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Martin Smoliner

The Integrated Timetable in Liberalised Railway Networks

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The Integrated Timetable in Liberalised Railway Networks

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Vorwort zur Schriftenreihe
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Das Institut für Eisenbahnwesen und Verkehrswirtschaft der Technischen Universität Graz beschäftigt sich als Teil der Fakultät für Bauingenieurwissenschaften mit der Eisenbahninfrastruktur, und zwar den bautechnischen Fragen des Errichtens des Fahrwegs, des Betrieb der Strecken und damit eng verknüpft seiner Wartung und Instandsetzung. Damit sind sämtliche für eine Betrachtung des gesamten Lebenszyklus der Infrastruktur erforderlichen Bausteine abgedeckt.
So gelingt es, die Infrastruktur nachhaltiger und kostengünstiger auszugestalten. Der Nutzen der Infrastruktur wird jedoch erst durch den auf ihr abgewickelten Betrieb realisiert. Das führt zur Beschäftigung mit Betriebskonzepten, wobei sich das Institut in diesem Bereich auf Fragen des Integrierten Taktfahrplans konzentriert. Diese basieren auf Arbeiten zur mathematischen Formulierung des Taktfahrplans. Darauf aufbauend wurden die Möglichkeiten der vertikalen Integration des Taktfahrplans untersucht. Aktuell steht das Thema der Umsetzung eines Integrierten Taktfahrplansystems im liberalisierten Markt des Eisenbahnbetriebs im Fokus.
Mit dem Ansatz, neben der Forschung im Infrastrukturbereich auch im Bereich Betrieb und Fahrplan Entwicklungsvorschläge zu erarbeiten, versucht das Institut für Eisenbahnwesen und Verkehrswirtschaft seinem Anspruch, das System Eisenbahn in Forschung und Lehre zu vertreten, gerecht zu werden.

Das Einbeziehen wirtschaftlicher Bewertungen der Lebenszyklen erlaubt den Schwerpunkt „Nachhaltigkeit" umfassend in technischer, betrieblicher und wirtschaftlicher Sicht abzudecken. Die Forschungsfragen betreffen dabei das Gleislageverhalten, mit der Zielsetzung dieses prognostizierbar zu machen und damit die Voraussetzung für präventive Instandhaltung zu schaffen. Die Forschung des Instituts in betrieblicher Hinsicht umfasst Fahrplangestaltung und eine auf Nachfrageprognosen aufbauende Netzentwicklung sowie Auswirkungen unterschiedlicher Verfügbarkeiten. Alle diese Themen werden im Forschungsbereich Life Cycle Management einer umfassenden wirtschaftlichen Bewertung zugeführt.
Mit diesem Ansatz versucht das Institut für Eisenbahnwesen und Verkehrswirtschaft seinem Anspruch das System Eisenbahn in Forschung und Lehre zu vertreten gerecht zu werden.

The Integrated Timetable in Liberalised Railway Networks

Die schrittweise Umsetzung der Ausbaumaßnahmen des österreichischen Eisenbahnnetzes, die sich aus dem Zielfahrplan ergeben, ist eine Erfolgsgeschichte. Dieser Zielfahrplan, ein Integrierter Taktfahrplan (ITF), bestimmt die Ausbauerfordernisse wesentlich mit, Abschätzungen dazu gehen von zumindest 30% Infrastrukturausbaukosten des Netzes aus. Die Grundidee eines ITF ist die Gesamtreisezeit durch eine Verkürzung der Umsteigzeiten zu reduzieren, da in Netzen mit vielen nicht weit entfernten Knoten mittlerer Größe Direktzüge zwischen allen Knoten nicht angeboten werden können.

Der ITF ist ein hoch vernetztes Fahrplanmodell, das Gesetzmäßigkeiten unterliegt, um das Grundprinzip - die Züge treffen sich in den Taktknoten – zu erfüllen. Damit gibt es eine begrenzte Anzahl von Takttrassen, die zudem in ihrer zeitlichen Lage an den Taktknoten definiert sind. Ein zeitliches Abweichen der Zugtrassen von diesen „Taktslots" reduziert den Nutzen eines ITF deutlich, da damit die Umsteigezeiten verlängert statt minimiert würden. Es kann damit der Fall auftreten, dass einzelne nachgefragte Trassen den ITF beschädigen. Dies kann aktuell im Sinne der Marktöffnung kaum verhindert werden.

Hier setzt die Forschung von Dipl.-Ing. Martin Smoliner an. Er beschreibt ein anderes, ebenfalls diskriminierungsfreies Modell der Trassenvergabe, das diesen Fall ausschließt. Demnach erfolgt die Trassenvergabe in zwei Schritten, zuerst werden Taktzugstrecken am Markt angeboten und erst danach alle jene Trassen, die diesen Takttrassen nicht negativ beeinflussen. Diese einfache Grundidee erfordert vertiefte betriebliche Analysen, die unter anderem die Fragen: Was ist eine Takttrasse? Welche Form muss eine für den Taktfahrplan reservierte Trasse aufweisen, um eine diskriminierungsfreie Ausschreibung zu ermöglichen? Welche Trassenbündel müssen ausgeschrieben werden, um ein kundenfreundliches Angebot zu erstellen? umfassen. Nach detaillierten betrieblichen bzw. fahrplantechnischen Analysen wird ein Vergabemodell vorgestellt, das den scheinbaren Widerspruch zwischen ITF und liberalisiertem Netzzugang auflöst.

Darüber hinaus wird der Frage der rechtlichen Rahmenbedingungen nachgegangen, um etwaige erforderliche Anpassungen des rechtlichen Rahmens für Trassenvergaben, die zur Umsetzung des vorgeschlagenen Vergabemodells erforderlich sind, zu identifizieren.

Peter Veit

Abstract

The liberalisation of the European railway market fosters competition which has led to many improvements but also some challenges. The improvements include a growth in passenger numbers, reduced ticket prices as well as increased quality levels. Challenges arise in particular in the context of self-sustaining Open Access services and the Integrated Periodic Timetable (ITF[1]). These issues are compatibility of self-sustaining Open Access services with the ITF, the allocation of train path requests of several railway undertakings and effective utilisation of a cost-intensive ITF-optimised infrastructure. Even current legislation considers the ITF, self-sustaining Open Access services prevent the ITF from being implemented in an optimal way and pose a major challenge to infrastructure managers and public transport authorities in ITF-oriented countries such as Austria or the Czech Republic. Furthermore, cost-intensive construction of railway infrastructure requires long-term planning, which is not possible with short-term self-sustaining services.

This thesis presents a holistic approach to combining the ITF and competition in the long-distance railway market. System train paths (STP) competitively tendered as public service obligations (PSO) form the backbone of clocked railway services. If priority is given to STP in the train path allocation process, the ITF can be fixed. Self-sustaining Open Access services can be operated in so far as they do not come into conflict with system train paths. With the competitive allocation of STP, a fair and non-discriminatory process can be ensured. This concept (i) allows for the application of the ITF, (ii) fosters network-wide competition for tendered PSO services and allows for self-sustaining Open Access services and (iii) customers benefit from well-connected and integrated services. System train paths are thus a planning tool that make possible the joint implementation of ITF and competition.

The feasibility of the system train path concept is presented in detail. First the legal boundary conditions and an approach that guarantees prioritised implementation in the train path allocation are discussed. Then the parameters of system train paths are analysed and the feasibility is demonstrated on sections of the Austrian Southern and Western Line. A procedure for creating bundles is presented and applied on a test model. Finally, tendering procedures are evaluated and a suggestion for a stepwise tendering in a long-distance railway network is made.

The proposed procedure shows how customer benefits, competition and an effective use of an ITF-aligned infrastructure can be combined. It is expected that this topic will become more and more relevant in the future as continuous improvements to infrastructure will

[1] ITF is short for German „Integrierter Taktfahrplan“ meaning Integrated Periodic Timetable

attract further Open Access services, while an attractive network-wide public transport offer is gaining increasing importance. In this context, not only will the intensity of competition be increased but also the need for a clearly defined, legally feasible procedure.

Kurzfassung

Die Liberalisierung des europäischen Eisenbahnmarktes stärkt den Wettbewerb, was zu vielen Verbesserungen, aber auch Herausforderungen geführt hat. Zu den Verbesserungen gehören steigende Fahrgastzahlen, günstigere Ticketpreise sowie ein verbessertes Qualitätsniveau. Diese Herausforderungen ergeben sich insbesondere im Zusammenhang mit eigenwirtschaftlichen Open-Access-Angeboten und dem Integrierten Taktfahrplan (ITF). Relevante Themen sind die Vereinbarkeit von eigenwirtschaftlichen Verkehren mit dem ITF, die Vereinbarkeit von individuellen Trassenansuchen unterschiedlicher Eisenbahnverkehrsunternehmen und die effektive Nutzung der kostenintensiven ITF-optimierten Infrastruktur. Auch wenn die aktuelle Gesetzgebung den ITF berücksichtigt, verhindern eigenwirtschaftliche Open-Access Verkehre eine optimale Umsetzung des ITF und stellen Infrastrukturbetreiber und Aufgabenträger in ITF-affinen Ländern wie Österreich oder Tschechien vor große Herausforderungen. Zudem erfordert der kostenintensive Bau von Eisenbahninfrastruktur eine langfristige Planung, die mit kurzfristigen, eigenwirtschaftlichen Leistungen nicht möglich ist.

Die vorliegende Dissertation beschreibt einen ganzheitlichen Ansatz zur Kombination von ITF und Wettbewerb im Schienenpersonenfernverkehr. Systemtrassen (STP[2]), die als gemeinwirtschaftliche Leistungen (PSO) im Wettbewerb ausgeschrieben werden, bilden das Rückgrat eines vertakteten Angebots. Um den ITF fixieren zu können ist den STP in der Trassenvergabe Vorrang einzuräumen. Eigenwirtschaftliche Open Access Verkehre können in Trassenlagen verkehren, die nicht in Konflikt mit Systemtrassen stehen. Mit der wettbewerblichen Vergabe von STP kann ein fairer und diskriminierungsfreier Prozess sichergestellt werden. Dieses Konzept ermöglicht (i) die optimale Anwendung des ITF, (ii) fördert den netzweiten Wettbewerb um ausgeschriebene PSO-Leistungen und ermöglicht eigenwirtschaftliche Open Access Verkehre, zudem (iii) profitieren Kunden von einem gut verknüpften und integrierten Angebot. Systemtrassen sind somit ein Planungsinstrument, das die gemeinsame Umsetzung von ITF und Wettbewerb ermöglicht.

Die Machbarkeit des Konzepts wird detailliert beschrieben. Zunächst wird die rechtliche Umsetzbarkeit einer priorisierten Behandlung von STP in der Trassenvergabe diskutiert. Anschließend werden geeignete Parameter für Systemtrassen analysiert und die Machbarkeit von STP auf Abschnitten der österreichischen Südbahn und Westbahn demonstriert. Weiters wird ein Verfahren zur Bündelungsbildung vorgestellt und in einem Testmodell angewendet. Abschließend werden verschiedene Vergabeverfahren untersucht und ein Vorschlag für eine stufenweise Ausschreibung von Fernverkehrsnetzen präsentiert.

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[2] Auf Englisch: System train paths (STP)

Das vorgeschlagene Verfahren zeigt wie Kundennutzen, Wettbewerb und die effektive Nutzung einer ITF-optimierten Infrastruktur kombiniert werden können. Es ist zu erwarten, dass dieses Thema in Zukunft weiter an Bedeutung gewinnen wird. Eine kontinuierlich verbesserte Infrastruktur wird weitere Open Access Verkehre anziehen, zudem wird ein attraktives netzweites ÖPNV-Angebot immer wichtiger. In diesem Zusammenhang wird nicht nur die Intensität des Wettbewerbs zunehmen, sondern auch der Bedarf an einem klar definierten, rechtlich umsetzbaren Verfahren.

CONTENT

LIST OF ACRONYMS

CA	Competent Authority
EMU	Electrical Multiple Unit
ERA	European Railway Agency
FBS	Fahrplanbearbeitungssystem[3]
IC	Intercity
IR	Interregio
IM	Infrastructure Manager
ITF	Integrated Periodic Timetable[4]
OA	Open Access
OAO	Open Access Operation
OD	Origin-Destination
PaP	Pre-arranged Train Paths
PTA	Public Transport Authority
PPP	Public-Private-Partnership
PSO	Public Service Obligation
RU	Railway Undertaking
SOA	Self-sustaining Open Access Operation
SNNB	Network Statement of ÖBB-Infrastruktur AG[5]
STP	System Train Path
TAC	Track Access Charge

[3] in English: Timetable Design System
[4] in German: Integrierter Taktfahrplan
[5] in German: Schienennetz-Nutzungsbedingungen

1

Introduction

1.1 Motivation

The appearance of railways in Europe has changed dramatically over recent decades. While most of the railway undertakings (RUs) have been structured as vertically integrated monopolistic companies for almost a century, the liberalisation of the European railway sector has significantly changed organisational structures, infrastructure development and timetable design. In vertically integrated RUs the coordination of infrastructure development and timetable design was closely linked and within the company's (commercial) interest. With the restructuring and stepwise opening of the European railway market this connection was lost. Competition in the railway market, especially in passenger services, has led to considerable effects on timetabling and infrastructure development.

As railway infrastructure is a long-living asset and requires large-scale investments, long-term planning is essential. Once railway infrastructure is built it is difficult to adapt, thus making an effective utilisation crucial. The "Integrated Periodic Timetable" (ITF)[6] is a systematic concept for the joint development of infrastructure and timetables. On the one hand the ITF is suited perfectly for the needs of medium-sized countries[7] that lack the potential for high-speed trains and which have an adequate spatial structure and popula-

[6] ITF is short for German „Integrierter Taktfahrplan" meaning Integrated Periodic Timetable.
[7] The term "medium-sized" country refers to countries with railway networks of a size big enough to consist of regional and long-distance services as well as a network size of at least 2,000 km line length.

tion density with a dense railway network. On the other hand, it requires a soundly designed network centred on a long-term infrastructure development strategy. The ITF is based on a strict schedule that consists of clearly defined hubs, which are connected by railway lines with systematic edge riding times. Despite the fact that the ITF may require a cost-intensive upgrade of the railway network, it allows for a long-term joint development of timetable and infrastructure.

The liberalisation of railway markets affects timetabling and long-term infrastructure development. It concerns countries with high traffic volumes and systematic timetables such as the ITF in particular. Increased competition leads to conflicting timetables and challenges in the train slot allocation process. Furthermore, infrastructure requirements of the ITF and short-term oriented self-sustaining Open Access services (SOA) do not necessarily correspond. While SOA competition leads to more frequent connections on the long-distance level, regional train services can be negatively affected. Hence, customers cannot benefit from the advantages of an ITF and cost-intensive infrastructure investments are to be questioned. Although legislation in many countries supports the ITF, slot allocation processes may potentially result in deterioration of the overall network performance due to vague implementation rules. This is the reason why in such cases the benefits of the ITF are not being fully exploited. Nevertheless, these aspects are of special interest to policy-makers, as infrastructure development costs billions of taxpayers' money.

Since both, timetable and infrastructure, must be developed jointly in order to justify the costly and long-lasting infrastructure measures, it is not financially sustainable to design infrastructure upon demand for short-term self-sustaining services only. As suggested in Smoliner et al. (2018c) and Smoliner (2019) the approach of so-called system train paths (STPs) can ensure the functionality of the ITF. STPs are aligned with the clear ITF rules and assure the full utilisation of the cost intensive infrastructure investments. With regards to the current legislation, this is not guaranteed with uncoordinated train path requests in on-track competition. In a liberalised railway market, infrastructure managers (IM) are challenged by competing requests aiming for the most attractive slots. As new players enter the market, a non-discriminatory slot allocation for passenger trains in the framework of an ITF is becoming increasingly challenging. Therefore, a procedure is needed to guarantee optimal infrastructure utilisation with regards to an ITF in a liberalised railway market. By applying a systematic schedule of pre-arranged STPs, the advantages of on-track competition and the ITF could be combined.

1.2 Scope

Intention

This thesis intends to present a procedure for implementing an ITF with long-term infrastructure development in a fully liberalised railway market. In consideration of this area of conflict, the focus is on long-distance passenger rail services. While some issues will be covered in detail, others are only slightly touched.

This topic is driven by the liberalisation of the European railway system and its effects on timetables and infrastructure development. Hence this thesis focuses on the impacts of competition *for* the market as well as competition *in* the market. Processes for train path allocation are investigated, while vertical segregation of railway bodies or track access charges are only considered implicitly. Competitive tendering of rail services is one of the main instruments for the introduction of competition. The goal is to create a procedure for designing system train path bundles that can consequently be tendered and thereby enabling competition *for* the market.

Constraints

The focus of this thesis is on network-wide timetabling and infrastructure development aiming for a maximised connectivity. Long-distance passenger services play a crucial role here as the backbone of the railway network. Fast point-to-point services, regional services as well as freight services are examined in terms of their feasibility and capacity, and how these transport modes could be integrated into a holistic approach. However, they will not be covered in detail.

The basis for liberalisation is determined in EU legislation. Any procedure to be developed has to follow the current legislation on a European and national level, as well as the corresponding network statements of IMs. If changes are necessary, legislative adaptations will be suggested. However, the focus of this investigation is on the aspects of railway operation and research on legal issues are done to a limited extent. The considerations of this thesis were developed on the basis of European legislation with references to selected European countries. However, the focus, in particular of the legal considerations, is based on Austrian law. Therefore, if not stated otherwise, it is referred to Austrian legislation and the network statement of ÖBB-Infrastruktur AG, the IM of Austria's main railway network. As legislation is a matter of national as well as supranational jurisdiction, the following thesis requires adaptation if it is to be applied in other countries.

Non-intention

The ITF is the proven basis for highly successful network-oriented railway systems. In order to make an ITF work smoothly the application of basic rules is necessary. This thesis focuses on a strategic level; therefore no optimisation of the ITF has been carried out. Furthermore, the research was conducted on a macroscopic timetable level not covering microscopic operation, disposition or signalling.

1.3 Objectives

The following objectives are covered within this thesis:

- **Evaluation of Status Quo**: Provide a holistic overview of competition in long-distance railway services in Europe with a focus on the status of competition *in* and *for* the market, legislation regarding train path allocation and timetabling and long-term infrastructure development.
- **Target Functions:** Define target functions for a sustainable coordination of the ITF and infrastructure development within the framework of EU legislation. The target functions should aim at enabling the highest network-wide benefit of an ITF paired with an optimal use of the cost-intensive long-term infrastructure investments.
- **Combination of competition and ITF**: Develop a timetable approach to combining systematic train path for ITF and competition.
- **Legal Applicability**: Provide proof of the applicability of the presented approach with regards to European and Austrian legislation as well as the network statement concerning train path allocation and tendering of train path bundles. If necessary, adaptations of Austrian and European legislation will be outlined.
- **System Train Path bundles**: Design a procedure for creating lines and bundles of system train paths that could be acquired by RUs. Timetable, infrastructure and vehicle parameters will be considered as well as aspects of transport planning (demand) and railway operation.
- **Tendering of System Train Path Bundles**: Develop a method and procedure for tendering long-distance ITF services in a railway network.
- **Application on real infrastructure:** Verify the approach on infrastructure by applying realistic boundary conditions of medium-sized countries.

1.4 Structure and Methodology

This doctoral thesis is based on a wide range of sources such as an extensive literature review supplemented by expert interviews, research of legal documents and application in a timetable design software as well as simulations in a test model. The different methods are used as follows:

Chapter 2 offers a detailed overview on the evolution of liberalisation in the European railway market based on a review of the most recent scientific publications. The focus is on the development and status quo of liberalisation in selected European countries. Furthermore, the basics of the ITF are described. Its significance for long-term infrastructure development is underlined based on a comparative literature research and expert interviews covering different European countries. In addition, a rough estimate of the proportion of ITF-related infrastructure investments in the Austrian railway network is evaluated. Experiences and procedures from different countries are inspected on how to optimise the coordination of timetable and long-term infrastructure development given both, an ITF and commercial Open Access train services. Finally, the research gap is explained, and the approach of system train path bundles described.

Chapter 3 discusses how system train paths can be imbedded in European and Austrian legislation as well as in network statements by analysing the respective legal documents.

Chapter 4 defines and describes the design and scope of system train paths. The relevant parameters are discussed based on literature review. In addition, the concept of system train paths is applied to different stretches of the Western Line and Southern Line in Austria with the research and teaching version of the timetable software "FBS".

Chapter 5 discusses literature on bundle design, followed by an investigation of the relevant parameters and their evaluation through expert interviews. The findings are merged into a process for line and bundle planning which is applied to a model network.

Chapter 6 discusses different options for offering bundles of system train paths to railway undertaking. Furthermore, conditions for tendering with regards to processing, responsibilities and accompanying measures are described based on the literature review and expert interviews.

1.5 Fundamentals

The most commonly used tools and nomenclature are explained in the following.

Hub and Edge Model

An integrated periodic timetable is based on a network of hubs and edges as shown in Figure 1.1 (Uttenthaler, 2010). Hubs schematically depict railway stations in large cities or railway junctions or geographically relevant positions. Edges depict railway lines between these hubs.

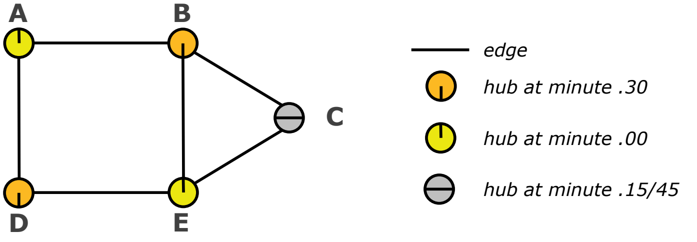


Figure 1.1: Hub and edge model

The hub-edge model is not to be confused with the train-path-diagram.

Path-Time Diagram

Train trajectories and system train paths are best illustrated in a path-time diagram or graphic timetable (Figure 1.2).

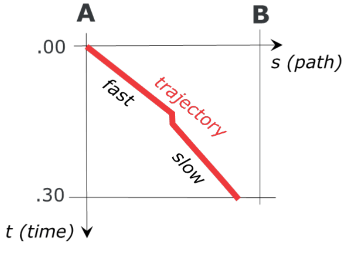


Figure 1.2: Train trajectory in a path-time-diagram

In this work distances are depicted on the horizontal axis, while time is depicted on the vertical axis. Consequently, train runs are shown as trajectories, which are simplifications of blocking times, including time reserves (Goverde et al., 2013).

Hub Clock

The hub clock shows arrival and departures at a hub (Walter, 2016). The graphical representation shows the sequence and distribution of arrivals and departures in a hub.

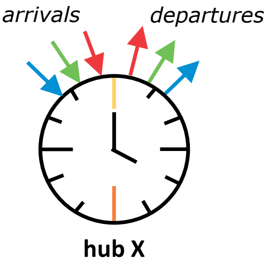


Figure 1.3: Hub clock showing departures and arrivals

Planning Process

In railway operation, several planning stages need to be considered from the fundamental planning of a network and timetable concept down to the final train run (Desaulniers and Hickman, 2007). Walter (2016) and Canca et al. (2019) describe them as strategic, tactical, operational and real-time planning which each cover various planning tasks (Figure 1.4). Strategic planning covers the planning tasks of network, infrastructure and line planning. Tactical planning includes line and timetable planning. Operational planning covers the fields of vehicle and duty scheduling (Michaelis and Schöbel, 2009) and (Liebchen, 2008).

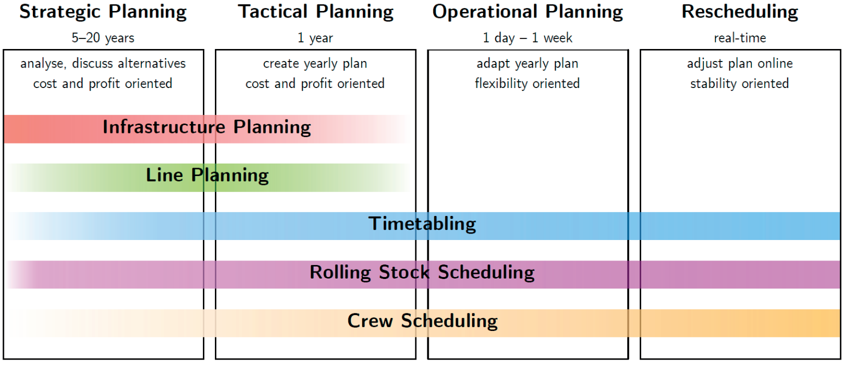


Figure 1.4: Design steps in railway planning according to Walter (2016)

Different process types have been developed on how to deal with the different planning stages and if they should be planned sequentially, iteratively and or in other forms. For more details on the sequence of such a process, see Caimi (2009). However, all stages are interdependent and different tasks have to be dealt with iteratively, as Walter (2016) shows in his mixed sequential-iterative design model.

Within the different planning stages, various levels of planning accuracy can be distinguished. In the present thesis, the focus is on a macroscopic level, which is intended to show the interrelationships at the network level and to prove the feasibility (Ropelius and Schröder, 2017). A microscopic examination at the level of block sections and signals considering a blocking time stairway and detailed infrastructure elements would go beyond the scope of this paper and would require a significantly higher amount of data. The essential statements can already be derived from the macroscopic level. A detailed comparison of advantages and disadvantages of micro- and macroscopic planning stages can be found in (Ropelius and Schröder, 2017).

Naming and Writing

Hubs and stations are written in their local language in order for them to correspond with timetables and maps.

Arrival and departures at hubs are written as ".xx"; e.g. the departure time of a train with an hourly interval departing at 12.02, 13.02 and so on will be written as ".02.30".

Units

The following general and railway-specific units and their abbreviations are used:

min	minute
km	kilometre
train-km	train kilometre (distance covered by any train run)
pass-train-km	passenger train kilometre (distance covered by one passenger train run)
pass-km	passenger kilometre (amount of kilometres travelled by passengers in trains)

1.6 Definitions

Definitions generally refer to Directive 2012/34/EU. However, the most important and frequently used ones in this thesis shall be presented here.

Railway Undertaking (RU)

The term railway undertaking is used in Directive 2012/34/EU where it is defined as "*any public or private undertaking licensed according to this Directive, the principal business of which is to provide services for the transport of goods and/or passengers by rail with a* *requirement that the undertaking ensures traction; this also includes undertakings which provide traction only*".

Infrastructure Manager (IM)
The tasks of an IM as defined in Directive 2012/34/EU are "*operation, maintenance and renewal of railway infrastructure on a network*" and the development of the railway infrastructure. Operation of infrastructure in this context includes path allocation, traffic management and infrastructure charging.

Integrated Periodic Timetable (ITF)
An ITF is a periodic timetable with systematically recurring train services that allow for optimised transfers through a precisely defined scheme. For an explanation of the exact mode of operation, advantages and disadvantages, see chapter 2.4.

SNNB (ÖBB-Infrastruktur AG)
An IM is obliged to publish a network statement which covers access conditions, capacity allocation procedure, services and charges. As the Austrian long-distance network is exclusively owned by ÖBB-Infrastruktur AG, the following explanations refer to their network statement called SNNB[8]. If not stated otherwise the SNNB in its 2021 version is being referred to.

Train Path
Train path means "*the infrastructure capacity needed to run a train between two places over a given period*" according to Directive 2012/34/EU. The term infrastructure capacity is frequently used as well in this matter; however, it has a slightly different meaning. It is the "*potential to schedule train paths requested for an element of infrastructure for a certain period*" (2012/34/EU). It is not to be confused with the term infrastructure capacity used in UIC 406 (UIC, 2004).

System Train Path (STP)
There is no generally accepted definition of a system train path. However, it is closely connected to the train path defined above and the systematic ITF-timetable. In the following, system train paths describe in a particular, predefined set of train paths in rail services between two hubs. The arrival and departure times at the hubs allow for an optimal transfer among different transport services (and modes). For a more detailed description on the function and characteristics of a system train path, see chapter 4.

[8] SNNB in German means „Schienennetz-Nutzungsbedinungen"

Bundle

In the following, a bundle is a timewise and/or geographical combination of two or more lines of system train paths. Compare with "*parts of the same network or package of routes*" in 1370/2007/EC .

Long-Distance Services

The principles of system train paths and system train path bundles in this thesis are, if not stated otherwise, applied to long-distance services. Long-distance services here mean fast trains that serve hubs in the ITF network, connect at least two larger cities or regions with each other and therefore form the backbone of an ITF network. In this thesis these trains are also called Intercity or Interregio services, while fast trains that do not serve every hub and offer short riding times are called sprinter trains. It is considered that a long-distance service runs more than 100 km and takes at least one hour. Further characteristics of train types are clarified in chapter 5.4.2.

Competent Authority

A competent authority describes "*any public authority or group of public authorities of a Member State or Member States which has the power to intervene in public passenger transport…*" (1370/2007/EC). The sphere of influence of a competent authority extends to a specific geographical area such as a country or region.

Public Transport Authority

These are government-related organisations that deal with infrastructure and transport planning, as well as Public Service Obligations. The PTA is an independent body closely linked to the competent authority supporting it in the aforementioned areas.

Public Service Obligation (PSO)

A public service obligation is a non-commercial service which is ordered by a competent authority in the general interest to ensure public passenger transport. This service would not be served in the same extent or under the same conditions on a commercial basis without reward (1370/2007/EC). PSOs cover compensation payments or grant exclusive rights (Kramer and Hinrichsen, 2018).

Open Access (OA)

Open Access describes a railway market that is open to be accessed by any licensed RU as regulated in Directive 2012/34/EU. For commercial services in liberalised railway markets see self-sustaining services.

Self-Sustaining Services

Self-sustaining services are commercial services that are operated without any rewards by a competent authority. The term Open Access services is also often mentioned in this context, albeit misleadingly. Strictly speaking, Open Access means that a service takes place in a deregulated railway network with free network access. This alone does not describe the economic motivation of the service. However, the term self-sustaining can be just as misleading. In Germany and Switzerland, long-distance services are self-sustaining by definition, though this does not necessarily describe the economic motivation. While in Germany the long-distance market is open there are high track access charges. In Switzerland, the market is closed to any commercial operators other than the SBB and their partners due to a concession for long-distance services. While some long-distance services are profitable, some lines are not. However, the SBB argues that all long-distance services as a package are self-sustaining (SBB CFF FFS, 2018). Therefore, "Self-Sustaining Open Access" (SOA) services are best described by offers such as Westbahn or Regiojet in Austria or Flixtrain in Germany. For the sake of simplicity, the term "self-sustaining service" is used as well.

2
Framework

In order to address the issues related to railway liberalisation and the ITF, it is worthwhile to look at the basic framework of these subjects. This includes the liberalisation of European railways and the resulting competition in passenger transport, timetable concepts such as the ITF, the tension between competition and the ITF as well as the corresponding solution approach.

2.1 Liberalisation in the European Railway Market

The railway sector, being an extremely cost-intensive industry, has seen a long tradition of state investments and state influence alongside private investments. After different phases of private and public dominance in the railway sector, today the railway legislation at the European level is aiming for an open but regulated market. The regulation aims to raise the overall system efficiency through competition (Finger and Messulam, 2015b).

Natural Monopoly versus Contestable Markets

Network industries like railways, telecommunications, or energy supply, are referred to as natural monopolies. Natural monopolies are characterised as having high fixed costs, low variable (operating) costs, ruinous competition, need for reserve capacities, imbalance of traffic flows and one-sided state intervention (Kahl, 2005). Schivelbusch (2002) concludes trat a transport monopoly by a single railway company is required, uniting the operation of rolling stock and infrastructure under one management, since a complex system like a railway network does not tolerate market participants who are independent from each other. However, the theory of contestable markets challenges the idea of a natural monopoly. This theory argues that a monopoly can be split into sub-units which do not necessarily constitute a natural monopoly by themselves. Sub-units with relatively low stranded costs are attractive for private operators as financial risks and barriers to market entry are low (Kahl, 2005). Therefore, railway operation is an interesting sub-unit for private investment, while stranded costs in railway infrastructure usually are too high to be relevant for private investment (Segalla, 2002). The separation of railway infrastructure and operation was consequently implemented in the privatisation of the British railway sector in the 1990s (Segalla, 2002). The privatisation of the railway infrastructure turned out to be a failure and was followed by renationalisation. Railway operation, however, is still done by private railway undertakings (RUs) in a franchise-system as discussed in chapter 6.1.

Development of the European Railway Market

Railway liberalisation was originally pushed by the steady decline of the sector in the 1970s and 1980s and the idea of the single European market. With a lack of competitiveness and high consumer prices the loss of modal share to the intensively developed road sector was inevitable. With the obvious disadvantages of heavy car traffic and the high socio-political importance of the railway sector, the European railway regulation aims to open the market and force monopolistic incumbents to become competitors (Segalla, 2002). A series of directives and regulations deregulated and opened the market in order to split infrastructure from operations and establish competition *in* and *for* the market. On the other hand, the market was regulated by establishing uniform technical standards and railway regulators (Finger and Messulam, 2015a). The economic rationale, for regulation according to Baldwin et al. (2012) is to:

- make (natural) monopolies more efficient and lower consumer prices,
- guarantee continuity and availability of non-profitable services,
- prevent anti-competitive behaviour,
- plan for future generations,
- claim public interest in the allocation of scarce commodities,
- rationalise and coordinate the railway market.

