to fewer overtakings and stops of freight trains, but also to sufficient stability of proposed timetable. Technical measures can improve accuracy of train driving and targeted infrastructure measures can remove the most critical bottlenecks. PFTPs as operational concept have great potential to specify requirements of freight railway for infrastructure more precisely.

Another dilemma is, how many segments of PFTPs (with different allowed mass, speed and length of freight trains) are meaningful to be designed. The more segments of PFTPs, the more tailor-made offer of capacity for FRUs, but also longer period of each segment and higher complexity of timetabling.

Answers to questions from sub-chapter 1.4

1. *When and in which way do freight trains have direct impact on railway capacity utilisation?*

   Two cases should be distinguished

   a) Freight trains are in particular sections not able to run equally fast than passenger trains (because of technical reasons). Thus, potential of higher capacity utilisation by speed bundling is restricted.

   b) There are scheduled stops of freight trains on lines with mixed traffic. Braking or acceleration of (usually heavy, long or both) freight train increases heterogeneity of its train path and passenger train path. Thus, potential of higher capacity utilisation by speed bundling is restricted.

2. *When and in which way can this impact be reduced?*

   a) If freight train is faster (at least in the sense of average speeds because of no scheduled stops) than the most frequent PuT segment, freight train paths can be adjusted for smaller scheduled speed than technically possible (e.g. 50 km/h instead of 80 km/h). In the opposite case, impact of freight trains on capacity utilisation cannot be reduced.

   b) In some cases, stops of freight trains can be avoided, or scheduled outside bottlenecks, as proposed above. In other cases, some timetabling, technical or infrastructural measures are inevitable, otherwise impact of freight trains on capacity utilisation cannot be reduced.

3. *How much can be stopping of freight trains in bottlenecks reduced?*

   The reduction is often possible by mere choice of an appropriate PFTP through bottleneck (with the help of proposed framework process).

   In the opposite case, if it is also impossible to schedule the stop outside bottleneck, it is necessary to use some additional measure mentioned above.

4. *How much is targeted regulation of freight train running possible and appropriate (in terms of accurate runtime, accurate arrival time in bottleneck area etc.)?*

   This targeted regulation is without doubt appropriate in bottleneck areas, especially in busy stations and junctions with at-grade intersections. The more precise running, the lower buffer times can ensure the same (required) timetable stability. The lower buffer times and the less stops of freight trains directly in node stations, the more train paths for particular time unit can be scheduled through bottlenecks.

   Automatic train operation for freight trains is possible, according to interview with Lieskovský, but real-time rescheduling process has to cope with longer reaction time of freight trains due to large mass and longer brake pipe. Further research in this field is desirable.

5. *In which conditions is it rightful to penalise passenger transport (e.g. by longer dwell time or adjustment of stopping pattern), if it results in increase of usable capacity for freight transport?*

Penalisation of passenger transport is rightful, when both following conditions are fulfilled:

a) There is clear, indisputable superiority of cargo flows over flows of penalised passengers, which lasts more than one year and can be awaited in future. The problem is, how such superiority can be calculated. In the case of absence of economic assessment, comparison of one passenger to one net ton can be used as a rule of thumb.

b) The penalisation is either only few minutes of travel time, or can be compensated by service of other means of passenger transport (bus as a rule). In the second case, lengthening of travel time is more serious. There is often one more change of service. So, number of penalised passengers should be very low.

CONTRIBUTIONS OF THE THESIS

The most significant scientific contribution of this thesis is *new paradigm of railway capacity allocation for freight trains*. Qualitative research in this thesis has contributed to development of theory of railway capacity management. Contrary to (even periodic) freight train paths for particular railway line, *a new structure of offer of capacity for entire network was developed*.

Another scientific contribution of this thesis is foundation of synthesis of theory of planing of public transport offer (IPT) and railway capacity management, which includes also freight trains with their specific needs. For this purpose, some innovations in terminology were necessary, as well as definitions of new terms.

As this thesis was written in English, there was necessary careful choice of used terms from synonyms, for the sake of consistency. Usually, for basic terms, the most frequent synonyms were chosen (based on internet search on frequency of usage of particular terms). Then, derived terms were chosen (for instance, „signal aspect“ from „signal“). In some cases, another synonyms had to be chosen for the sake of unambiguity.

Freight train paths are integrated to a system of network-bound, periodic capacity as a offer for FRUs, which represents *an analogue to IPT, but takes needs of freight railway into account*. This new structure is regular and periodic in macroscopic scale, but it can be irregular in microscopic scale (different section runtimes or different stations for overtaking for each direction). Special attention was paid to relationship between requirement for unified (zero) symmetry and diference in runtimes of a heavy freight train on various directions in the case of lines with high gradient. PFTPs can be ether used by some freight train or not (or partially), but are periodically available to make freight railway transport more flexible.

From the paradigm mentioned above, an original, *generic framework process for construction of network offer of periodic capacity for freight trains* was derived. Attention was consequently paid to preference of passing through bottlenecks and overtaking in compensation zones.

The framework process is understood as a *building set* – it is possible to use only parts (according to particular topology, lever of interlocking and operational concept of passenger transport, either for annual timetabling, or for strategic planning). The results can be used *for more precise formulation of requirements of freight railway transport for infrastructure adjustments*. Such targeted investments can save public budgets significantly.

The offer of periodic capacity for freight trains is understood not only in the sense of more efficient capacity utilisation, but also as a helping tool for simplification of operative traffic management. Assumed that timetable is being fulfilled on time, a freight train which uses a PFTP has “green wave“ until the station of regular overtaking or crossing. Last but not least, PFTPs help to allocate railway capacity to FRUs, whose trains have “common“ parameters. OneStopShop – an international coordination of train paths, can be simplified as well. The proposed framework process makes capacity allocation process more transparent – with less space for discrimination. Train paths or their parts not allocated for annual timetable can be offered in almost real time.

The framework process is applicable “now and here”, indifferent to interlocking system or actual values of minimal headways. Generally, both locomotive drivers and dispatchers have to be instructed about necessity of passing through station on exact time. Mutual radio or GSM connection is necessary (or, better, real-time rescheduling system).

To author’s knowledge, in Study 1 and 2, *netgraph for PFTPs with marked minutes of passing through stations*, was published for the first time.

Another contribution in this thesis is a way of depiction of simplified train diagram for conceptual purposes, which gives good overview about timetable outline within chosen period and about actual symmetry of train paths. This level is appropriate for conceptual planning of timetable. This depiction includes node diagrams.

A contribution of this thesis, which is specific for Czech railway network, is, that both theoretical approach and presented studies consider in advance 60-min-period of passenger service (or even 30 min) as a standard. The related timetabling problems occur at present only in few agglomerations, and thus are not perceived yet as urgent enough. The author hereby emphasises that capacity conflicts between passenger and freight railway can be conceptually solved using proposed framework process, before launching of more dense passenger service.

RECOMMENDATIONS FOR FURTHER RESEARCH

The field of timetabling coordination between passenger and freight railways, reduced into 1-hour period, has turned out to be very broad field of research – even in only qualitative manner - which can be focused from the viewpoint of conceptional planning, mid-term or annual timetabling, capacity allocation process and actual railway operation. The reason is that proposed framework process for design of PFTPs creates new constraints into timetabling, but also more exact infrastructure requirements. In this thesis, only basic problems and proposals for their solution were mentioned.

The proposed auxiliary timetabling, technical and infrastructure measures, which can lead to higher capacity utilisation, were only briefly proposed. So, further research in each of the mentioned fields is desirable.

Charging of capacity allocation for freight trains, if network-bound PFTPs will be introduced, is another field of further research. Thanks to character of such capacity offer, some algorithms for allocation of time slots for aircraft can be probably adapted, but specific attributes of railway transport must be considered.

The next promising field of further research is tradeoff between more qualitative PFTPs and penalization of public passenger transport offer. The key question is, which ratio of freight flows to passenger flows can justify such penalization (and in which scope). This field is very interdisciplinar – from railway traction energetics to planar offer (service) of public transport (trains and buses). Legal issues are another part of this problem.

Another promising field for either practical research is innovation of production processes of FRUs to enable utilisation of advantages and minimise impact of disadvantages of PFTPs.

Technical development in the field of Automatic Train Operation and real-time rescheduling brings new possibilities to design such level of capacity utilisation, which is at present considered as not feasible because of too low stability in practical operation. Thus, software tools for simulation of railway operation should be developed so that they can take account of this new technical equipment and system runtimes of freight trains. This way, practical feasibility of operational concept proposed in this thesis can be validated (likely under some conditions) or disproved.

The framework process has been designed for manual or partially manual timetabling. If algorithmized and implemented as a software tool, it requires extensive data interchange with information systems for infrastructure, rolling stock and passenger timetables, as well as traffic management systems with feedback in the field of timetable quality and parameters and frequency of real freight trains etc. Apparently, consequent usage of *RailML* standard is inevitable. By mathematical modelling and algorithmization process, every simplification must be carefully examined to avoid extraction of possible efficient results from solutions space. Thus, in the author's opinion, the framework process should be implemented as an *extension of some present timetabling tool, rather than separate software*.

SHRNUTÍ

Nejprve je rozebrána problematika tvorby jízdních řádů nákladních vlaků v rámci integrovaného taktového jízdního řádu osobní dopravy. Vzhledem k povaze nákladní železniční dopravy je učiněn závěr, že má smysl zavádět spíše periodické grafikonové trasy jako nabídku kapacity, než systematické jízdní řády pro nákladní vlaky.

Tato nabídka je pojata jako obdoba ITJŘ v osobní dopravě, která ovšem vychází vstříc různorodým požadavkům nákladní dopravy – je pravidelná, avšak flexibilní díky alternativním napojením v uzlových stanicích do různých směrů. Důraz je kladen také na vyloučení zbytečných zastavení nákladních vlaků. Na základě těchto požadavků je zformulován koncept nákladního taktového uzlu a obecně použitelný měkký postup pro tvorbu síťově propojených periodických tras pro nákladní vlaky. Postup je aplikovatelný jak při tvorbě provozního konceptu pro roční jízdní řád, tak při strategickém plánování. Konstrukce tras probíhá v periodickém, zpravidla hodinovém, výřezu. Postup je doplněn o návrh vhodných technologických, technických a infrastrukturních opatření pro dosažení lepších výsledků.

Postup je následně ověřen na dvou platných jízdních řádech osobní dopravy (zjednodušených na zcela systematické) v oblasti pražského uzlu. Za nákladní taktový uzel je zvolena uzlová stanice pro nákladní dopravu Praha-Malešice.

V první studii došlo aplikací navrženého postupu k ušetření 104 zastavení nákladních vlaků, což představuje 34% zastavení nákladních vlaků ve vzorovém jízdním řádu.

Ve druhé studii došlo aplikací navrženého postupu k ušetření 187 zastavení nákladních vlaků, což představuje 53% zastavení nákladních vlaků ve vzorovém jízdním řádu.

Dále je na výhledovém jízdním řádu osobní dopravy vyzkoušeno technologické opatření – úprava intervalu, časové polohy a zastavovací politiky osobních vlaků, umožňující konstrukci periodických tras pro nákladní vlaky s nižším počtem zastavení.

Výsledky tedy potvrzují značný ekonomický přínos navrženého postupu.

ZUSAMMENFASSUNG

Zuerst, die Probleme von Fahrplanung der Güterzüge im Rahmen des Integralen (Integrierten) Taktfahrplans des Personenverkehrs werden analysiert. Angesichts des Charakter des Eisenbahn-Güterverkehrs, eine Schlussfolgerung ist getan, dass eher Takttrassen (als Angebot der Kapazität) als Taktfahrplan sind sinnvoll für die Güterzüge.