Markets are regulated to make competition beneficial for society. Competition is beneficial if the price mechanism works in such a way that inefficient firms are excluded for example. Competition *in* and *for* the market give further incentives for RUs to reduce costs and raise efficiency (Baldwin et al., 2012). The danger of unregulated competition is putting pressure on companies to become more efficient without respect to public benefit (Jaag, 2017).

Targets of EU Legislation
Until the 1990s, rail passenger transport was almost exclusively run by state monopolies. The EU Commission chose liberalisation to establish a single European market by fostering competition and regulatory mechanisms (Catharin and Gürtlich, 2015). Liberalisation in the European railway market aims to revitalise the rail sector, make it more competitive and raise infrastructure usage and modal share of the railway sector by improving quality of services and raising cost-effectiveness (European Commission, 2013).

2.2 Competition in and for the Market

Competition in the railway passenger market can be divided into "competition *in* the market" and "competition *for* the market".[9] These two forms of competition can be defined as:

- Competition *in* the market: Competitors offer comparable services on the same route and compete against each other. Since the alternative term "Open Access Operation" (OAO) can be misleading regarding the economic motivation of the services (chapter 1.6), the term "Self-Sustaining Open Access Operation" (SOA) is used in this thesis.
- Competition *for* the market: Operators compete in a tender to receive subsidies or exclusive rights for services on one line, a bundle of lines or on a network. These services called "Public Service Obligations" (PSO) are competitively tendered or can, under certain circumstance, be directly awarded (chapter 6.1).

Competition *in* the market typically occurs on lines that can be operated on a self-sustaining basis, while competition *for* the market is typically chosen on non-profitable lines. There is no clear differentiation which types of transport services are profitable and which ones are not, however, mostly commuter and regional services are subsidised, while Interregional (IR), Intercity (IC), Airport Express Services and High-Speed services are rather operated on a commercial basis (Ait-Ali et al., 2017). This definition falls short as it depends on the railway market, geography, demography and demand whether a service is profitable or not. In most countries, only parts of IC and IR services are profitable.

With the fourth railway package the European Commission (2013) promotes a combination of both forms of competition to foster market opening and to increase efficiency. While competition *for* the market is controlled and organised by public transport authorities,

[9] Also known as "competition *for* the tracks" and "competiton *on* the tracks".

competition *in* the market and therefore self-sustaining services are a matter of "market forces". Hindrances for self-sustaining services are economics of density, economics of scale, potential stranded costs and low cost models of competitors (Bacares et al., 2019). In contrast, low track access charges (TACs), attractive train slots and open distribution channels push competition *in* the market (Feuerstein et al., 2018).

Railway markets in the European Union are quite diverse. In some markets both forms of competition are mixed together. In other markets one of the two or neither one of these forms exists, and some have competition *in* the market only on the level of international services (Figure 2.1). Direct awards are still frequently applied, and SOA services have not yet been introduced in all countries on a national level yet. The only fully liberalised railway network so far is Sweden, where all services run under competitively tendered PSO contracts or are operated as SOA services (Scordemaglia and Katsarova, 2016). Even in Great Britain, where railway liberalisation has had a long tradition, some franchises are directly awarded to "*manage and sustain a realistic and properly resourced programme of franchise competitions and a healthy bidding market*" (Department for Transport, 2013).

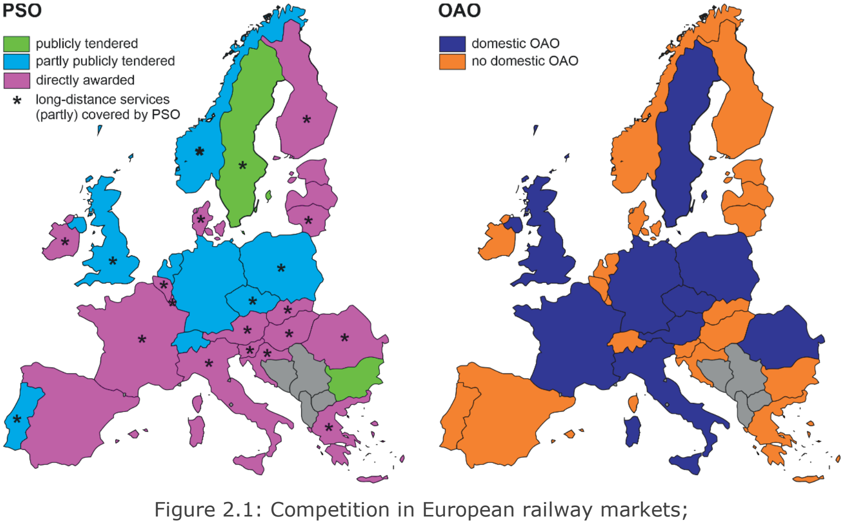


Figure 2.1: Competition in European railway markets;
left: PSO awards 2013-2017, own depiction based on IRG-Rail (2019a);
right: OAO Status 2020, own depiction based on IRG-Rail (2020)

2.2.1 Effects of Liberalisation in the European Railway Markets

The effects of railway liberalisation on a European level are covered by a wide range of literature (IBM Business Consulting Services, 2011), (Durrer et al., 1986), (Cartmell et al., 2016). The seven “Rail Market Monitoring” reports (European Commission, 2021) and the eight “Market Monitoring Report” reports (IRG-Rail, 2020) provide information about the evolution in the European railway markets. Furthermore, the Community of European Railway and Infrastructure Companies (Caramello-Álvarez, 2017) provided a holistic analysis on PSO services in Europe. Best practices for different types of railway markets based on role models are analysed by Nash (2015). Sweden is discussed for an efficiently low-density, mixed traffic system and Switzerland for a densely mixed traffic system. An up-to-date overview on how to liberalise passenger services analysing the markets in Germany, Great Britain and Sweden can be found in Nash et al. (2019).

Competition *in* and *for* the market is analysed for selected countries in the following and is summarised in Table 2.1. The status quo in these countries is discussed by giving a general overview on market shares, overall costs and effects of competition *in* the railway market. The markets chosen for the analyses are characterised either by

- an ITF or a periodic timetable (AT, CH, CZ, NL)
- a more or less intense competition of self-sustaining OA services (AT, CZ, DE, GB, IT, SE)

Perennes (2017) analysed the different types of competition with a focus on commercial SOA operation in seven of the aforementioned countries. Smoliner et al. (2018a), Smoliner et al. (2018b) and Smoliner et al. (2018c) give an overview regarding competition *in* and *for* the market, as well as infrastructure planning and funding for most of the above-mentioned markets. The Williams Rail Review (2019) gives a broad overview of the situation in several European countries by discussing network utilisation, passenger growth and quality factors. An in-depth investigation of the effects of liberalisation on the passenger railway market in Poland, the Czech Republic, Slovakia and Austria has been done by Taczanowski (2015).

Table 2.1: Overview of the market situation in long-distance services

Parameters								
Market entry of competitors	2011	-	2011	2000	2000	2012	1996	2009
Type of timetable	ITF	ITF	ITF	periodic timetable	partly periodic timetable	periodic timetable	ITF	partly periodic timetable
Long-distance services self-sustaining?	mostly covered by PSO	yes	mostly covered by PSO	yes	integrated into franchises	partly covered by PSO	yes	yes, except for IR-services
Financing of services if not self-sustaining	direct award	concession	direct award / competitive tender	-	franchise	direct award	concession	partly competitive tender
Type of competition	in the market	-	in/for the market	in the market	in/for the market	in the market	-	in/for the market
Long-distance services self-sustaining?	mostly covered by PSO	yes	mostly covered by PSO	yes	integrated into franchises	partly covered by PSO	yes	yes, except for IR-services
Status of Open Access	main axes	-	main axes	niche markets	niche markets	HS network	-	main axes
No. and name of OA operators with regular long-distance services	3 ÖBB, Westbahn, Regiojet	1 SBB (partly in cooperation with other RUs)	4 CD, Regiojet, Leo, Arriva	4 DB, Flixtrain, HBX, Thalys	3 Eurostar, Grand Central, Hull Train	4 Trenitalia, NTV, SNCF, Trenord	1 NS international in cooperation with DB, Eurostar, Thalys	4 SJ, MTR, Transdev, Skandinaviska Jernbanor
Sources	IRG-Rail (2020)	Railway Gazette (2019a)	Tomeš et al. (2014), Nash (2015), Dvořák (2018)	Finger et al. (2016), Wulff (2020), Warnecke and Götz (2012), Séguret (2009)	Williams Rail Review (2019), van de Velde (2015), CMA (2016)	Beria (2019), Finger (2017), IRG-Rail (2020)	Preston (2009), Railtech (2021)	Nilsson and Jonsson (2011), Virgren (2016)

Int… International | HS… High Speed

2.2.2 Status in Selected Countries

In **Austria,** the first privately owned, self-sustaining OA service was launched by Westbahn in 2011, followed by Regiojet in 2018 (IRG-Rail, 2020). Three long-distance lines are declared to be self-sustaining[10], while the rest of the network is operated by the incumbent within a PSO contract (Figure 2.2).

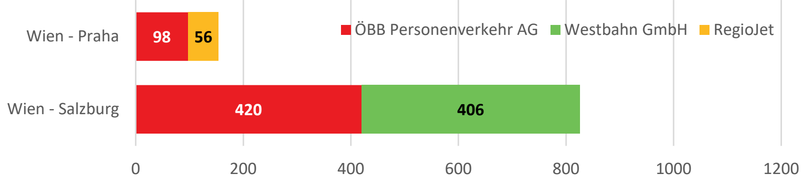


Figure 2.2: Number of trains running per week on routes with self-sustaining OA services in Austria, timetable 2019; based on IRG-Rail (2020)

In 2018, 33% of pass-km of long-distance services were commercial (European Commission, 2021). However, the offers of commercial operators can be quite volatile, even before the Covid-19 pandemic. Due to a renewal of its fleet, Westbahn sold half of its vehicles in 2019 (i.e. before the Covid-19 pandemic) resulting in a reduction of services by 50% in the timetable for 2020 (Railway Gazette, 2019b).

In **Switzerland**, long-distance services are self-sustaining by definition and are operated by SBB on a country-wide concession. Therefore, other national and international train operators have to cooperate with SBB. Two other Swiss RUs, BLS and SOB, operate national services under a sub-concession (Railway Gazette, 2019a). According to Arx et al. (2018) there are plans to offer unused long-distance train paths in off-peak hours for commercial night train services. Similar slots could be offered to international day trains or to allow newcomers to enter the market.

In the **Czech Republic**, between Praha and Ostrava (Figure 2.3), one of the busiest lines in terms of self-sustaining OA service in Europe can be found (Tomeš et al., 2014). Due to low track access charges, a high priority for long-distance trains in the slot allocation process and attractive travel times the percentage of commercial services reaches about 50% on this section (Nash, 2015). Commercial services represent 14% of the country-wide traffic volume (European Commission, 2021). In 2017, a procedure was started to award long-distance lines under PSO in a stepwise manner. These services are combined into

[10] These are the Western Line between Wien and Salzburg, its eastern extension between Wien and Hegyeshalom and the Brenner via Innsbruck.

bundles according to operational aspects and are tendered as direct awards after market consultations (Janoš and Kříž, 2019).

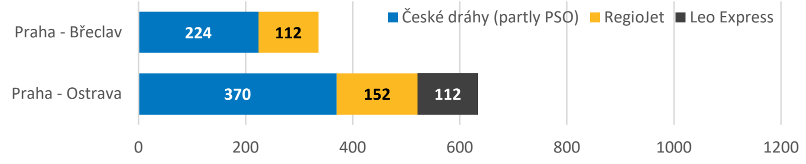


Figure 2.3: Number of trains running per week on routes with self-sustaining OA services in the Czech Republic, timetable 2019; based on IRG-Rail (2020)

In **Germany,** no PSO contracts are granted on the long-distance level. Due to high track access charges (TACs) and restrictive train path allocation procedures, the incumbent dominates the market with more than 95% market share (Wulff, 2020). There were several attempts to enter the market, mostly unsuccessful in the long-term (Casullo, 2016; Séguret, 2009). In 2021, DB, Thalys (in cooperation with DB), Flixtrain and HKX offer self-sustaining services (Figure 2.4).

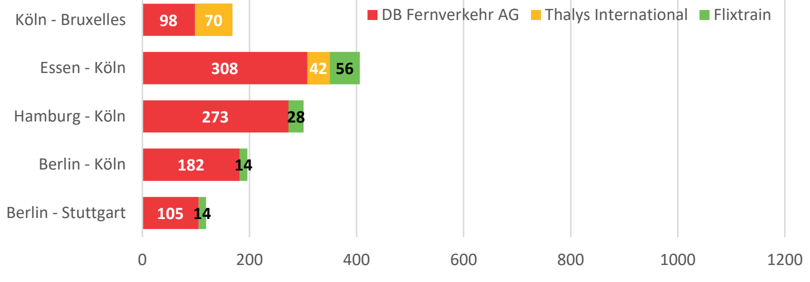


Figure 2.4: Number of trains running per week on routes with self-sustaining OA services in Germany, timetable 2019; based on IRG-Rail (2020)

Great Britain completely liberalised its railway market in the 1990s. British Rail was split up with the consequence that there is now no genuine incumbent in the market anymore. The whole network is served by (mostly) competitively awarded franchises (see chapter 6.1.1) covering urban, regional and long-distance services. The franchises are partly owned by foreign incumbents (Figure 2.8). Four self-sustaining OA services operate in niche markets due to the priority of franchises in the train path allocation. The system was criticised for both maximising revenues instead of quality and overoptimistic revenue calculation and is therefore under review at the moment (Campaign for Better Transport, 2019). The so-called "Williams Rail Review" is expected to bring an end to franchising by replacing it with a system of concessions in the long-term (Jackson, 2020).

Italy is the only European country so far to have seen an intensive competition *in* the market in high-speed services at a national level. The incumbent Trenitalia and its private competitor NTV offer frequent services on the high-speed lines and beyond. Other operators of long-distance services are Trenord (subsidiary of Trenitalia) cooperating with DB and ÖBB on international connections and SNCF Viaggiatori Italia offering services from France to Italy (Figure 2.5).

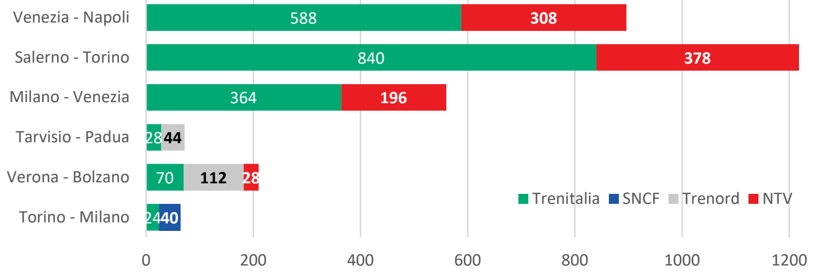


Figure 2.5: Number of trains running per week on routes with self-sustaining OA services in Italy, timetable 2019; based on IRG-Rail (2020)

In the **Netherlands,** long-distance IC services are operated by the incumbent NS under a concession. On international connections, IC, ICE, Thalys and Eurostar services are offered by NS international (a NS subsidiary) in cooperation with DB, SNCB and SNCF (NS International, 2021). A potential opening of the national market for OA services is currently being investigated in the form of a market consultation (Railtech, 2021).

The liberalisation in **Sweden** is also called the "accidental liberalisation" as it happened unintentionally in 1988 when reforming the railway sector, long before the respective EU-legislation was passed an (Alexandersson, 2010). The early opening of the market makes it one of the most liberalised railway networks in Europe with competitive tendering on the urban and regional level and self-sustaining OA services on most long-distance lines (Finger and Messulam, 2015a). In 2019, SJ AB, Skandinaviska Jernbanor (Blå Tåget), Transdev (Snalltåget) and MTR offered long-distance services (Figure 2.6). Blå Tåget services were cancelled in summer 2019 due to the poor profitability of its services but announced it was getting back on track after the Covid-19 pandemic (Blå Tåget, 2021).

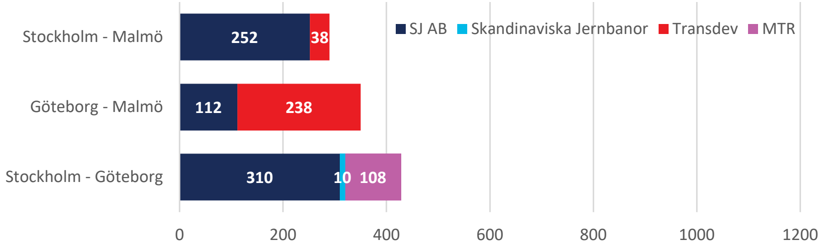


Figure 2.6: Number of trains running per week in Sweden on routes with self-sustaining OA services, timetable 2019; based on IRG-Rail (2020)

2.2.3 Market Share and Entry Barriers

Across the European Union, market shares of competitors in the PSO and OA segment in national passenger railway markets have increased on average from 19% to 25% of pass-km between 2011 and 2016 (European Commission, 2019). However, incumbents are still dominating the railway market. While the percentage of competition *in* the market remains relatively low in many European countries, new market entrants were able to gain significant market shares in Italy, Sweden, Slovakia, Austria, the Czech Republic and others (Figure 2.7 and Figure 2.8). The additional offers by new market entrants in some countries led to a reduction of services provided by the incumbent or under PSO (Kvizda and Solnička, 2019).

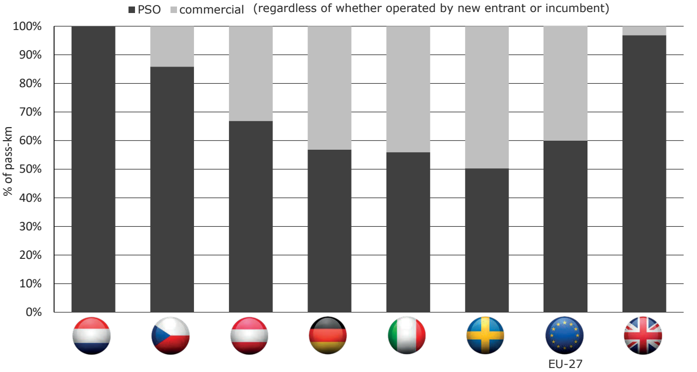


Figure 2.7: Share of passenger traffic offered respectively under PSO and commercial rail services per country in % of pass-km in 2018, based on IRG-Rail (2020)

Finger et al. (2016) summarise the findings of competition in Austria, the Czech Republic, Sweden, Italy and the UK, regarding ticket prices and market share. It is shown that competition (i) is often limited to a few lines and a few competitors, (ii) has a positive impact for passengers and (iii) the railway system as a whole can be negatively affected. Tomeš and Jandová (2018) provide a holistic approach about entry barriers, business models, market development and regulatory challenges in ITF regimes such as Austria and the Czech Republic. IRG-Rail (2020) identifies direct awards and the incumbent's knowledge as the most commonly observed entry barriers for PSO markets. High investment costs for rolling stock and lack of access to qualified personnel applies to non-PSO markets as well as PSO markets.

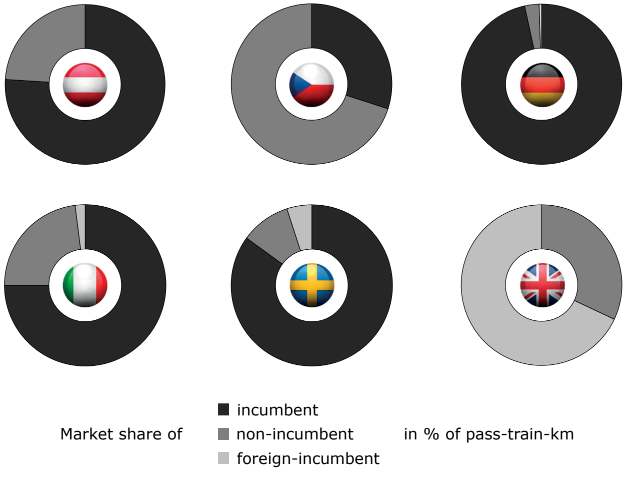


Figure 2.8: Market share in non-PSO services in several European markets in 2018, measured in pass-train-km, based on IRG-Rail (2020)

2.2.4 Ticket Prices, Overall Costs and Effects

In countries with OA competition, a significant ticket price reduction and an increasing number of services are observed. Bacares et al. (2019) analysed that train frequency on the Roma – Milano route increased by 80% since NTV entered the market. In Austria, the train frequency on the Wien – Salzburg line almost doubled between 2010 and 2019 (Tomeš and Jandová, 2018). Significant ticket price reductions were reported in Austria, the Czech Republic, Italy and Sweden, as shown in Figure 2.9.

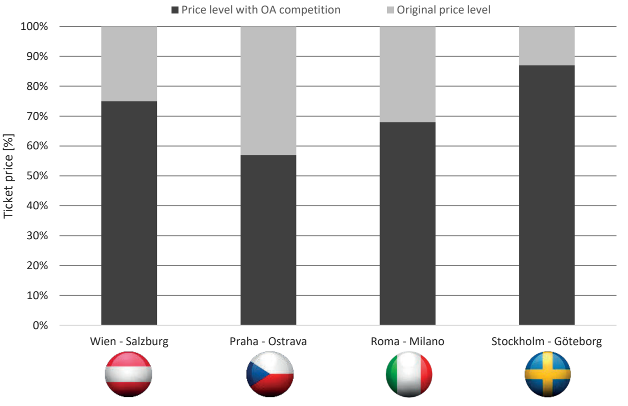


Figure 2.9: Development of ticket prices on routes with self-sustaining OA competition on the long-distance level, based on Bacares et al. (2019), Virgren (2016) and Tomeš and Jandová (2018)

Casullo (2016) analysed the impact of OA entries in Austria, the Czech Republic and Italy and showed that OA competition has not led to major efficiency improvements from an economic perspective. Therefore, taxpayers in countries with OA competition may end up with higher costs than in countries with monopoly passenger services. These additional costs result from a loss of economies of density, duplication of large initial investment costs and higher coordination costs. Tomeš and Jandová (2018) argue that fierce competition *in* the market involving high investments in rolling stock and quality enhancements may lead to higher costs for taxpayers. In the Czech Republic, compensation payments for long-distance services increased when new competitors entered the market, as students are granted state-imposed discounts also on OA services (Jandová and Paleta, 2019). As a considerable amount of passengers in OA services are students, compensation payments almost doubled between 2011 and 2017. While in 2011 the incumbent CD was able to benefit from the majority of state compensation payments, the distribution changed significantly in favour of Regiojet (operated by the company "student agency") and other commercial operators in 2017 (Figure 2.10).

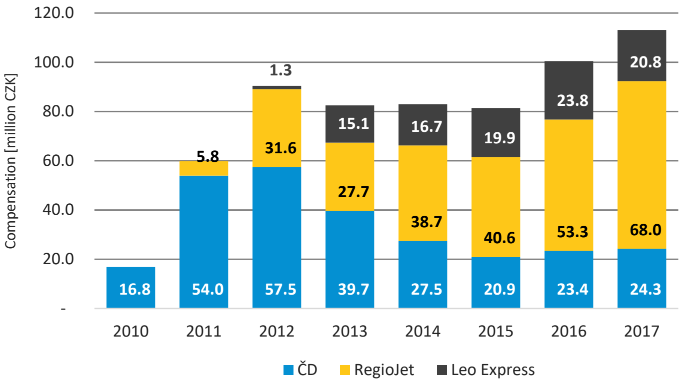


Figure 2.10: Compensation for state-imposed discounts in the Czech Republic (Jandová and Paleta, 2019)

From an economic point of view it is difficult to argue whether PSO or OA services are more advantageous. PSO services are most often subsidised but ensure a network-wide attractive offer. Theoretically, OA services are therefore more beneficial since they do not receive any subsidies. However, these services operate on profitable routes with track access charges covering only parts of the actual infrastructure costs. This means OA services are partly paid by the taxpayers (Finger, 2017). Figure 2.11 shows the ratio of ticket revenues in commercial and PSO services (above horizontal axis) to PSO compensation payments (below horizontal axis). The contribution margin from ticket revenue varies and has to be compensated by higher or lower additional payments from the public sector.

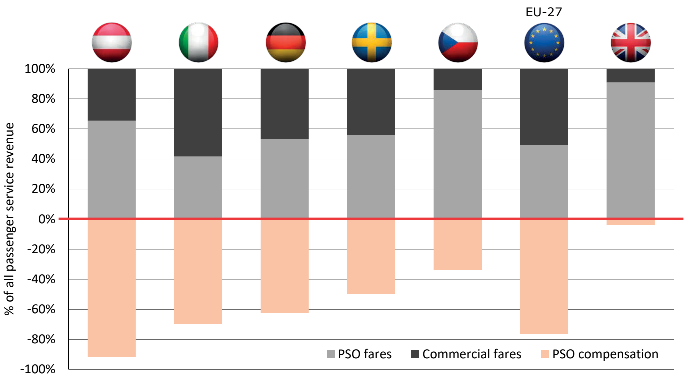


Figure 2.11: Sources of passenger railway undertakings' revenue per country in 2018 (European Commission, 2021)

2.3 The Optimal Timetable

A timetable is closely related to the characteristics of a railway network – both forming an interrelated system. Regardless of whether a timetable planning process is operational or infrastructure-driven, it starts with numerous assumptions that can only be replaced by concrete facts in an iterative process (Scheidt, 2016). This process can be significantly simplified and made more efficient by a timetable that requires clear and stable assumptions such as the ITF. The advantages of an ITF for medium-sized countries and the link to infrastructure development and competition in railway services are explained in this chapter.

2.3.1 Approaches to Judging an Optimal Timetable

The optimal timetable is closely linked to the objectives defined for a railway network and depends on geographic and demographic constraints. Different boundary conditions call for different optima or rail network configurations.

Extensive descriptions of relevant parameters and approaches on suitable timetables can be found in (Kroon et al., 2008), (Cacchiani and Toth, 2012) and (Stergidou A. et al., 2013). Svedberg (2018) gives a detailed explanation on how the societal cost-benefit ratio could be applied to timetabling and train path allocation. A model is presented for how to develop the optimal timetable in order to maximise the societal cost-benefit. Profit maximisation of RUs are covered as well as political considerations for welfare. Ait-Ali et al. (2017) give a comprehensive literature review about the value of increased capacity and the advantage of a duopoly as opposed to a monopoly. The optimal timetable in a liberalised railway market and the importance of system train paths is discussed by Smoliner et al. (2018c).

Timetables have a crucial impact on transport planning and infrastructure development. In a timetable, not only are departures, arrivals and riding times defined, it also defines capacity, reliability and economic effects in a network. All these parameters are interdependent and should aim to reach the so-called pareto efficiency (Opitz, 2009). Theoretically, full competition leads to a pareto-efficient allocation of these parameters. Eliasson (2019) analyses the optimal timetable with regards to the value of capacity from a transport economic point of view. He defines the optimal timetable as function of travel time and waiting time and derives how a capacity increase can lead closer to the optimum. Providing railway infrastructure to allow for certain timetables is extremely costly. Therefore, a stable long-term approach for designing timetables is required.

2.3.2 High-Speed Point-to-Point Railway Networks

When discussing the design or development of railway networks ever so often the construction of high-speed lines is suggested. This type of railway is attributed as modern, fast, demand-driving, pushing the economy, etc. (Givoni, 2006). If it is taken into account that borders pose a relevant transport resistance (as they still do even within most parts of the EU), these expectations might be fulfilled in large countries, but it is not a one-size-fits-all solution. Fröidh (2014) presents a model to define the optimal design speed for new high-speed lines. Campos and Rus (2009) evaluated 166 high-speed railway projects around the world analysing the costs in the planning and operation phase. Givoni (2006) concludes that high-speed railway services offer a much higher capacity and reduced travel time and therefore lead to mode substitution. However, the high investments outweigh the economic development and therefore cannot be justified.

High-speed services require a high demand between two or more metropolitan areas located at least 300 km from each other. This correlation and the responding potential can be derived by applying Lill's law of travelling as presented by Smoliner and Walter (2019), based on Mayrhofer (1991). They calculated the potential of high-speed lines for selected European countries. It is shown that especially France and Italy have a considerably high potential due to a favourable settlement structure with few big metropolitan centres in a distance of about 500 km. In Germany with many small or medium-sized metropolitan areas the potential is considerably smaller. Countries like France, Italy or Spain aligned their network primarily along the requirements of long-distance high-speed services rather than on regional network-oriented services. This underlines that high-speed networks can only be justified under specific conditions.

2.3.3 Network-Oriented Timetables

In medium-sized countries the potential for a high-speed network is usually rather low. Furthermore, the demand in many regions is not high enough to offer direct connections between all hubs. As a result, a high number of transfers is necessary and travel times are often rather unattractive due to poorly connected services. To improve this situation a network-oriented timetable like the ITF is recommendable. It is an efficient timetable due to short interchange times on a specially adapted infrastructure (Brezina and Knoflacher, 2014). The introduction of the ITF made Switzerland the country with the highest number of pass-km per person per year globally. In consideration of the strong demand increase after the implementation of an ITF, as shown in chapter 2.4.2, the country is a role model for a successful ITF. As further European countries successfully aligned their timetables to an integrated or periodic timetable including the Netherlands, Hungary, the Czech Republic or Austria, it can be assumed that the ITF is the optimal timetable for medium-sized railway networks (Smoliner et al., 2018c; Wardman et al., 2004).

2.4 The Integrated Periodic Timetable

The Integrated Periodic Timetable (ITF), also known as Integrated Clock-Faced Schedule (Wardman et al., 2004), Integrated Timed Transfer (Clever, 1997) or Integrated Fixed-Interval Timetable (Liebchen, 2006), has a wide and detailed reception in literature. In the absence of a satisfactory phrase in English the German term "Taktfahrplan", which (Johnson et al., 2006) literally call "rhythm-journeyplan", is used as well. As subsequently established in literature the German abbreviation "ITF" ("Integrierter Taktfahrplan") is used.

While the ITF was first introduced in the Netherlands in the 1930s and was later applied to ferry services in Denmark, Switzerland became the role model of a successful ITF application (Meiner, 2019). A small group of engineers at the SBB, the so-called "Spinnerclub" gave distinction to the term "Taktfahrplan" when suggesting a periodic timetable with only slightly higher costs but 21% more service kilometres in 1970. This plan was finally put into practice in 1982 (Meiner, 1991). Building on this the project "Bahn 2000" was introduced in 2004 by further extending intervals, reducing travel times and modernisation of rolling stock (Durrer et al., 1986). The principles of the ITF were described early by the Swiss railway engineers who also shaped the importance of the planning triangle between infrastructure, demand and vehicle (Meiner, 2019). ITF timetables have clear requirements for the infrastructure and need detailed planning processes of networks as shown by Lichtenegger (1990) or Wardman et al. (2004). Weis (2005) and Uttenthaler (2010) presented how infrastructure development in Austria and Central Europe can be aligned to a target timetable. Walter and Fellendorf (2015) expanded this approach to iteratively developing demand modelling, infrastructure, and timetable construction. SMA have developed an ITF timetable for Germany called "Deutschlandtakt" (BMVI, 2021).

In Switzerland and the Netherlands, Intercity-trains nowadays run every 10 to 15 minutes. This is not only an evidently improved service offer but also lowers the relevance of transfer connections as trains run frequently. However, systematic timetables such as the ITF will become more important in the future as well, even an adaptive timetable will gain relevance with dense intervals (Stähli, 2019).

2.4.1 Principles of the Integrated Periodic Timetable

The ITF is based on (i) hubs for interchanges all over the network, (ii) an adequate interval and (iii) a network of edges connecting the hubs within a defined edge riding time. A strict set of rules defines how edges are systematically linked to hubs. The application of these rules requires coordinated long-term timetabling and infrastructure development.

The main characteristic of an Integrated Periodic Timetable is a smooth connection between long-distance trains, regional trains and buses as all services meet in hubs at the same time (Figure 2.12). A sufficient number of tracks, switches and platforms is required in the hubs while edges (Figure 2.13) have to be adapted for appropriate edge riding times.

In an ITF edge riding times as well as arrival and departure times in hubs are systematically defined and coordinated. Regional trains need to arrive in the hubs before long-distance trains; long-distance trains leave first, regional trains follow. This pattern offers optimal network-wide inter- and intramodal connections for passengers and reduces transfer times and ultimately riding times.

Another feature of the ITF is regular services in continuous intervals ranging from two hours down to 15 minutes or less. In long-distance services, the interval is usually a full hour allowing for services to meet in hubs at minute .00 and .30 provided they are .00-symmetrical. To enable transfers among different services, trains need to arrive before the full or half hour and depart a few minutes later (Figure 2.12).

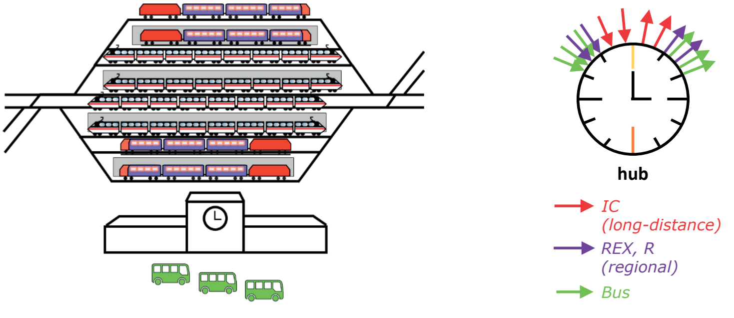


Figure 2.12: Left: Ideal railway hub with interchanges amongst long-distance, regional and bus services; Right: Respective arrivals and departures in this hub

In order to integrate a network, a certain edge riding time between the hubs is required. The fundamentals of the ITF, the rule of edges and the rule of cycles, were defined by Lichtenegger (1990) and were extended for application on regional networks by Walter (2016). The edge riding time is defined as an integer multiple of half the interval (Figure 2.13).