Dieses Angebot wird aufgefasst als eine Analogie zum ITF, die entgegengehen soll der Anforderungen des Güterverkehrs – Regelmäßigkeit, aber auch Flexibilität dank alternativen Anschlüssen in Knoten in mehrere Richtungen, und möglichst wenige unnötige Hälte für Güterzüge. Auf Grund dieser Anforderungen, das Konzept des Güter-Taktknotens und ein weiches allgemein anwendbares Verfahren für Konstruktion der netzgebundenen Takttrassen für Güterzüge, werden formuliert. Dieses Verfahren is anwendbar sowohl Entwurf von Betriebskonzept für jährliche Fahrplanung, als auch für langfristige Planung. Die Konstruktion findet in periodischem Zeitfenster (meistens eine Stunde) statt. Das Verfahren wird ergänzt durch Entwurf für Anwendung der geeigneten fahrplantechnischen, technischen und infrastrukturellen Maßnahmen, die zu besseren Ergebnissen führen.

Das Verfahren wird nachfolgend erprobt an zwei gültigen Fahrplänen des Personenverkehrs (die wurden an Taktfahrpläne idealisiert) in Prager Eisenbahnknoten und Umgebung. Der Knoten-Güterbahnhof Praha-Malešice wird als Güter-Taktknoten ausgewählt.

Im ersten Fall, 104 planmäßige Hälte der Güterzüge wurden dank dem obengenannten Verfahren erspart. Das entspricht 34% von Anzahl der planmäßige Hälte der Güterzüge im damals gültigen Fahrplan.

Im zweiten Fall, 187 planmäßige Hälte der Güterzüge wurden dank dem obengenannten Verfahren erspart. Das entspricht 53% von Anzahl der planmäßige Hälte der Güterzüge im damals gültigen Fahrplan.

Weiter wird eine fahrplantechnische Maßnahme an künftigem Fahrplan erprobt – Anpassung des Taktes, Zeitlage und Haltepolitik von Regionalzügen, um Anzahl von Hälte der Güterzüge zu senken.

Die Ergebnisse bestätigen, dass vorgeschlagene Verfahren geeignet ist und bringt deutliche Ersparnisse.

ANNEXES

A Map of Czech railway network

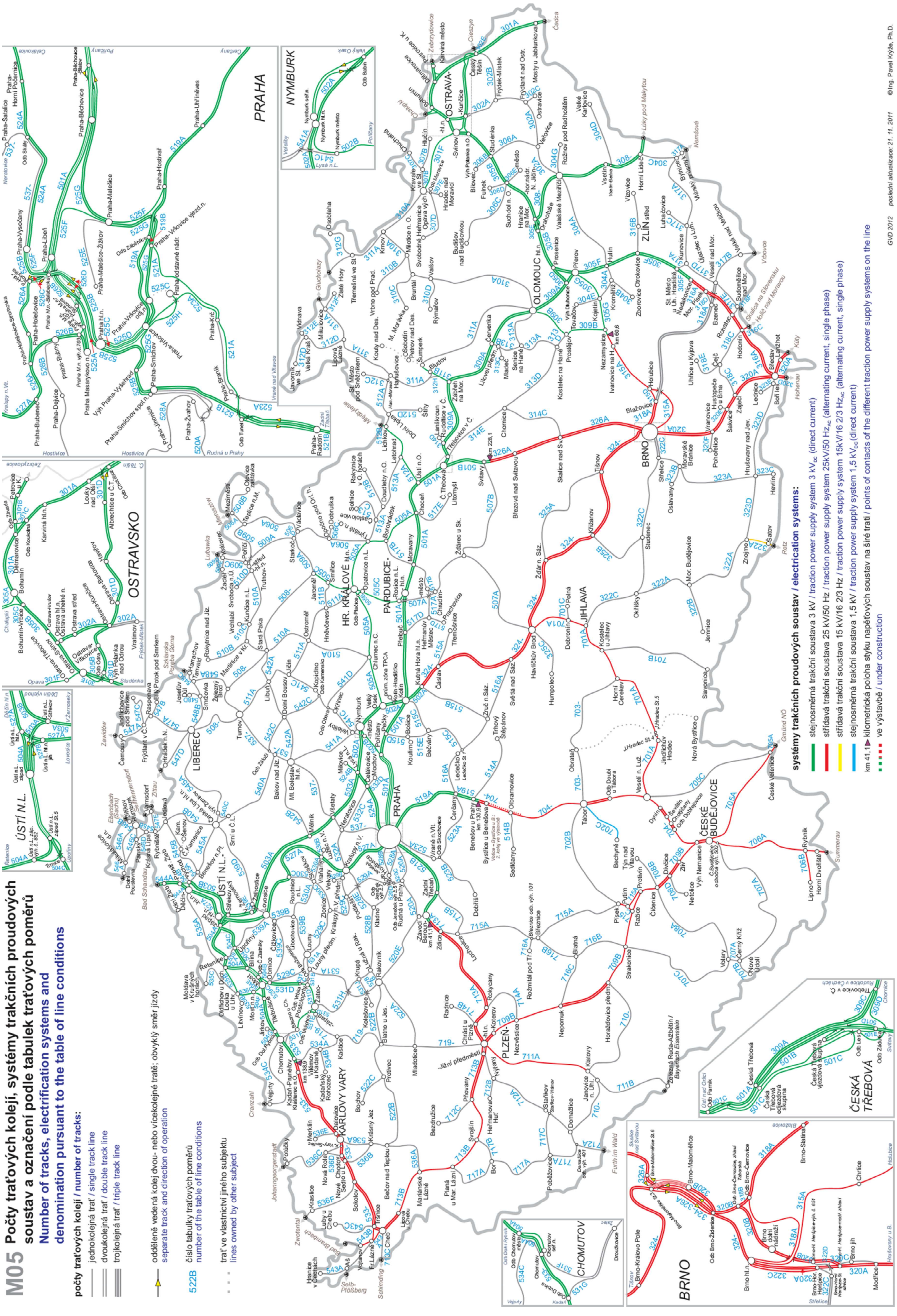

Figure A.1 Official map of Czech railway network (SŽDC 2011a).

B Study 1: Determination of minimal runtimes for PFTPs

The minimal runtimes for construction of PFTPs in Study 1 were determinated by analysis of really scheduled runtimes for freight trains from SŽDC (2008) under following rules

- In the sections, where stops of trains were often in SŽDC timetable, runtimes with no stop or one stop in the ends of particular section were chosen for the analysis. In Table B.1, runtimes for such sections are marked **bold**.
- In other sections, only runtimes of freight trains passing through entire section (including both ends) without stop were chosen for the analysis.

  Runtimes in the section Praha-Běchovice – Praha-Libeň are marked in *italics*.

Then, minimal runtimes chosen for PFTPs were chosen by following soft process, which was connected with the construction of PFTPs itself

1. Choose maximum of collected relevant runtimes.
2. IF the maximum is greater than required system runtime for PFTPs in particular section, THEN lower chosen runtime to required value.
3. IF the required system runtime is maximum sum of runtimes in neighbouring sections, THEN change chosen minimal section runtimes iteratively, until they achieve value of percentile of similar percentage of really scheduled section runtimes of freight trains.
4. IF the maximum is lower than required system runtime for PFTPs in particular section, THEN enlarge chosen runtime to required value (facultative step)

Results in Table B.1 show that system runtimes in few sections are critical for entire offer of PFTPs (in the sense, for how many freight trains this offer can be suitable). *This approves the prerequisite that slight adjustment of passenger train paths can increase quality of PFTPs significantly.*

This approach was chosen because of unknown rules for time supplemens used by SŽDC for scheduled runtimes of freight trains.

In the Table D.1, each station (except the first one in particular direction) should be understood as end station of particular line section. This rule is also valid for the Table D.1, G.1 and J.1.

% of RTs, less or equal than chosen RT	Chosen minimal RTs	Line 519A/221	Chosen minimal RTs	% of RTs, less or equal than chosen RT
		Benešov u Prahy	**32**	0,75
1,00	**34**	Strančice	14	0,89
1,00	16	Praha-Uhříněves	**7**	0,93
1,00	**7**	Praha-Hostivař	**7**	0,77
1,00	**7**	Praha-Malešice		
		minimal percentage		0,75

% of RTs, less or equal than chosen RT	Chosen minimal RTs	Line 527A/090	Chosen minimal RTs	% of RTs, less or equal than chosen RT
		Praha-Malešice	**8**	0,96
0,96	**7**	Praha-Libeň	10	1,00
1,00	8	Praha-Holešovice	3	1,00
1,00	2	P.-Holeš. Stromovka	9	0,94
0,80	10	Roztoky u Prahy	15	0,88
1,00	17	Kralupy nad Vltavou	39	0,83
0,80	34	Roudnice n. L.	18	0,82
0,92	17	Lovosice	22	1,00
0,81	20	Ústí n. L. hl.n. os. n.		
		minimal percentage		0,8

% of RTs, less or equal than chosen RT	Chosen minimal RTs	Line 501A/011	Chosen minimal RTs	% of RTs, less or equal than chosen RT
		Kolín	8	0,93
0,83	8	Velim	6	0,95
0,76	6	Pečky	6	0,80
1,00	7	Poříčany	6	0,93
0,82	5	Český Brod	10	0,89
1,00	13	Úvaly	9	0,92
0,94	9	Praha-Běchovice	***16*** 9	*1,00* 0,97
1,00	*→ **13***	*→ Praha-Libeň*		
0,74	8	Praha-Malešice		
		minimal percentage		0,74

% of RTs, less or equal than chosen RT	Chosen minimal RTs	Line 521A/171	Chosen minimal RTs	% of RTs, less or equal than chosen RT
		Praha-Malešice	**7**	0,75
1	**8**	Praha-Vrš. ček. kol.	**9**	1,00
0,81	**8**	Praha-Krč	**13**	0,96
0,97	**13**	Praha-Radotín	14	1,00
0,90	14	Řevnice	16	0,72
1,00	17	Beroun.		
		minimal percentage		0,72

Table B.1 Chosen minimal runtimes and percentage of relevant freight train runtimes from SŽDC (2008) that are less than or equal to chosen minimal runtimes.

C Study 1: Train diagrams

For higher clarity, train diagrams are depicted separately for each direction.

Passenger train path are marked as follows:

——— 60-min-period

------- periodic peak services

Coloured fields stand for various potential conflicts.

60-min-period

running excluded due to boarding of passengers

At the time of timetable 2008/09, there was only double-track line between Praha-Běchovice and Praha-Libeň.

Line 501A/011[9]

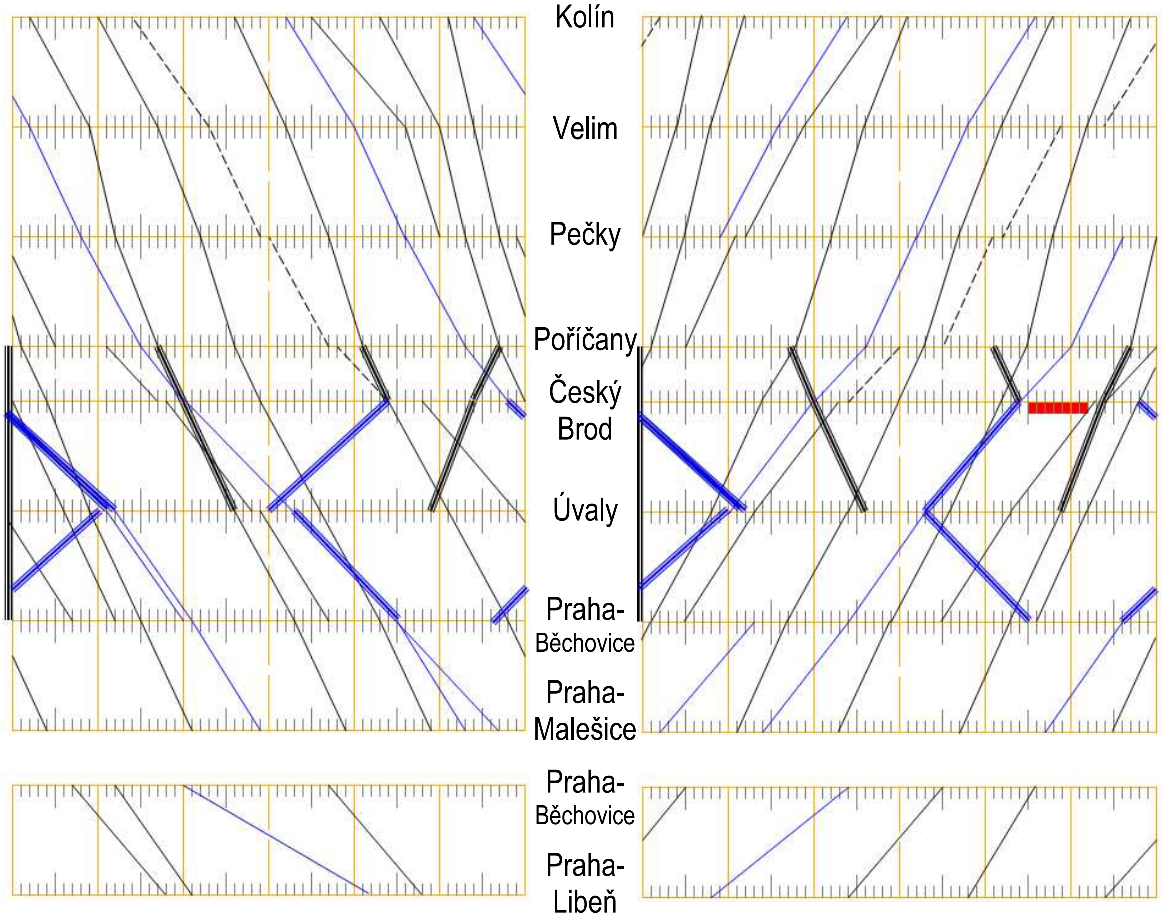

Figure C.1 Proposed train diagram of PFTPs for the line 501A/011.

[9] Triple vertical line stands for three-track railway line section. Triple line in train path stands for running at 0. track (middle track out of three).

Line 519A/221

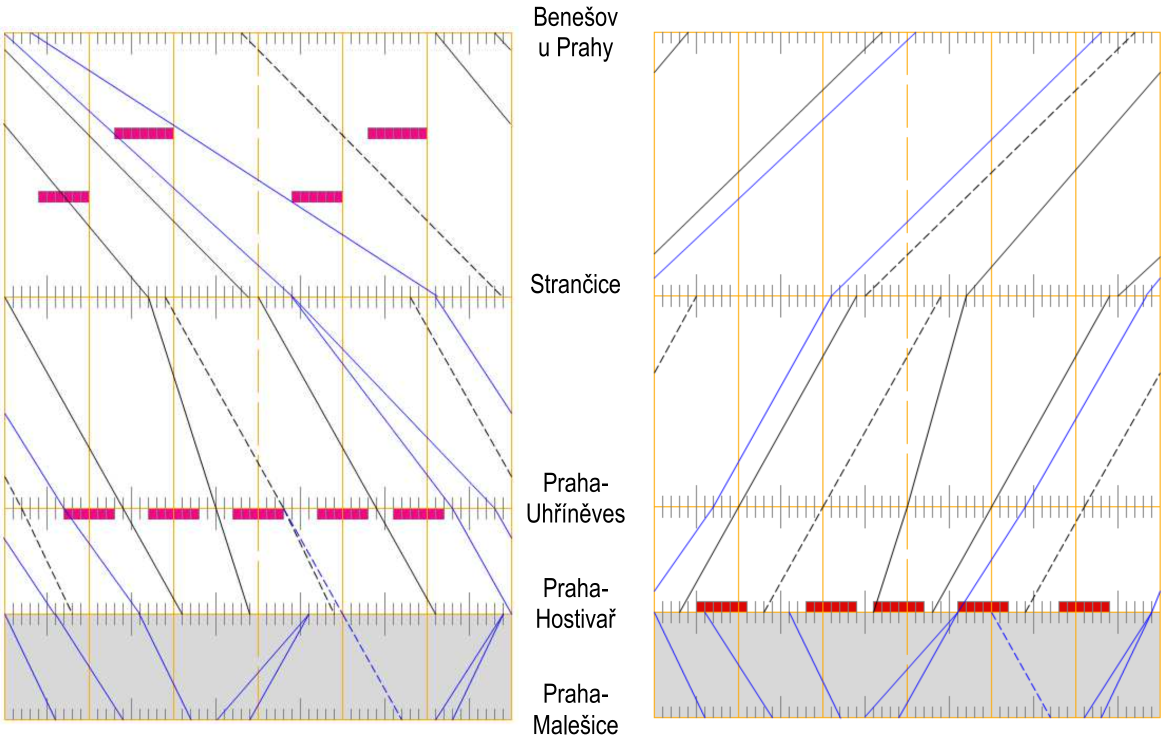

Figure C.2 Proposed train diagram of PFTPs for the line 519A/221.

Line 521A/171

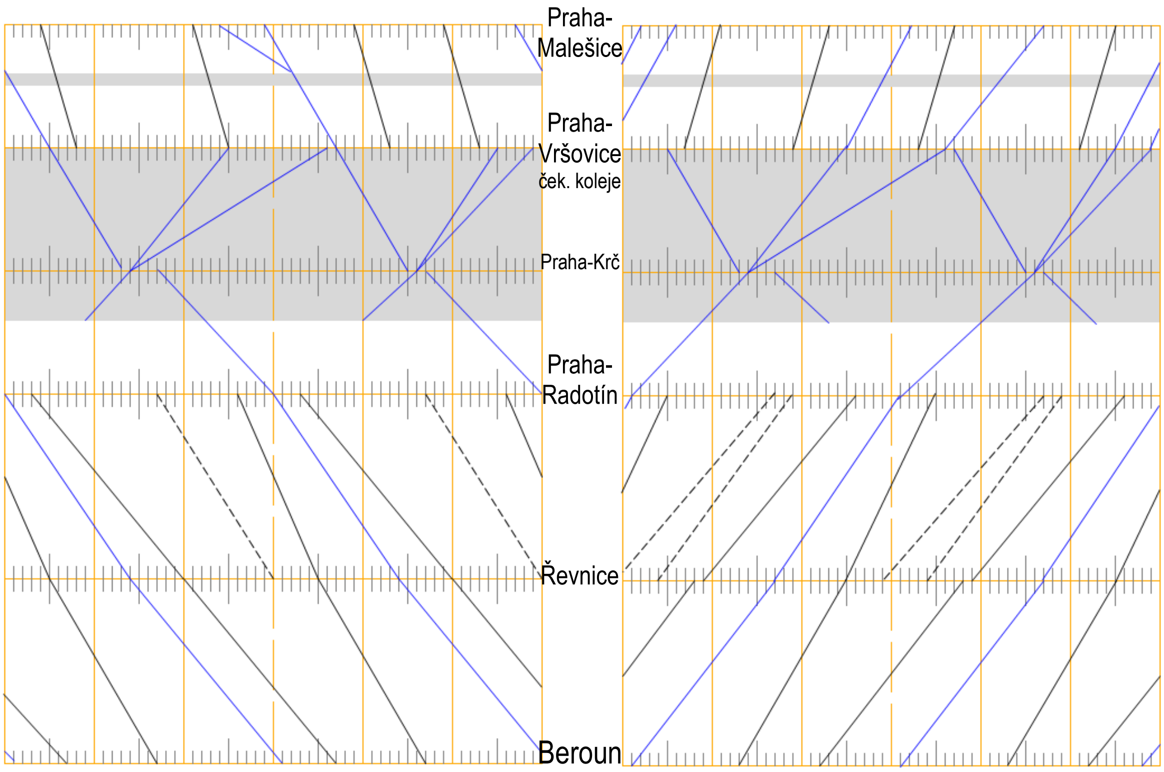

Figure C.3 Proposed train diagram of PFTPs for the line 521A/171.

Line 527A/090

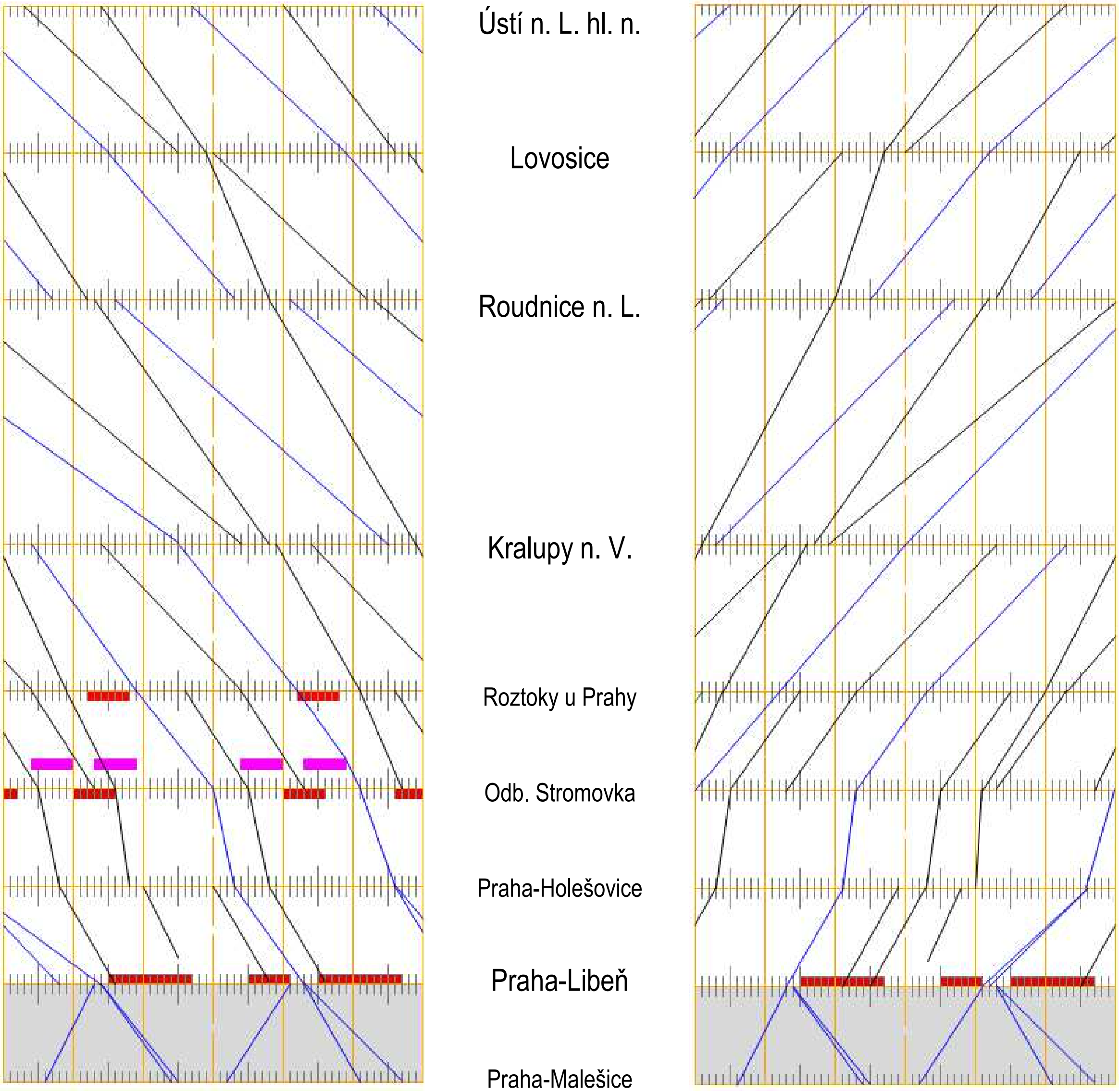

Figure C.4 Proposed train diagram of PFTPs for the line 527A/090.