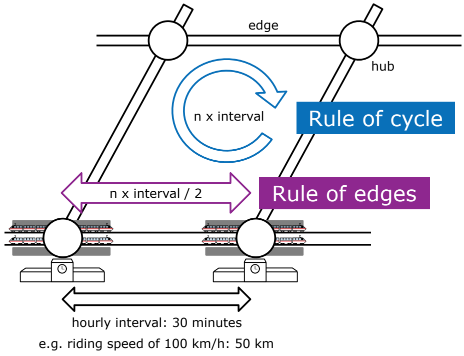


Figure 2.13: Rule of edges and rule of cycle in an ITF

The given edge riding times in the existing network often do not correlate with the calculated edge riding times. On the one hand this results in full hubs not being served at the intended minute .00 or .30 and therefore not offering interchanges in every direction. These hubs are called asymmetric hubs. On the other hand, edge riding times clearly show which lines need to be upgraded in order to shorten riding times. Figure 2.14 illustrates how these rules are applied in the Austrian railway network. Since many edges do not fit the planned schedule in the existing network, infrastructure measures have been and will be undertaken to enable an increased number of edge riding times by 2040. In an ITF network, it is more economical to travel as fast as necessary than to travel as fast as possible (Meiner, 1991). Consequently, a clear demand for operational improvements and infrastructure development in the network is defined. The described boundary conditions ensure connectivity and reduce travel times within the network as transfers are coordinated and waiting times are minimised.

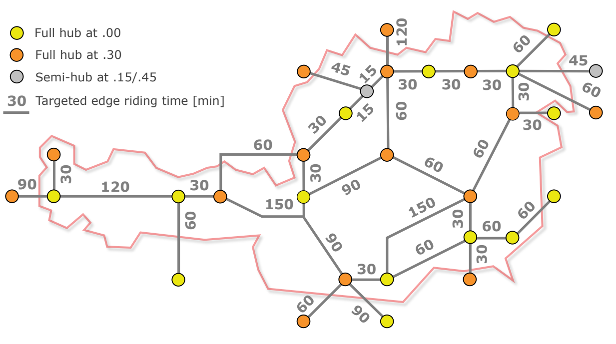


Figure 2.14: ITF model of hubs and edges for the Austrian railway network 2040 based on Uttenthaler (2010)

2.4.2 Advantages of the Integrated Periodic Timetable

The advantages of an ITF amongst customers, RUs and IM are manifold:

Customers benefit from a timetable that…

- … is easy to remember,
- … offers comfortable and time-saving interchanges and
- … therefore, ensures short travel times.

For RUs, an ITF allows for…

- … long-term planning stability,
- … systematic and effective vehicle circulation and
- … staff dispatching.

Finally, IMs benefit from…

- … a systematic infrastructure demand, based on long-term timetable and infrastructure development,
- … a predictable timetable and
- ... an effective capacity allocation.

The repeating pattern with every service having a mirror-image in the reverse direction (symmetry) is simple to market and easy to remember for **customers**. Its methodology delivers a coherent timetable across the network. A well-defined hierarchy of services optimises connectivity for a journey on any relation (Johnson et al., 2006). Therefore, an ITF is a solid basis for a more effective promotion of rail services amongst non-users (Wardman et al., 2004). It combines advantages such as attractive network-wide travel times and high connectivity.

Research shows that in well-connected rail networks **RUs** serve up to 50% more passengers than in stand-alone corridors. Moreover, infrastructure utilisation is increased while costs are driven down (U.S. Department of Transportation, 2014). This improved connectivity strongly supports regional rail lines. Minimal waiting time between long-distance and regional trains as well as buses reduces travel time. Patronage can be increased, and regional areas can be served more economically.

As Switzerland is the role model of a successful ITF implementation the number of pass-km is compared to Austria. Figure 2.15 shows how the implementation of an extended ITF called "Bahn 2000" helped to strongly increase passenger kilometres in Switzerland in comparison to Austria. Nevertheless, a remarkable increase of the Austrian traffic performance was observed with the implementation of the so-called "Plan 912" by combining several measures such as introducing additional regional clocked services (Pfeiler et al., 2012).

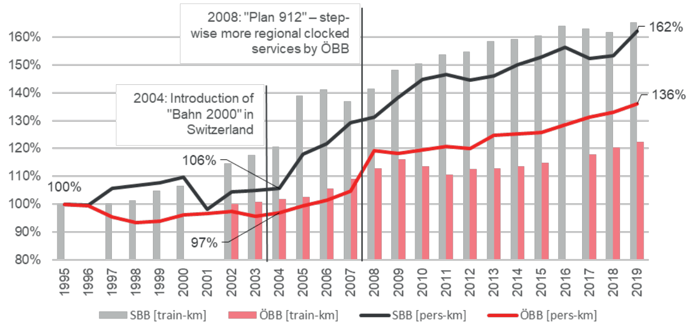


Figure 2.15: Evolution of demand [pers-km] and service offer [train-km] in Switzerland and Austria after an (partial) ITF implementation, based on UIC (2021a) and UIC (2021b)

In the Czech Republic, where periodic train services were introduced between 2003 and 2005, the increase of passengers amounted to about 40% (Janoš and Baudyš, 2012). In England the introduction of regular integrated services increased ridership by 12% compared to a timetable with a random set of departures (Wardman et al., 2004). Passenger flows in London and its surroundings have been raised by more than 70%. Effects have been lower on the long-distance level as some riding times became longer due additional stops of the edge-hub-model. In general, the introduction of an ITF-like timetable was positive in terms of user benefits, revenue and non-user benefits (Johnson et al., 2006).

The systematic planning and regularity of the ITF allows **IMs** to utilise infrastructure capacity efficiently (Stähli, 2019). The ITF-aligned development of a network is cost-intensive since targeted edge riding times and hub requirements need to be implemented. This means upgrades or line extensions cannot be done where it is cheap to do so due to the topography or the density of settlements. On the contrary, realignments and upgrades are necessary only in sections where the travel time of the existing network is too long. Furthermore, longer travel times may occur on some relations while others experience travel time reductions due to ITF-related measurements. However, even if investment costs are high, they are based on a systematic and objective long-term plan and therefore allow for the highest possible customer benefit. The successful implementation of an ITF requires a network-wide timetable design, political willingness and cooperation amongst different stakeholders (Walter, 2016).

2.4.3 Infrastructure Investments of the Integrated Periodic Timetable

Despite the ITF allowing for a long-term joint development of timetable and infrastructure, it requires a cost-intensive upgrade of the railway network. Using the example of the Austrian railway network, the share of ITF-related infrastructure investments was evaluated by Smoliner (2019).

In a detailed evaluation of infrastructure investments of ÖBB-Infrastruktur AG from 1990 up to 2040, the overall investment sum was calculated and divided into different categories as shown in Figure 2.16. Reinvestment projects are not considered here, as this evaluation focuses on upgrades and extension of the railway network. The overall investment sum of projects in the network of ÖBB-Infrastruktur AG between 1990 and 2040 amounts to 67 billion euros.

Three approaches with different granularity on defining the relevance of projects for the ITF have been developed. While the first approach is based on the definition of the target network (Zielfahrplan 2025+), the second and the third approach distinguish the relevance of a project in much more detail. In the second approach projects of the target network and their effect on the ITF are investigated in detail. The third approach differentiates if projects are built for capacity reasons or for the ITF by analysing the top speed before and after the infrastructure investment.

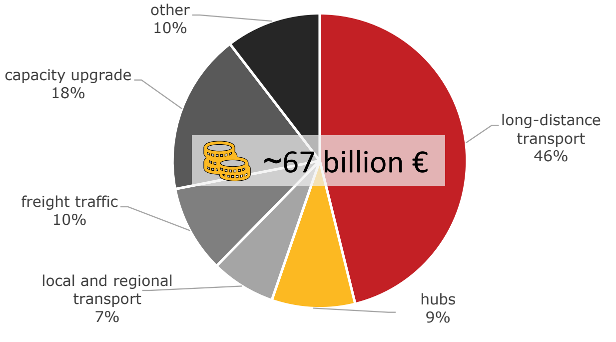


Figure 2.16: Ratio of infrastructure investments per category

When applying the aforementioned criteria on the overall investment sum the percentages shown in Figure 2.17 are derived. According to the target timetable 2025+ (approach 1) 51% of all investments in the Austrian railway network until 2040 are ITF related. The more detailed approach 2, excluding major base tunnels and other projects, gives a percentage of 36%. Finally, approach 3 attributes 31% of the overall investments to the ITF.

At least 31% of all infrastructure investments represent an investment of more than 20 billion euros. Relevant evaluations for other countries are not available, but it is estimated that the percentage of ITF-related investments are comparably high.

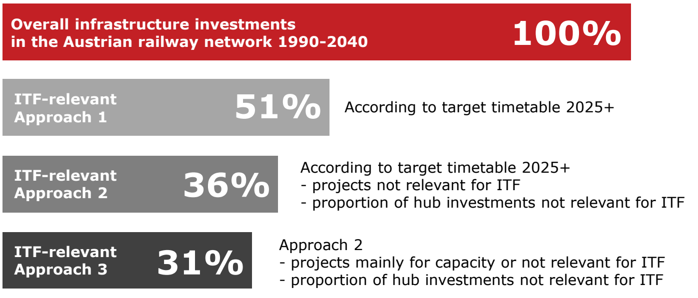


Figure 2.17: Percentage of ITF-relevant infrastructure investments according to different approaches

This underlines the importance of an effective utilisation of the network according to the advantages of the ITF. These high investments in the provision of an ITF-compliant infrastructure show how important effective use in terms of regular service is.

2.5 Problem Statement

Infrastructure vs. Unbundling

Aside from the opening of the railway markets, the vertical separation of former state-owned companies is a main goal of liberalisation. However, missing coordination between disintegrated railway companies might be a costly obstacle to system-wide optimisation. The separation into single railway companies and competition also fosters a trend towards short-term planning in a system that should have a long-term focus due to long service lifes and high investment costs. According to van de Velde (2015) there is "*growing concern about defective coordination and misalignment in the policies*" amongst researchers and practitioners. Missing coordination in the market requires regulation or guidance from rail authorities to facilitate an optimal overall performance (van de Velde, 2015).

Timetable vs. Train Path Allocation

When competition leads to a growing number of train services, the struggle for attractive train slots results in major challenges for IMs. It becomes increasingly difficult to combine competition with efficient timetabling in constrained networks. The challenge is to make infrastructure capacity available to OAOs and designing a timetable that is reliable, minimises journey times and offers attractive connections (Cartmell et al., 2016). In particular, this concerns railway markets aligned to the principles of the ITF such as Austria or the Czech Republic. Tomeš and Jandová (2018) provide a holistic approach on entry barriers, business models, market development and regulatory challenges in countries with ITF regimes. The effects of on-track competition in ITF regimes on long-term timetabling and infrastructure development are found in Janoš and Baudyš (2013) and Smoliner et al. (2018c).

2.5.1 Timetable-Based Infrastructure Development

Infrastructure development often focuses on top speed or minimal travel time from point to point. However, for a long-term perspective and optimal utilisation, infrastructure should be developed based on a timetable. The systematic concept of an ITF is the perfect tool for the joint development of infrastructure and timetables. On the one hand, the ITF is perfectly suited for the needs of medium-sized countries that lack the potential for high-speed lines. On the other hand, it requires a soundly designed network service (Pfeiler et al., 2012).

This chapter gives an overview of how timetable-based infrastructure development is executed in several European states and how an ITF (positively) affects this process. For a more detailed analysis on this topic compare Smoliner et al. (2018a) and Smoliner et al. (2018b) as well as Smoliner et al. (2018c).

Timetable Concepts and Infrastructure Investments

In liberalised railway markets the question is who initiates infrastructure investments. These can either be strategically planned by using long-term concepts such as the ITF, or they can be planned according to the short-term needs of the market. If train path allocation is the result of individual requests, reactive infrastructure measurements can only be implemented afterwards. Different strategies in Europe are summed up in Table 2.2.

An ITF-oriented approach is being pursued in Austria (ÖBB-Infrastruktur AG, 2011) and Switzerland (BAV, 2021), where long-term target network plans are developed based on an ITF.

In the Czech Republic and the Netherlands mixed triggers are applied while there is essentially a strong focus on the ITF timetable-wise. In the Netherlands, ITF-oriented infrastructure developments are predominantly carried out on a regional level. On the main corridors, the focus is on capacity upgrades, increasing top speed and reducing riding times (van de Velde, 2018). In the Czech Republic measures are implemented quite slowly, especially on the long-distance level (Ministerstvo dopravy, 2019).

In Germany (BMVI, 2020), Sweden (Trafikverket, 2021a) and Great Britain (Davies, 2017), the focus is predominantly on (reactive) capacity improvements for passenger and freight services. In addition, prestigious high-speed lines are planned and implemented. Target timetables on a national scale do not exist. In Germany the so-called "Deutschlandtakt" is discussed (Berschin et al., 2019). As the development plans are not yet specific (for a certain target timetable) the infrastructure has to be flexible in order to accommodate future operational concepts (Planungsgesellschaft Bahnbau Deutsche Einheit mbH, 1995).

Table 2.2: Timetable concept and infrastructure development

							
Focus of infrastructure development	ITF (network)	ITF (network)	capacity ITF (regional)	capacity high-speed	capacity ITF (regional)	capacity high-speed	capacity high-speed
Planning basis	target timetable	target timetable	capacity analysis regional ITF concepts	-	capacity analysis regional ITF concepts	-	-

Market-Oriented Infrastructure Development and Stranded Investments

Infrastructure investments, such as tunnels, might have a lifespan of up to 150 years. Additionally, tracks have service lives of more than 30 years. Yet, the length of a PSO contract does not usually exceed ten years. Moreover, train paths of railway services, most notably for self-sustaining services, are guaranteed for one year only. Obviously, there is a significant gap between the planning horizons of infrastructure development and the infrastructure requirements of short-lived commercial train path requests. As the latter cannot be planned over the long-term, there is no possibility for coherent infrastructure development, and measures can only be taken according to a short-term perspective. This means placing the risk of inefficiencies and stranded investments on the one hand, or investment backlogs and bottlenecks on the other hand. Both scenarios imply cost-intensive impacts on public funds. An overview is given in Table 2.3.

In Austria and the Czech Republic, an established concept on how to react to the needs of self-sustaining train paths has not yet been developed. However, these railway networks suffer from bottlenecks or lack of capacity as self-sustaining train paths are not (primarily) part of the long-term infrastructure development plans (Tomeš et al., 2014). In Switzerland, there are no OA self-sustaining services, as long-distance services are covered within a concession. In Germany, the market share of OA operators has not yet led to any significant infrastructure measures.

In Great Britain inputs from the market are considered as franchisees are invited to submit innovative proposals for timetable optimisation or infrastructure improvements. However, the IM is not obliged to implement these proposals in any way (Network Rail, 2017). As a rule, it is not possible to consider expansion proposals by operators of commercial transport services, since this market is too short-lived for infrastructure investments (Davies, 2017). Intensive studies are carried out in order to cover the risk of major projects such as high-speed lines that will predominantly be used by self-sustaining services (Shadow Strategic Rail Authority, 2000).

The Netherlands and Sweden have experienced examples of major infrastructure investments intended to mainly serve self-sustaining passenger services, but the newly built capacity was never adequately utilised. In the Netherlands, the High-Speed Link HSL Zuid was built to mainly serve self-sustaining services. However, this line has so far predominantly been used by domestic passenger services (van de Velde, 2018). In Sweden, the Malmö – Göteborg line received a double-track upgrade after capacity constraints occurred due to extended commercial services. After the upgrade, the services on the line proved to be unsustainable for two RUs operating in parallel. Consequently, services were cancelled and extensive investments in infrastructure expansion were therefore redundant, at least temporarily (Fröidh and Nelldal, 2015). Furthermore, the planned high-speed lines between Stockholm, Göteborg and Malmö are intended for self-sustaining traffic, however, it is not clear as to what extent the lines can actually be operated on a self-sustaining basis. Although there are currently three commercial operators successfully operating on the Göteborg – Stockholm route, a government committee recommended a competitive tender for future operation of all long-distance services in 2015 (Alexandersson, 2016).

Table 2.3: Market-oriented infrastructure development

							
Effects of self-sustaining services?	capacity shortages	-	capacity shortages	-	-	-	capacity shortages
Are needs of self-sustaining services considered?	-	-	-	-	high-speed lines	high-speed lines	high-speed lines capacity shortages
Stranded investments so far?	-	-	-	-	HSL Zuid	-	Malmö – Goteborg

Financing of Infrastructure Investments

According to Directive 2012/34/EU, the IM operates, maintains and renews railway infrastructure. The financing of cost-intensive infrastructure projects is done differently in each country. The height and the calculation of TACs differ from country to country and accordingly contribute to the budget of the IM to a different extent. Compare Marschnig (2016) for a detailed discussion on TACs. High TACs make it more difficult for self-sustaining services to enter the market and compete with the incumbent.

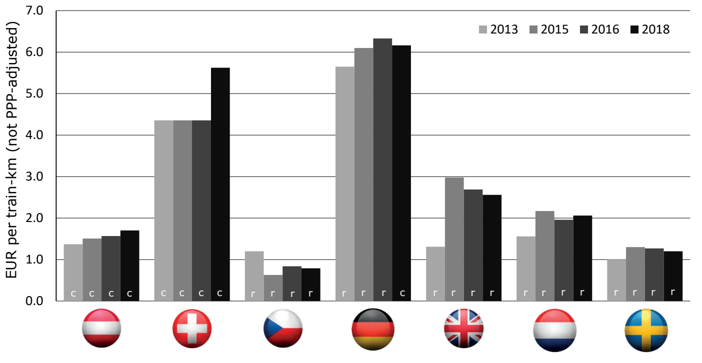
In all investigated countries the infrastructure is developed by the IM, with Sweden as the only exception (Table 2.4), where the transport administration is responsible (Trafikverket, 2021a). In Great Britain major projects such as Thameslink or HS2 are developed by special companies owned by the government (Department for Transport, 2009).

Table 2.4: Financing of railway infrastructure

							
Who is responsible for infrastructure development and renewal?	IM	IM	IM	IM	IM	IM + separate companies for major projects	transport administration

TACs for conventional long-distance services are comparably low in the Czech Republic and Sweden with about 0.5 up to 1.2 euros per train-km in recent years (Figure 2.18), resulting in several companies operating self-sustaining services.

TACs are moderate in the Netherlands and Great Britain with 1.5 up to 3.0 euros per train-km. However, due to the concession system in the Netherlands, all long-distance services are operated by or in cooperation with the incumbent. In Great Britain, with the franchise system covering long-distance services, only a few OA operators are active in the network (Williams Rail Review, 2019). Interestingly, in Germany, where all long-distance services are classified as self-sustaining, TACs for conventional long-distance trains constantly cost more than 5.5 euros per train-km in the last years. The market share of new entrants has been clearly less than 5% since the opening of the market (chapter 2.2).



r… value from Rail Marketing Monitoring
c… value calculated based on the following sources and assumptions:
AT 2013, 2015, 2016: passenger train, train mass 500 t, other international line; 2018: PSO train, train mass 500 t
DE 2018: segment „Metro day", average speed 110 km/h (= mix IR and IC)
CH 2013, 2015, 2016, 2018: track category B, demand factor 2, long-distance service in concession 1,25,
mass factor 500 t, assumed average conversion rate EURO-CHF: 1,1

Figure 2.18: TACs (excluding mark-ups) for conventional long-distance passenger trains according to RMMS 2018 (European Commission, 2019), RMMS 2020 (European Commission, 2021) and the national network statements[11]

Marschnig (2016) shows how the IM's income is divided into TACs, other IM's revenue and public subsidies (Figure 2.19). The TACs contribute to the IM's income in varying degrees. In Sweden, the low TACs represent only a small part of the IM's income. In contrast, in Germany and Great Britain, the ratio is clearly different.

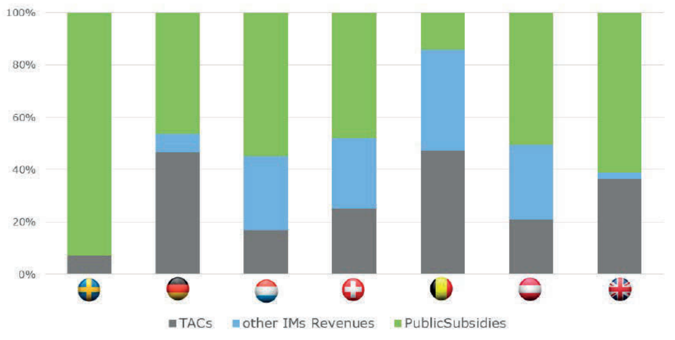


Figure 2.19: Income of the IM according to Marschnig (2016) based on data from RMMS 2014 (European Commission, 2014)

[11] AT: ÖBB-Infrastruktur AG (2012), ÖBB-Infrastruktur AG (2014), ÖBB-Infrastruktur AG (2015), ÖBB-Infrastruktur AG (2020c); CH: SBB CFF FFS (2013), SBB CFF FFS (2014), SBB CFF FFS (2015), SBB CFF FFS (2017); GER: DB Netz AG (2017).

2.5.2 International References

While self-sustaining services are primarily profitable on long-distance services, there is a major impact on regional rail services as can be observed in busy OA markets like in Austria or the Czech Republic. Consequently, train slot allocation procedures and therefore the quality of implementing integrated periodic timetables are facing considerable challenges.

Austria

The case of the hub Amstetten in Austria shows how current procedures can fail if two competing operators of self-sustaining services apply for integrated clocked train paths as shown by Smoliner (2019) and in chapter 3.3.4. This is a logical result as in a competitive market RUs aim for the most attractive and customer-friendly train slots. The prioritisation of clocked train paths incentivises an RU to apply for similar train paths within a band width of five minutes. If two operators apply for the same train path, they have to be allocated one after another. Consequently, at least one RU ends up with a semi-optimal timetable and a hub spreading results A hub spreading implies several negative effects for regional services and passengers changing trains:

- Edge-riding times for regional trains are reduced.
- This leads to cancelled train stops or shorter line services.
- Additional costs for rail replacement services or a higher vehicle demand due to suboptimal vehicle circulation occur.
- Not all trains are connected to each other resulting in a reduced network-wide benefit for customers.
- Some transfers are technically possible but given the non-integrated ticketing between RUs this leads to additional losses and a less comfortable ticket acquisition process for passengers.

While competition leads to frequent connections on the long-distance level, regional train services are negatively affected. Hence, customers cannot benefit from the advantages of an ITF and additionally cost-intensive infrastructure investments are to be questioned. In the long run, this has a negative impact on the overall system and a reduction of the customer’s benefits.

Czech Republic

The busiest line in terms of SOA operation in Europe is found between Praha and Ostrava in the Czech Republic. Due to low track access charges (TACs) and high priority for long-distance trains in the slot allocation process, it is estimated that the market share of OA operators exceeds 50% (Nash et al., 2015). Janoš and Baudyš (2013) observed that liberalisation in the Czech Republic resulted in fierce competition in the rush hour while services in off-peak-hours were reduced. On the main line OA operators offered frequent services with low capacity in peak hours causing a lack of capacity and unstable timetables. Additionally, heterogeneity, caused by commercial operators, lowers the capacity (Janoš and Baudyš, 2013). Furthermore, timetables are changed frequently by self-sustaining operators. Departure times, stopping schemes and vehicles changing every year make it difficult to integrate these services in an ITF.

In countries that are aligned to integrated periodic timetables (ITF), priority rules emphasize integrated and clocked services. However, Janoš and Baudyš (2013) show that prioritisation rules for clocked services are useless if they are overruled by long-distance or international train services. If commercial trains are preferred in train slot allocation processes, this may lead to less attractive train paths or overtaking of PSO services. The benefit for PSO customers is reduced by longer travel and waiting times. Furthermore, vehicle circulation is negatively affected leading to a higher vehicle demand.

However, regional PSO services that are tendered for ten years are based on an ITF-timetable. The lack of planning stability versus long-term infrastructure and timetable planning is obvious. A massive number of OA services in peak hours result in missing capacity for freight transport (Janoš, 2020a). The introduction of a mixed PSO and concession system is thought to be a possible solution (Burroughs, 2020).

Switzerland

The Swiss railway system has been based on the ITF for decades. Timetable as well as infrastructure development are closely linked and planned on a long-term basis. All long-distance services are by definition self-sustaining and are operated by SBB under a concession since 2004 (Bundesamt für Verkehr, 2021). Self-sustaining international services that are operated by SBB and partner RUs are either integrated into the ITF system (e.g. Railjet Wien – Zürich, TGV Paris – Zürich, ICE Karlsruhe – Zürich) or are on separate train paths that cannot interfere with or harm the stability of the ITF. These kinds of train paths could be offered to private operators in the future (Stähli, 2019). However, as OA services do not exist there have not been conflicts in the allocation of passenger services yet.

However, the exclusive concession for SBB was questioned by BLS AG in recent years who requested to offer long-distance services in the Bern area. SBB refused to give up its long-distance concession, pointing out among other things that only a network-wide concession is economically viable, as this is the only way to cross-finance unprofitable long-distance services. Finally, SBB agreed to hire BLS and SOB as contractors of sub concessions for five long-distance lines (Railway Gazette, 2019a).

Germany
Large-scale investments in the railway infrastructure in Germany were made in recent decades without a clear target timetable. Furthermore, no relevant long-term OA competition has been established yet. TACs are high, self-sustaining operators are struggling to get attractive train paths and, because of these uncertainties, have great difficulties in establishing stable business models and investing in long-distance vehicles. In any case, the status quo has shown to be a dead end in terms of transport policy and competition (Berschin et al., 2019). The "Deutschlandtakt", however, is said to ultimately favour competition on the railways (Burgdorf et al., 2019). "*The Deutschlandtakt might be a chance to foster competition but only if the model needs to allow slots for private OA-operators*" argue Bernau and Brankovic (2020). Interests of self-sustaining RUs will not lead to a network-wide implementation of an ITF with dense intervals, rather a further thinning out of services in peripheral regions, is the case (Berschin et al., 2019). However, a stronger engagement of the state will be necessary to achieve a target timetable of a "Deutschlandtakt". Several suggestions for the implementation for a network-wide "Deutschlandtakt" with dense intervals on the basis of (i) system train paths, (ii) system train paths with incentives or (iii) concessions have been presented by Berschin et al. (2019).

2.5.3 Research Demand

Status quo
The ITF, which aims for the best network-wide performance and customer benefit, has been implemented in several medium-sized countries in Europe. In the Netherlands and Switzerland, where an ITF network with dense intervals has been successfully implemented, long-distance services are covered in a concession. In countries with an ITF and self-sustaining services on the long-distance level like Austria or the Czech Republic, RUs ask for train paths designed to their specific demand. This often leads to conflicts with systematic, long-term planned timetable approaches (Figure 2.20). This reduces an efficient infrastructure utilisation, a full exploitation of the connectivity of the ITF and therefore lowering the network-wide passenger benefits.

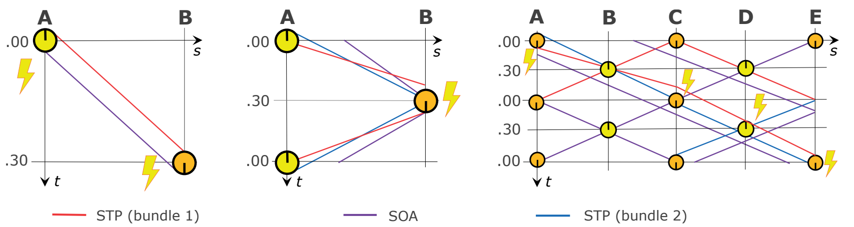


Figure 2.20: Conflicts of individual train paths with ITF services on edges (left), in hubs (middle) and in networks (right)

Relevance

New market participants are entering and are anticipated to keep entering the European railway markets as a result of the ongoing expansion of the infrastructure and increasing passenger potential. It is to be expected that, especially on double-track long-distance lines, there will be many conflicts over train paths in networks with systematic timetables like the ITF.

An optimal timetable as presented in chapter 2.3 is given if attractive network-wide services can be combined with long-term timetable and infrastructure development. An approach handling the antagonism of ITF and OA services is to be analysed in order to fit the boundary conditions of EU legislation, long-term infrastructure development and the ITF.

Research Gap

The question of how to implement an ITF in a liberalised railway system and how to ensure its full functionality has hardly been addressed on a scientific level yet. This is partly due to the fact that few countries in Europe apply a full ITF, and there is not yet competition at the long-distance level in all countries. However, as competition is pushed on a European level and railway traffic is steadily growing, it will become increasingly difficult to implement self-sustaining services and the ITF. Consequently, there is an urgent need for a solution that takes into account infrastructure, ITF and competition and aims for the optimum solution for passengers.

Considering the status quo of the ITF and OA services in several countries with its advantages, shortcomings and relevance, the following requirements, can be derived to:

- ensure long-term infrastructure and long-term timetable development
- allow for efficient utilisation of cost-intensive ITF infrastructure
- exploit the full benefits of the ITF
- foster a network-wide sustainable competition
- ensure legal feasibility

- design systematic train paths within the framework of an ITF
- allow for a network-wide applicability of the approach with line and bundle design
- depict challenges and ways of solving it for real-world implementation

2.6 System Train Path Approach

To overcome the challenges described above, an approach based on system train paths (STPs) is suggested. A system train path is the logical consequence of the ITF and provides a feasible solution in terms of transport planning, railway operation and infrastructure development.

Transport Planning

STP ensure the infrastructure capacity for systematic long-distance services which are the backbone of the ITF. If those STPs are offered as single train paths to RUs this will most probably result in cherry picking and fragmented timetables with services missing. Therefore, system train paths have to be combined to lines with intervals and further to bundles covering the entire network. Then STP bundles are awarded to RUs in a competitive tendering process. Taking all advantages and disadvantages of different tendering schemes into account, a PSO tendering seems to fulfil this requirement best (Feuerstein et al., 2018; Smoliner et al., 2018c). This means STPs are combined along a route in intervals to a bundle. All STPs considered relevant for the service intention are integrated into bundles. These bundles are then tendered as a PSO (Figure 2.21). Alternatively, train path catalogues could be applied (see chapter 2.6.2).

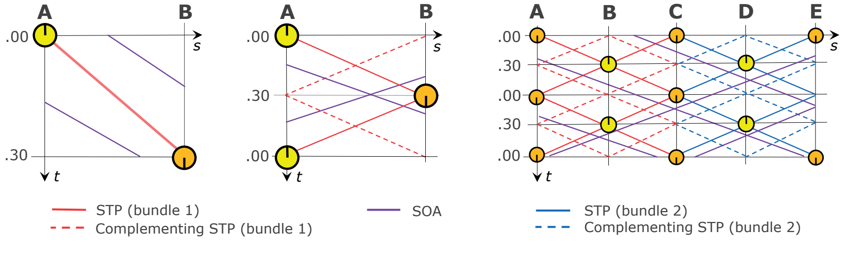


Figure 2.21: STP between two hubs (left), combined STPs (middle) and STP bundles geographically combined (right)

The main challenges of tendering are to define an appropriate size of STP bundles as well as to offer attractive vehicle circulation considering locations of maintenance facilities (Schröder, 2018). Therefore, bundling and tendering have to be investigated in detail. A competitive tendering has to be launched within a fair, objective and non-discriminatory process. This approach allows for a transparent overview of available train paths, gives predictability for train path requests and promotes competition with a certain investment security (Berschin, 2020).

In order to comply with the complex conditions of an ITF, a long-term planning of pre-defined system train paths by a Public Transport Authority (PTA) is essential. Furthermore, tariff integration and net utilisation plans are necessary (Walf, 2019). This may be criticised as harming the open market or the entrepreneurial freedom. However, an in-depth analysis shows that a missing timetable planning stability is a significant market barrier for open access operators and their operational concepts (Feuerstein et al., 2018). System train paths reduce this barrier significantly, as they are planned beforehand on a long-term basis. The train path is predefined; but remains flexible and makes it possible to add or skip stops according to the characteristics of the rolling stock used.

Railway Operation

For economic reasons it seems highly unlikely that operators of self-sustaining services will implement an ITF aimed at comprehensive coordination on their own initiative (Knauff, 2019). This is especially true for long-distance services that are often – given an attractive infrastructure – more focused on fast point-to-point services than network-oriented services. Therefore, a structured network-wide ITF is only feasible with pre-defined STPs instead of individual train services of SOA operators. In a monopolist market such as Switzerland, the ITF can be optimally planned on a long-term perspective by applying the planning circle demand – infrastructure – rolling stock. As rolling stock is not known beforehand in a competitional market, STPs need a flexibility to cover a certain range of vehicle characteristics.

A fundamental principle of operators of self-sustaining services is to design their individual timetable based on specific vehicles resulting in a unique selling proposition. This is either possible by (i) designing STPs while allowing for a certain flexibility covering different stopping patterns and vehicle properties or (ii) to offer individually designed train paths which do not interfere with the ITF. The first option is STPs forming the backbone of the ITF with accurately defined arrivals and departures in hubs to optimise connectivity and still allow for a certain flexibility on the edges between the hubs. The second option allows SOA operators to offer fast point-to-point services, etc. However, these train paths do not have attractive transfer connections in the hubs.