D Study 1: Numbers of FTPs and numbers of freight train stops

In the Table D.1, each horizontal line stands for end of line section (or sequence of them) with equal number of FTPs (or number of scheduled stops of freight trains) in particular direction.

SŽDC timetable		Study 1		Line section	Study 1		SŽDC timetable	
No of FTPs (4:00 - 24:00)	No of stops	No of FTPs (4:00 - 24:00)	No of stops		No of FTPs (4:00 - 24:00)	No of stops	No of FTPs (4:00 - 24:00)	No of stops
				Benešov u Prahy	40	0	2	9
4		40		Praha-Uhříněves	40		11	
10	10	53	0	Praha-Hostivař				
		53	20	Praha-Malešice	40	0		
				Praha-Libeň	40	0	30	33
29	20	40	0	Praha-Bubeneč	40	60	28	48
28		40		Kralupy nad Vltavou	40		35	
35		40		Hněvice				
				Lovosice	40		41	
45	45	40	60	Ústí n. L. hl.n.				
				Kolín	40	40	29	33
26		40		Poříčany	40		33	
38	18	40	0	Praha-Běchovice				
		40	0	Praha-Malešice	40	0		
				Praha-Vršovice ček. kol.	40	0	26	34
25		40	40	Praha-Radotín	40		29	
27	30	40	0	Beroun				
		Station		Praha-Malešice (total)				26

Table D.1 Numbers of FTPs and daily numbers of scheduled freight train stops between 4:00 and 24:00 in SŽDC (2008) and in Study 1.

E Study 2: Parameters of chosen freight trains

To gain knowledge about real demand of FRUs for FTPs, three scheduled freight trains for each line and direction were chosen. The train 69713 appeared on two lines.

Each train out of three varied in brutto mass of load and/or maximum speed. Theoretical and practical maximum speed of a train should be distinguished. Theoretical maximum speed is the lowest maximum speed of all vehicles in the train. Practical maximum speed considers maximum speed on line sections and constraints caused by awaited braked weight percentage of the train.

By all trains, the same braking regime as by passenger trains is used. The only exceptions are trains 59630 and 69713.

Numbers of Czech locomotive classes, which are scheduled for chosen freight trains, distinguish first digit according to traction system of the locomotive:

- 1 for electric DC
- 3 for electric AC/DC
- 7 for diesel

No of train	**Brutto mass of load** [t]	**Maximum allowed speed** [km/h]		**Locomotive class**
		Theoretical	Practical	
41300	1600	100	100	163
41305	1600	100	100	163*
42191	1300	100	100	363*
42192	1100	100	90	363
47513	1600	90	90	363*
47556	1600	90	70	2x 740
47720	1800	100	100	130
47749	1950	100	100	2x 753.7
48353	1560	90	85	163
59520	1800	100*****	100*****	121 or 2x 753.7
59630	2400	90	85	181**
61760	1600	90	90	163
62562	2000	90	85	130 or 163**
65522	1350	90	85	122 or 123
65670	2100	90	90	122 or 123**
65791	1800	90	85	122 or 123
66891	2350	90	90	363***
67411	1500	90	90	122 or 123
67461	2160	90	85	163**
67780	2350	90	80	122 or 123***
68660	1300	90	90	122 or 123
69713	2500	90	85	130 or 2x 741*

*with rear-end assistance
**with double rear-end assistance
***with head-end assistance and rear-end assistance
****rear-end assistance always necessary.
The only train with freight braking regime (with slower reaction of the air brake)
*****90 km/h in the case of locomotive class 121

Table E.1 Parameters of chosen freight trains, as scheduled in SŽDC (2009a).

F Study 2: Calculation of technical runtimes for PFTPs

Because of lack of information about rules for construction of FTPs by SŽDC, the author calculated technical runtimes of fictious freight trains in FBS timetabling software. Information basis about solved railway lines maintained by research group of Janoš and Baudyš was used. The data about railway lines in FBS software corresponded to real state of railway lines in 2009. Two types of freight trains were modelled – see Table F.1. For both trains, locomotive class 163/363 was used.

Train type	Maximal allowed speed [km/h]	Brutto mass of load [t]	Type of wagons	No of wagons	Braked weight percentage [%]
Fast	100	1620	container	18	70
Slow	90	2000 (519A: 1520)	open, for coal	25	60

Table F.1 Parameters of model freight trains.

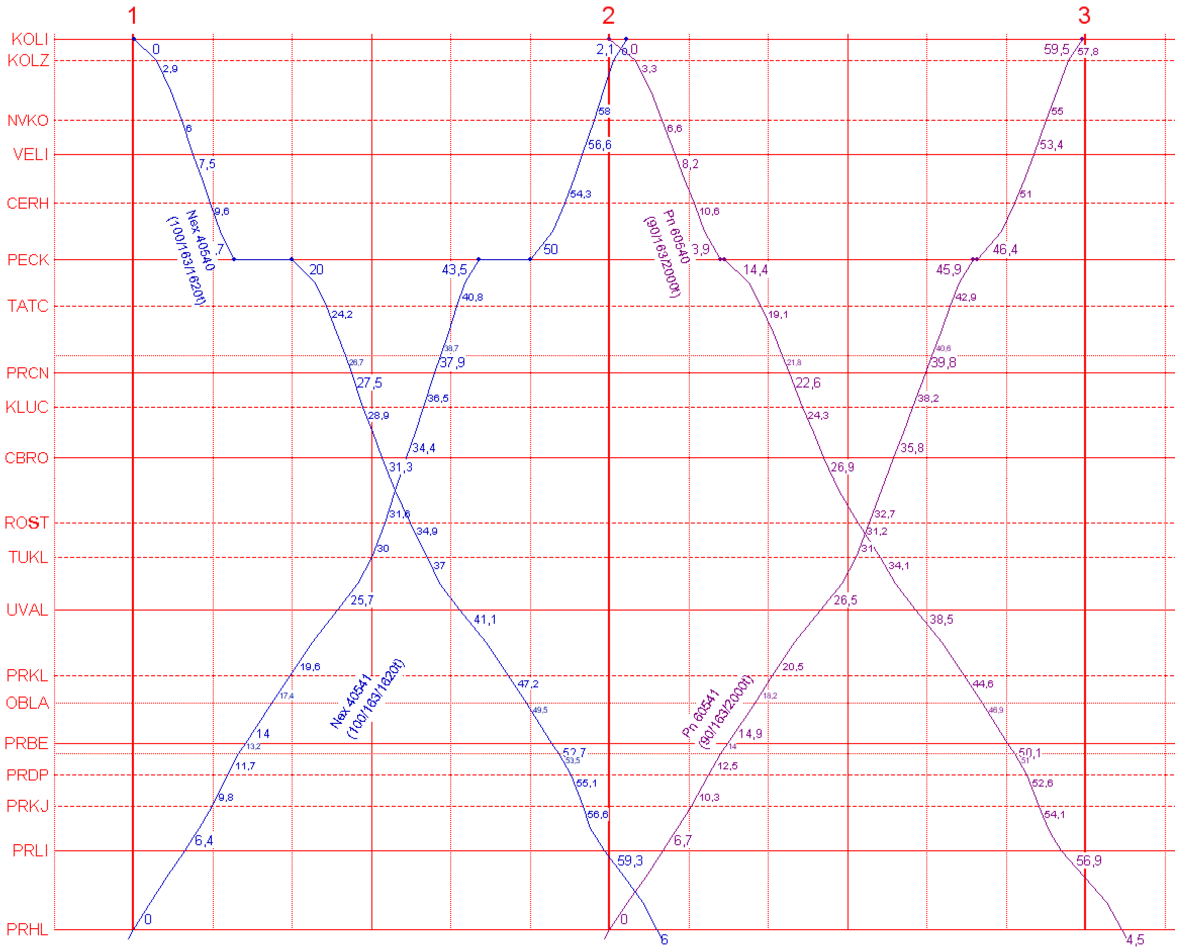

Figure F.1 Train diagram of model freight trains on the line 501A/011, section Kolín – Praha hl. n.

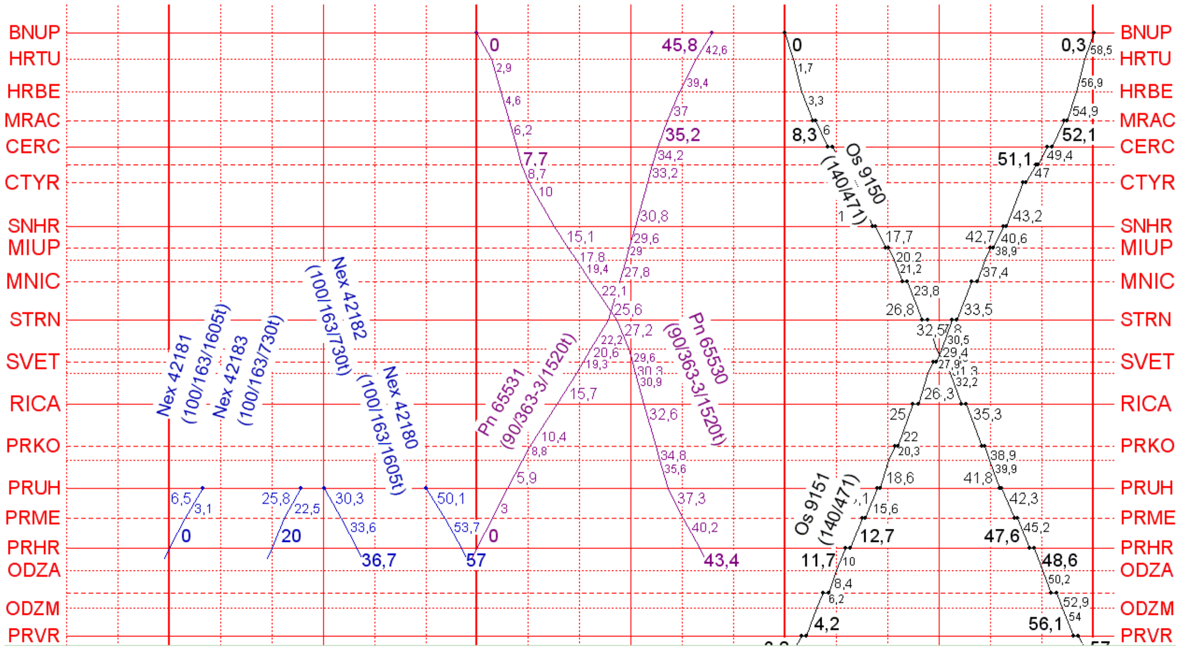

Figure F.2 Train diagram of model freight trains on the line 519A/221, section Benešov u Prahy – Praha-Hostivař.

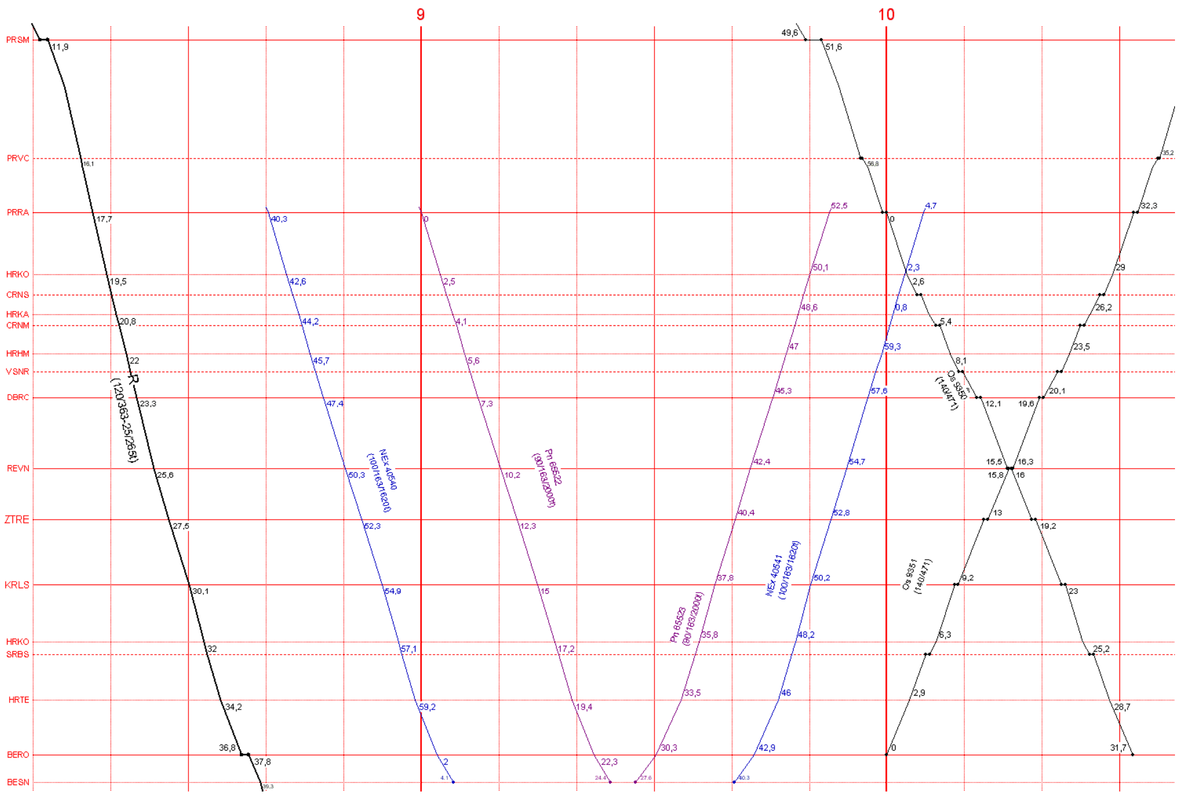

Figure F.3 Train diagram of model freight trains on the line 521A/171, section Praha-Radotín – Beroun marshalling yard (Beroun seř. n.).

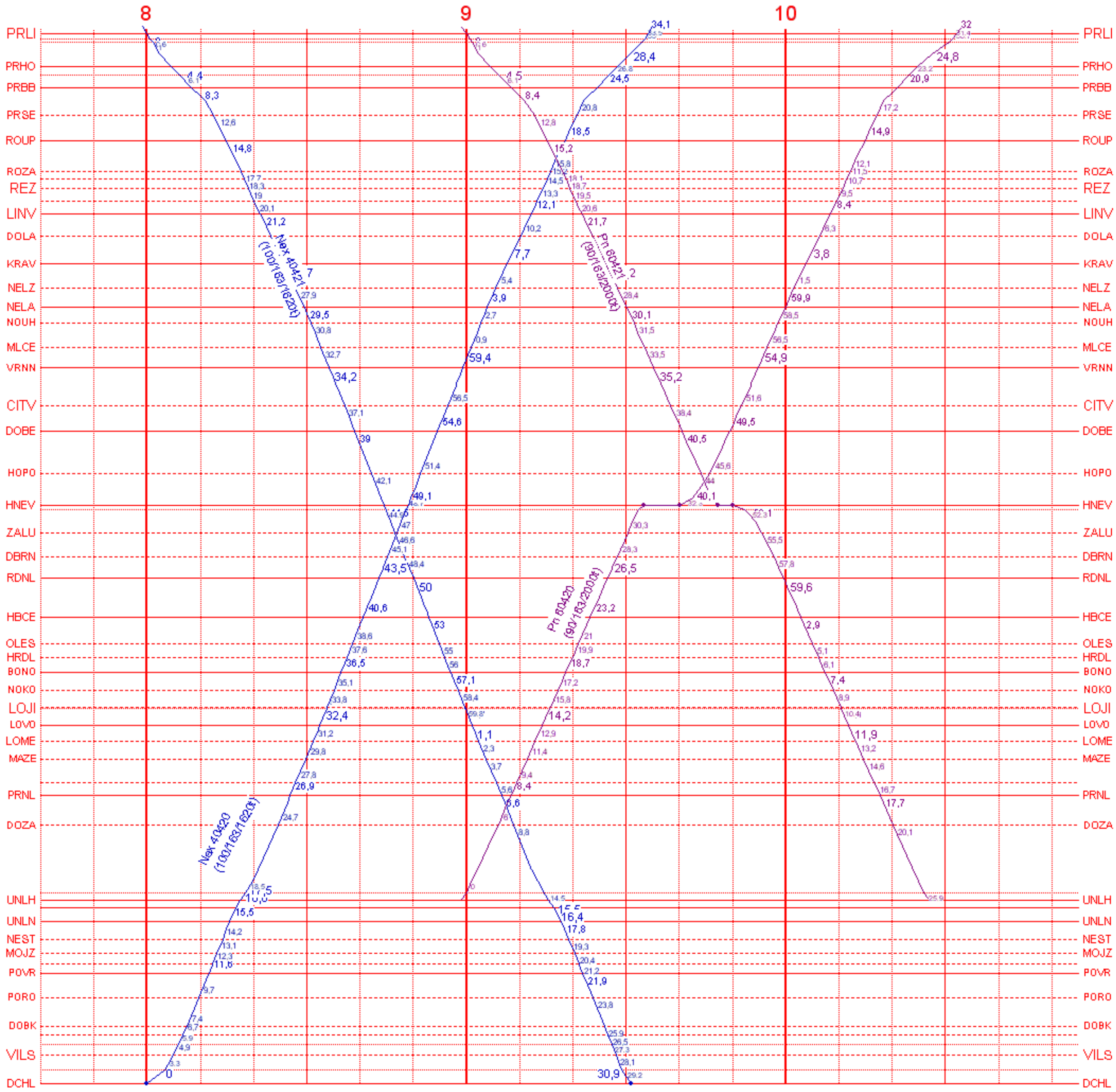

Figure F.4 Train diagram of model freight trains on the line 526A + 527A/090, section Praha-Libeň – Děčín hlavní nádraží.

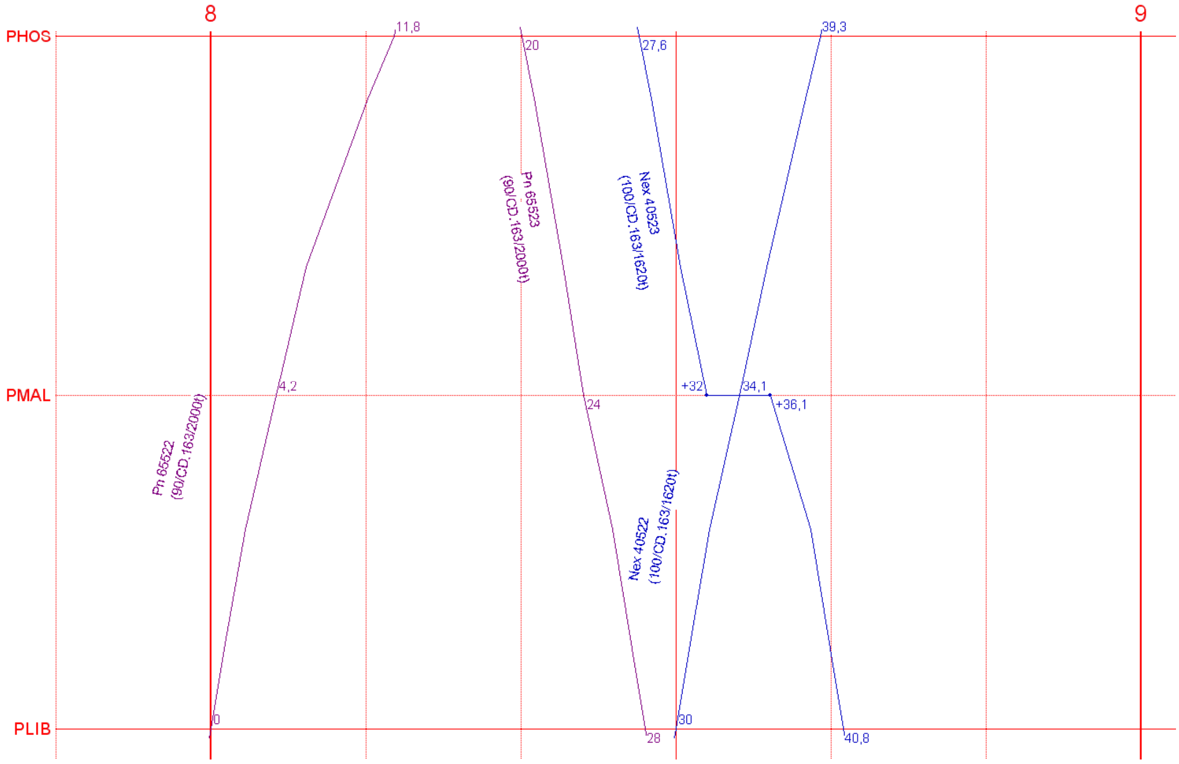

Figure F.5 Train diagram of model freight trains on the freight bypass line 525F, section Praha-Hostivař – Praha-Libeň.

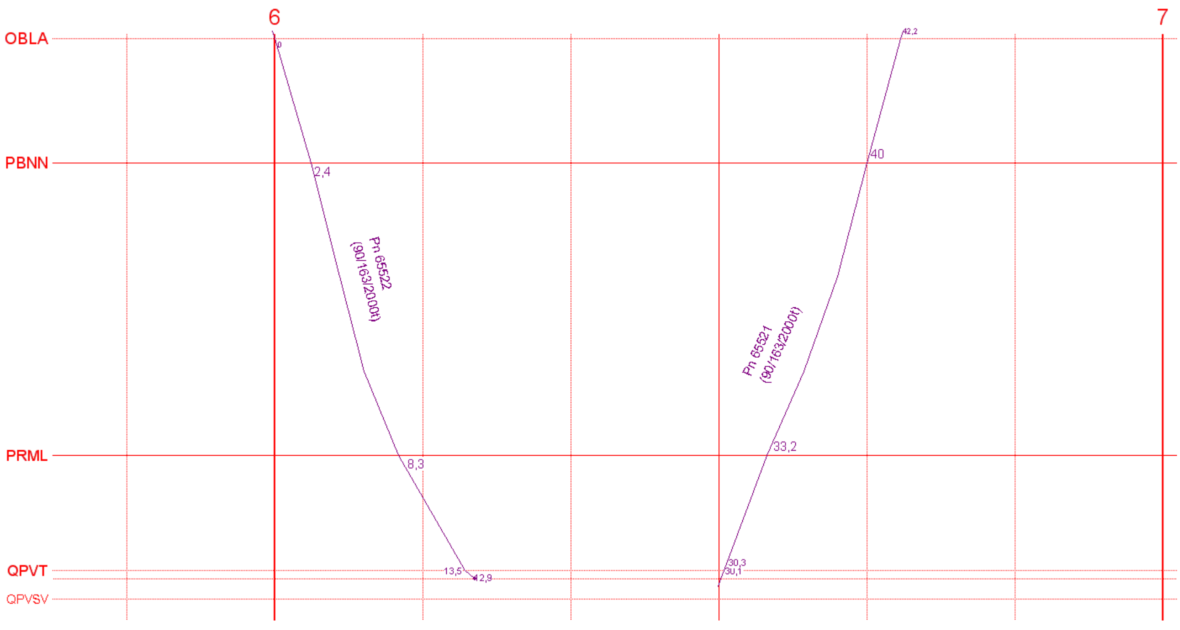

Figure F.6 Train diagram of model freight trains on the freight bypass line 525G, section Odb. Blatov (part of the station Praha-Běchovice) – Praha-Malešice – Praha-Vršovice čekací koleje.