Infrastructure Development

It is not financially sustainable to design infrastructure upon demand for short-term open access services only. The functionality of the ITF can only be ensured if STPs are served instead of individual ones. By applying a schedule of systematically pre-planned system train paths, the advantages of on-track competition and ITF could be combined in order to fully utilise cost-intensive infrastructure based on the principles of the ITF (Smoliner, 2019). In a long-term perspective, STPs allow for a targeted and sustainable infrastructure development, especially in the important hub areas (Gipp, 2015).

The concept of STPs is the reversal to the hitherto predominant principle of RUs applying for individually optimised train paths. These uncoordinated train path requests often lead to conflicts which require great effort from the IMs in order to be solved (Burgdorf et al., 2019). Given the current legislation, a full utilisation of infrastructure is not guaranteed in on-track competition. Target timetables are defined, infrastructure is planned and built accordingly and only then will attempts be made to implement competition. However, this order does not work well, and competition must therefore be considered from the outset. As competition is usually predictable and occurs on routes with high demand and/or attractive travel times, it can be considered beforehand (Scherrer and Büchel, 2020).

In a liberalised railway market, IMs are challenged with competing requests aiming for the "best" slots. Complex slot allocation procedures often result in compromises that worsen the overall network performance. This is the reason why in such cases the benefits of the ITF are not being exploited fully.

The ITF itself guarantees a high utilisation of mixed traffic networks by considering a mixture of slow regional and fast long-distance trains in a clear and predictable order. While capacity optimisation strategies might allow for a higher degree of capacity allocation for certain train categories, the ITF guarantees the highest network-wide benefit for customers. Consequently, STPs represent a transparent systematic approach for a long-term timetable development. STPs could also be applied to freight services or strategic infrastructure planning of the IM.

2.6.1 Description of System Train Paths

Arrival, departure and edge riding times of STPs are predefined by the ITF. As these parameters are known, the STPs can be designed as pre-defined train paths.

Approach

The application of STPs is – up until now – primarily known in freight transport. STPs are based on a set of parameters with a certain band width rather than using specific vehicle parameters as they are unknown beforehand. STPs have to fit in the target edge riding times (Figure 2.22). For a network-wide application STPs on edges are combined to lines and bundles. These bundles form the backbone of the ITF and are tendered as PSO. Further self-sustaining train paths are possible; however, they must not interfere with STPs.

Boundary Conditions

System train paths need to be precisely defined regarding riding times and hub service times to guarantee the full functionality of the ITF. For optimal transfer connections, a slim hub is essential, and STPs can serve a hub only in a narrow band width. STPs run between a certain number of hubs. By definition these are at least two but usually several consecutive hubs. The number of hubs is defined by the question of how many hubs should be connected to one line (see chapter 5).

2.6.2 Implementation of System Train Paths

STPs need to be carefully designed beforehand in order to be tendered as bundles.

Idea

The IM defines STPs for long-distance services like the network utilisation plan is done in Switzerland (BAV, 2020). The train paths of feeder connections are matched to these system paths. Any provider of self-sustaining services must accept that train paths not interfering with STPs also have less attractive connections in hubs. The preference for symmetrically timed train paths as applied today in Austria will be replaced by STPs in PSO regimes. These always have priority at the hub and allow for ideal transfer connections.

Other Services

System train paths run every hour or every half an hour depending on the demand and the connectivity of the ITF network. Even if these frequent services require a certain amount of infrastructure capacity, there is still a sufficient amount of capacity that can be allocated to other services such as self-sustaining passenger services, freight trains or regional services. In a variation of today’s slot allocation process, remaining slots for (accelerated) long-distance services, regional services or freight services are considered.

The following ranking is suggested:

- Predefined international passenger and freight trains
- Open Access passenger services
- Regional ITF services

The capacity could be allocated (i) according to respective criteria in the working timetable process or (ii) by pre-defining them in a train path catalogue as described below.

In option (i), considering the criteria of the working timetable process, self-sustaining operators can apply for train paths with the IM. In the event of conflicts with system train paths, OA train paths are not considered or are altered as STPs are preferred.

Option (ii) calls for a long-time and detailed demand projection and transport planning, furthermore the extent of the catalogue describes the possibility of requesting individual train paths. However, PaPs have several advantages such as predictability, systematic train path allocation and therefore effective infrastructure utilisation. Through system train paths and a train path catalogue, it should be possible to accommodate more train paths on the existing infrastructure than has been the case to date. Despite more specifications and alleged restrictions on network access, systematic train path planning should thus create better competitive conditions in the medium and long-term, which would benefit all four traffic segments.

The same consideration can be applied to freight trains. Applying a train path catalogue like in Switzerland would make infrastructure more predictable for RUs and, once they are established, ad-hoc requests can be processed faster. In the working timetable process, freight trains may experience more interruptions as STPs are allocated in fixed intervals and not bundles as nowadays. At least one freight train slot per direction per hour should be considered during peak hours.

Shape

The STP can be defined as a parallelogram in a time-path-diagram (Figure 2.22). Two edges of the parallelogram touch the hubs at the clocked time. STPs with this form fit the requirements of an ITF best as shown in (Smoliner, 2019). Arrival times of STPs in hubs are clearly defined to guarantee optimal transfers to all trains. However, restrictions apply as to how precisely an STP can be described between two hubs to prevent a predetermination on exact vehicle properties, and thus operators.

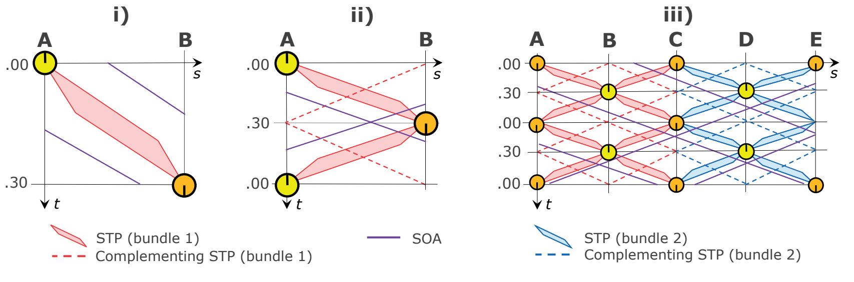


Figure 2.22: STP as parallelogram (left), combined STPs, and bundles of STPs

A certain flexibility is needed on edges allowing RUs to adopt the timetable with regards to stopping pattern, energy savings or timetable stability. Infrastructure parameters including top speed or number of tracks shape the STP. Furthermore, buffer is needed for IM to consider speed restrictions due to maintenance works or minor disruptions.

Bundles

In order to be able to serve STPs efficiently, a combination into STP bundles appears feasible. The size and composition are based on various criteria such as passenger flow, vehicle demand or optimised vehicle circulation. Furthermore, these system train paths should be given away only in periodic series of train path bundles, as to consider efficient operating schedules and prevent cherry-picking of rush-hour paths only. Creating smaller packages for long-distance services would increase the amount of new competitors to enter the market. Thereby capacity or customer service would not be compromised on the rail network (Campaign for Better Transport, 2019). The composition of these bundles could be carried out by a PTA. Finally, these STP bundles for are tendered as PSO.

Tendering

This raises the question of which distribution procedures are feasible for STP bundles. Furthermore, an approach needs to be established to ensure that STPs are preferred for the train path allocation.

In consideration of the fourth railway package and the requirements of an ITF, PSO contracts awarded by an independent railway agency best fulfil the criteria of joint long-term development of timetable and infrastructure. Publicly tendered PSO contracts for system train paths are recommended to provide the optimal timetable as shown by Smoliner et al. (2018c). These contracts guarantee a coherent network-wide application of the ITF and enable the highest network-wide connectivity as well as customer benefits. The prerequisite, however, is that PSO services are in any case to be preferred over self-sustaining services in train path allocation. Given the comparably low-cost coverage of TACs, self-sustaining railway services can also be considered as being state subsidised due to the great amount of infrastructure costs covered by taxpayer money (Finger, 2017). Therefore, a tendering of integrated long-distance services allows for an efficient use of this money. Bundles tendered in manageable sizes all over the network will therefore allow new RUs to enter the market. Niche segments such as accelerated point-to-point services will be open for self-sustaining open access trains as long as they do not interfere with clocked services. This allows for both network-wide "competition *for* the market" as well as "competition *in* the market".

The system train path bundles are to be awarded by a public transport authority as PSO. A well-thought-through tendering process regarding size, revenue, etc. is essential to attract potential RUs (Jaag, 2017). Train path bundles are allocated every five to ten years. Given the 30-year service life of railway vehicles, this commitment to several years seems justifiable. During this time, there is a stability for train paths, but also an obligation to maintain the offer. As the commercial potential of long-distance train paths is relatively high, RUs are prepared to fulfil these service contracts at very low charges, or even bid money for doing so. Therefore, higher costs are not necessarily to be expected (Walf, 2019). On routes without economic potential, transport service contracts are necessary to cover the network anyway. It is expected that the level of network-wide costs for transport services will not change significantly or even decrease since market revenues can rather be expected to stay in the system, rather than being skimmed off. If PSO tendering cannot be implemented for political reasons or transport planning, train path catalogues can be used as described below.

Cross-border connections are an essential part of ITF connections and should be integrated into the bundles. If international services running through several countries like proposed in the TEE-concept using train paths for clocked services (Scheuer, 2020) and STPs cannot be integrated into a national PSO tendering scheme, the required train paths should be left out of STP bundles or should run on separate train paths.

Integrated ticketing is necessary if the different bundles are served by different operators. However, RUs can still offer flat rates and practise yield management. Those RUs that serve a bundle are obliged to implement the ITF in this area. This results in a constraint that must be considered by the allocation body according to § 65, Abs. 6 EisbG, which means that these transports must be given priority in serving hubs.

Train Path Catalogue

An alternative approach to applying STPs to a greater extent can be found with a train path catalogue. In this catalogue, not only are train paths for STP bundles predefined, but also further long-distance passenger services or freight services. RUs would then be forced to choose out of a catalogue of train paths instead of applying for individually designed train paths. Such a catalogue can cover a limited amount of train paths or cover the entire timetable. In terms of a long-term infrastructure development and planning stability for RUs this would be the optimum (Scherrer and Büchel, 2020). As in a completely free market, conflicting train path requests are a logical consequence, and a train path catalogue would clearly define infrastructure requirements ahead. However, the market needs would be required to be identified beforehand.

A train path catalogue called “Netzfahrplan” is applied in Switzerland. Here the whole track capacity is filled with pre-arranged train paths (PaPs) years ahead. This considers the argument that for open access competition, it is essential to be transparent on which train paths are free to operate (Feuerstein et al., 2018). However, this approach will not be considered further as it would limit the possibilities of operators of self-sustaining services to be free to choose between network-oriented ITF services and fast point-to-point or other services. Furthermore, OA operators would possibly rather focus on fast or frequent connections than on ITF services. However, considering capacity constraints on many lines this could be a further step to ensure efficient infrastructure utilisation and long-term timetable and infrastructure development.

2.7 Target Functions

Target functions are to be constructed that (i) achieve the customer’s maximum benefit by (ii) fully using the ITF and (iii) considering a competitive long-distance railway market. They are derived on the aforementioned findings and presented in Table 2.5.

Table 2.5: Target functions

Target function	Goal	Objective for STP-bundles
optimal connectivity	full functionality of hubs	minimum hub spreading time
full-service availability	offer STPs for all relevant day-time connections network-wide	prevent cherry-picking, guarantee full functionality of ITF
minimal travel time A-B including transfers	attractive travel times and minimal number of transfers	maximum number of direct connections
efficient infrastructure utilisation	full utilisation of infrastructure	maximal number of trains per hour per section
fostering competition	attract private companies for tendering process	manageable bundle sizes
optimal vehicle circulation	offering bundles allowing for economic vehicle circulation	minimum number of vehicles, routes of similar train composition
demand coverage	align connections to passenger flow providing sufficient capacities	optimal demand coverage

3 Legal Implementation

A discussion about the technical approach of STP bundles only makes sense, if the legal feasibility to implement the approach is verified. As real-life examples have shown, the train path allocation process is of great importance in this case, as it is here that the allocation of the train path in the annual timetable is determined. In railway networks with high traffic volumes and OA operators, there are frequently overlapping requests for train paths. If the conflict cannot be resolved on a mutual basis in the coordination process, a conflict resolution process is initiated in accordance with the provisions of Directive 2012/34/EU. "*In an open access system, network scheduling is done by the train operating companies while train scheduling is done by the infrastructure operator*" (Pachl, 2006). Therefore, in a network with tendered and self-sustaining services the slot allocation process must define the framework for the best possible allocation. Therefore, a detailed discussion of (i) the framework and evolution of the respective regulations, (ii) the slot allocation process and (iii) the procedure for dealing with conflicting train paths are discussed in order to find a useful and sustainable solution for all market participants.

3.1 Evolution of the European Railway Legislation

The most important milestones of European legislation in the context of liberalising the railway market is given in the following.

3.1.1 A Common Market

The core concern of the European Union, and its predecessor the European Community, is the free internal market. This common market enables citizens to enjoy the four fundamental freedoms, with competition as one of the dominating principles of the treaty (Kahl, 2005). Thus, an indirect obligation to liberalise arises from primary Union law.

The evolution of European railway law from the finding of the "inactivity verdict" of 1985 with the introduction of the free market and the implementation of Directive 91/440/EEC which lays the foundation of the splitting of railway undertakings up to Directive 2001/14/EC on the allocation of infrastructure capacity was discussed by Segalla (2002) and Bergantino et al. (2015). Nash (2010) and Finger and Messulam (2015a), describe the evolution of White Papers and railway packages from 1996 to 2016.

In the context of this thesis, the following regulations and directives of the railway packages are of particular interest:

- **Regulation 913/2010/EU** defines pre-arranged train paths for international passenger or freight trains
- The opportunity to offer competitive commercial services and the right to participate in tendering procedures was implemented with the third railway package in **Regulation 1370/2007**

3.1.2 Fourth Railway Package

The latest relevant directives and regulations were published in the course of the fourth railway package in 2016. This railway package is divided into a technical pillar and a market pillar (Scordemaglia and Katsarova, 2016), whereas the market pillar aims for (i) an open railway market enabling savings of public money and (ii) a benefit for customers through additional services and improved quality.

This is regulated amongst other issues, in

- the so-called **"PSO Regulation" Regulation 1370/2007/EU** (amended by Regulation 2338/2016/EU), and
- the so-called **"SERA-Directive" 2012/34/EU** for a single European railway area (amended by Directive 2016/2370/EU).

The content of the latter two is presented here merely as an overview; its content is discussed in chapters 3.2 and 3.3.

- **Directive 2012/34/EU** regulates transparent and non-discriminatory access to railway infrastructure and defines the pricing of infrastructure capacity. It aims (i) to contribute to a reduction in the costs of transport to be covered by society and (ii) to define a long-term guiding strategy for the development of railway infrastructure.

- **Directive 2016/2370/EU** the recitals call for better coordination between infrastructure managers and RUs in order (i) to ensure "*high quality for all passengers*" and (ii) to introduce an "*Integrated Timetable system for domestic rail passenger services*".

- **Regulation 2338/2016/EU** amending EU-Regulation 1370/2007 with regards to competitive awards and the provisions on public service obligations. It defines (i) up to which extent direct awards are permitted, (ii) which exceptional cases can be applied, (iii) that these specifications should, "*as far as possible, bring about positive network effects*" and (iv) an improvement in the quality of service and the overall efficiency of public transport (2338/2016/EU).

3.1.3 Railway Legislation in Austria

Relevant regulations in Austrian law are primarily to be found in the Austrian Railway Act (EisbG), the network statement of the ÖBB-Infrastruktur AG (SNNB) and the Local Public Transport Act (ÖPNRV-G). These are based on the respective European legislation, which is partly expanded and detailed.

EisbG

The section relevant for this thesis is part 6, which covers the regulation of the railway market. Amongst others, the masterplan for railway infrastructure development, access to the railway of the railway market infrastructure and train path allocation is defined.

Network Statement SNNB

Chapter 4 of the SNNB is particularly important as it deals with fair and non-discriminatory allocation of train paths as well as effective use of railway infrastructure. In the event of train path conflicts, the general allocation principles, the preferential treatment of so-called symmetrically interlocked traffic and a catalogue of priorities are defined (ÖBB-Infrastruktur AG, 2020b).

ÖPNRV-G

The ÖPNRV-G corresponds to the national implementation of the "PSO Regulation". It regulates the awarding of transport services for rail and motor vehicle service (buses). It covers the role of transport associations, the avoidance of parallel transport and the improvement of links, financing and quality criteria (ÖPNRV-G, 1999).

3.2 Access to Railway Infrastructure – Status Quo

In principle, the general regulations on a European level are addressed and supplemented by additions or details at national level and are then implemented in the network statements. Beside the network statement of ÖBB-Infrastruktur AG, network statements of other EU countries are considered as well. While Switzerland is not a member of the EU, a considerable proportion of the railway-related European legislation is applied there. The network statement of SBB is modelled according to Directive 2012/34/EU, and is therefore considered as well.

The general rules, the procedure and the framework for the timeline for train path allocation are outlined on a European level in Directive 2012/34/EU. They are then transformed, with some adaptations, into national law. In Austria, this is the EisbG 1957 in its current version. And finally, they are implemented in the network statement of the respective IM. In the main network of Austria, this is the network statement (SNNB) of the IM ÖBB-Infrastruktur AG (ÖBB-Infrastruktur AG, 2020b). The process of how the different levels are linked is shown in Figure 3.1.

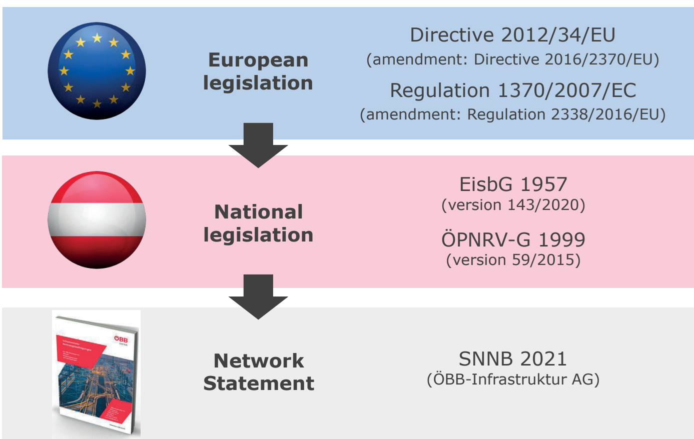


Figure 3.1: Link between different levels of legislation in the context of STPs

3.2.1 Fundamentals

The railway infrastructure allocation process is a crucial instrument for a liberalised railway market to function fair and efficiently (Ait-Ali and Eliasson, 2019). Capacity allocation is a complex process, involving technical, legal and economic considerations (Stojadinović et al., 2019). In most cases, the number of market participants and conflicting train path applications is particularly large in highly congested network sections (Klabes, 2010) leading to numerous conflicts and law suits (Stöger, 2018). It is assumed, that through a large number of market participants, the IM is confronted with an uncoordinated demand. All requests should be treated equally on the basis of objective conditions. RUs do not know each other's train path requests before the start of the annual timetable process, they can only assume similar requests of their competitors as in recent years. This leads to uncoordinated train path requests and conflicts in the allocation process.

All train movements in a railway network have to be allocated by the IM. As the working period of the network timetable is limited to one year this process has to be undergone every year. Furthermore, this should prevent grandfathering. An overview of the process is given in Figure 3.2.

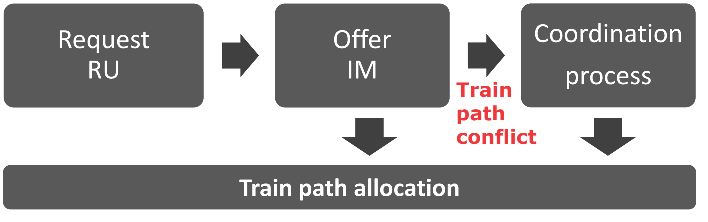


Figure 3.2: Procedure train path allocation

According to Directive 2012/34/EU, the IM shall, as far as possible, meet all requests for infrastructure capacity, including requests for train paths across different networks. Furthermore the IM shall, as far as possible, take into account all constraints to which applicants are subject, including the economic impact on their business (2012/34/EU, 2012). This European legislation is implemented in the countries' national laws. Ait-Ali and Eliasson (2019) give a comprehensive overview of track capacity allocation processes in France, Germany, Sweden, Spain, Switzerland, the United States, Belgium, Japan and the Netherlands. Comments on the legal situation in Austria can be found amongst others in Segalla (2002), Lewisch (2002), Catharin and Gürtlich (2015), Schweditsch (2017) and Pürgy and Hofer (2019).

3.2.2 Involved Parties

The timetable allocation process basically involves IM, RU and the regulatory body. If train path conflicts cannot be solved among those three, courts come into play. PTAs can be involved in the process too; however, this is rather the exception. For further considerations regarding the access parties, see in Segalla (2002), Catharin and Gürtlich (2015) and Pürgy and Hofer (2019).

Infrastructure Manager

According to Directive 2012/34/EU, the train path allocation and design of the working timetable has to be done by the IM or alternatively allocation body. To guarantee non-discriminatory and fair infrastructure access, the IM or allocation body have to be independent from any RU (Art. 7, Directive 2012/34/EU). Once a train path is assigned to an RU, a private law contract is signed between IM and RU.

Railway Undertaking

According to Directive 2012/34/EU any licensed RU may request infrastructure capacity. In the Austrian network statement, "non-railway undertakings" (nRUs) subject to Regulation 1370/2007/EC, may also apply for infrastructure capacity. Capacity requests by an nRU must only be used by an RU. Allocated train paths may not be transferred to other RUs (§ 63 Abs. 3 EisbG).

Regulator/Court

In the event of an appeal, the RU may lodge a complaint with the independent rail regulator (ÖBB-Infrastruktur AG, 2020b). In Austria, this is the Schienen-Control Kommission (SCK)[12]. If the appeal is not successful, the complaint may be submitted to the Bundesverwaltungsgericht (BVwG)[13] (Gast and Autengruber, 2019).

3.2.3 Procedure

The annual allocation process, the so-called "working timetable", has to be established every year as the reservation of specific train paths is limited by Art. 43, Directive 2012/34/EU, to one year (Schneider, 2013). Alternatively, so-called framework agreements can be concluded between IM and RU exceeding one timetable period and lasting up to 10 or 15 years (§ 63 Abs. 5 EisbG).

[12] In English: Rail Control Commission
[13] In English: Federal Administrative Court

The process for the annual working timetable lasts 18 months (Figure 3.3). If RUs want to operate new passenger train services on routes with existing PSO services, such an intention must be submitted to the regulator 18 months in advance (§ 65 Abs. 5 EisbG).

Before the national working timetable process starts, train path requests on an international level have to be handled. International train paths and pre-arranged train paths (PaPs) are coordinated between the IM of the concerned railway networks at least 11 months before the working timetable change. If possible, these train paths shall not be altered in the following procedure of the national working timetable. The coordination of international train paths is done on separate conferences amongst IMs (Segalla, 2002). In order to avoid antitrust problems, according to Art. 40, Directive 2012/34/EU, only IMs shall decide upon the allocation of trans-network train services, RUs shall not be involved.

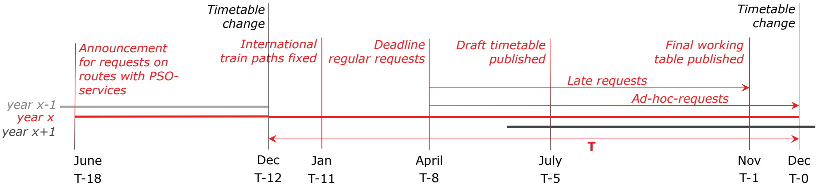


Figure 3.3: Timeline for train path allocation

Requests from the RU are accepted by the IM one year ahead (Art. 43 and Annex VII, Directive 2012/34/EU) or by April of the same year at the latest (4.3.1.1, SNNB). Not more than four months later, a first working timetable draft is designed with, if necessary, minor adaptations for requested train paths (Directive 2012/34/EU). Afterwards, a coordination of the conflicting train path requests is carried out. The national legislation and network statements define the procedure for coordinating conflicting train path requests. The different approaches and rules applied in Austria and other EU Member States are described in chapter 3.3.

Requests arriving later than April can only be considered if they do not harm the working timetable. Alternatively train paths that have already been allocated can be adapted in coordination with the affected RU.

The final working timetable is published one month before it comes into effect and is equivalent to the regular timetable for the upcoming year. It comes into effect after the second Saturday of every December. Train path requests announced later can be considered as “ad hoc” requests, which will be adapted to fit in the existing working timetable.

Considerations and further literature about the timeline and procedure set by the ÖBB-Infrastruktur AG and the EisbG can be found in Segalla (2002), Catharin and Gürtlich (2015).and Holoubek and Potacs (2019).

3.2.4 Categories of Train Paths

Basically, four train path types can be distinguished.

Regular Train Path
A regular train path is the capacity that is needed to run a train between two places within a certain period. The request by the RU is made within the regular procedure of the working timetable, meaning before the regular application deadline. Requests cover passenger services as well as freight services (§ 65, EisbG).

International Passenger Train Paths
International passenger trains serve stations in different countries and cross at least one border. The requests are made before the working timetable process starts. If at all possible, they are not to be adapted throughout the entire process of the working timetable by the IM. To ensure this is the case, they are to be given preferential treatment in accordance with Directive 2012/34/EU.

Pre-arranged Path (PaP)
Pre-arranged paths are usually freight services that are planned in advance of the regular working timetable procedure. These are requested by RUs and agreed within the framework of Rail Net Europe (RNE) by the IM. They are intended to ensure attractive freight transport options on cross-border routes within the European Union.

Regulation 913/2010/EU defines PaPs for freight trains. Art. 40, Directive 2012/34/EU foresees that IMs or different countries should jointly design corridors and PaPs. These are integrated into the national network statements and have priority in the train slot allocation. While this legislation in principle is intended for international train connections, system train paths can also be applied for national passenger or freight services (Gipp, 2015).

Ad-hoc Train Path
These train paths can be requested on a short-term basis. The IM has to respond to these requests within five days (Art. 48, Directive 2012/34/EU). Usually these requests are made for freight trains or short-term passenger charter trains.

3.2.5 Framework Agreements

Regular train paths have to be ordered anew each year. As STPs are planned for a longer period of time a long-term perspective would be useful. Framework agreements for train paths can be appointed for five years or even longer (Art. 42, Directive 2012/34/EU). They are agreed upon between the IM and RU in order to be able to provide planning stability, e.g. for large-scale investments in rolling stock. For the completion of a framework agreement, several aspects such as the commercial needs of application, needs of passengers, efficiency in the operation of infrastructure or commercial needs of freight corridors have to be considered in Art. 42, 2012/34/EU.

Characteristics

Framework agreements do not define train paths in detail, but a time frame which provides sufficient flexibility for the annual scheduling of train paths (Schneider, 2013). Framework agreements might be adapted in the annual working timetable procedure, as they must not prevent other train path requests from being located according to § 63 Abs. 4 EisbG. Train services may have different needs for precision when it comes to timing, which should be reflected in different widths of the time frames. However, capacity should be allocated loosely to a two-hour control period Art. 2, (545/2016/EU). Furthermore, framework agreements might be limited to certain sections of a network (ÖBB-Infrastruktur AG, 2020b).

If a framework agreement cannot be allocated in the annual working timetable process as predicted, a coordination process considering business models of RUs or obligations from a PSO contract are to be taken into account (545/2016/EU, 2016). In the event of a conflict resolution process, preference might be given to undertakings with existing framework agreements (Directive 2012/34/EU). Nevertheless, as framework agreements only cover a band width, the allocated train paths depend on the respective prioritisation criteria specified in the network statement (Schneider, 2013). Details and criteria concerning framework agreements are settled in Regulation 545/2016/EU.

Duration

Competition might be jeopardised if framework agreements hinder other train path allocation (Catharin and Gürtlich, 2015). Therefore the contract duration is restricted to prevent grandfathering of incumbents who insist on capacity which has been at their disposal before (Segalla, 2004). The duration is usually a maximum of five years but might be extended under certain circumstances to up to 15 years (Art. 42-6, Directive 2012/34/EU and Regulation 545/2016/EU). An even longer arrangement of framework agreements is only allowed if especially high investments or contractual obligations are involved (2012/34/EU).

Practical Applications of Framework Agreements

Framework agreements should not block too much capacity. The example of the motorail train Sylt in Germany has shown that framework agreements can function as exclusive rights that exclude other services: In a disagreement over framework agreements on the single-track line between Niebüll and Sylt, a pro forma application of a competitor was neglected. As up to 75% of the infrastructure capacity can be devoted to framework agreements, other applicants had hardly any chance (Recker and Westenberger, 2015). Hence, in Germany, framework agreements are no longer awarded due to bureaucracy, low predictability due to wide band widths for freight services, and availability of lines due to maintenance works (Berschin, 2020). In Spain, the infrastructure capacity of the high-speed network was recently split into three tendering packages, covering about 70% of the available capacity with framework agreements (Montero and Melero, 2020).

Evaluation

Framework agreements are useful tools for high-speed lines involving large-scale investments for rolling stock. While the long duration of framework agreements would be beneficial, the non-ability to fix a concrete train path and to reserve a band width instead, would lead the matter ad absurdum.

3.2.6 Pre-Arranged Train Paths

Regular train paths are arranged in the annual working timetable process. However, international passenger and freight services may be coordinated between the national IMs in advance.

According to Art. 40, Directive 2012/34/EU the IM is obliged to establish appropriate procedures to organise train paths across more than one network. IM shall assess the need for international train paths in order to facilitate ad hoc freight trains. The IM is to decide which cross-border train paths are considered in the working timetable. These train paths have to be fixed before the start of the working timetable process and adjustments have to be kept at a minimum (2012/34/EU).

Freight Train Path

Rail freight corridors (RFC) concerning a European rail network for competitive freight were established with Regulation 913/2010/EU. IMs are supported in establishing train paths for international freight corridors within the framework of RailNetEurope (RNE) which is the European association of IMs. Every single RFC has a One Stop Shop (OSS) which serves as the exclusive point of contact for freight train path requests along the corridor. The OSS coordinates cross-border freight train paths among the different IMs of a corridor. The OSS requests wish lists from RUs one and a half years ahead of the timetable change. For this so-called wish list detailed train parameters have to be submitted.

PaPs are offered via an international platform (PCS) one year ahead of the timetable change and may be requested until the start of the working timetable procedure. If several RUs apply for the same PaP, the RUs who use the PaP on more days for a longer distance will receive it (Bscheid, 2020).

Similar to framework agreements, PaP do not define a concrete train path but a band width. This band width is defined by the IM and therefore varies from network to network. While, in some countries, the PaP defines a band width of 15 minutes, it might be an entire day in other countries. Furthermore, the resulting train path offers of the IM are not necessarily completely coherent with the original request (Bscheid, 2020).

International Passenger Train Path

There is no formalised procedure for the coordination of international passenger train services yet. An action to redesign the international timetable process called TTR Migration was launched by RailNetEurope and Forum Train Europe in 2020. It aims to optimise the timetable allocation process of IM throughout Europe (RNE, 2020). Amongst RUs, there is the Forum Train Europe and on the other hand informal bilateral coordination between different RUs (mostly incumbents) regarding adaptations of timetables (Forum Train Europe, 2021).

In the event of RUs develop new cross-border services, they need to declare this interest if they run on the same lines as existing PSO services. Before train paths are allocated, it needs to be verified by the regulator whether the economic equilibrium of PSO-services is not in danger (EisbG, 1957).

Train Path Catalogue

Pre-arranged train paths can also be applied on a national level. In Switzerland, train path catalogues of PaPs are published for international freight trains according to Art. 40, Directive 2012/34/EU via the independent Swiss capacity allocation body (Trassenvergabestelle, 2021). Freight train paths along the North-South corridors are designed beforehand to fit the ITF timetable. A certain number of freight trains per hour per day is allocated per line. The coordination with the ITF results in generalised train paths that require certain rolling stock properties. These generalised train paths for freight trains provide transparent information about the available capacities (Bscheid, 2020). While these train paths are not tailor-made, they are predictable and stable (Pöhle et al., 2012).

3.3 Conflicts in the Working Timetable Process

The working timetable process starts with the IM allocating all train path requests received (Figure 3.4). In the event of conflicting requests, the IM is allowed to adapt train paths "within reasonable limits". The adapted train paths are presented to the respective RU including the applied criteria (Art. 46-2, Directive 2012/34/EU). These reasonable limits depend on the train type. Here, clocked services and international train paths are least flexible (Catharin and Gürtlich, 2015).[14] If the modified train paths are not accepted by the RU, a coordination process between the involved parties and the IM is launched. If no amical solution can be found, a dispute resolution process has to be initiated along predefined formal criteria.

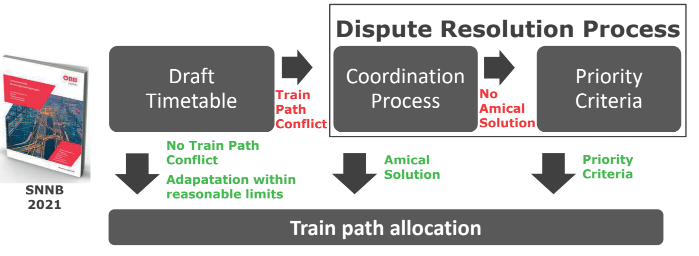


Figure 3.4: Conflict and dispute resolution process

When defining a procedure for STPs this process has to be considered. In the suggested procedure, the exact position of the STP has to be guaranteed in order to serve hubs at the respective arrival and departure times.