G Study 2: Determination of minimal runtimes for PFTPs from calculations and runtimes of chosen freight trains

The minimal runtimes for construction of PFTPs in Study 2 were determinated by expert estimation, based both on of really scheduled runtimes of chosen freight trains from SŽDC (2009a) and calculation of technical runtimes by FBS timetabling software.

For each of chosen freight trains, sections, with a stop in one end[10] are marked bold. Runtimes to/from Ústí nad Labem západ and in the section Praha-Běchovice – Praha-Libeň are marked in *italics*.

Because of inconsistency in scheduled runtimes of freight trains in some sections[11], an expert estimation instead of exact procedure was chosen. However, to achieve physical feasibility of scheduled runtimes for PFTPs, the condition was adopted that sum of scheduled runtimes for PFTPs between bottlenecks must be greater than or equal to sum of scheduled runtimes for these sections and chosen maximum brutto mass both for FBS calculations and for chosen freight trains whose brutto mass of load corresponds to parameters of PFTPs. As a bottleneck, here is understood every section where passenger and freight train are scheduled to run close behind each other.

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[10] Sections neighbouring to Praha-Malešice can sometimes represent an exception. Some chosen freight trains stop in both stations.

[11] For instance, scheduled runtime of train 62562 (brutto mass of load 2000 t) from Řevnice to Karlštejn is 1 minute lower than scheduled runtime of train 65522 (brutto mass of load 1350 t). For both trains, the same locomotive class is scheduled.

RTs of chosen trains			Chosen minimal RTs		Line 519A/221	Chosen minimal RTs		RTs of chosen trains		
47556	68660	42192	Slow	Fast		Fast	Slow	42191	47513	66891
					Benešov u Prahy	21	32	9	11	11
10	13	10			Čerčany			6	8	9
16	7	7			Senohraby			6	11	9
23	7	7	30	24	Strančice	16	16	5	5	6
8	7	6			Říčany			5	7	5
8	8	7	15	14	Praha-Uhříněves	7	7	7	9	8
7	8	5	6	6	Praha-Hostivař	5	5			
6	6	6	6	6	Praha-Malešice					

RTs of chosen trains			Chosen minimal RTs		Line 527A/090	Chosen minimal RTs		RTs of chosen trains		
65670	59520	41300	Slow	Fast		Fast	Slow	41305	47749	69713
					Praha-Malešice	6	6	8		
8	8	6	6	5	Praha-Libeň	6	7	6	8	8
6	7	6	6	6	Praha-Holešovice	1	2	1,5	2	2
0,5	2	0,5	1	1	P.-Holeš. Stromovka	7	7	1,5	3	2
2,5	3	2,5			Praha-Bubeneč			6	8	6
5	5	6	9	8	Roztoky u Prahy	12	16	7	8	12
9	8	8			Libčice nad Vltavou			5	8	7
7	7	5	16	13	Kralupy nad Vltavou	17	23	5	8	6
6	8	4			Nelahozeves			6	7	8
10	6	6			Vraňany			6	7	9
7	6	6	21	15	Dolní Beřkovice	7	9	7	7	9
7	6	6	7	6	Hněvice	6	10	6	8	10
7	6	6	7	6	Roudnice n. L.	14	16	3	5	4
4	3	4			Hrobce			6	6	7
6	5	6			Bohušovice nad Ohří			5	5	5
5	5	5	15	15	Lovosice	15	20	7	6	8
7	7	7			Prackovice n. L.			8	10	12
10	9	9	17	16	Ústí nad Labem jih	2	*8*	2	*7*	*9*
→ *5*	→ *5*		→ *6*		→ *Ústí n. L. západ*		↗		↗	↗
		2		2	Ústí n. L. hl.n. os. n.	23		23		
		20		18	Děčín freight station					

RTs of chosen trains			Chosen minimal RTs		Line 501A/011	Chosen minimal RTs		RTs of chosen trains		
59630	61760	47720	Slow	Fast		Fast	Slow	47749	67411	69713
					Kolín marshall. yard	1	1	1		1
1	3	1	1	1	Kolín	6	7,5	6		8
7	6	6	7	6	Velim	6	6	5		9
6	5	5	6	5	Pečky	6	6	6		8
6	6	6	6	6	Poříčany	6	6	6	7	8
6	4	4	6	4	Český Brod	10	10	10	9	12
13	10	11	12	10	Úvaly	9	11	11	10	12
9	8	8	10	8	Praha-Běchovice	8	*8* 8	*12*	9	*13*
		→ *6*	*6*		→ *Praha-Libeň*		↗	↗		↗
9	8		6	6	Praha-Malešice					

RTs of chosen trains			Chosen minimal RTs		Line 521A/171	Chosen minimal RTs		RTs of chosen trains		
67781/0	62562	65522	Slow	Fast		Fast	Slow	48353	65791	67461
					Praha-Malešice	4	5	8		9
8	8	9	7	6	Praha-Vrš. ček. kol.	6	6	6		8
8	7	6	8	6	Praha-Krč	5	5	6		5
4	4	4	4	4	Odb. Tunel	6	6	5		6
6	6	6	6	6	Praha-Radotín	13	13	12	10	10
9	11	11			Dobřichovice			5	3	3
3	3	6	13	12	Řevnice	6	6	6	6	6
7	5	6	7	7	Karlštejn	8	8	7	8	8
10	9	9	9	9	Beroun	3	4	3	4	4
3	4	3	4	3	Beroun marsh. yard					

Table G.1 Scheduled runtimes of chosen freight trains and chosen minimal runtimes for Study 2.

H Study 2: Analysis of minimal departure headways and buffer times of bottlenecks

The analysis was elaborated according to UIC (2004). The analysis is approximate, as exact calculation is not purpose of this thesis. For timetable study, accuracy of few seconds should be sufficient.

For each bottleneck and direction, a relevant block section was derived. Time periods for run route release and formation were assumed from SŽDC (2001). They differ for mechanical interlocking - for two following run routes either with or without resetting switches in between - and for relay interlocking. Time for approach section was set 0,2 min, as minimal value required by SŽDC (2001). Section runtime, time for clearing and time for approach section were interpolated from timetable runtimes, with the aid of approximate average speed of particular train in relevant area.

The sequence of trains, which is critical for minimal headway, was always determined by freight train paths construction in the context of passenger timetable. Runtimes for both passenger and freight trains were assumed from SŽDC (2009a).

Buffer times were implicated in regular runtimes. Buffer times for passenger trains were not known to the author, buffer times for freight trains varied between 0 (only in very short sections) and 25% - usually not less than 10%.

On the lines 501A, 521A+B, 525F+G, 526A and 527A, all stations were equipped with relay interlocking.

On the line 519A, station Praha-Hostivař was equipped at that time with mechanical interlocking system. Station Praha-Uhříněves, as well as further stations, were equipped with electronic interlocking. The intermediate section was divided with one automatic block signal only in direction Praha-Hostivař.

On the line 521B, stations Praha-Radotín and Beroun were equipped with relay interlocking. All stations in between, as well as block posts, were equipped with mechanical interlocking and telephone communication (with cell phones in the case of emergency).

Line	**519A**	**519A**	**519A**	**521B**	**521B**	**521B**	**527A**	**527A**
Section	Hostivař station	Hostivař – Uhříněves	Hostivař – Uhříněves	Korno–Tetín	Tetín – Korno	Tetín – Korno	section behind Bubeneč	Bubeneč station
Sequence of trains (relevant for minimal departure headway)	freight suburb.	freight fast	freight suburb.	suburb. freight	fast freight	freight suburb.	suburb. freight	freight fast
Length [km]	0.5	1.8	1.8	3.1	3.1	3.1	1.2	1.2
Approximate average speed of first train [km/h]	40	40	40	60	80	80	60	60
Runtime of first train[min]	0.7	2.7	2.7	3.1	2.3	2.3	1.2	1.2
Time for clearing [min]	0.9	0.9	0.9	0.1	0.1	0.5	0.1	0.6
Time for run route release and formation [min]	1.3	1.3	1.3	0.8	0.8	0.8	0.3	0.3
Time for approach section [min]	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Time for approach section of second train [min]	1.1	0.8	1.1	0.5	0.5	0.7	1.4	1.2
Minimal headway [min]	**4.2**	**5.9**	**6.2**	**4.8**	**4.0**	**4.5**	**3.2**	**3.5**

Table H.1 Relevant block sections of bottlenecks and derived minimal departure headways (in both directions).

I Study 2: Train diagrams

For higher clarity, train diagrams are depicted separately for each direction.

Passenger train path are marked as follows:

——— 60-min-period

- - - - - - - periodic peak services

Coloured fields stand for various potential conflicts with passenger trains as follows:

60-min-period

periodic peak services

periodic peak services – alternative station track (opposite side of a station)

single services

single services – alternative station track (opposite side of a station)

running excluded due to boarding of passengers

running excluded due to boarding of passengers – more aperiodic times

Originally 120-min-periods are marked as follows: one little grey square stands for odd hour, two squares for even hour.

Passenger trains, running from or to neighbouring section, are marked by arrows, if they represent potential conflicts. Arrows stand for arrival, departure, or passing through, as follows:

60-min-period

peak services (usually periodic)

single services

Line 501A/011[12]

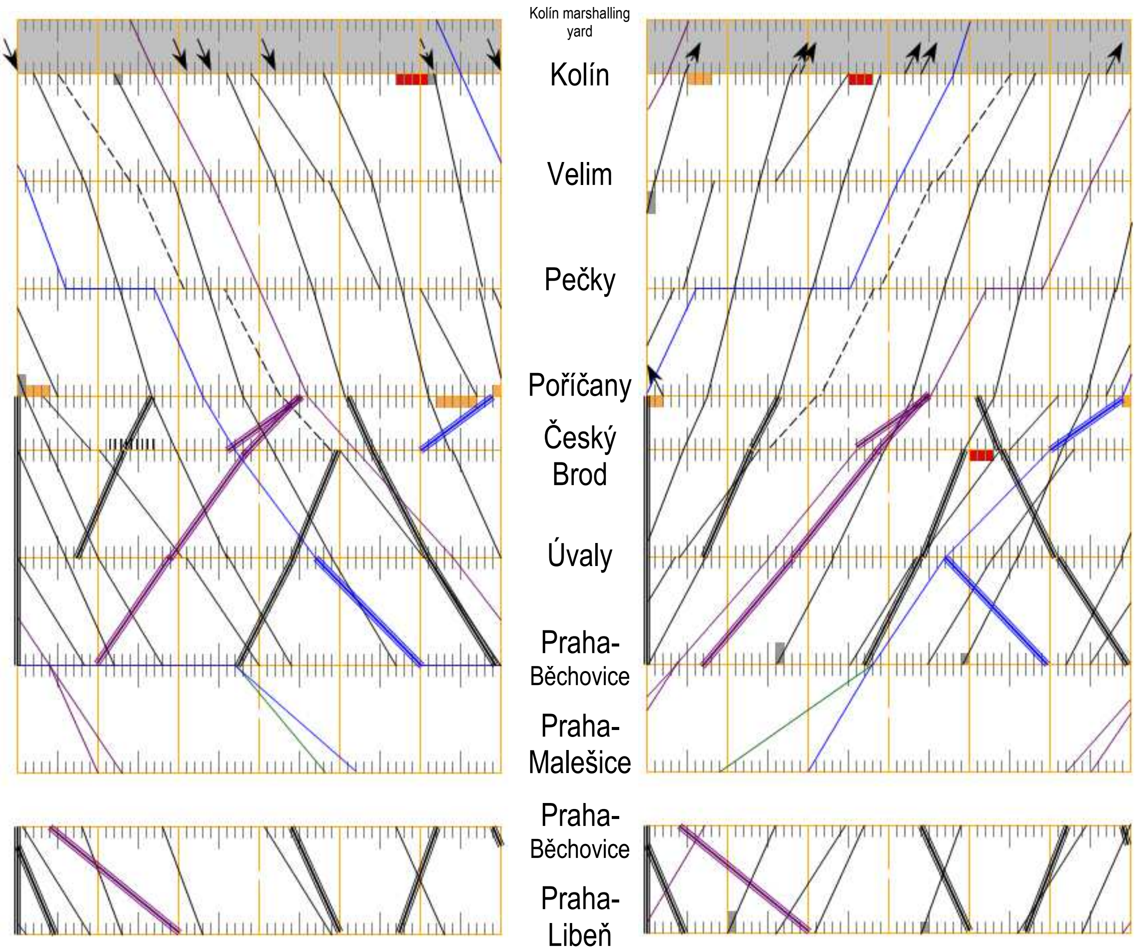

Figure I.1 Proposed train diagram of PFTPs for the line 501A/011.

12 Triple vertical line stands for three-track railway line section. Triple line in train path stands for running at 0. track (middle track out of three).

Line 519A/221

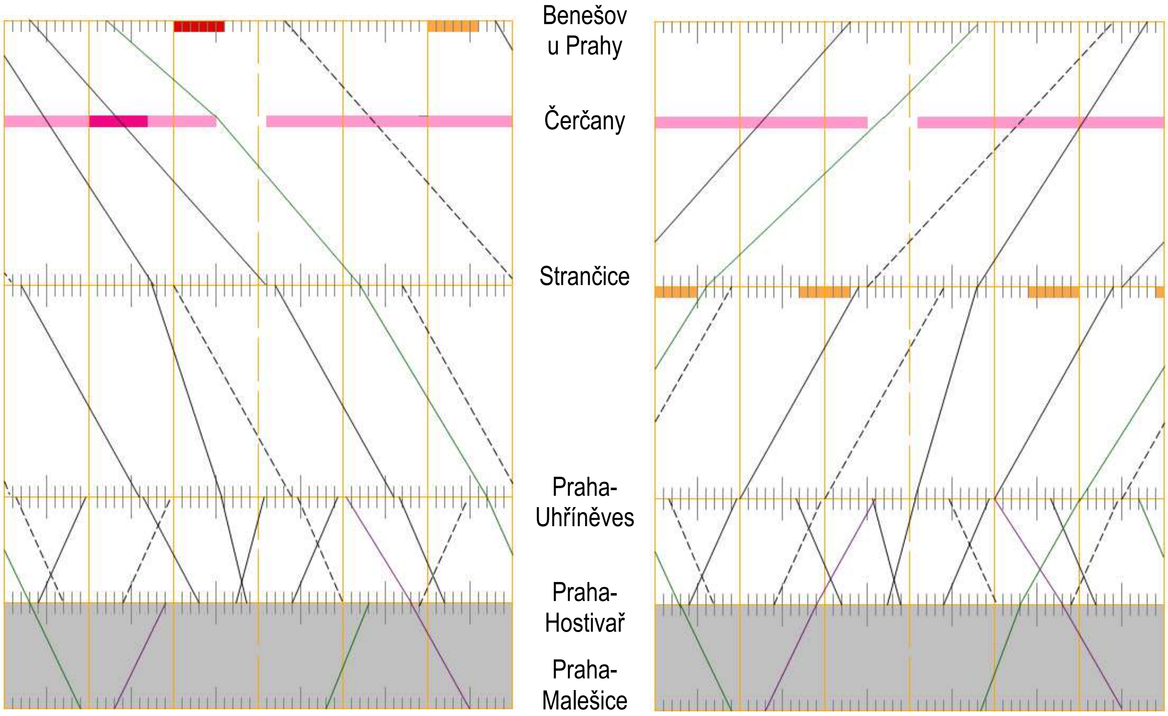

Figure I.2 Proposed train diagram of PFTPs for the line 519A/221.

Line 521A/171

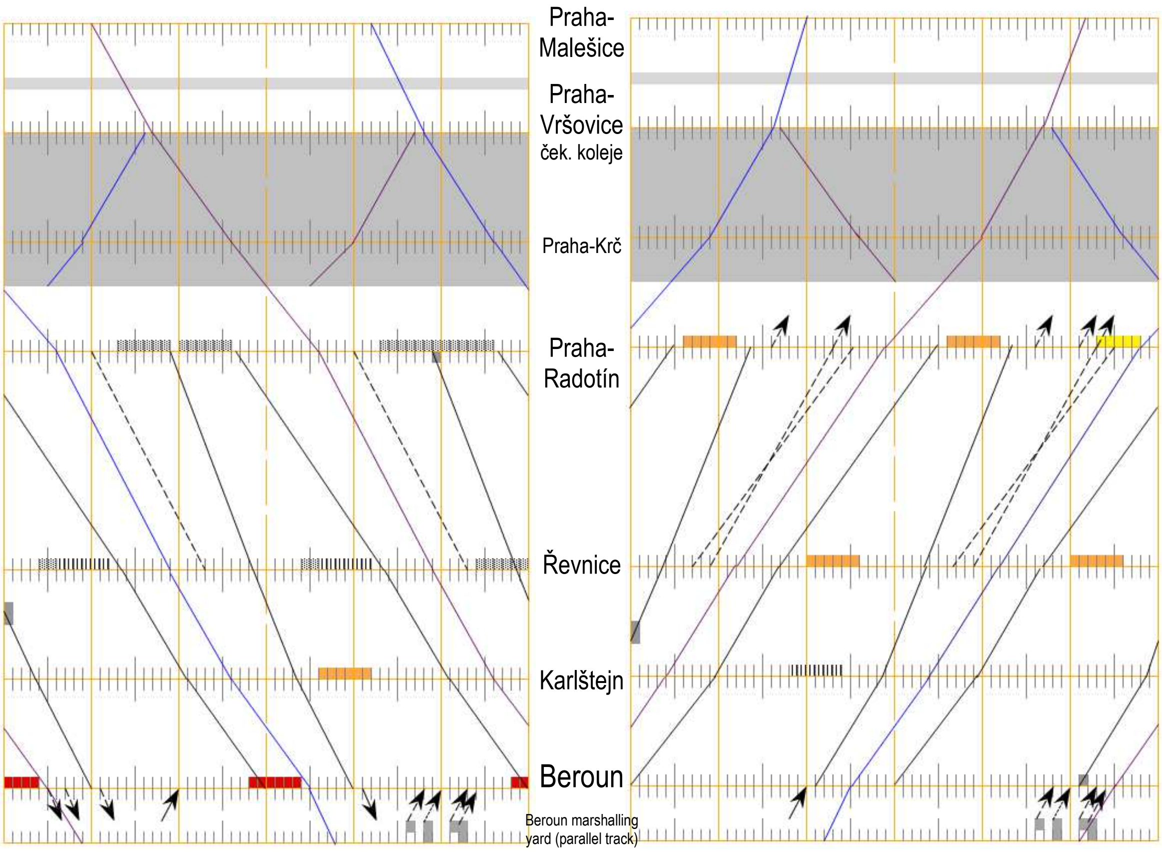

Figure I.3 Proposed train diagram of PFTPs for the line 512A/171.

Line 527A/090[13]

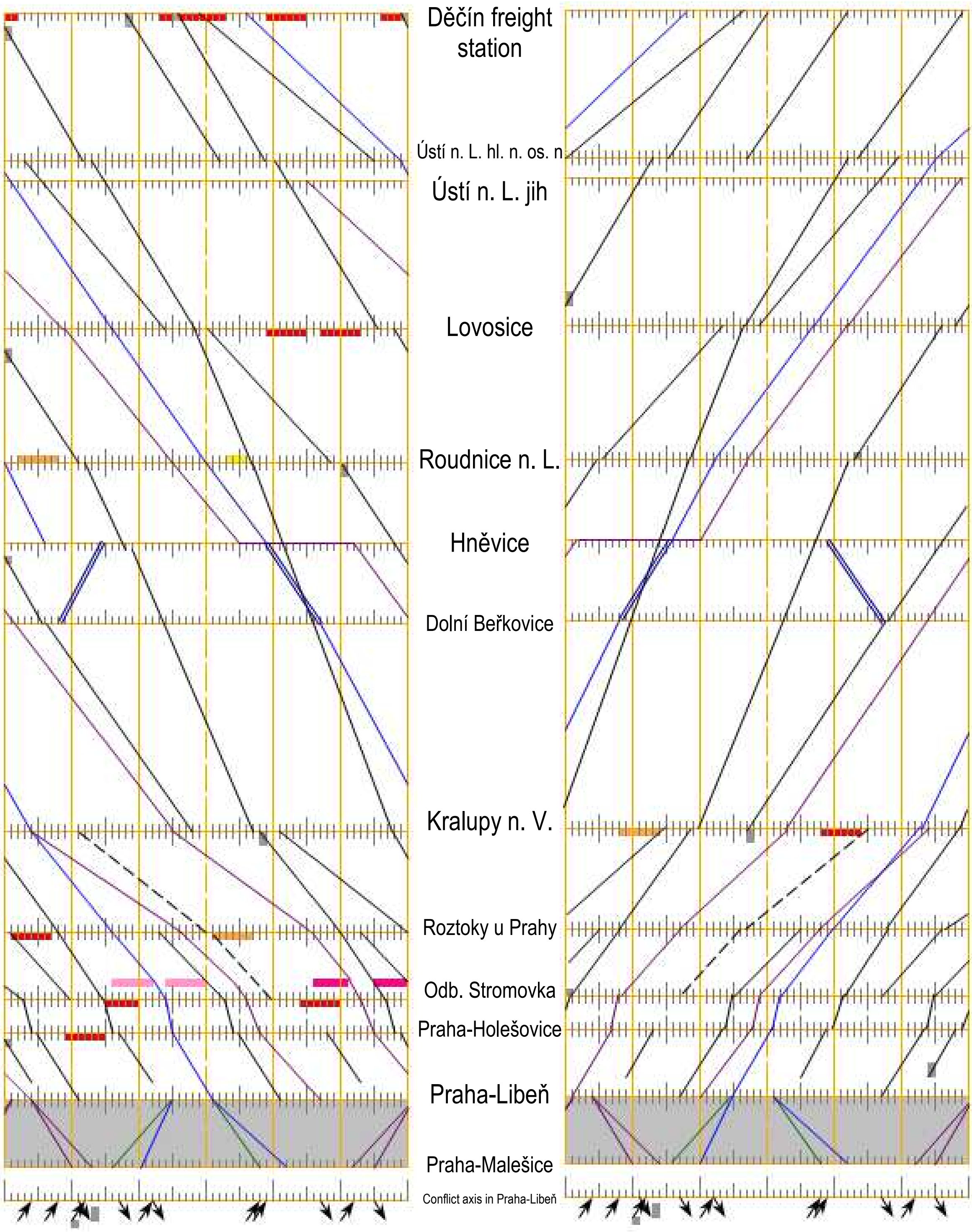

Figure I.4 Proposed train diagram of PFTPs for the line 527A/090.

[13] Double line for train path stands for running on opposite track (active overtaking).