In the first phase of the coordination process, an amicable solution between the RU concerned and the IM is aimed for. The IM shall attempt to allocate all requests through a coordination process before applying priority criteria. The principles for this process have to be defined in the network statement, taking into consideration the arrangement of international train paths and ITF services (§ 65b Abs. 3 EisbG). If the coordination process does not lead to an amicable solution, the second phase of the coordination process, the dispute resolution process, is started (§ 65b Abs. 1 EisbG).

In Austria, the dispute resolution process is outlined in the SNNB based on §65b EisbG. In chapter 4.4.1 of the network statement, the principles and priority regulations to be applied

[14] In Italy, for example, the time window reaches from +/- 10 minutes for commuter trains, +/- 15 minutes for regional PSO services to up to +/- 30 minutes for freight trains according to Rete Ferroviaria Italiana (2020).

are described (ÖBB-Infrastruktur AG, 2020b). It foresees three stages with different criteria, as shown in Figure 3.5. Firstly, general principles are applied. Secondly, symmetrical clockface passenger services are considered. Thirdly, priority regulations are applied.

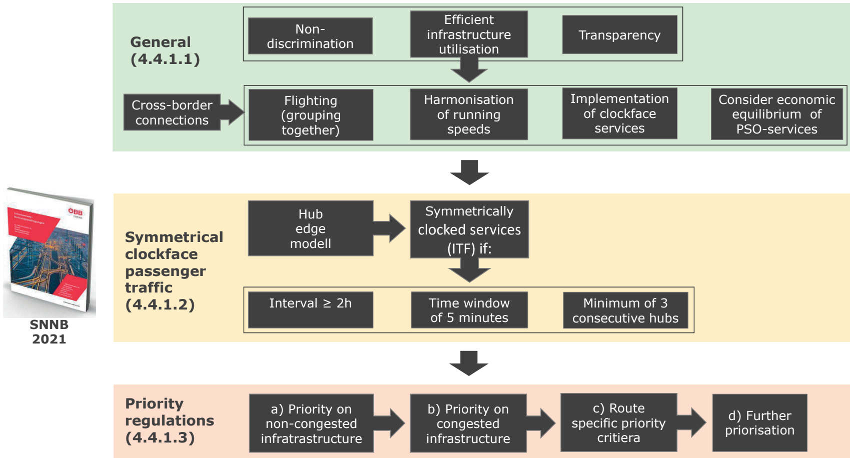


Figure 3.5: Principles and priority regulation in SNNB 2021

In the dispute resolution process, a solution has to be found within ten days once the process has been started. In any case, the infrastructure has to be declared congested. A congested infrastructure is an infrastructure where, even after a coordination process, not all train path requests can be fully satisfied (2012/34/EU).

The third step of priority regulations is divided into:

- Non-congested infrastructure
- Congested infrastructure
- Line specific
- Further priority

3.3.1 General Principles

In the train path allocation process, general principles of Directive 2012/34/EU and regulations of the national law must be considered. In the dispute resolution process, the IM is free to add further considerations as long as they do not conflict with the legislation (Catharin and Gürtlich, 2015). The importance of the general principles is stressed by the network statement of ÖBB-Infrastruktur AG by putting it in the first stage of the dispute resolution process. These principles are based on 2012/34/EU and EisbG, 1957:

- Accordance with the law of the European Union (Art. 39, Directive 2012/34/EU)
- Fair, transparent and non-discriminating treatment (Art. 39, Directive 2012/34/EU, § 63 Abs. 1 EisbG)
- Efficient use of rail infrastructure (Art. 26, Directive, 2012/34/EU, § 63, Abs. 1 EisbG)
- Economic equilibrium (Art. 11, Directive 2012/34/EU)

Aside from the self-evident first principle and the importance of fair, transparent and non-discriminatory treatment, the third and fourth principles are of special interest for the arrangement of STPs.

Fairness, Transparency and Non-discrimination

A "*fair and non-discriminatory*" behaviour in the context of train path allocation means that all applicants should be treated equally, regardless of their transport purpose. Equal, fair and non-discriminatory treatment as emphasised in Directive 2012/34/EU and § 63 Abs. 1 EisbG means, for example, to banish grandfathering rights of incumbents on certain train paths (Lewisch, 2002). Furthermore, non-discrimination means on equal terms for everyone. However, in the context of scarce capacity – at least in terms of timing – a deviation must be accepted if based on fair and transparent reasons (Cetin, 2015).

Effective Infrastructure Utilisation

IM have the legal obligation to "make optimum effective use of the available infrastructure capacity" (Art. 26, Directive 2012/34/EU). Directive 2012/34/EU requires an "effective" use of infrastructure capacity. However, "efficient" is also sometimes used. The effective use of infrastructure is not defined further while the term "efficient railway system" is used in the context of economic principles such as the following: establishing a regulatory, providing an efficient allocation process and opening up the market for commercial business (2012/34/EU). In § 54 EisbG, an economic and efficient use of railways is defined in terms of creating competition, encouraging the entry of new railway undertakings, ensuring access and creating supervision against abuse of the dominant position. An effective infrastructure utilisation is, again, not defined. However, § 55a Abs. 2 EisbG is more precise when defining the guiding strategy or master plan for infrastructure development. This master plan identifies the requirements that will make it possible to gradually introduce, in the interests of passengers, the interconnection of symmetrically clocked services in hub stations (ITF). In § 63 Abs. 1 EisbG, the word "effective" is used in the context of infrastructure utilisation; however, its meaning is not described further.

Lewisch (2002) argues that an efficient use of infrastructure requires a differentiation of the offer in economically terms. Such a differentiation – if it is objectively justified - does not constitute discrimination. Furthermore, priority criteria are inevitably useful in case of high capacity utilisation. They are to a certain extent contradictory to non-discrimination and must therefore be objectively justified. However, when considering PSO-services, which are financially weak by definition, the prioritisation to achieve optimal and effective infrastructure utilisation is inevitable (Segalla, 2002).

Since the words effective and efficient are used in different phrases in different contexts, a significant portion of the legislation is left to interpretation. As railway infrastructure is a complex so-called "scarce capacity", it is assumed that efficiency not only means the maximisation of the number of train paths, but also the use according to the purpose this infrastructure is assigned to. In the case of a mixed traffic route that allows for the realisation of the ITF, this must therefore be a central concern. Thus, it is assumed, that effective use in this context means (among other things) the implementation of the ITF.

Economic Equilibrium

The right of access may be limited if the economic equilibrium of a public service contract could be compromised (Art. 11, Directive 2012/34/EU). In case a commercial operator wants to offer services on a line with PSO services in the same segment, an objective economic analysis should be carried out by the regulatory body. If the economic equilibrium cannot be guaranteed, the PSO operator might be awarded an "exclusive right" (2012/34/EU). The PSO operator is then allowed "*to operate certain public passenger transport services on a particular route or network or in a particular area, to the exclusion of any other such operator*" (1370/2007/EC). In the Czech Republic, potential capacity constraints caused by new commercial services call for a proof of financial equilibrium in the event an additional RU would apply for slots (Správa Železniční Dopravní Cesty, 2019).

Benchmark General Principles

Different procedures are applied in the dispute resolution process in Europe. In most countries, a stage of applying general rules is chosen before applying priority criteria (see chapter 3.3.3). When comparing network statements, it can be seen that general allocation principles differ considerably. Table 3.1 shows which approaches are taken in the first step after a failed coordination process. The applied approaches are hierarchy of train types, level of track access charges (TACs), utilisation of train paths and social cost-benefit analysis (IRG-Rail, 2019b). Usually the following categories are distinguished:

- PSO services,
- International (freight) trains,
- Passenger and freight trains

Table 3.1: Approaches after coordination process fails and order of priorities if applied

								
Directly applying priority rules				**1.**	**1.**	**1.**	**1.**	
General Rules	**1.**							
PSO Services			**1.**					
International Passenger Services	**3.**		**4.**					
International Freight Services	**3.**		**5.**					
National Passenger Services								
National Freight Services			**2.**					
ITF	**2.**							
Framework Agreements			**3.**					
Social Benefit Analysis							**1.**	
Other criteria / pre-scheduling		**1.**						**1.**

In **Austria**, the principle of an efficient use of rail infrastructure is defined in the SNNB, chapter 4.4.1.1. It refers to "*internationally recognised and established principles*" in order to maximise railway infrastructure capacity. These principles are described by ÖBB-Infrastruktur AG (2020b) as:

- "*Flighting (grouping together) of trains [sic!] paths with similar speeds and/or stopping patterns…"*
- "*Harmonisation of running speeds […], e.g. by accumulating run-time reserves and/or running traffic with complementary stopping patterns*"
- "*Implementation of symmetrical clockface passenger services […], for an effective use of the rail infrastructure*."

The third principle is further explained as providing advantages of a regularly repeating operation and production plans, continuous symmetry and constant connections as well as train changes for passengers. Furthermore, the consideration of cross-border train paths is mentioned in so far as that they should not be adapted in the working timetable process.

Schneider (2013) speaks of coordination procedures as a tool towards an efficient use of rail infrastructure. "*Harmonising the average speed of trains in order to increase line capacity does not seem recommendable*" (Schneider, 2013). Homogenous train paths are defined as an instrument for maximising capacity, while at the same time the ITF is mentioned as a form of effective infrastructure use. However, the bundling of train paths or harmonisation of speeds partly contradicts the idea of an ITF with different train types and speeds.

In **Switzerland**, train paths are allocated according to the network utilisation plan which defines certain capacities for different train categories before the allocation process (SBB CFF FFS, 2020). A four-stage process is applied in the **Czech Republic** which ranks PSO services first, followed by combined transports and framework agreements and finally international passenger and freight transport (Správa Železniční Dopravní Cesty, 2019).

In **Germany**, **Italy** and the **Netherlands**, a priority catalogue is applied first (Ait-Ali and Eliasson, 2019), while in Sweden requests are considered according to the societal benefit of a train service (chapter 3.3.3). **Italy**, however, seeks a harmonisation of train paths (Rete Ferroviaria Italiana, 2020). As mentioned this is the case in Austria as well.

In **Great Britain**, if coordination fails, a request may be launched to a timetabling panel and, if unsuccessful, an appeal to the Office of Rail and Road may be made. Interestingly, there are no further principles or priority criteria applied.

3.3.2 ITF Services

On a European level the ITF is not explicitly mentioned in Directive 2012/34/EU. However, in the amending Directive 2016/2338/EU, the recitals in the preamble specify that Member States "*may attach specific conditions to the right of access to the infrastructure in order to allow for the implementation of an Integrated Timetable scheme for domestic passenger services by rail*" (2338/2016/EU). These specific conditions for Integrated Timetables may be applied as long as non-discriminatory access is ensured.

In Austria, in the SNNB symmetrical clockface passenger services or ITF services are considered in the second stage of the dispute resolution process. This underlines the importance of the ITF as stated in the EisbG. According to §55a Abs. 2 EisbG, the master plan for railway infrastructure has to consider the implementation of an ITF. ITF services are defined as rail passenger services provided at fixed intervals and symmetrically clocked.

Consequently, if railway infrastructure in hubs allows for the connection of ITF services, the IM is entitled to determine the infrastructure capacity necessary for this purpose for the provision of rail passenger services (§ 63 Abs. 2 EisbG). The required information has to be published in the network statement. Furthermore, the requirements of international train paths for freight services in cross-border freight corridors according to Art. 14, Regulation 913/2010/EU have to be considered.

The SNNB defines in chapter 4.4.1.1 so-called “*symmetrical clockface passenger services*” as tool to increase efficient use of infrastructure capacity and to smoothen railway operation. A minimum of three stops in consecutive ITF-hubs is required in order to be classified as such a service (ÖBB-Infrastruktur AG, 2020b). Figure 3.6 shows the relevant hubs in the edge-hub-model of the Austrian railway network.

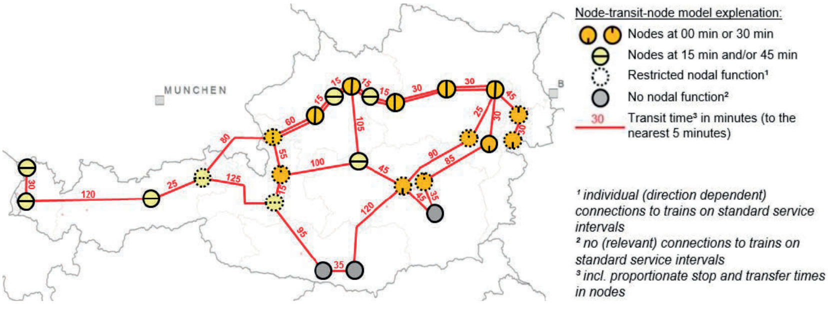


Figure 3.6: Modell of hubs and edges in the network statement of (ÖBB-Infrastruktur AG, 2020b)

Furthermore, the requested train paths need to arrive and depart within a time window of approximately five minutes at the hubs and run at least every two hours throughout the entire day (Figure 3.7). If these criteria are fulfilled, trains are to be privileged over other passenger trains in the train slot allocation process (ÖBB-Infrastruktur AG, 2020b).

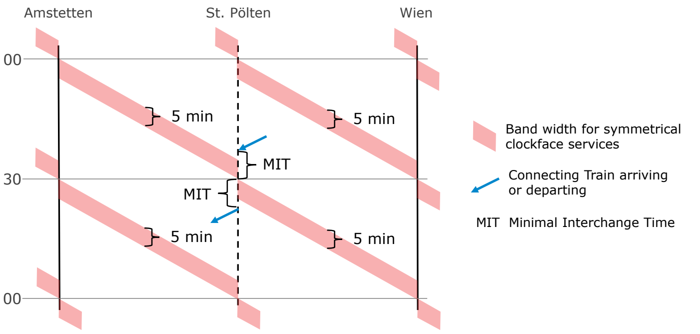


Figure 3.7: Band width of corridors for symmetrical clockface services according to the SNNB, own depiction based on ÖBB-Infrastruktur AG (2019a)

This measure is supposed to guarantee the utilisation of the infrastructure with respect to the ITF. Consequently, RUs are encouraged to apply for long-distance services that fit into the mentioned time window. This increases the likelihood of conflicting train path applications. Whatever solution is found in the coordination or dispute resolution process, the train paths must be adapted and arranged one after the other. This may result in train paths potentially ending up outside the time window. This in turn may lead to trains no longer offering attractive transfers to regional trains and may also increase the hub spreading (Walter, 2016). While the time window was meant to fix the clockface timetable, the procedure turned out to be ineffective.

In Switzerland, clocked services are not directly preferred in the first phase after the coordination procedure; however, the network utilisation plan is based on the ITF. This means the number of clocked services is considered, but the allocation itself is not. However, the network statement prefers them later on in the process within the priority criteria (SBB CFF FFS, 2020). The situation in the Czech Republic is similar. Here, clocked services are only indirectly covered in the priority criteria (Správa Železniční Dopravní Cesty, 2019).

3.3.3 Priority Criteria

The use of priority criteria comes with certain restrictions. Art. 45, Directive 2012/34/EU stipulates that criteria may only be used on the grounds mentioned in Art. 47 and 49, Directive 2012/34/EU. These are (i) a declaration of congestion for a certain stretch of infrastructure or an expected declaration of congestion and (ii) a designation of specialised infrastructure. In practice, many IM apply priority criteria even if neither of the two reasons can be applied for several reasons (IRG-Rail, 2019b):

- For the construction of train paths in the scheduling process
- For informally referring to priority criteria in the coordination process
- For formally deciding on the order of train path in the coordination process before declaring infrastructure congested

Principles of Priorities

Directive 2012/34/EU provides the basic framework for the application and consideration of priority criteria:

- Value to society relative to any other service that will be excluded
- Complying with public-service requirements
- Developing national and international rail freight services

While mentioned last in the list above, the importance of developing rail freight services has to be emphasised. The task of formulating detailed priority criteria falls to the IM according to Art. 47, Directive 2012/34/EU. It can be assumed that priorities should focus more on consumer demand and market efficiency rather than on technical parameters (Ait-Ali and Eliasson, 2019).

The legislator or the IM have to interpret the EU-Directive and define the value to society. While some IMs end up with a (hierarchical) catalogue of priority criteria (most Member States), some countries apply priority models (e.g. Sweden, Switzerland, Great Britain). The latter countries use a more or less elaborate social cost-benefit model. These models cover the costs of allocating/moving trains, maintenance, and others and should contribute to a socio-economically efficient use of infrastructure. However, most countries developed a priority catalogue based on certain train types. Usually IM give the highest priority to PSO and subsequently international and freight train services. Another method is the ranking according to the properties of the requested train path (IRG-Rail, 2019b).

Not only are priority rules different in every country, but also often difficult to interpret which can be problematic (Ait-Ali and Eliasson, 2019). If there is a strict right for prioritisation, big well-established companies could be anti-competitively preferred (BVwG, 2019). They must therefore be applied with care.

Tools for the Application of Priority Criteria

Various tools have been developed by the IMs for applying priority criteria. The most common are catalogues of (hierarchically) listed priority criteria, focusing on certain premises according to legislation or a defined social value. Others are economic algorithms to calculate, for example, social benefit of a train path or train path auctions.

Socio-economic methods aim to mathematically define the social value of a train service to society. Sweden, for example, allocates track capacity according to societal benefit to allow for a socio-economically efficient use of the infrastructure. Ait-Ali et al. (2017) give an insight on how societal benefit can be calculated with an elaborate theoretical model the timetable in a simulation. In Great Britain, the so-called code of practice includes an objective which serves as the definition of importance of a service to society (IRG-Rail, 2019b). For an optimal timetable and its value for society, see also chapter 2.3.

The idea of auctions is to have a neutral, objective approach which treats all requests equally. Just like other allocating methods all auctions are imperfect. However, it is stated that "*auctions are better than the current system of inherited train path capacity and pri-*

ority rules" (Stojadinović et al., 2019). The willingness to pay shows the worth of an infrastructure capacity of the applicants. Auctions in the context of train path allocation can be divided into several groups and mechanisms, as outlined by Stojadinović et al. (2019) and (Perennes, 2017). Further approaches for railway infrastructure auctions are proposed by Parkes and Ungar (2001) and Isacsson and Nilsson (2003). Eliasson and Aronssen (2014) suggest a four-step timetabling process, the second step being an auction for commercial traffic. It is assumed that an operator willing to pay more, will likely offer the most fruitful service to his customers and attract the highest demand. PSO are excluded from the auctions as this would bring the market out of balance (Svedberg, 2018). At the moment, auctions are used in train path allocation, e.g. in Germany and Switzerland. In both countries a bidding procedure is the final step in the dispute resolution process (DB Netz AG, 2019; SBB CFF FFS, 2020). For further aspects of auctions in railway infrastructure allocation, see chapter 6.1.1.

Priority Criteria for Non-Congested Infrastructure

Several Member States apply priority criteria for non-congested infrastructure directly after the coordination process has failed for several reasons, as mentioned above. A conflict of train path requests does not necessarily mean a section is congested if there is still enough free capacity (BVwG, 2019). A congestion is only implied if a train path cannot be allocated to an appropriate extent (Segalla, 2004).

IMs consider the following aspects when defining priority criteria (IRG-Rail, 2019b):

- Frequency of service, long-distance trains, number of additional stops
- Estimated total number of passengers
- Significance of trains in the transport system and the onward connections
- Affecting rolling stock and duty rotations
- Passenger trains in peak hours
- Energy-efficient freight operations

While in **Italy** priority criteria are only applied in case of congestion, most network statements consider prioritisation rules in the final stage of a conflict resolution processes underlining the importance of periodic or ITF train services.

The network statement of ÖBB-Infrastruktur AG in **Austria** applies priority rules for non-congested infrastructure. Symmetrical clocked train paths are to be preferred, followed by framework agreements and consequently clocked integrated trains and international trains. In this case, short-distance services providing integrated clocked services shall be preferred in hubs in order to be able to implement an ITF (ÖBB-Infrastruktur AG, 2020b). It is worth mentioning that framework agreements are taken into account, but only second to ITF paths. In combination with the time windows applied for allocating train paths of a framework agreement, it shows the lack of planning certainty of framework agreements.

In **Switzerland**, in the case of high capacity utilisation but not necessarily congestion, priority criteria are applied for infrastructure allocation. A distinction is made among different types of conflicts between passenger services and between passenger and freight services. However, framework agreements come first in both cases. If the conflict involves passenger services only, clocked services are preferred before services who pay a higher TAC. Freight trains are preferred over passenger services if they fulfil certain criteria (SBB CFF FFS, 2020).

In the **Czech Republic**, like in Switzerland, priority criteria are applied whether infrastructure is congested or not. Contrary to most other countries, the application of priority criteria happens during the coordination process. In this process, PSO services take precedence over open access products in train path allocation. However, once all services are allocated, the timetable construction proceeds by considering train categories. These train categories are combined transports, international freight transports, regular international transports, regular domestic transports and regular domestic freight transports (Správa Železniční Dopravní Cesty, 2019). As the final slot allocation is linked to train categories, PSO services are treated like self-sustaining trains in certain cases. According to the regulation, commercial long-distance trains are prioritised over regional trains (Janoš and Baudyš, 2013). This causes frequent overtaking of regional trains leading to extended riding times and less possibilities for transfer connections of ordered services (Tomeš et al., 2014). If the conflict resolution process fails, the respective infrastructure has to be declared as exhausted. However, lines are declared exhausted and not congested. Janoš (2018) gives an insight as to why the route Praha and Česká Třebová is declared "overloaded" but not congested, and which motives are relevant amongst RUs and IMs.

If the coordination procedure fails in **Germany**, regular-interval or integrated network services have priority over cross-border train paths and train paths for freight traffic. Integrated services can be passenger as well as freight services. In the case of passenger services, at least two connections to other train paths or services with short turnarounds have to be given. If these priority criteria do not help, the services which pay higher TACs or, finally, applicants who are willing to pay a higher charge supplement are preferred (DB Netz AG, 2019). While Berschin (2020) says they do not ensure the ITF, Stoffregen et al. (2017) argue that these criteria are not helpful at all. Furthermore, newcomers do not have a chance to be preferred.

In the **Netherlands**, the IM defines priority criteria; however, they only work as a "tool" or guideline in the coordination procedure and are not formally applied. Basically, "transport takes precedence over traffic", which means that commercial services are preferred over non-commercial transport (ProRail, 2020). Distinctive freight trains are considered first, and daily services are preferred over irregular services. While there are several periodisation rules for freight trains, the allocation of passenger trains is quite vague. As NS has exclusive rights on the core-network, it is relatively autonomous in setting the timetable. Regionally tendered services need to adapt their timetables in order to guarantee attractive connections to the Intercity trains (Kummer et al., 2013). Commercial international services run on a different network (Thalys, Eurostar and Intercity Direct) or are well integrated into the Intercity scheme (IC and ICE).

If the coordination process in **Sweden** fails a priority ranking based on the calculation of societal benefit of train service is done as described above (Ait-Ali and Eliasson, 2019). Eliasson and Aronssen (2014) argue that de facto, priority criteria are used instead of a calculation of the societal benefit.

The situation in **Great Britain** is rather different since franchise operators are privileged in train slot allocation. First, priority criteria and then decision criteria are applied, considering improvement of network capability, reflection of demand, journey time or commercial interest of (ProRail, 2020).

Priority Criteria for Congested Infrastructure

Art. 47, Directive 2012/34/EU states that the IM has to declare the infrastructure to be congested directly after the failure of the coordination procedure or if an infrastructure *"can be expected to suffer from insufficient capacity in the near future*" (2012/34/EU). For congested infrastructure, a capacity analysis has to be carried out and a capacity enhancement plan has to be implemented if not already done. Directive 2012/34/EU defines the form of a capacity analysis (Art. 50) and the enhancement plan (Art. 51). Consequently, priority criteria may be applied "*where charges in accordance with Article 31(4) have not been levied or have not achieved a satisfactory result and the infrastructure has been declared to be congested*" (2012/34/EU).

Priority criteria may be applied after the failure of the coordination process and in the event that the respective infrastructure is declared congested as stated in Art. 47-3, Directive 2012/34/EU. The IM can employ priority criteria to exclude applicants, including for framework agreements, only in the event of congestion of the infrastructure (Montero and Melero, 2020). Figure 3.8 and Table 3.2 give an overview of priority criteria in the case of congestion in selected European countries. The respective procedures for capacity enhancement plans can be found in IRG-Rail (2019b).

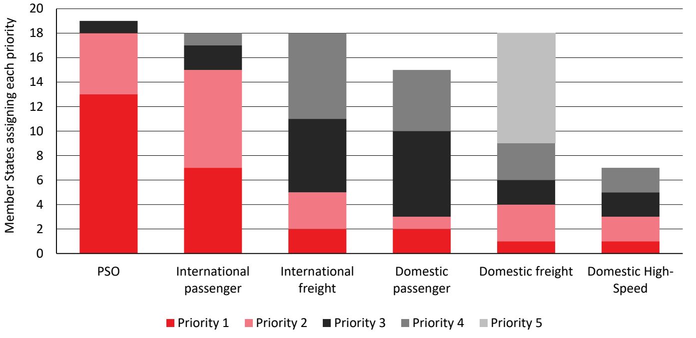


Figure 3.8: Priority criteria amongst Europe, based on European Commission (2021)

In **Austria**, EisbG § 65c Abs. 3 requires an enhancement plan after train path allocation failed in the coordination process and infrastructure was declared congested. The SNNB defines four steps of priority criteria which have to be applied. Firstly, clocked services according to § 63 Abs. 2 should be considered; secondly, PSO services during "*peak traffic times*"; and thirdly, services ranked according to the importance of the service for society, especially cross-border freight trains. Fourthly, long-term framework agreements are considered (ÖBB-Infrastruktur AG, 2020b).

Table 3.2: Order of applied priority criteria for congested infrastructure

								
Directly applying priority rules								
General Rules								
PSO Services	**2.**		**1.**					
International Passenger Services			**4.**	**2.**				
International Freight Services	**3.**		**3.**	**2.**				
National Passenger Services			**5.**					
National Freight Services			**2., 6.**	**4.**		**1.**		
ITF	**1.**	**2.***		**1.**		**2.**		
Framework Agreement	**4.**	**1.***	**3.**					
Social Benefit Analysis							**1.**	
Other criteria		**3.***				**3.**		

* In case of conflict between passenger services only

In **Germany**, the **Czech Republic**, the **Netherlands** and **Switzerland** priority criteria are applied, regardless of whether the infrastructure is declared congested or not. For the discussion of the priority criteria, see (i) non-congested infrastructure. In **Great Britain**, the infrastructure is declared congested and experts are consulted to find a solution (Ait-Ali and Eliasson, 2019). For congested infrastructure, the Code of Practice is applied.

In **Italy**, the order of consideration is framework agreements, PSO services, high-speed services using dedicated infrastructure as well as international passenger services and finally freight services. If this does not lead to any solution further priority criteria considering overnight freight services, clocked services, frequency of trains or track utilisation are applied. Furthermore, a section can be utilised by one train category by no more than 60%. Exceptions apply to specialised lines (Rete Ferroviaria Italiana, 2020).

In **Sweden** train paths are allocated on the basis of a criteria catalogue to ensure the most economically efficient use (Trafikverket, 2021b). At the same time, a capacity analysis is prepared which shows short and long-term proposals for measures to be taken. In the "Capacity Reinforcement Plan" based on this analysis, possible alternatives are presented under consideration of a cost-benefit analysis. The final instance is a clarification of the route conflict by the railway supervisory authority Transport Styrelsen (Trafikverket, 2021b).

Line Specific Priority Criteria
Art. 49, Directive 2012/34/EU makes it possible to apply priority criteria for specific infrastructure if there are suitable alternative routes available. These criteria might be applied for high-speed lines or specified freight lines and are used e.g. in Germany and Austria. The Austrian IM gives priority to fast passenger trains (faster than 160 or 200 km/h) during the day and to long-distance freight trains during night time on upgraded high-speed lines where parallel lines are available (ÖBB-Infrastruktur AG, 2020b).

Further Priority Criteria
One of the most sophisticated division of priority criteria can be found in Austria. In the fourth step of the priority regulations "*symmetrical clockface passenger traffic*" that has a denser interval of clockface trains during the day (higher number) or serve more hubs is preferred. If this does not clarify the situation, requests "*with a higher train-km quotient*" are given priority over "*re-quests with a lower train-km quotient within a working timetable period*" (ÖBB-Infrastruktur AG, 2020b). This is the final decisive category if no decision has been made beforehand.

3.3.4 Practical Application of Priority Criteria in Austria

As described in chapter 2.5.1 several examples show the difficulty of combining the ITF with self-sustaining services. A particular challenge is the train path allocation and application of priority criteria, as will be explained in more detail by using the example of the hub Amstetten on the Western Line in Austria.

In 2019, the two competing RUs ÖBB-Personenverkehr AG (ÖBB) and Westbahn Management GmbH (Westbahn) applied for similar train paths in the timetable 2019. Both the incumbent ÖBB and Westbahn applied for a half-hourly interval each between Wien and Salzburg at almost the same time slots, only separated by a few minutes. Train paths fulfilling the criteria of symmetrical clockface traffic were requested as incentivised in the network statement (chapter 3.3.2). As the hub spread time is only determined by a loosely defined frame, both operators were able to meet the requirement to serve three consecutive hubs while running at almost the same time. However, as train paths serving the hubs cannot be allocated at the same time, they were arranged one after the other (Figure 3.9).

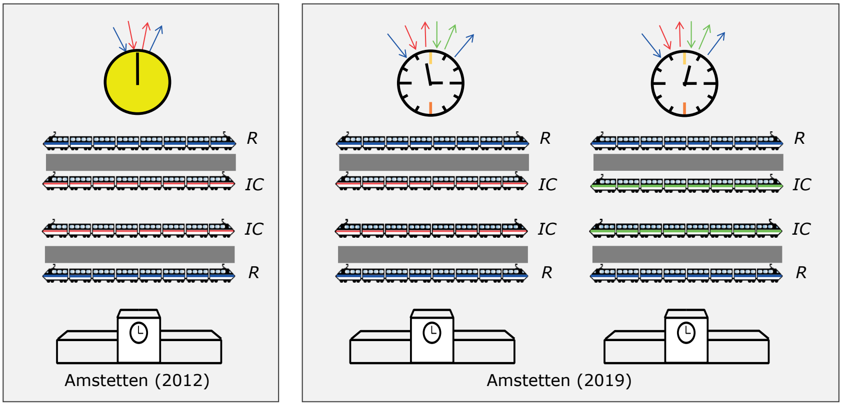


Figure 3.9: Transfers in the hub Amstetten without (2012, left) and with competition (2019, right)

In Figure 3.10, the left hub clock shows the original concept of the hub Amstetten with long-distance trains arriving and departing at the full hour and regional trains arriving before and departing after the long-distance services. Finally, in 2018, the RUs served the hub one after another as shown in the right hub clock. After the number of IC trains at the full hour was doubled, the duration between the arrival of the first IC train and departure of the last one increased from two to twelve minutes.

As an amicable solution could not be found during the coordination process, the IM allocated the train paths of Westbahn as requested and moved the requests of ÖBB in the course of the dispute resolution process. This resulted in a (i) hub spreading and (ii) lost transfers from regional train services to long distance services of ÖBB. The suggested alternatives were denied by ÖBB and led to the application of priority criteria. Consequently, the train paths of ÖBB were adapted, since moving the train paths of Westbahn would have resulted in extensive adjustments in the region around Vienna.

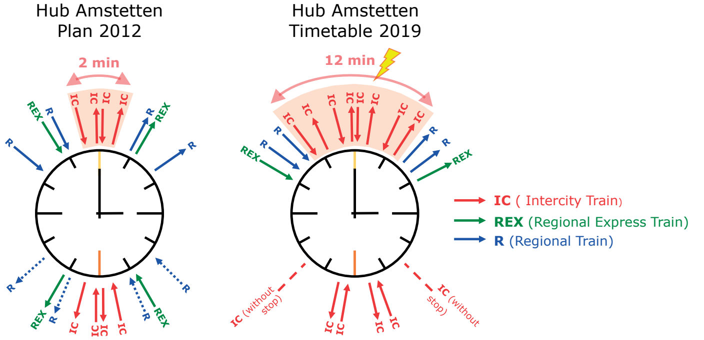


Figure 3.10: Hub spreading in Amstetten. Left: The original planning, according to Uttenthaler (2012). Right: Timetable 2018, according to ÖBB-Personenverkehr AG (2018)

In the final timetable, both RUs could only serve half of the hub (either towards or from the hub) each, but only the incumbent offered continuous tariffs. The lost network connections on regional branch lines had to be replaced by additional service orders and even some bus replacements (BVwG, 2019). Adapted departure times have a minor impact on long-distance services. However, there is a more significant impact on connections to the regional train network and regional services themselves.

ÖBB subsequently filed several complaints against this decision of the IM at the regulator SCK. ÖBB argued that only their train path requests fulfil the requirements of the network statement and that the current solution puts a high number of commuters at a disadvantage. In 2018, Westbahn applied for the same request as were fixed in the coordination process of 2017. However, the resulting train paths did not fit the requirements of the hub-edge model laid down in the network statement.

This case shows that predefined prioritisation of integrated services by law, since it cannot cover all cases a priori, ensures neither the implementation of a nationwide ITF nor the planned usage of infrastructure. Although the process is fundamentally aligned with the

ITF, the wrong incentives are established, which ultimately do not lead to an optimal outcome. The train path conflict was negotiated over several instances.

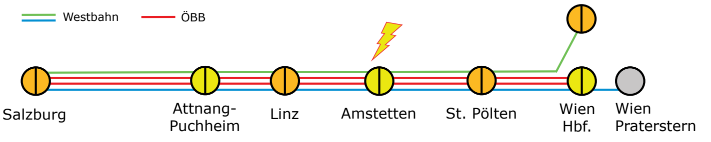


Figure 3.11: Conflicting train paths on the Western Line in Austria in 2019

Over the course of the complaint the Schienen-Control Kommission (SCK) rejected ÖBB's application by arguing that in general all train path requests should be considered. Prioritisation criteria on a non-congested infrastructure should only be applied when not all train paths can be allocated, which then de facto constitutes a congested infrastructure. Furthermore, the following arguments were put forward (Schienen-Control GmbH, 2018):

- Generally, all train path requests should be considered and allocated (§ 65 Abs. 6 EisbG).
- Prioritisation is only to be applied for congested routes or specialised infrastructure (Art. 45, Directive 2012/34/EU), otherwise all requests considering constraints shall be taken into account.
- A strict prioritisation of ÖBB leads to follow-up conflicts that affects far more passengers than the option decided on.
- Infrastructure capacity shall be allocated under reasonable, non-discriminatory and transparent conditions in accordance with the principles of equal treatment and an effective use of railway infrastructure (§ 63 Abs. 1 EisbG).
- Suggested alternatives of ÖBB were neglected as they would imply secondary conflicts[15] and as a result would have negative effects on the operation of Westbahn and their economic constraints.

Following this dismissal, ÖBB appealed to the next higher instance, the Federal Administrative Court (BVwG), arguing again that its request had to be considered over Westbahn. ÖBB raised several arguments as to why their services should be considered (BVwG, 2019):

- The request of ÖBB fits in the hub-edge model and serves three consecutive hubs (St. Pölten – Amstetten – St. Valentin) unlike Westbahn.

[15] As Westbahn has run every second service from Praterstern via the "Stammstrecke", the main route for regional and commuter services in Wien, shifts of Westbahn train paths would have resulted in shifts of these regional and urban train services. Therefore, far more commuturs would have been affected than by shifting ÖBB train paths not running on this dedicated route for commuters.

- As symmetrical clockface services are explicitly listed in the principles and fulfilled by ÖBB.
- According to the EisbG, priority rules are not limited to congested infrastructure, as it is not explicitly excluded to apply priority criteria on non-congested routes.
- If it were illegitimate to set priority criteria for non-congested infrastructure the network statement would not be legally compliant.
- Legislation emphasises infrastructure expansion for ITF and the importance of clocked services. Therefore, it seems logical that the network statement prefers clocked services, and this has to be applied.
- Arguments against alternative ÖBB train paths suggestions because of short turnaround times for Westbahn-services are questioned by referring to short turnaround times of the ÖBB Intercity-trains at Flughafen Wien.

In its statement, the BVwG confirmed the SCK's view and added further arguments (BVwG, 2019):

- There is no absolute claim on train paths for clocked services whether the infrastructure is congested or not.
- All train path requests shall be complied by the IM (§ 65 Abs. 5 EisbG) and all constraints shall be considered as far as possible (§ 65 Abs. 6 EisbG).
- The respective infrastructure is not considered to be congested. Even if there are conflicting request, the adapted train path can be allocated within an acceptable range.
- A strict prioritisation of ÖBB would lead to negative secondary effects which would affect a relatively large number of passengers.
- Incumbents could be favoured by applying prioritisation criteria.
- No grandfathering may arise from previous timetables (including previous coordination procedures).
- In the sense of a cross-company view, the idea of the clock hub is maintained within the network.

Besides referring to the legal considerations of Directive 2012/34/EU and EisbG as being transparent, non-discriminatory and handling all requests equally, the lower number of passengers affected and the economic constraints of the competitors were rated higher than the compliance of the requests with the ITF (BVwG, 2019). The ruling must be considered in the light of the fact that ÖBB is the incumbent. It is assumed that a court would therefore be rather critical of the incumbent in the sense of preserving competition (Casati, 2020). It remains to be seen how prioritisation rules on routes that are not congested should be dealt with. SCK and BVwG refer to Directive 2012/34/EU which only sets such rules for congested and specialised infrastructure. However, as prioritisation criteria for non-congested infrastructure are also applied in other Member States it does not mean that the application of such rules is null and void. While the EisbG clearly underlines the importance of the ITF regarding infrastructure development and supports that clocked services shall be facilitated on this infrastructure, a clear approach for how to achieve a fully functioning ITF has yet to be devised.

3.4 Findings of Status Quo in Infrastructure Capacity Allocation

From the aforementioned, the following statements concerning ITF and competition can be derived:

- Fair and non-discriminatory allocation and effective infrastructure utilisation are the basic principle of train path allocation (Art. 38, Directive 2012/34/EU).
- All constraints on applicants, including the economic effects on their business, should be considered (Art. 47, Directive 2012/34/EU).
- Allocation methods differ in dealing with train types, types of train path requests and socio-economic calculation models between different countries.
- The significance of infrastructure development for the ITF and the enabling of clocked services on the infrastructure is defined in EisbG (§ 54 and § 62 Abs. 2).
- The importance of integrated services is foreseen on a European level (preamble of Directive 2016/2338/EU).
- Priority criteria are foreseen for congested and specialised infrastructure as mentioned in Art. 45, Directive 2012/34/EU. However, several IM apply priority criteria also for non-congested infrastructure.
- Even if priority criteria are applied, there is no absolute or exclusive right on infrastructure. Exclusive rights can only be granted if the economic equilibrium of a PSO service is at risk (Art. 11, Directive 2012/34/EU).

3.5 System Train Path Approach – Allocation Principles

Legal feasibility is crucial for the practical application of STP bundles. A sequential procedure is chosen where STPs are prioritised in order to fix departure and arrival times in hubs for an optimal connectivity.

3.5.1 Legal Aspects of the Proposed Procedure

The following considerations were identified in order to ensure the priority of STPs. The proposed logic, which requires only minimal changes in the SNNB, builds on this.

ad Non-Discrimination
The infrastructure allocation has to be based on fair, non-discriminating and objective criteria that are published in the network statement. These criteria need to aim for improving quality of services in the network or improving infrastructure utilisation. Consequently, ITF services can be given more weight than other services even if it might be a disadvantage for some RUs. This ensures a high quality of services by promoting competition with clear rules.
The precept of non-discrimination derives from the principle of equal treatment under Union law. It means, that comparable situations should not be treated differently and different situations are not to be treated in the same way. Consequently, it is fair to treat all RUs equally. Treating unequal requests unequally based on fair and objective criteria that are published beforehand is fair (Catharin and Gürtlich, 2015).

ad ITF
Prioritisation for regular integrated network services can be found in many Member States. Although Directive 2016/2370/EU does not specifically mention the ITF, the recitals in the preamble do stress the importance of integrated network services. According to § 63 Abs. 2 EisbG the IM is obliged to foresee capacity for ITF services if the infrastructure is capable of it. As the infrastructure is continuously developed according to the ITF (§ 54 EisbG), this implies an effective utilisation of infrastructure. Furthermore, an ITF has shown to be the reason for an increase in ridership (chapter 2.4), which makes the market more interesting for competitors and thereby stimulating competition. Another argument is RU constraints (§ 65 Abs. 6 EisbG). Beside economic constraints an RU serving tendered STP bundles has the constraint to serve STPs. Therefore, tendering system train paths as PSO bundles strengthens the prioritisation of these pre-defined train paths in the infrastructure allocation process.

According to the SNNB, ITF services are to be given preference for both congested and non-congested infrastructure, provided that they fulfil the requirements of the hub-edge model. However, not every train path conflict leads to a declaration of congestion, and priority rules for non-congested lines are not covered by EU law (see chapter 3.1). Nevertheless, this ranking provides a strong argument for giving preference to system paths on both congested and non-congested lines. Furthermore, the SNNB gives priority to certain train types on specialized infrastructure if alternative routes are accessible. These rules should be extended in line with the development of the network; however, they reach their limits where no viable alternative routes are available.

ad PSO

PSOs are defined by Directive 2012/34/EU amongst one of the services that shall be considered in the case of prioritisation. This specification of priority criteria has to be clarified on a national level, as the Directive 2012/34/EU only sets the boundary conditions (Karl, 2015).

Priority criteria should consider the importance of a service to society relative to other services that will be excluded or adapted. On the one hand, an absolute priority for PSO services is critical, as, according to Directive 2012/34/EU, only relative priority should be granted. On the other hand, this might lead to situations where regional PSO services with a few passengers are prioritised over self-sustaining clocked passenger services with several hundred passengers (Segalla, 2002). Furthermore, it is not possible to distinguish between different types of PSO services as shown in (Schneider, 2013). In the SNNB of ÖBB-Infrastruktur AG, clocked services are ranked higher than PSO services, which are considered in second place in the case of congested infrastructure (ÖBB-Infrastruktur AG, 2020b). Giving absolute priority to PSOs should therefore be avoided and the importance to society should be stressed (Segalla, 2004). Considering that PSO-services rely on taxpayer money and that services using STPs have to fulfil the constraint (§ 65 Abs. 6 EisbG) of serving the ITF, which requires additional taxpayer money, the importance to society of serving STPs is obvious. Therefore, it is essential to define a coherent solution that takes into account the requirements of different types of transport – PSO as well as self-sustaining – and long distance as well as regional. If clocked long distance services run under PSO as well as regional services, all services serving an ITF-hub will be prioritised and self-sustaining services will consequently get train paths outside of this range.

ad PaP

Train paths predefined by the IM are compatible with EU law, as shown in particular by the provisions on international freight train paths. Further applications are pre-arranged freight train paths in Switzerland (Trassenvergabestelle, 2021).

In order to implement STPs as PaPs, a stable situation in the infrastructure allocation process must be ensured. This means that the position of STPs must not be changed during the course of the working timetable preparation or at least they must be prioritised over other applications. In the comments on the "Deutschlandtakt" (Gipp, 2015) and Austrian case law (BVwG, 2019), it is argued that there is no absolute right on train paths, even if

OA operation is promoted. An RU is therefore not entitled to every conceivable infrastructure capacity. In this context, it is consequently crucial that STPs are prioritised over other train path applications. According to EU law, all train path requests should fundamentally be covered as far as possible. Nevertheless, priority is given to cross-border services and especially international freight services. The resulting ranking alone limits access to infrastructure capacity for national passenger transport (Gipp, 2015). Furthermore, there is the option of an exclusive right on train path in the form of a concession which would make allocation rather clear. According to Art. 2(e), Directive 2016/2370/EU, concessions are only possible if such rights were granted under a PSO before 16th June 2015.

When designing STPs as PaP, the capacity of a line may not be fully covered with STPs, thus preventing other services from running on a certain section of railway infrastructure. To guarantee freight train paths in particular, these could be pre-planned as well if they do not interfere with STPs. However, when applying STP it must be ensured that in the infrastructure allocation process, PaP for freight have a lower priority than STPs.

STPs are a type of PaP designed to fit the requirements of the ITF in a liberalised market. These STPs are combined to form lines and, in turn, bundles. Finally, these STP bundles are tendered as PSOs.

Suggested Logic

Based on these considerations, the following logic for allocating STPs is suggested:

- Firstly, only STPs which serve all hubs of a route adequately and, according to the rules of an ITF, will enable the ITF to be implemented in the best possible way, thus allowing the infrastructure to be used effectively. The importance of the ITF and the corresponding infrastructure development is clearly emphasised in both the SNNB (4.4.1.2) and the EisbG (§ 55a Abs. 2). From this alone, a significant constraint can be derived to consider STPs before other train path requests.
- Secondly, it is advisable to award STP bundles in the form of a competitive PSO tender where every licensed RU is free to apply. If the winner of a competitive tender gets awarded the STPs, a non-discriminating allocation in accordance with the principle of equal treatment is guaranteed. The winner of the tender is contractually required to order STPs, which further strengthens the argument of the ITF being a constraint for the train path request.
- Thirdly, PSO services are already to be given preference in the allocation of train paths.

3.5.2 Need for Adaptation in Legislation and Network Statement

For the procedure described above, the preference of PSO traffic for non-congested infrastructure should be in second place in the SNNB. By this logic, STPs are to be preferred in any case over other train path requests. Furthermore, the form of STPs has to be included in the network statement to block the respective infrastructure allocation in advance. In the course of the working timetable process when the RU and its rolling stock serving a system train path is known, the STP can be reduced to a single train path.

Furthermore, it would be useful to describe the implementation of ITF services in EisbG in more detail. Art. 39, Directive 2012/34/EU allows Member States to define a guideline for the allocation of capacity which can then be formulated by the IM. Clarifying the functionality of an ITF hub in § 63 EisbG would establish the basis for defining STPs in the network statement.

4

Operational Concept of System Train Paths

System train paths (STPs) are the basic concept for combining ITF and competition. First, the concept of the STP is described by current examples. Then, the proposed approach and the associated parameters are discussed. The handling of regional, sprinter and freight trains will be addressed as well. Subsequently, the creation of STPs is described and applied to real infrastructure examples.

4.1 Description System Train Path

System train paths are standardised train slots that fit to the target timetable, consider the infrastructure properties and represent a band width of realistic vehicle properties but not one vehicle in particular. "Systematic" means a certain set of features in a (mostly) repeating pattern. The opposite of a systematic timetable is a set of train paths with individual properties in any desired time sequence.

When defining an STP, several boundary conditions have to be considered such as the number of useful STPs and train paths for other train services. Furthermore, minimal train sequences, stopping times or conflicts on the route like crossings are relevant (BAV, 2020).

An STP runs from one hub to another hub, and describes a certain band width rather than a single individual train path. The path-time diagram in Figure 4.1. depicts the difference between an individual train path and an STP. The STP allows for a certain band width, it is however precisely defined in the hub to allow for optimal connectivity. The band width is defined by the parameters of timetable, infrastructure and vehicles. STP are created according to parameters such as time, distance, train length, traction, weight or speed. They thus represent predefined train paths for certain times and with a band width of characteristics.

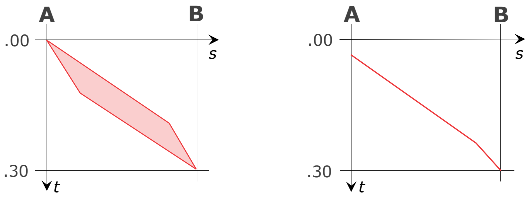


Figure 4.1: System train path in the shape of a parallelogram vs. individual train path

The allocation of STPs usually corresponds to a timetable type like the ITF, although in some countries STPs are applied for freight services without being integrated into an ITF (Monopolkommission, 2017). Kühne and Pöhle (2018) argue that STPs ensure a more homogenous train path configuration and optimise capacity usage.

STPs for Freight Services

STPs are used in freight train slot allocation in Germany. Opitz defines an STP as a (freight) train path that is calculated and allocated after allocating passenger services (Opitz, 2009). Streitzig et al. (2016) show that STPs significantly improve the quality of freight traffic and can lead to more freight connections in general by clustering freight train paths according to vehicle properties. Since the vehicle properties of freight trains vary considerably, there is no one-size-fits-all. In Germany the clustering of similar vehicle dynamics into groups makes it possible to incorporate 80% to 90% of all freight trains (Pöhle, 2018). These STP for freight are based on “real” requests. Freight train path requests of an RU may be neglected if the vehicle properties do not match. In networks with mixed traffic, freight services as well as fast passenger traffic have to be considered when designing STPs (Pöhle, 2018). Pöhle and Feil (2014) argue that system train paths ensure a more homogenous train path configuration and optimise capacity usage. The automated design of STPs for freight is described in Kümmling (2018). A further model for the optimal insertion of STPs for freight services into an existing timetable are discussed in Nachtigall et al. (2014).

STPs for Passenger Services

System train paths for passenger services can rarely be found in strategic planning documents or network statements e.g. in ITF-oriented railway networks.

In **Switzerland**, the Bundesamt für Verkehr[16] (BAV) publishes network utilisation concepts which define the number of long-distance, regional and freight trains in a model hour. The network utilisation plan 2035 is designed by the respective IM (SBB) in coordination with the BAV (BAV, 2020). The plan determines train paths for long-distance services with exactly predefined arrival and departure times in the hubs and provides a detailed description of the paths for 2035 (Figure 4.2). While these times may vary by a few minutes in the final version of the timetable, the standard of detailed long-term planning and transparency is remarkable.

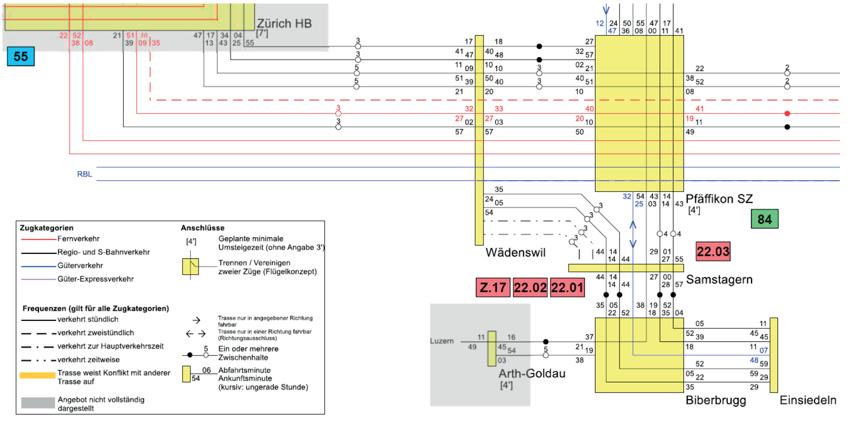


Figure 4.2: STPs in the network utilisation plan 2035 of SBB (BAV, 2020)

In the network statement of the **Austrian** IM, so-called "*symmetrical clockface passenger services*" are defined to attract long-distance services to be integrated into hubs. As many consecutive ITF hubs as possible should be served in order to be classified as such a service. Furthermore, the requested train paths need to arrive and depart at hubs within a time window of approximately five minutes (Figure 3.7). The interval has to be at most two hours during daytime. If these criteria are fulfilled, trains are privileged in the train slot allocation process compared to other passenger trains (chapter 3.1).

In 2019, the **Spanish** ministry for transport decided to launch a PSO tendering in order to establish competition in its high-speed railway network to increase infrastructure utilisation. Three bundles of system train paths with different sizes were designed to cover the main routes of the network from Madrid to Barcelona, Valencia and Sevilla. The perfectly

[16] In English: Federal Office of Transport

coordinated timetables were constructed by the IM defining departure times, stopping pattern, average speed and waiting times in stations. This way the capacity was increased by 60% compared to the timetable in 2019. However, the designed timetables including train paths are not binding and may be adapted after the tendering procedure by the RUs that won the competition (Montero and Melero, 2020).

Beside these descriptions of system train paths in the network statements, detailed descriptions of the characteristics of a system train path for passenger transport can be found in Smoliner (2019).

4.2 System Train Path Approach

Requirements for System Train Paths

Before designing system train paths, the requirements have to be defined that influence the characteristics and therefore the shape of a system train path.

An STP must be sufficiently well-defined to meet the requirements of the ITF and should still be flexible enough to allow for different vehicle characteristics, infrastructure conditions and stopping patterns. To achieve this, a set of parameters has to be considered in hubs and on the edges when designing STPs as listed in Table 4.1.

Table 4.1: Requirements for STPs

Parameters	Timetable	Infrastructure	Vehicle
Hub	minimal stopping time, transfer times	track layout, speed limit of tracks and turnouts	time of passenger exchange, door size, opening speed of doors, low floor vehicle
Edge	stops in-between, time reserves / timetable stability, capacity	distance, limited top speed, unplanned track changes due to disruptions	top speed, acceleration, energy saving

The IM defines basic **timetable** parameter such as minimal stopping time in hubs, transfer times between different platforms, minimum reserve times and considers capacity. In addition, an RU decides on the stopping pattern and additional time reserves in order to guarantee a stable timetable.

The IM specifies the **infrastructure** in hubs like track layout, speed limit of tracks and turnouts as well as the length of edges, top line speed and others. Furthermore, maintenance work or track changes due to timetable reasons affect train path design.

The **vehicles** of the RU strongly influence the riding time. The time of passenger exchange is affected by the vehicle design, like interior car layout, low floor entries or the arrangement of doors. Door size and opening speed of doors affect the stopping time in hubs. On the edges vehicle properties like top speed, acceleration, deceleration, uncompensated lateral acceleration or driving modes considering energy saving are essential.

Shapes of STPs

The aforementioned requirements result in a variety of possible shapes of system train paths. Depending on which objective is being pursued, this results in different forms, which were also examined when creating the model in the SNNB by ÖBB-Infrastruktur AG (Pavel, 2018).

A stochastic approach for the description of STPs is based on evaluating real or fictitious train paths as **boxplots**. Figure 4.3 shows boxplots each representing a set of train paths as discussed in Schittenhelm and Richter (2009) and Scheidt (2019). The size of the boxplots differ according to varying vehicle parameters. However, the band width might become rather large and claim a lot of capacity while not completely covering the requirements of an ITF.

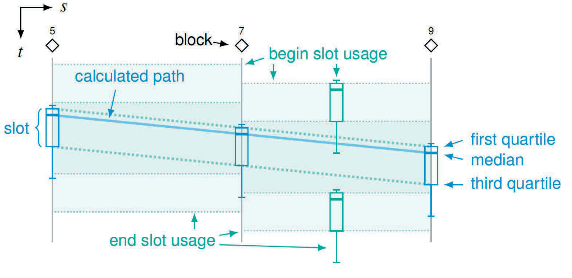


Figure 4.3 STP as box plot according to Scheidt (2019)

The Swiss approach of STPs defines accurate **lines** as shown in Figure 4.4. Departure and arrival times in the hubs are clearly defined in addition to the train journey on an edge. Despite including time reserves, the timetable stability is relatively low as there is no buffer for disruptions or reduced speed limits caused by maintenance works, etc. Therefore, the design of STPs needs to be carefully aligned to infrastructure and vehicle parameters. This detailed determination of the capacity on the route is optimal in the sense of the ITF, but it requires in-depth knowledge of the vehicle and stopping pattern in advance. In an open market, the rolling stock is dependent on the respective RU, unless there is an independent pre-defined vehicle fleet. Furthermore the detailed stopping pattern is also part of the unique selling proposition of the RU.

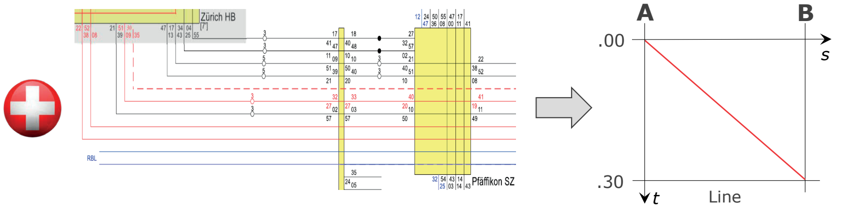


Figure 4.4: STP in Switzerland – approach line

The approach currently applied in Austria is a **band width** (Figure 4.5). A time window for serving hubs provides the RU with the opportunity to vary riding times. This enables companies to develop a unique selling proposition. Hub arrivals can be switched within the band width. Fast vehicles with high acceleration parameters can potentially serve additional stops. The concept of band widths can be seen as a simplified form of a more elaborate or detailed shape. Band widths can be defined easily and quickly for the whole network. However, as shown in the example Amstetten, this does not guarantee an optimal ITF utilisation and leads to hub spreading.

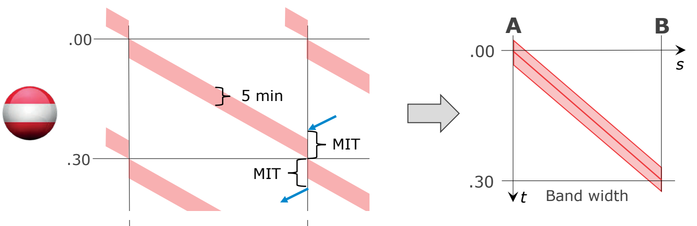


Figure 4.5: STP in Austria – approach band width

The shape of a **double cone** Figure 4.6 defines train paths with relative precision on the edges while there is a large possible variation in the hubs. It is a combination of the before-mentioned shapes. This approach might be useful for allocating a maximum number of trains on the edges or similar constraints. Nevertheless, there is considerable potential for a hub spreading, negative effects on transfer quality and the regional train network. Additionally, it might be difficult to define the exact shape of the edge without knowing the exact vehicle parameters beforehand.

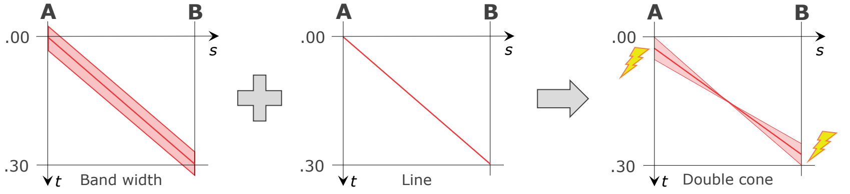


Figure 4.6: Combination of band width and line – approach double cone

Another combination of the line and band width approach is the shape of a **parallelogram** (Figure 4.7) which is iteratively designed by Caimi et al. (2009). The shape of a parallelogram best fulfils the requirements mentioned above. This form allows the characteristics of the infrastructure, rolling stock and timetable to be addressed flexibly, while at the same time ensuring the functionality of the ITF. Departure and arrival time in the hubs are clearly defined while the train run in-between is variable with respect to different line or vehicle dynamics, disruptions, energy optimisation or adoption of the stopping pattern. Furthermore, the band width on the edges allows for consideration of reduced line speed due to construction work or maintenance. To design a parallelogram for an entire network might be labour-intensive. Therefore, a simplified form should be identified, the detailed form of which can be determined more precisely if necessary.

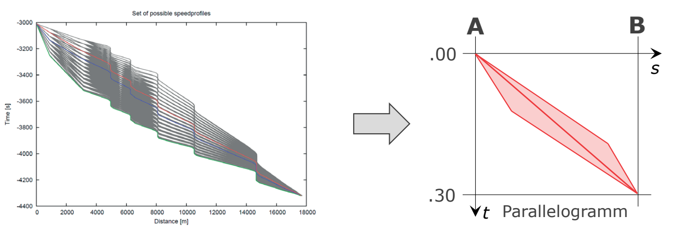


Figure 4.7: STP shape of a parallelogram. Left: speed profiles according to Caimi et al. (2009); right: shape simplified as parallelogram

4.3 System Train Path Parameters

The ITF sets clear constraints regarding arrival time in hubs and targeted edge riding times. The planning triangle consisting of track infrastructure, vehicle dynamics and operational parameters influence the possible set of parameters to design an STP. In the following considerations, it is assumed that an STP covers an infrastructure capacity between two hubs with an edge riding time of 30 or 60 minutes. A combination of system train paths running across several hubs and forming lines of STPs will be considered in chapter 5.

4.3.1 Railway Operation

The shape of the STP is in particular defined by operative requirements. These include minimum stopping times in hubs, time buffers for serving end-route stations or smaller hubs or vehicle turns at line ends (Figure 4.8).

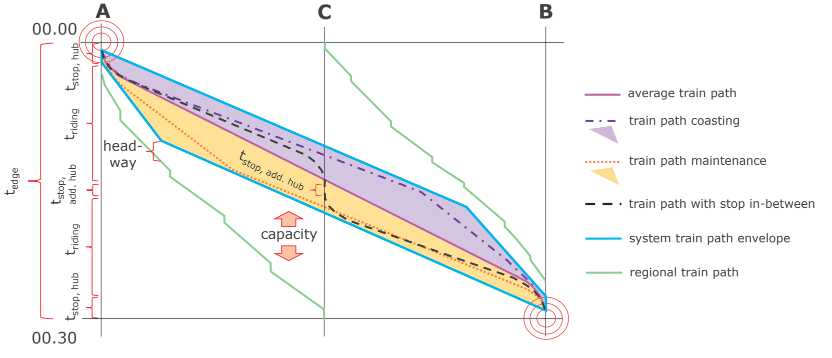


Figure 4.8: Parameters STP – railway operation

The following parameters for railway operation are dealt with on a macroscopic level in the operational sense as described in chapter 1.5. If not stated differently, the times mentioned are those defined in the SNNB of ÖBB-Infrastruktur AG. Those times might differ in other railway networks.

ITF

The hub and edge model of a network (Figure 2.14) defines hubs where smooth transfers amongst long-distance services and regional services are possible. Furthermore, edge riding times define the riding times for STPs between hubs. This is the essential basis for all further considerations on STPs.

The edge riding time is calculated as described in chapter 2.3 and is usually 15, 30 or 60 minutes. In the Austrian network, as shown in Figure 2.14, edges with a riding time of 30 and 60 minutes are dominant. Trains therefore serve hubs at a hub time of .00 or .30. The edge riding time includes the riding time between two hubs and any proportional hub stopping times [1].

$$t_{edge} = \frac{t_{hub,A}}{2} + t_{riding} + t_{hub,add} + \frac{t_{hub,B}}{2} \quad [1]$$

t_{edge}...	edge riding time
t_{riding}...	riding time
$t_{hub,A}$...	proportional stopping time of hub A
$t_{hub,B}$...	proportional stopping time of hub B
$t_{hub,add}$...	stopping time of additional hub

The geometric definition of STPs as a parallelogram provides slim hubs. The actual arrival and departure time result from the proportional hub stopping time. The proportional hub stopping time covers the stopping time and any shifts because of asymmetrical hubs or due to operational processes like splitting or turning-around of vehicles. Therefore, the earliest possible departure is 0.5 minutes after and the latest 5.0 minutes after the hub time. This applies vice-versa for arrivals at hub time. Further values can be found in Table 4.2.

Table 4.2: Parameters STP – hub time

Parameters hub time [minutes]	Total value	Proportional value*	Source
Min. stopping time	1.0	0.5	ÖBB-Infrastruktur AG (2020b)
Max. stopping time	3.0	1.5	
Splitting	8.0	4.0	
Turnaround	10.0	5.0	

* The proportional value is the total value split amongst the two edges starting/ending at a hub

Stopping Pattern

The shape of a parallelogram clearly defines the STP at the hubs but allows for a flexibility between the hubs. Therefore, RUs can decide to introduce additional intermediate stops if the vehicle dynamics allow staying within the boundaries of the targeted edge riding time. Most edges allow for one additional stop, only in the event of a short riding time a second intermediate stop will be considered. When designing an STP these potential hubs have to be considered as this might affect the shape. Considered will be hubs which:

- are stations that are suitable to function as semi hubs at .15 or .45 (Walter, 2016)
- are already served by long-distance services today or
- indicate an attractive passenger potential due to their population, size or location

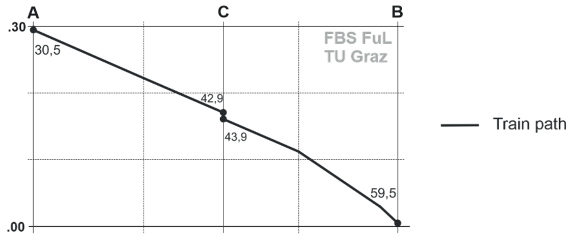


Figure 4.9: Train path with stop in-between

Stopping Time

The minimum stopping time in hubs depends on the passenger volume and the importance of the hub. Furthermore, the passenger exchange time of vehicles strongly affects the length of the stopping time. Timetable-related are the stopping time, synchronization time, handling time as wells as minimum transfer times and transition buffer time (Figure 4.10). The vehicle related parameters are described in chapter 4.3.3.

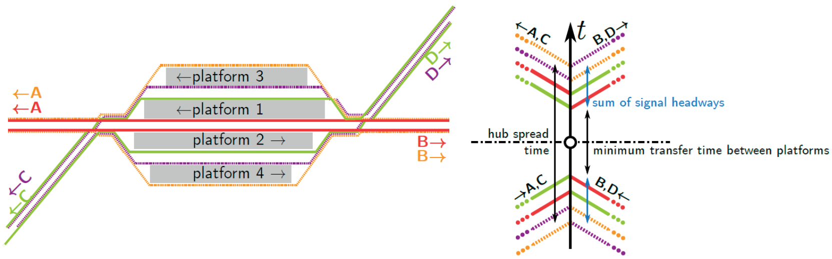


Figure 4.10: Parameters STP – transfer time according to Walter (2016)

Transfer times describe the time needed for the transfer from one vehicle to the other which depends on soundly designed platform layouts (Brezina and Knoflacher, 2014).