J Study 2: Numbers of FTPs and numbers of freight train stops

Each horizontal line stands for end of line section (or sequence of them) with equal number of FTPs (or number of scheduled stops of freight trains) in particular direction.

SŽDC timetable No of FTPs (4:00 - 24:00)	SŽDC timetable No of stops	Study 2 No of FTPs (4:00 - 24:00)	Study 2 No of stops	Line section	Study 2 No of FTPs (4:00 - 24:00)	Study 2 No of stops	SŽDC timetable No of FTPs (4:00 - 24:00)	SŽDC timetable No of stops
				Benešov u Prahy	20	0	10	14
11		20		Praha-Uhříněves	40		29	
24	11	40	0	Praha-Hostivař				
		40	20	Praha-Malešice				
				Praha-Libeň	40	20	41	45
32	32	40	0	Praha-Bubeneč	40	20	40	63
35		40		Kralupy nad Vltavou	40		45	
40		40		Hněvice				
				Lovosice	40		51	
47		40		Ústí n. L. hl.n.	40		31	
29	48	40	20	Děčín				
				Kolín	40	40	30	23
31		40		Poříčany	40		33	
32	11	40	40	Praha-Běchovice				
		40	0	Praha-Malešice	40	0		
				Praha-Vršovice ček. kol.	40	0	22	19
21		40		Praha-Radotín	28		23	
24	32	28	0	Beroun				
		Station		Praha-Malešice (total)				52

Table J.1 Numbers of FTPs and daily numbers of scheduled freight train stops between 4:00 and 24:00 in SŽDC (2009a) and in Study 2.

K Glossary of chosen English terms used in this thesis and their official Czech equivalents

The English terms for this thesis were carefully chosen especially from Hansen, I., Pachl, J. et al. (2008) and UIC (2004). Further, Czech railway terms were translated into English. From English synonymes, the ones with highest frequency in Google search were chosen. The other condition was consistency of derived terms, e.g. *line* and *line section*. To ensure such consistency, derived terms were chosen according to main terms – also in cases that there were not usually used in such way in practice.

Czech terms were chosen from legal documents and railway directives - Česká republika (2006), ČSD (1966), Ministerstvo dopravy (2003), SŽDC (2011b, 2011c, 2012).

English term	Czech term
acceleration	rozjezd
active overtaking	letmé předjíždění (bez zastavení)
allocation of infrastructure capacity	přidělování či přidělení kapacity (dopravní cesty)
at-grade intersection	úrovňový rozplet či křížení
at-grade platform	úrovňové nástupiště
automatic block	automatický blok
Automatic Train Operation	automatické vedení vlaku
balise	balíza
block post	hradlo
block section	prostorový oddíl
block signal	oddílové návěstidlo
block train	ucelený vlak
brake release	odbrzdění
braked weight percentage	brzdicí procento
braking regime	způsob brzdění
brutto mass of load	dopravní hmotnost
bulk cargo	hromadné substráty
cab signalling	přenos návěstních znaků na hnací vozidlo
capacity utilisation	využití kapacity
catalogue train path	nabídková trasa provozovatele dráhy (katalogová trasa)
class	řada (hnacího vozidla)
clear signal aspect	návěst "Volno"
coasting	výběh
conflicting routes	současně nedovolené vlakové cesty
corridor	koridor (UIC 406)
crossing	křižování
departure	odjezd
dispatcher	dispečer
distant signal	předvěst (samostatná i na hlavním návěstidle)
disturbed train operation	nutnost snížit rychlost vlaku z důvodu zpožděné jízdy jiného vlaku
disturbing train	rušící vlak
double-track line/section	dvojkolejná trať/úsek
doubling (of the track)	zdvojkolejňování
dwell time	doba pobytu
flyover	mimoúrovňový rozplet či křížení
gradient	sklon

English term	Czech term
head-end assistance	přípřež
heterogeneity	heterogenita (UIC 406), nerovnoběžnost grafikonu
changing time	přestupní doba
infrastructure manager	provozovatel dráhy, manažer infrastruktury
Integrated Periodic Timetable	integrovaný taktový jízdní řád, integrální taktový jízdní řád, integrální taktový grafikon
IPT-node	taktový uzel (uzel ITJŘ)
junction	odbočka
junction station	uzlová stanice
line	trať
line section	traťový úsek
load	náklad
local freight service train	manipulační nákladní vlak (Mn)
locomotive driver	strojvedoucí
locomotive train	lokomotivní vlak (Lv)
main signal	hlavní návěstidlo
marshalling yard	seřaďovací stanice
minimal arrival headway	příjezdné mezidobí
minimal departure headway	následné mezidobí
minimal headway	provozní interval
mixed traffic	smíšený provoz (osobní doprava dálková, regionální a nákladní doprava)
node	železniční uzel
operational concept	provozní koncept
optional train path	trasa vlaku zaváděného podle potřeby
order of trains	pořadí vlaků (po téže traťové koleji bez ohledu na směr)
overtaking	předjíždění
overtaking track	předjízdná kolej
passing through	průjezd
periodic freight train path	periodická trasa pro nákladní vlaky
periodic train path	periodická trasa
permissive signal aspect	návěst dovolující jízdu vlaku
PuT line	linka
PuT segment	segment nabídky osobní dopravy (dle četnosti zastavení), vrstva (segment) obsluhy
railway undertaking	dopravce
rear-end assistance	postrk
regular runtime	pravidelná jízdní doba
relevant block section	relevantní prostorový oddíl (UIC 406)
rolling resistance	jízdní odpor
run route	vlaková cesta, jízdní cesta
runtime	jízdní doba (technická i pravidelná)
sequence of trains	sled vlaků (ve stejném směru po téže traťové koleji)
shunting	posun, posunovací
signal	návěstidlo
signal aspect	návěst
single-track line/section	jednokolejná trať/úsek
speed bundling	svazkování (rovnoběžných tras vlaků)
station	stanice, výhybna
station master	výpravčí
station track	staniční kolej

English term	Czech term
stop signal aspect	návěst "Stůj"
stopping pattern	zastavovací politika
switch region	zhlaví
system runtime	synchronizační jízdní doba
system travel time	systémová jízdní doba
technical runtime	technická jízdní doba
time for approach section	doba na přibližovací úsek (UIC 406)
time for clearing	doba na rušení vlakové cesty (UIC 406)
time for route formation	doba na přípravu vlakové cesty (UIC 406)
time for route release	doba na rušení vlakové cesty (UIC 406)
time supplement	přirážka (k technické jízdní době)
timetable	jízdní řád
track layout plan	dopravní schéma
tractive force	tažná síla
traffic	provoz
train diagram	nákresný jízdní řád
train path	trasa vlaku
trainset	souprava (i pro nákladní vlak)
trainset train	soupravový vlak (Sv)
travel time	cestovní doba
turnout	výhybka
usable length of the track	užitečná délka koleje
wagonload transport	doprava vozových zásilek

Table K.1 Glossary of chosen English terms used in this thesis and their official Czech equivalents.

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Interviews

Organisation	Person	Subject
BLS	Martin Wyss	Excursion on railway traffic dispatching on Lötschberg corridor
Czech Ministry of Transport	Josef Buriánek	Strategic planning in railway transport, implementation of European transport policy
Czech Ministry of Transport	Josef Buriánek and Jan Ilík	European rail network for competitive freight
ČD Cargo	Gustav Slamečka, MBA - Chairman of the Board	Possibilities of improvement of core processes for FRU
ČD Cargo	locomotive drivers	Journeys in locomotive of a freight train
IVT ETH Zürich	Dr. Marco Lüthi	Experience with real-time rescheduling of freight trains in Lucerne area
IVT ETH Zürich	Prof. Ulrich Weidmann	Overall consultation on the thesis
IVT ETH Zürich	Jost Wichser	Practical issues on Swiss freight railway transport
Metrans Rail	Petr Šimral - Executive Director and locomotive driver	View of privately owned FRU on dispatching and train path allocation on Czech, German and Dutch railway network, increase of maximum speed up to 120 km/h for freight trains
SBB Infrastruktur	Christian Reinhard	Excursion at marshalling yard Limmattal
SBB Infrastruktur	Max Blaser	Planning of periodic freight train paths on Swiss railway network
SŽDC	Petr Šlegr	Priorities in railway traffic management for passenger and freight trains
SŽDC	Miloš Futera	OneStopShop, ad hoc allocation of freight train paths
SŽDC	Pavel Krýže	Periodic capacity for freight trains
SŽDC	Vladimír Tuma, MBA - Head of Dispatching District Praha-Libeň	Dispatching of freight trains on main railway line Prague - Děčín - Dresden
AŽD Praha	Dr. Aleš Lieskovský	Possibilities of ATO for freight trains

Software used

Microsoft Excel

FBS – Fahrplanbearbeitungssystem, module FPL – Bildfahrplan (construction of train diagrams), © Institut für Regional- und Fernverkehrsplanung iRFP, 1993 – 2012, license for CTU FTS – www.irfp.de.

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MICHAL DRÁBEK – **CURRICULUM VITAE**

Born 4. 8. 1983 in Prague, lives in Prague

Current position	Assistant Professor at CTU FTS, Department of Logistics and Transport Management

Education

2007 – 2012	PhD student at CTU FTS, branch Technology and Management in Transport and Telecommunications
2010/2011	one-year research stay at Swiss Federal Institute of Technology in Zurich, Institute for Transport Planning and Systems, under guidance of Prof. Ulrich Weidmann (Sciex programme)
2010	State Doctoral Examination with distinction
2008/2009	one-year research stay at Swiss Federal Institute of Technology in Zurich, Institute for Transport Planning and Systems, under guidance of Prof. Ulrich Weidmann
2007	graduated with distinction at CTU FTS, branch Management and Economics of Transportation and Telecommunications, diploma thesis „Concept of Rail Transport Services in Area of Airport Praha Ruzyně“
2005/2006	one-year study at Technische Universität Dresden, Faculty of Transportation and Traffic Sciences "Friedrich List" – highlights: rules for planning of Integrated Periodic Timetable, lines, vehicle run cycles and duty rosters planning in public transport, theory of transport systems, integration of various means of transport and innovative disposals in public transport

Projects

2011 – 2012	Co-edition of book High Speed Rail even in the Czech Republic (published by Centre for Efficient Transport, Association)
2011	Utilisation of experience of Swiss Confederation for development of railway and public transport in the Czech republic, 1st Phase – organization and partial realization of four study visits of Switzerland
2011	Analysis and steps in the process of opening market of railway transport
2010 – 2011	Information Technologies in Future Transport Economy (Sciex programme)
2008 – 2009	Swiss National Science Foundation Project No. 100014-118279 “Sustainable Freight Transport on the Local Level“

2007 – 2009	research Project CG723-138-190 “Configuration of IPT-nodes in Czech Railway Network“ on behalf of Czech Ministry of Transport
2007	Assessment of Variants of Railway Connection Praha – Airport Praha-Ruzyně - Kladno
2007	Co-organization of 5th Conference of European Students of Traffic and Transportation Sciences in Prague and Pardubice

Tuition

2011/2012	Whole subject Technology of Transport/Technology of Transport and Logistics in CTU FTS Department in Děčín, translation of part of lectures into English, tuition in English
	Preparation of part of lectures of subject Projecting of Public Transport Service
2008 - 2011	Exercises of Technology of Transport/Technology of Transport and Logistics
	Organization of excursions for students of CTU FTS

Membership in professional societies

Since 2011	Candidate member of IAROR (International Association of Railway Operations Research)
2010 – 2013	member of Centre for Efficient Transport, Association
2007 – 2011	member of Deutsche Verkehrswissenschaftliche Gesellschaft
Since 2006	founding member and till summer 2012 president of Rail Transport Student Association at CTU FTS (Drážní společnost)

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