Hub stopping times are defined in Table 4.3 and can be assumed as:

- 1 minute in case of hubs with low passenger volume or trains with fast passenger exchange
- 2 to 3 minutes in case of medium passenger volume
- 4 or more minutes in case of high passenger volume or operational reasons like coupling, splitting, turnaround driver or locomotive change

Table 4.3: Parameters STP – hub stopping time

Type of hub and stop [minutes]	Absolute value	Proportional hub stopping time	Resulting arrival / departure	Source
Request halts	1.0	0.5	.59.30 / .00.30	ÖBB-Infra-struktur AG (2020b)
Intermediate stations and stops	2.0	1.0	.59.00 / .01.00	
Large stations and railway junctions	3.0	1.5	.58.30 / .01.30	
Large stations (including buffer time)	4.0	2.0	.58.00 / .02.00	-

Timetable Stability and Recovery Time

Recovery times are an essential part of the travel time and make it possible to make up for delays, planning inaccuracies or other imponderables. Several influences cannot be assumed accurately ahead such as the coefficient of friction (adhesion) or the train driver behaviour (Pachl, 2021). Recovery times are defined in the network statement and are based on international empirical values such as those defined by the UIC (2000). They usually represent a percentage surcharge on the journey time. In addition, reserves in hubs can be planned in the form of a longer duration of stay. Standard values for line-related recovery times are:

- 5% recovery time (UIC, 2000)
- 7% recovery time for speeds higher than 200 km/h + distance related margin (UIC, 2000)
- 10% recovery time for strategic planning of ITF-timetables (Uttenthaler, 2010)

The recovery time is usually higher in an early planning stadium while it becomes smaller as soon as the various boundary conditions are known more precisely. Furthermore, recovery times may be reduced by the IM to better fit a train path in the timetable construction or raised to increase timetable stability. RUs may also be interested in a higher travel time reserve in order to achieve energy-efficient driving or to ensure greater timetable stability for their customers. This can be achieved by a lower top speed level or driving at the allowed top speed and apply coasting in approximately the last quarter of the edge until reaching the hub (Sivanagaraju et al., 2010). However, recovery time should not be too high in order to not tempt staff to dawdle (Weigand and Berschin, 2020).

For a detailed analysis of the effects/interrelationships of buffer times and surcharges, see the ATRANS 1 project (Ullrich et al., 2020) or Streitzig et al. (2016). An improvement model for allocating recovery times and buffer times to raise stability in given timetables is presented in Kroon et al. (2008). As the ITF requires a high punctuality and vehicle and infrastructure parameters may change over time, 10% is chosen for calculations to ensure timetable stability (Uttenthaler, 2010). In addition, since the creation of STPs takes place well before the creation of the working timetable, this ensures a greater flexibility and stability in the creation of the timetable.

Overtaking

In case of mixed transport services, it might be necessary for fast long-distance passenger services to overtake slow regional passenger or freight services. Therefore, track changes should be considered which might limit the top line speed. A track change should be carried out in such a way that, in the event of low top line speed, a slow train moves to the tracks of the other direction. In case tracks and switches allow for a relatively high top speed the fast train moves to the other direction. In busy rail networks with dense intervals in regional and long-distance services four track lines are necessary for capacity reasons (Janoš and Kříž, 2016).

Mixed Traffic and Capacity

In order to optimise capacity, IMs are interested in limiting the band width of STPs in order to achieve a homogenous distance spacing and increased capacity. As stated above, the focus of this research is on long-distance passenger transport. It must be pointed out, however, that other train categories also need to be considered in the timetable. Train paths for regional trains, freight trains and fast point-to-point passenger trains are taken into account. The number of tracks has a major impact on the flexibility of railway operation.

On multi-purpose, multi-route railways trade-offs between the commercial requirement for different types of service and the obligation to obtain the best return on the cost of the infrastructure are unavoidable (Johnson et al., 2006). This contradiction is illustrated in Figure 4.11.

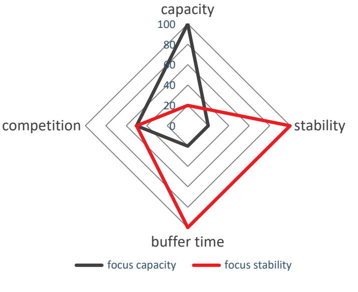


Figure 4.11: Relation of competition, capacity, stability and buffer time based on UIC 406 (UIC, 2004)

On highly utilised routes in multi-purpose networks at least one freight train per hour should be considered as it is done in Switzerland (BAV, 2020). However, as mentioned above, the shape of the parallelogram with a certain band width has considerable advantages and should therefore be retained until the annual train path allocation. The band width is larger than the current one of five minutes (see chapter 4.6). As soon as the RU operating the system path announces its concrete path based on vehicle parameters, stopping patterns, etc., unneeded capacity can be released in the working timetable.

4.3.2 Infrastructure

For infrastructure, the number and arrangement of tracks in the hubs and on the lines as well as the respective top speeds are decisive. In addition, delays due to maintenance works, slow speed sections or changes to tracks with lower top speed have to be considered.

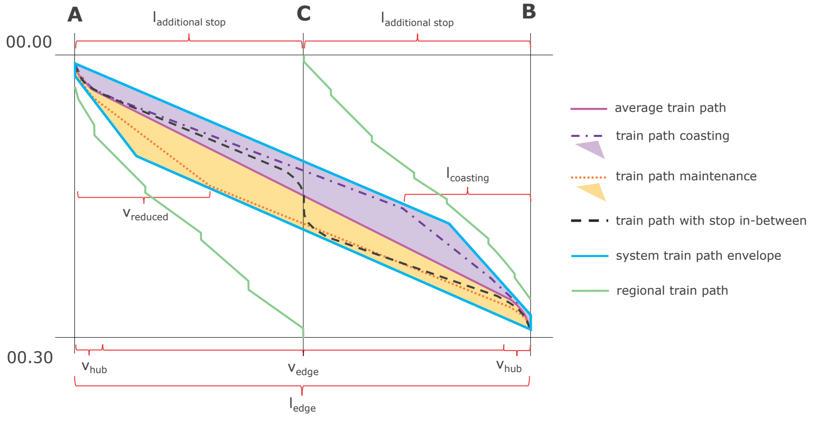


Figure 4.12: Parameters STP – infrastructure

Hub Parameters

Riding times within hubs are affected by the track layout and the top speed of the tracks and turnouts. Track and platform lengths, switch geometry as well as platform designs play a role for travel time (RFC Rhine-Alpine, 2020). Furthermore, track occupancy, entry and exit conflicts and the possibility of continuous connections have to be considered (BAV, 2020). In urban areas and in the proximity of hubs, the top speed is often reduced due to the alignment in densely populated areas.

Line Parameters

The most important parameter influencing edge riding times is the length of the railway line between hubs and the permitted top speed. The top line speed is affected by the alignment, signalling system, etc. Where the infrastructure is aligned to the ITF, the top speed is adjusted to allow for the targeted edge riding time of 15, 30, 60, etc. minutes.

The number of tracks does not influence the riding speed but enables operational flexibility and allows for attractive riding times even if one track is closed, occupied or under maintenance. For the effects of signalling systems on riding time and line capacity refer to Hansen et al. (2014) and Pachl (2021).

Maintenance and Disruptions

Maintenance works or disruptions may temporarily affect the top speed on sections or even entire edges and may require track changes. It is essential to consider capacity for maintenance works to guarantee the stability of STPs and the timetable in general (Gestrelius et al., 2019). In the event of maintenance on one track of a double-track-line, the top speed for the second track can be reduced. Depending on several parameters like safety systems, distance between tracks, top speed of the considered track, etc. the resulting top speed reaches from 80 km/h to 160 km/h (ÖBB-Infrastruktur AG, 2019c). The effects of such speed limitations are shown in Figure 4.13.

To ensure the stability of STPs it is essential to consider these effects of maintenance works and sections with reduced top speed on the shape of the STPs. Otherwise STPs will only be feasible in an optimum condition and will easily become instable and useless. This is relevant as intensive construction activity is to be expected on many long-distance routes and highly loaded turnouts have to be renewed regularly (Fellinger, 2020).

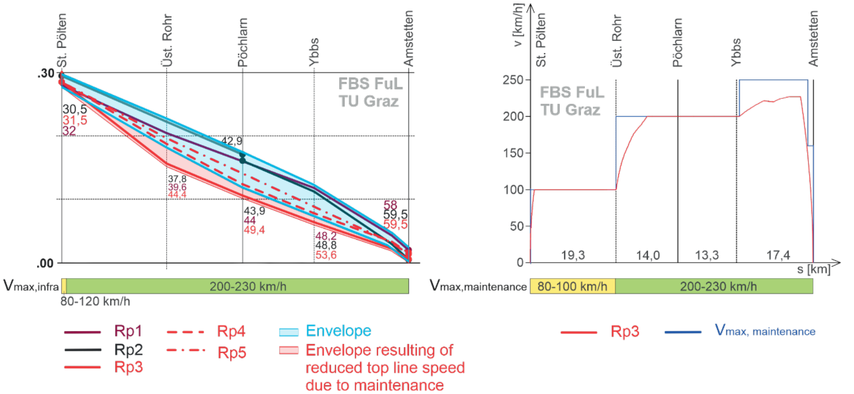


Figure 4.13: Reduction of line top speed due to maintenance works and effect on STPs

However, it is not possible to cover every possible renewal measure with STPs, otherwise too much capacity would be consumed, and edge riding times would not be feasible anymore. In the event of extensive renewal measures, an adaptation to the STP will be necessary for the period of construction.

When maintenance and disruptions are considered, the envelope of the STP becomes bigger and needs more capacity. However, maintenance works or detours also affect other trains whose trajectory also slows down in this section. The trajectories therefore shift relative to each other – the consideration of an STP does therefore not require additional capacity.

The strong interdependence of the ITF requires a high level of timetable stability and thus high infrastructure availability. As a high degree of resilience is requested buffer times are essential. These buffer times for maintenance and disruption can also be used to make up for delays from previous sections (Graffagnino, 2019). The yellow marked area in the STP (Figure 4.12) enables delays to be made up or provides a buffer in the event of maintenance works. Future upgrades for the ITF may be considered according to their planning status and detail.

4.3.3 Rolling Stock

While infrastructure parameters are clearly defined and usually do not change frequently, vehicle parameters can differ considerably depending on the vehicle type (EMUs or locomotive and waggons), manufacturer or model. These parameters differ with regard to the top line speed, acceleration, deceleration, etc. (Figure 4.14).

However, passenger services are more homogeneous regarding length, mass and vehicle dynamics compared to freight services. Given a wide variety of parameters in freight services, in Germany about 30 different profiles for freight services are applied in the design of STPs. Per line two to three different profiles covering slow and fast trains, train length or clearance profile are considered (Pöhle, 2018). In contrast, Switzerland no longer differentiates between traction classes in long-distance passenger transport, as the dense timetable requires fast, sprinting vehicles in any case (Graffagnino, 2019).

The relevant parameters for rolling stock covered in this chapter based on Rail Freight Corridor (2018) and Pöhle (2018) are:

- Train type (EMU or loco and waggon)
- Train length and mass (and profile)
- Vehicle dynamics (speed profile, acceleration and deceleration, top speed)

- Passenger exchange time
- Train control system

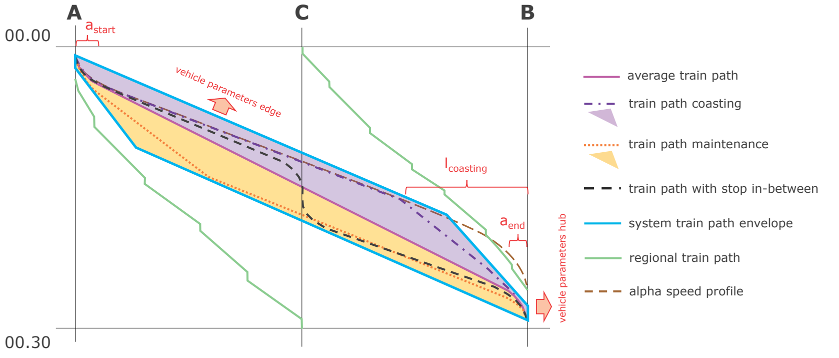


Figure 4.14: Parameter STP – rolling stock

Train Types

In passenger long-distance services, in Austria two types of rolling stock are used. Loco and waggon trains and electrical multiple units (EMUs). Loco and waggon trains are the traditional type of IC or EC trains and are still frequently used especially for services on lines with a top line speed of 200 km/h. A modern type of a loco and waggon train which is flexible in operation is the Railjet of ÖBB-Personenverkehr AG with a top speed of 230 km/h. EMUs are dominant on high-speed lines and are nowadays the standard type on conventional long-distance lines with top speeds of 160 – 280 km/h. In the following, those vehicles are described that allow a minimum speed of 200 km/h, as this is required to achieve edge times in the Austrian long-distance network.

The values given for EMU and loco and waggon trains in Table 4.4 are to be seen as simplified guidelines. They are based on EMUs commonly used in Austria, the Czech Republic and Switzerland. The values for loco and waggon trains are based on typical IC trains and the Railjet.

EMUs can be operated in single or double tractions with a standard length of 200 m per unit. Loco and waggon trains can be flexibly adjusted with four up to about 20 waggons, while standard configurations have about seven cars with a length of roughly 200 m. The standard length of EMUs in long-distance transport for IC and high-speed services are about 200 m per unit as well. For loco and waggon trains length differ between 100 m and 600 m. Double-deckers for long-distance services exist as EMU and loco and waggon trains and are extensively used in the busy network of SBB. EMUs usually have wide doors which allow for faster passenger exchange and a more spacious interior design than loco and waggon trains with standard door width and therefore allow for faster dwell times.

The different maintenance intervals of loco and waggon combinations are relevant when creating vehicle rotations. The same goes for the use of double traction which influences passenger capacity and plays a role in the line design (see chapter 5). For the design of STPs, double traction is not considered due to the rather small differences in vehicle dynamics.

The loading gauge is a relevant parameter for the design of STPs for freight (Kühne and Pöhle, 2018), however, as within this thesis the focus is on lines with long-distance services it is assumed that the clearance for single or double decker is not a criterion. EMU and loco and waggon further differ in wear and tear; however, as this is not relevant for the design of STPs they are not considered further.

Table 4.4: Comparison of EMU and loco and waggon combinations

Train type	EMU	EMU double decker	Loco and waggon
Vehicle / RU	Giruno / SBB ICE-T / DB+ÖBB Pendolino / CD	Kiss / Westbahn	Railjet / ÖBB IC / ÖBB
Composition	single or double traction	single or double traction	4 to 16 cars flexible
Length per unit [m] Mass per unit [t]	200 400	100 210	100 – 400 400 – 1050
Seating capacity per unit [pass]	single: 400 double: 600	500	flexible, 200-800
Door width	wide	wide	standard

Innovations in rolling stock can affect the shape of STPs. However, as long as edge riding times do not change, these effects are manageable. If innovations lead to a reduction of edge riding time the STP has to be recalculated anyway.

Vehicle Dynamics

Acceleration, deceleration, uncompensated lateral acceleration and top speed are crucial parameters for the edge riding time. Furthermore, RUs might be interested in adapting their speed in order to save energy.

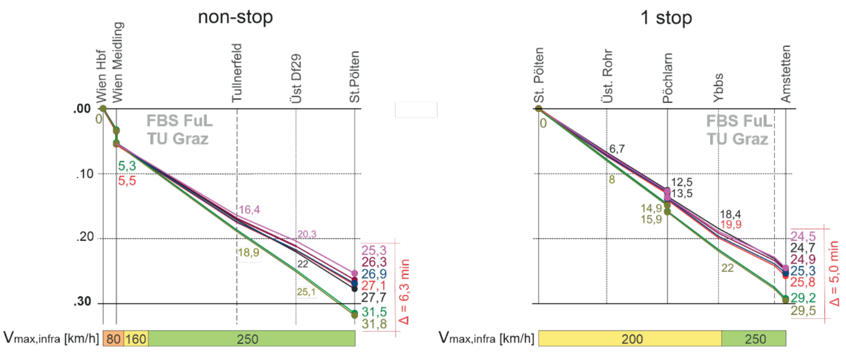
Acceleration and deceleration values are usually higher for EMUs, while strong locos can also reach high values like 0.4 till 0.5 m/s² below 50 km/h. In addition, for long-distance trains with few stops, acceleration at speeds higher than 100 km/h is relevant. A common value for braking is between 0.7 m/s² up 1.0 m/s² which is not only defined by vehicle characteristics but also by comfort and safety. The top speed of rolling stock for long-distance services is at least 160 km/h (Bmvit, 2018), which is the top speed for many conventional lines. As newly built lines for long-distance services usually have a higher top line speed, 200-250 km/h is a common speed for ITF networks. According to Bmvit (2018) minimum top speed of 200 km/h is required for "high-level" long-distance ITF services in Austria (Table 4.5).

Table 4.5: Parameters STP – vehicle dynamics based on FBS

Train type	EMU	EMU double decker	Loco and waggon
Vehicle / RU	ICE-T / DB+ÖBB Pendolino / CD	Kiss / Westbahn	Railjet / ÖBB IC / ÖBB
Acceleration [m/s²] (with 0 gradient) 0-50 km/h 50-100 km/h 100-200 km/h	 ≤ 0.5 0.45-0.3 0.3-0.1	 ≤ 1.0 0.95-0.65 0.65-0.2	 ≤ 0.6 0.55-0.5 0.5-0.1
Top speed [km/h]	160 – 280	200	160 – 230

The optimal speed profile is a combination of the target functions of maximum recovery time and minimal energy consumption. The so-called "alpha speed profile" describes the fastest possible speed profile given a starting time and velocity between two stations with minimum recovery time (Caimi et al., 2009). This profile, however, is not energy-efficient at all, therefore a "beta speed profile" with reasonable recovery time should be chosen. As shown in Figure 4.14 at the beginning of an edge it is more important to drive faster in order to gain time reserves, towards the end of an edge the time reserve can be used to let the train coast and thus save energy or to recuperate energy (Caimi et al., 2009). The optimal speed profile is marked in purple in the STP with coasting before a hub in Figure 4.14.

The effect of different speed profiles on the riding time is shown for the edges Wien – St. Pölten and St. Pölten – Amstetten in Figure 4.15. While a top speed of 160 km/h would be technically sufficient to achieve most edge riding times on the Western Line, the recovery time would not be enough. Trains with a top speed of 160 km/h need about four minutes longer for these edges than train with a top speed of at least 200 km/h. Therefore, a minimum top speed of 200 km/h is required to achieve the edge riding times. The band width of trains running at top speeds of 200 km/h up to 280 km/h is only about one to two minutes.



Speed profile	Type of rolling stock	Signature	V_{max} [km/h]	Vehicle	RU	Comment
Vehicle 1	Loco and wag-gon		160	Siemens Vectron + 7 waggons	RegioJet	Edge riding time not covered
Vehicle 2	EMU		160	Stadler Flirt	Leo Ex-press	
Vehicle 3	EMU		200	Stadler Kiss	Westbahn (4010)	
Vehicle 4	EMU		230	Siemens ICE-T	ÖBB (4110)	
Vehicle 5	Loco and wag-gon		230	Siemens Taurus + 7 waggons	ÖBB rj	
Vehicle 6	EMU		230	Alstom Pendolino	ČD (680)	
Vehicle 7	EMU		280	Siemens ICE 1	DB (401)	

Figure 4.15: Speed profiles of different trains

Dwell Time

The vehicle related parameters are also influenced by the stopping time. These include door opening time, dwell time, door closing time and stopping time reserve. The minimum length of stay in hubs could be reduced where fast passenger exchanges can be assured. The exchange might be faster than the standard time if low floor vehicles are used, the waggon doors are wide and open and close rapidly etc.

4.4 Regional, Sprinter and Freight Services

On mixed traffic lines, regional, fast point to point and freight services make up a considerable part of the line capacity. However, they should not interfere with STPs. Regional trains usually do not interfere with STPs as they are an integral part of the ITF scheme. Fast point-to-point or sprinter services should run with a time lag before or after STPs in order not to interfere. Freight trains might have to stop in hubs in order to guarantee a smooth execution of STPs of long-distance trains.

Ad-hoc requests are not considered here as these train paths are constructed after the working timetable has been fixed. If train paths for ad-hoc services are constructed within the working timetable, they are a kind of PaP that ultimately corresponds to an STP or a path catalogue.

4.4.1 Regional Services

Regional services are crucial in an ITF for attractive network-wide connections. Based on a major principle of the ITF slow regional trains arrive before fast long-distance trains. The order of these train types is fixed in hubs. Exceptions are selectively served hubs.

4.4.2 Sprinter Services

Fast long-distance or point-to-point services, also called Sprinter, can be tendered or in the event of high demand, be self-sustaining. These are complementary services that offer attractive riding times between larger urban regions and are not necessarily network-oriented (Weigand and Berschin, 2020). An ITF represents a strongly systematic service offer. However, it should be flexible enough to cover sprinter or on-top services (Büker, 2019). Sprinters which arrive in hubs before or after STPs increase infrastructure utilisation and help to better distribute passenger flows. In highly utilized railway networks like in Switzerland sprinters serve direct travel chains and backup regional connections. While STPs arriving in hubs at .00 or .30 serve the basic clocked services, additional sprinters arriving e.g. at .15 or .45 can serve additional regional services. This scheme is used in Bern and will be realised in Graz in 2027.

Fast train paths between major cities like Wien and Salzburg are attractive for self-sustaining services. These sprinter services might be interesting for OA operators or newcomers to enter the market outside of tendered STP bundles (chapter 5).

In case accelerated point-to-point services need to overtake STPs, this can only take place in hubs or – if there is a sufficient number of tracks – on the edge. Additionally STPs may need to overtake regional trains and freight trains. Figure 4.16 shows a schematic timetable combining STPs, sprinters and freight services.

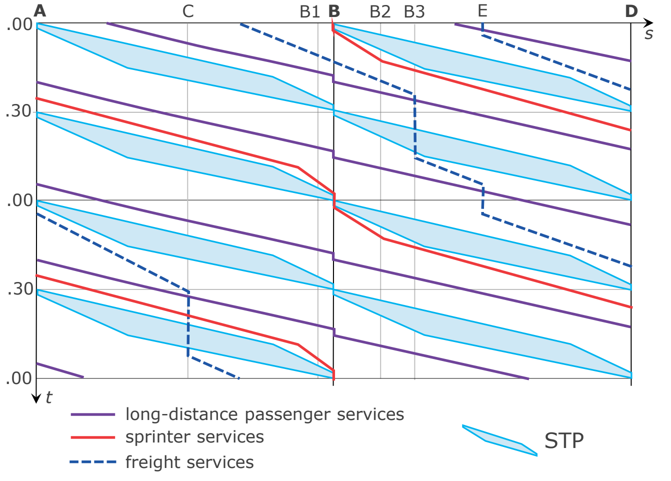


Figure 4.16: Schematic arrangement of STPs, long-distance, sprinter and freight services

4.4.3 Freight Services

The application of STPs must not lead to fewer or less attractive freight paths. The fact that this does not automatically have to be the case is shown by Switzerland's network timetable, where attractive freight train paths are offered on an hourly basis with only some restrictions during rush hour (BAV, 2020).

To ensure attractive freight paths, they are best planned in coordination with STPs as PaPs beforehand. IM could offer PaPs as is done in international freight corridors, which are tendered or allocated on a first come first serve principle (Monopolkommission, 2017). However, these train paths require precise coordination, as experience from the international corridors shows. The train paths created often no longer match the RU's original requests or needs (Bscheid, 2020). Alternatively, ad-hoc requests of freight services can be allocated – as they are today – if they do not interfere with STPs.

Berschin et al. (2019) argue that freight traffic with its special needs has to be considered on an equal basis. PaP for freight trains must be attractive and operationally feasible (Burgdorf et al., 2019). Standardised requirements to optimise infrastructure capacity such as traction power, velocity, mass and length need to be defined (Burgdorf et al., 2019).

4.5 Determining System Train Paths

The parameters described in chapter 4.3 are related to each other as depicted in Figure 4.17 and thus result in the riding profile for a train type. By knowing the shape of the STP, the procedure for defining an STP can be developed. This procedure is, as the shape of an STP, influenced by the infrastructure, railway operation and vehicles. There are three stages to cover: the stop in the hub, the time of departure and the riding on the edge. These stages happen at every arrival and departure in a hub. This process is to be repeated with the relevant riding profiles and finally the train path envelope can be formed which represents the STP for this edge.

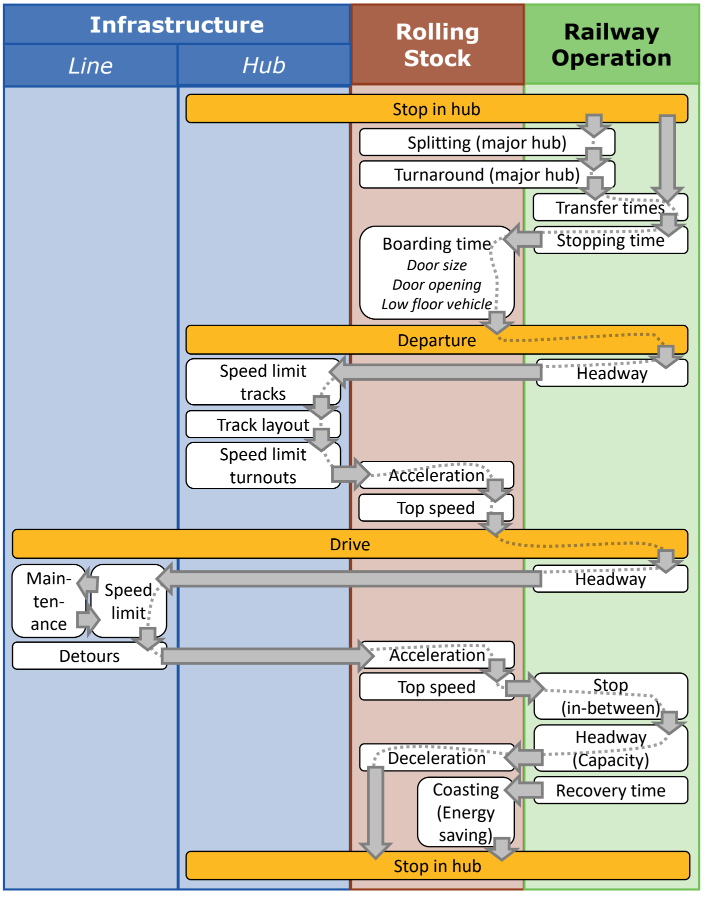


Figure 4.17: Parameters influencing the definition of STPs

The above-mentioned input parameters of STPs can be described in detail as shown in Figure 4.18. The optimal band width describes trains accelerating fast and running with top speeds during the first half of the edge. This ensures timetable stability through recovery time (purple area). In the second half of the edge trains start coasting in order to save energy. By contrast the suboptimal band width covers trains with delays, slow acceleration or reduced top line speeds due to maintenance or disruptions (yellow area).

This is approach is the most detailed so far to describe system train paths for long-distance railway services. The concept allows for an individual shape of the STP for every edge considering parameters of railway operation, infrastructure and rolling stock.

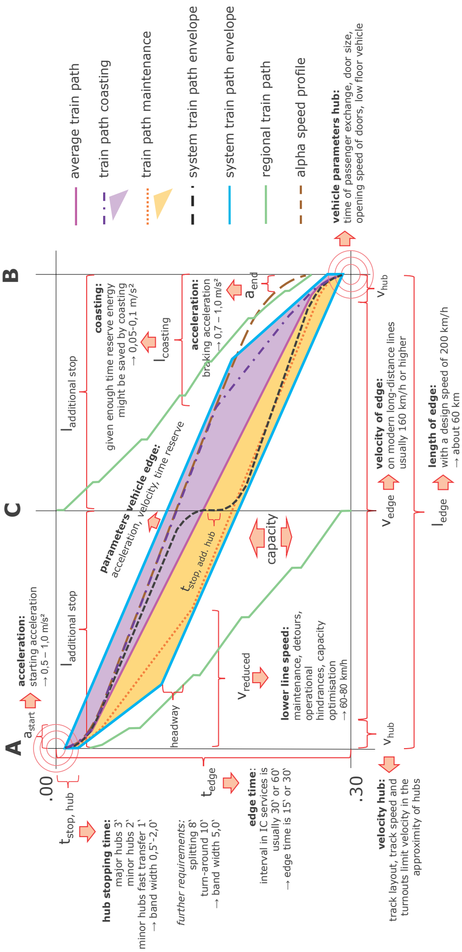


Figure 4.18: STP parameters – overview

4.6 Application of System Train Paths

To verify the parameters and concept, STPs are applied on the infrastructure of the target network 2025+ in Austria (ÖBB-Infrastruktur AG, 2011). The two major railway axes in Austria, namely the Western Line and the Southern Line, were chosen for the application of STPs. This allows, on the one hand to derive the concrete shape of STPs and, on the other hand, to verify the feasibility of allocation in the timetable in combination with other train paths.

A detailed approach is chosen to verify the concept of STPs. The essential ITF requirements are considered as well as train slot allocation procedures according to the SNNB. Path-time diagrams are used as basis for a comprehensive discussion and for identifying the shape of STPs influenced by infrastructure and vehicle characteristics as described in chapter 4.3:

(i) STPs are designed on the Western and Southern Line in Austria in order to validate the derived findings. Five different riding profiles of train types (Figure 4.19) currently running in the Austrian railway network are applied.

(ii) This makes it possible to define a train path envelope on the investigated edges.

(iii) These STPs are put on top of each other to derive accumulated train path envelopes that represent a generally applicable form of STPs (Figure 4.19)

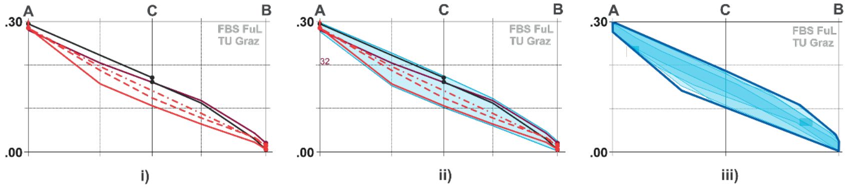


Figure 4.19: Forms of an STP – (i) riding profiles, (ii) train path envelope, (iii) STP accumulated by train path envelope

Timetable Software

Based on the aforementioned input data, the train paths of the different riding profiles are calculated with the timetabling software FBS. First the lines with their edges, hubs and stations are created and the infrastructure parameters such as top speed and gradient are implemented. Additional potential stops are defined in attractive hubs and transfer points are determined based on the track infrastructure. Then riding profiles of the different vehicle and timetable parameters are added. The length of speed restrictions is adapted to the stations of each edge. In an iterative process, additional buffer times are added in the event that riding times are shorter than the targeted edge riding time (including proportional hub stopping times).

Timetable

The basis for the ITF and therefore the STP is the edge-hub model of the target network 2025+. Throughout the network, at least one hourly interval is offered, resulting in a standard edge time of 30 minutes. As can be seen in Figure 4.20, this ideal typical edge time is deviated from on several edges due to the existing infrastructure. Therefore, edges with the following edge times are examined:

- 30 min edge time (standard)
- 60 min edge time (Attnang-Puchheim – Salzburg, Mürzzuschlag – Bruck an der Mur, Graz – Klagenfurt)

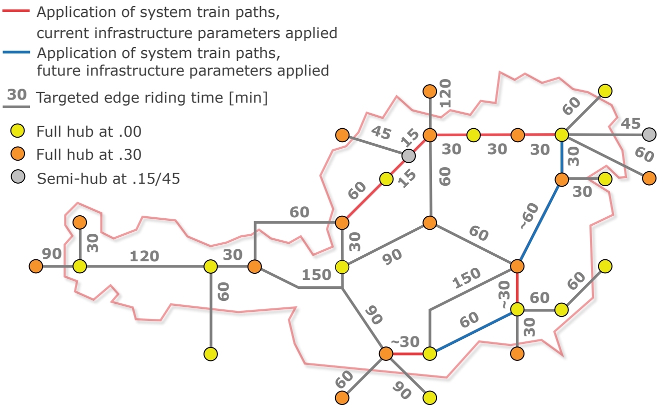


Figure 4.20: Investigated STP in the Austrian edge-hub-model

The riding profiles apply different departure and arrival times (Table 4.6). The locomotive-waggon train has generous hub stopping times of four minutes to represent an additional time buffer where possible. EMU I has a short standard stopping time of one minute according to its vehicle parameters (high acceleration, wide doors, fast passenger exchange), which is only extended to two minutes in major hubs Linz or Graz. Additional stops are scheduled for EMU I with a stopping time of one minute. For EMU II, hub stopping times of three minutes are assumed as an additional buffer because of the applied speed restrictions. If the riding time between two hubs only allows two minutes of stopping time this is accepted if the respective hub can be classified as "intermediate station" (ÖBB-Infrastruktur AG, 2020b). The recovery time is generally 10% and a lower value is only accepted if the edge time cannot otherwise be achieved according to construction work or diversions. If a time buffer remains coasting is applied on the last quarter of the edge.

Table 4.6: Timetable parameters STP application

Riding profile	No. of Riding profile	Signature	Hub stopping time	if hub time .00		Additional stop	Recovery time	Coasting
				Departure	Arrival			
Loco and waggon	**RP1**		4 min	.02.00	.58.00	no	10%	yes
EMU I	**RP2**		1 min	.00.30	.59.30	yes	10%	yes
EMU IIa	**RP3**		3 min	.01.30	.58.30	no	10%	in case of time buffer
EMU IIb	**RP4**		3 min	.01.30	.58.30	no	10%	in case of time buffer
EMU IIc	**RP5**		~ 3 min	flexible	flexible	no	10%	in case of time buffer

Rolling Stock

For the calculation, three commonly used trains in Austria were chosen, representing different train types and varying vehicle characteristics. These are one loco and waggon train and two EMUs (Table 4.7). The top speed varies between 200 km/h and 230 km/h, the total mass is between 320 t to 473 t. The maximal acceleration is 0.55-1.00 m/s^2, however, this value decreases differently with increasing speed. The loco and waggon train has a lower basic acceleration, but has a comparatively high acceleration at high speeds due to the strong traction effort of the locomotive.

Table 4.7: Vehicle parameters STP application

Train	Signature	No. of cars [-]	V_{max} [km/h]	Acceleration at low speeds [m/s^2]	Acceleration at high speeds (100-200 km/h) [m/s^2]	Decelertion [m/s^2]	Length [m]	Mass [t]
Loco and waggon		7	230	0.55	0.5 - 0.1	0.7	208	473
EMU I		6	200	1.00	0.65 - 0.2	0.7	150	320
EMU II		7	230	0.85	0.3 - 0.1	0.7	184	402

The **loco and waggon** train set has a high top speed and good acceleration at high speeds. The travel time on longer sections is therefore relatively short. For this reason, this train has generous buffer times which allow for timetable stability.

EMU I has a very strong acceleration, but a lower top speed. As it is equipped with a low floor and large doors this train is good for making frequent stops.

EMU II has a very high starting acceleration, a high top speed but a lower acceleration at high speeds. Therefore, it is a bit slower than the loco and waggon train and represents a kind of standard rolling stock. This vehicle is chosen to show the effects of speed restrictions on the riding profile.

The vehicle data for the loco and waggon train set as well as EMU I were provided by the timetabling software FBS which was used throughout this thesis. Data for EMU II was derived from data sets which are available online.

Infrastructure

The data used should reflect reality as well as possible in order to derive a realistic assessment of the feasibility of STPs. For all sections the following input parameters are incorporated:

- Standard gauge, electrified, line class D4
- Double-track line, in many sections complemented by a second double-track line
- V_{max} between 80 km/h and 120 km/h in the proximity of hubs and 120 km/h to 250 km/h on the edges
- Stations and transfer points for detours
- Simplified gradient based on the height above sea level of stations along the edges
- Lengths and stationing of tunnels

Furthermore, speed restrictions are applied to distinguish different riding profiles for EMU II. Three different speed restrictions with top line speeds of 100 km/h to 160 km/h over different lengths are applied:

- 160 km/h represents reductions of top speeds due to failures of track components
- 140 km/h represents a detour across a certain length (if available[17])
- 100 km/h represents for a restriction caused by maintenance work

While V_{max} 160 km/h is applied on the entire edge the maintenance work is assumed on the first 30% of the edge and detours on the first 50%. The last two restrictions at the beginning of each edge are assumed to have the most significant effect on the shape of the system path (Figure 4.8).

[17] A detour on another line is only possible on some edges in the network, specifically along the four-track Western Line.

Table 4.8: Infrastructure parameters STP application

Train	No. of Riding profile	Signature	Speed restriction		
			Yes/No	Vmax [km/h]	Proportional length of edge
Loco and waggon	RP1		no	-	-
EMU I	RP2		no	-	-
EMU IIa	RP3		yes	100	~ 30%
EMU IIb	RP4		yes	140	~ 50%
EMU IIc	RP5		yes	160	100%

The data of the existing infrastructure was obtained from the M-AMA portal of the IM (ÖBB-Infrastruktur AG, 2019b) supplemented with altitude data from the provincial GIS-systems[18]. Sections under construction were created based on data available via the competent authority (Land Steiermark, 2020).

Train Path Envelope

The STP is represented by the train path envelope resulting from the envelope of the different riding profiles (blue area in Figure 4.21). The fastest and slowest riding profile in each section form the upper and lower limit of the envelope. In addition, a buffer of half a minute is added to the riding profile to cover inaccuracies. This results in the STP as the band width in which riding profiles can differ under the named parameters.

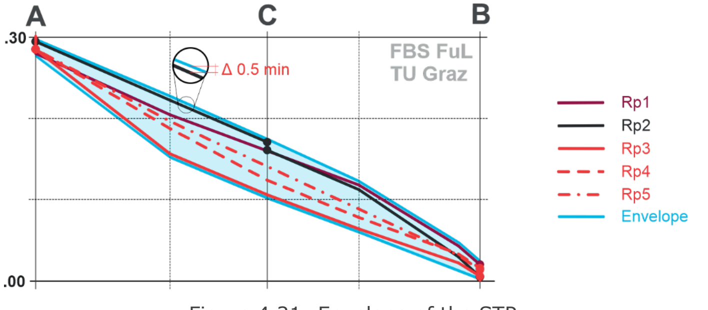


Figure 4.21: Envelope of the STP

4.6.1 System Train Paths on the Western Line

The Austrian Western Line from Wien to Salzburg is a good illustration for the application of system paths due to the different infrastructure characteristics in terms of top speed, number of tracks and the intervals of the hubs (Figure 4.22). The 312 km long line has

[18] ViennaGIS Stadt Wien (2021), NÖ Atlas Land Niederösterreich (2021), DORIS Land Oberösterreich (2021), SAGIS Land Salzburg (2021), GIS Steiermark Land Steiermark (2021), KAGIS Land Kärnten (2021).

already been upgraded from Wien to Attnang-Puchheim and in particular from Wien to Linz. The latter section has continuously four tracks and is designed for top speeds of up to 250 km/h. Between Linz and Salzburg the line is double tracked. While top speeds between Linz and Attnang-Puchheim reach up to 200 km/h, the top speed in the remaining section to Salzburg is 100 km/h to 160 km/h.

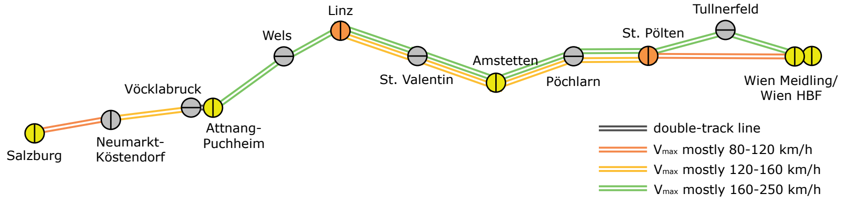


Figure 4.22: Western Line between Salzburg and Wien

According to the SNNB, five hubs at .00 or .30 can be found along this line. These are the hub pair Wien Hbf and Wien Meidling, St. Pölten, Amstetten, Linz and Attnang-Pucheim and Salzburg (Figure 4.23). All these hubs serve both hub times, at .00 and .30, meaning clocked services are to be provided every 30 minutes. St. Valentin and Wels serve as hubs at .15 and .45 as well.

Further potential stops considered in the design of STPs are Tullnerfeld, Pöchlarn, Vöcklabruck and Neumarkt-Köstendorf. The basic edge riding time along the Western Line is 30 minutes. This is already achieved with the infrastructure which is in place in 2021 aside from the section Salzburg – Attnang-Puchheim, which lasts 60 minutes.

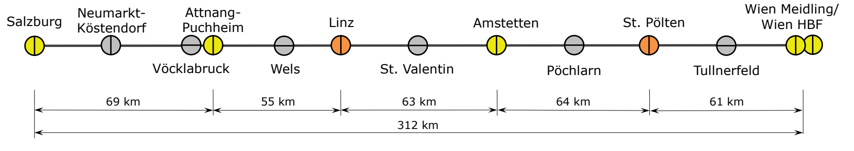
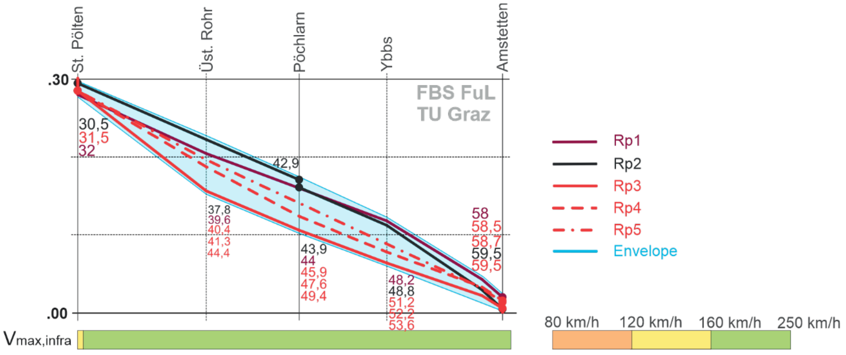


Figure 4.23: Hubs on the Western Line

The Western Line is described starting in Wien and going west to Salzburg as the train path diagrams are also oriented east to west. The edge St. Pölten – Amstetten is described here, further ones can be found in the appendix.

St. Pölten – Amstetten

The top line speed on the 64 km long section between St. Pölten and Amstetten is mostly 200 km/h with a significantly shorter section adjusted to 250 km/h. An additional stop is assumed in the minor hub Pöchlarn. Riding times are between 26.0 and 28.0 minutes, resulting in buffer times of 0.0 to 4.5 minutes per riding profile Figure 4.24.



Riding profile	Rolling stock	Signature	$V_{max, vehicle}$ [km/h]	reduced $V_{max, infra}$ [km/h] (in certain sections)	Recovery time	Coasting	Buffer time [min]
Rp1	Loco and waggon	▬▬	230	-	10%	yes	4.5
Rp2	EMU I	▬▬	200	-	10%	yes	4.1
Rp3	EMU IIa	▬▬	230	100 (St. Pölten – Üst. Rohr)	10%	no	0.0
Rp4	EMU IIb	▬ ▬	230	140 (St. Pölten – Pöchlarn)	10%	yes	0.3
Rp5	EMU IIc	▬ · ▬	230	160 (St. Pölten – Amstetten)	10%	no	0.0

Figure 4.24: STP edge St. Pölten – Amstetten

4.6.2 System train paths on Southern Line

The Southern Line in Austria extends from Wien southwards. With the construction of the “Koralmbahn” the Southern Line will run from Wien via Graz to Villach (Figure 4.25) in the future.

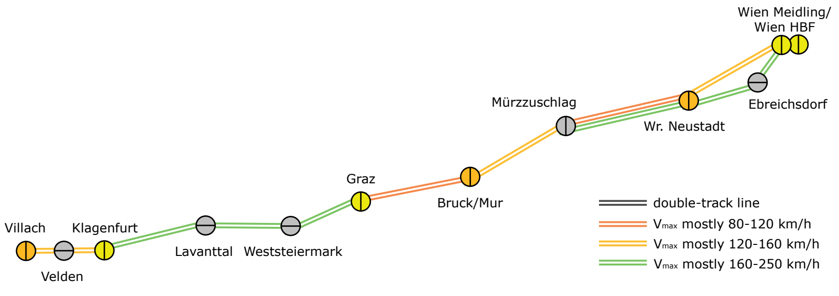


Figure 4.25: Southern Line from Wien to Villach

After ongoing infrastructure upgrades are finished most edges are double-tracked with alternative lines running separately. As soon as OA operators will find their interest in this route it can be assumed that infrastructure utilisation will be even higher than it already is on many sections. In particular, the Mürzzuschlag – Graz edge will then be at least as busy as the current Linz-Salzburg section is now.

In the target network five hubs at .00 or .30 are situated along this line. These are the hub pair Wien Hbf and Wien Meidling, Wiener Neustadt, Graz, Klagenfurt and Villach (Figure 4.26). Along this line a 30 minute interval is intended resulting in hubs being served at .00 and .30., Bruck an der Mur is an asymmetric hub due to an edge riding time of 35 minutes between Graz and Bruck an der Mur. Further potential stops considered in the design of STPs are Ebenfurth, Mürzzuschlag, Weststeiermark and Lavanttal. Edge riding times vary, as mentioned above, between 20 and 60 minutes.

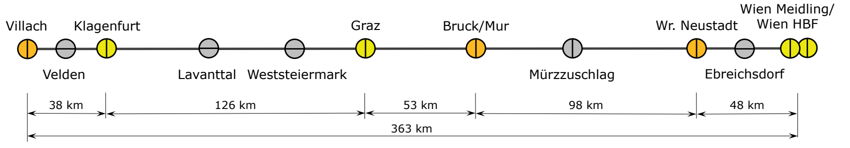


Figure 4.26: Hubs on the Southern Line

The Southern Line is described with the starting point in Wien going to Villach. The train path diagrams are oriented east to west can be found in the appendix.

4.6.3 Capacity Utilisation

As STPs take more infrastructure capacity than a single train path, the question arises how efficiently infrastructure is utilised. This is investigated on two different sections in the Austrian railway network. For the implementation of STPs in a timetable with other services, the 2019 timetable on the Western Line was selected. For the section Wien – Linz a schematic depiction was chosen as there are few capacity constraints on the two double-track lines. On the other hand a detailed depiction was chosen for the busy double-track line between Linz and Attnang-Puchheim.

Train Path Coordination

Between Wien and Linz, long-distance trains run almost exclusively on the tracks of the new line during daytime. The schematic representation in Figure 4.27 shows this occupancy in the 2019 timetable with four to five self-sustaining long-distance trains and one freight train per hour. If STPs are used, the same number of train paths can be handled (Figure 4.28). In addition to the half-hourly system paths, up to four self-sustaining train paths can be inserted as required. This implicates that there is sufficient capacity for STPs and OA services. These additional train paths can also be used for international long-distance connections, if they are not integrated in STPs.

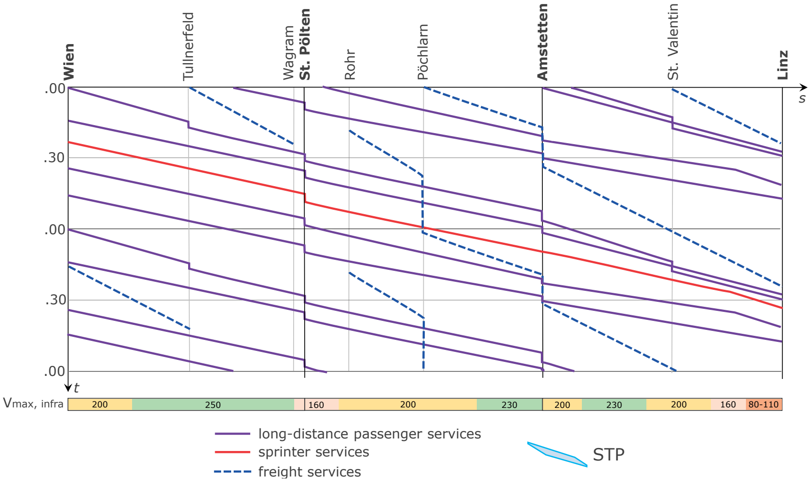


Figure 4.27: Timetable 2019 Wien – Linz

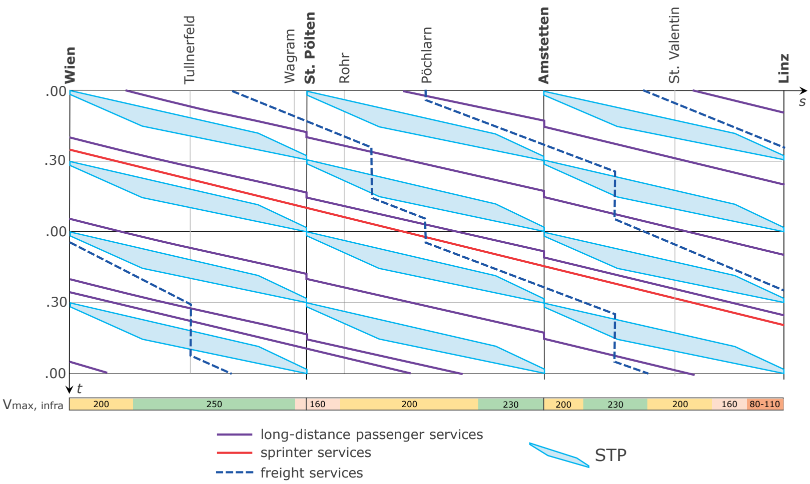


Figure 4.28: Timetable 2019 Wien – Linz with STPs

Evaluation of Line Capacity

For a detailed observation the section Linz – Salzburg on the Western Line was chosen. This double-track line is heavily used by long-distance, regional and freight services

(Figure 4.29). According to ÖBB Zielnetz 2025+ it is amongst the sections in Austria with the highest capacity utilisation (ÖBB-Infrastruktur AG, 2011). With up to five long-distance services per hour during daytime it was amongst the sections with the highest number of long-distance services per hour in 2019 in Austria.

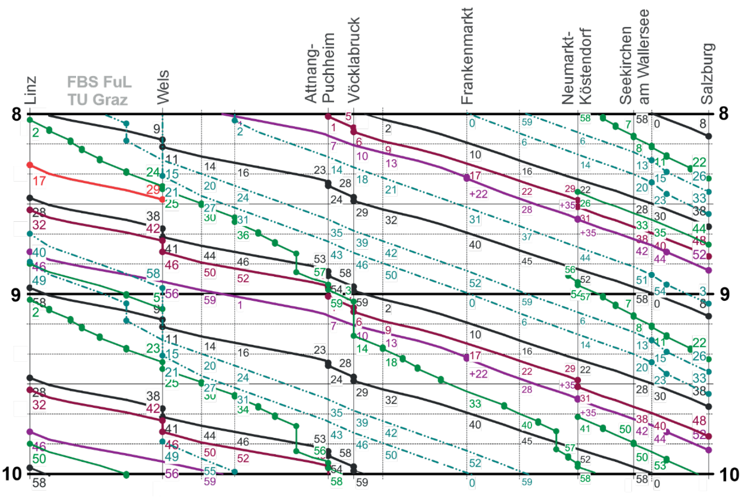


Figure 4.29: Train path diagram for the timetable Linz - Salzburg in 2019

When redesigning the timetable by allocating STPs, the riding profiles "Loco and waggon" and "EMU IIa" are allocated to represent the enveloping of an STP (Figure 4.30). A partial adjustment of some train paths is necessary.

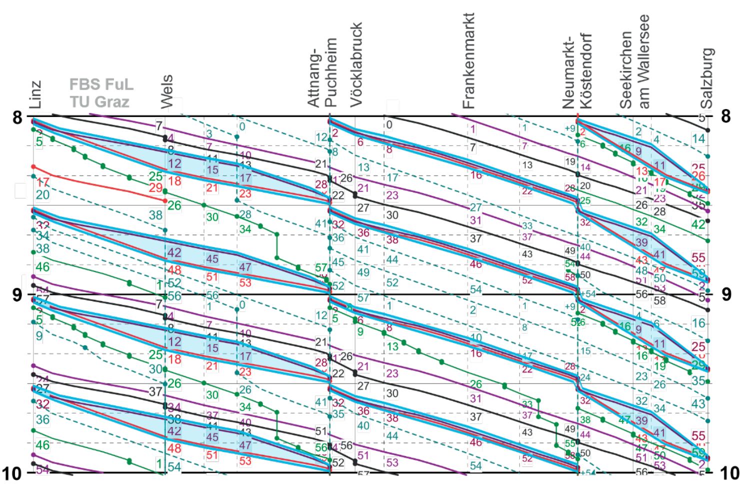


Figure 4.30: Adapted train path diagram for the timetable Linz - Salzburg 2019 with STPs

When comparing the number of train paths per section and train category, the timetable with the STP allows for at least the sum of train paths of the 2019 timetable (Figure 4.31 and Figure 4.32). Since the attempt was made to insert as many long-distance train paths as possible in addition to the STP, there are more long-distance train paths in some sections, but fewer freight train paths. However, if the same number of long-distance train paths would be used, the same number of freight train paths as in the existing timetable of 2019 were possible.

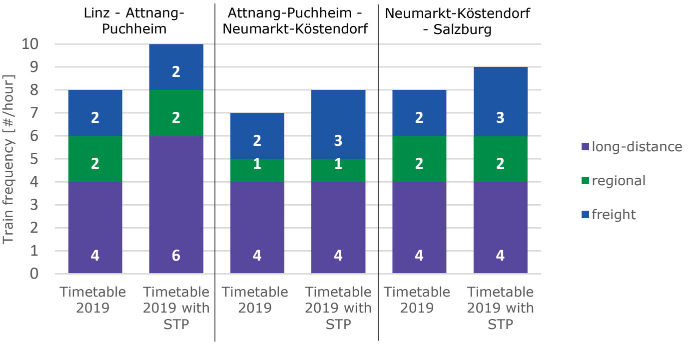


Figure 4.31: Number of trains on the section Linz – Salzburg between 08:00 – 09:00

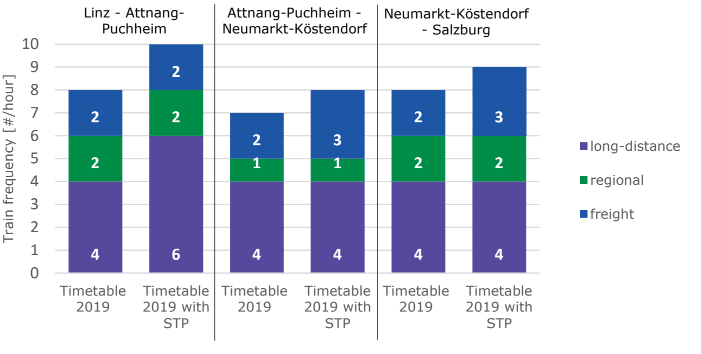


Figure 4.32: Number of trains on the section Linz - Salzburg between 09:00 - 10:00

The evaluations thus show that system train paths can be applied on routes with predominantly long-distance traffic as well as on mixed traffic routes without loss of capacity. As STPs are planned beforehand, they allow for a more systematic train path allocation. Furthermore, after the operator has been awarded STPs, train path requests for the annual timetable as well as parameters such as stopping pattern or vehicle properties need to be submitted. After that, the unused capacity can be released. Therefore, the introduction of STPs would not lower the capacity of a timetable.

Country Comparison

In the following the capacity consumption of STPs is compared with other highly congested long-distance routes. For this purpose, mixed traffic lines as well as high-speed lines in Austria, Switzerland, the Czech Republic and Italy were selected (Table 4.9).

Table 4.9: Capacity utilisation on international long-distance lines

Section	Linz – Wels	Dietikon – Othmarsingen	Kolín – Česká Třebová	Bologna – Roma
Type of line	mixed traffic	mixed traffic	mixed traffic	high-speed
ITF	✓	✓	✓	-
Competition	✓	-	✓	✓
Services rush hour	5	12	4	6
Source	ÖBB-Personenverkehr AG (2019b)	ÖBB-Personenverkehr AG (2020)	ÖBB-Personenverkehr AG (2020)	Bacares et al. (2019)

It is shown that other international corridors have an even higher utilisation of eleven to 14 trains per hour. Furthermore, the type of services are compared in Figure 4.33. The Linz – Wels section is the only one with freight traffic, therefore ten trains per hour seem acceptable.

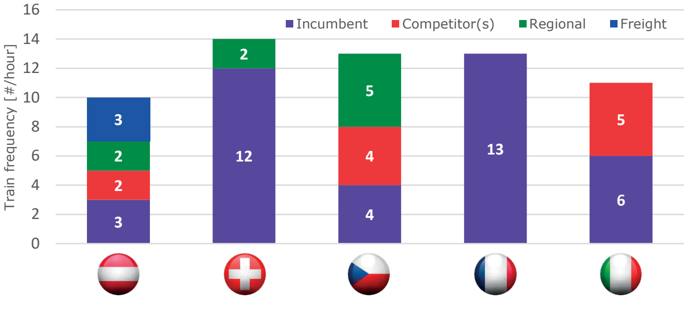


Figure 4.33: Capacity on designated double-track long distance lines during rush hour

4.6.4 Construction of System Train Path

From the evaluations, the shape of a parallelogram can be confirmed. Asymmetrical hubs lead to slightly different shapes. Furthermore construction methods can be derived.

Parallelogram Shape

As assumed in chapter 2.6 the shape of a parallelogram best corresponds to the idea of an STP. The variety of riding profiles and different stopping patterns creates a useful band width. This band width allows (i) RUs to freely decide on rolling stock and (ii) to choose the stopping pattern. For the IM, the assumed speed restrictions due to maintenance work or minor disruptions guarantee timetable stability.

Superimposing train path envelopes on ten different edges with the same set of vehicles (riding profiles), but different hub and infrastructure properties, again converges towards the shape of a parallelogram. However, in the area of the hubs, i.e. at the beginning and end of riding profiles, there are blurry areas. This can be explained by the fact that there are different hub types. While in symmetrical nodes the arrival and departure times are clearly defined at the .00 or .30, this is blurred in asymmetrical nodes.

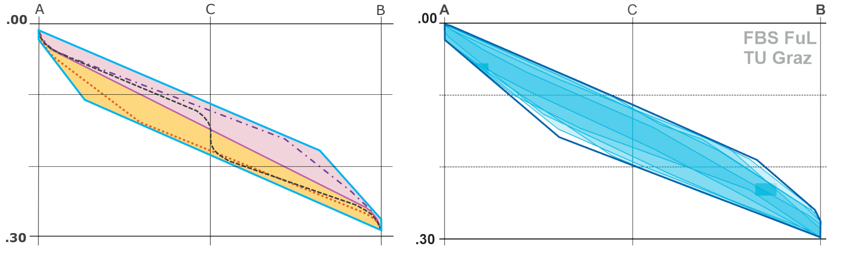


Figure 4.34: Parallelogram shape of an STP in theory (left) and practice (right)

Symmetric Hubs

Superimposing train path envelopes of edges with two symmetrical hubs result in a parallelogram (Figure 4.35). The train path envelopes hardly differ in the hubs, however, on the lines the different properties of the infrastructure can be recognised.

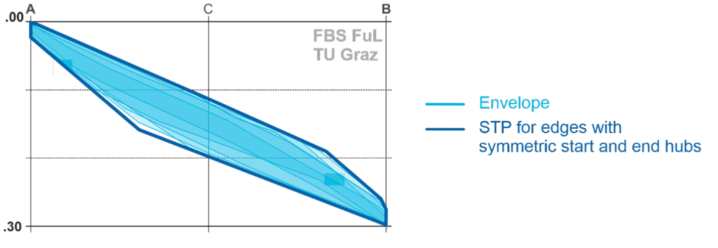


Figure 4.35: STP for edges with symmetric start and end hubs

Asymmetric Hubs

Edges where a hub is asymmetrical or where turnaround times are taken into account result in slightly different shapes close to the respective hub (Figure 4.36). The resulting STP then corresponds more to a band width or a polygon.

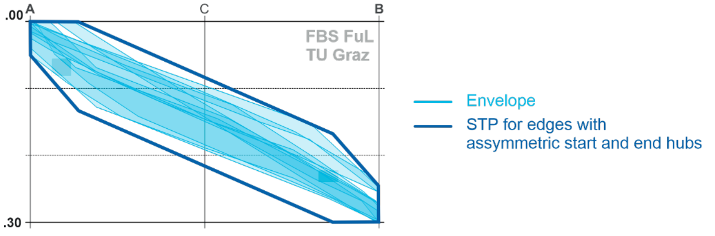


Figure 4.36: STP for edges with asymmetric start and end hubs

For optimal capacity utilisation, a distinction must be made between symmetric and asymmetric hubs when defining the demand for infrastructure capacity of an STP.

The shape of a parallelogram is a rough description of an STP. In order to determine the shape more precisely but to avoid the creation of five riding profiles per edge, two approaches can be chosen:

(i) A general standard form derived from superimposing known train path envelopes
(ii) An individual calculation of the relevant fastest and slowest riding profiles

For asymmetric hubs, approach (i) covers significant amount of capacity as the form depends on how far the asymmetry deviates from the ideal cycle time. Therefore, no generalised statement can be made.

Standard Form of the System Train Path

To determine the form of the parallelogram, train path envelopes of several edges with symmetrical hubs are superimposed. The resulting parallelogram shown in Figure 4.37 covers most train profiles for the following parameters:

- Maximal vehicle acceleration between 0.5 and 1.0 m/s²
- Maximal top speed of infrastructure and vehicles of 200-250 km/h
- Speed limits of minimum 100 km/h on maximum one third of a section

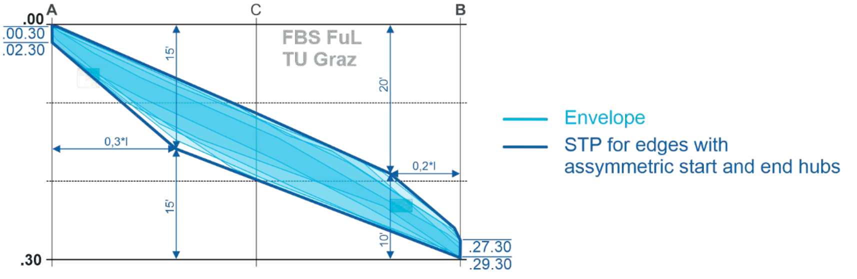


Figure 4.37: STP with symmetric start and end hubs – shape of a parallelogram

The resulting values which describe the parallelogram are shown on the example of an edge between hubs at .00 and .30. The hub arrival and departure times are fixed due to assumed stopping times. The departing takes place between .00.30 to .02.30 and the arrival between .27.30 and .29.30. The lower left corner of the parallelogram is at .15 and after 30% of the edge length. The upper right corner is at .20 and after 70% of the edge length.

The same can be applied to edges with asymmetric hubs as shown in Figure 4.38. The parallelogram becomes bigger as the band widths of arriving and departures times are further apart. The resulting values which describe the parallelogram are shown on the example of an edge between hubs at .00.00 and .30.00. The hub arrival and departure times lie further apart due to the asymmetry. The departing takes place between .00.00 to .05.30 and the arrival between .24.30 and .30.00. The lower left corner of the parallelogram is at .13 and after 18% of the edge length. The upper right corner is at .17 and after 82% of the edge length.

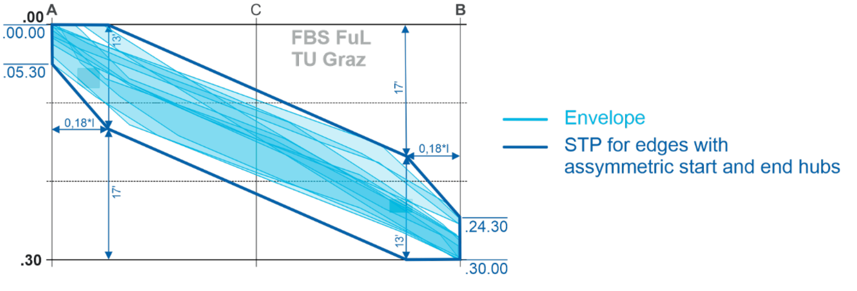


Figure 4.38: STP with asymmetric start and end hubs – shape of a parallelogram

This approach can be used for concepts or rough capacity estimations. With this estimation, STPs can be inserted into the timetable for planning, without the need for a detailed calculation of riding profiles. For a detailed planning, capacity optimisation and applications requiring a more precisely definition, approach (ii) is suggested.

Calculation of System Train Path

For detailed planning, detailed capacity optimisation and train path allocation, an edge-by-edge calculation of the STP is required. This can essentially be described by the upper limit which is the riding profile RP1 (loco and waggon) and the lower limit which is represented by the riding profile RP3 (EMU IIa) as shown in Figure 4.39. By adding an extra of half a minute on the outer surroundings, the resulting train path envelope results in the STP.

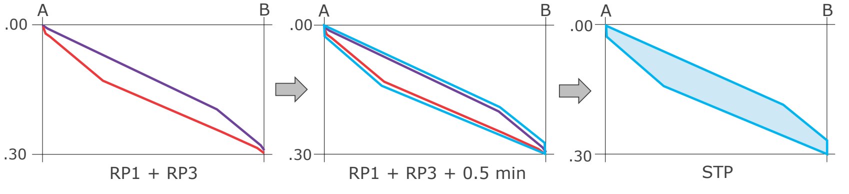


Figure 4.39: Calculation of STP

4.7 Conclusion System Train Paths

STPs in the shape of a parallelogram have several operational advantages, arrival and departures in hubs are clearly defined and additional stops on the edges are possible. Furthermore, speed limitations due to disruptions or maintenance work are covered. The parallelogram-shape can thus be suggested for STPs as depicted in Figure 4.37. It is shown that the theoretical shape of a parallelogram matches with the results of the practical application considering parameters for timetable, infrastructure and vehicles.

Two approaches are available to define the form of the STP in varying accuracy. The shape can be defined for edges with symmetric hubs using a standard form. For a more precise definition and edges with asymmetric hubs, the STP can be calculated with the riding profiles RP1 and RP3.

Finally, it is demonstrated that the STP does not lead to excessive capacity consumption. In addition, the STP can be reduced to a single train path in the working timetable process when the vehicle and stopping pattern of the train path using the STP is known. This allows parts of the band width to be released and used for other train paths.

It can be summarised:

- The shape of the STP as parallelogram is feasible
- The construction of the STP can be done based on a standard form or more precisely by calculating the two relevant riding profiles
- Capacity consumption is almost equal to conventional train path allocation in Austria and compared to other countries

In the process of the working timetable, unused band width of the STP is set free for allocating other services.

5

System Train Path Bundles

Up to this point, STPs were described per edge and thus isolated. However, the network-wide approach of the ITF automatically requires STPs to be applied network-wide. Therefore, STPs on edges need to be extended to lines and those to bundles to be able to tender them for RUs. While a line runs between one or more end points, bundles cover parts of a network. This raises the question of how long lines of STPs should be and how they are combined to bundles. Various combinations of train paths are possible, such as putting parallel, interdependent or train paths of various routes together. In DB Netz AG (2008) bundles are defined as groups of train paths with similar vehicle parameters (in the same direction). In Ullrich et al. (2020) train path bundles are described as "*a bundle of interdependent trains that have high probability of interfering with each other*". In the following, STP bundles are understood as a combination of system train paths on one or more routes in both directions. These cover some or all of the STPs that are necessary to create a regular daily ITF service.

5.1 From Edges to Lines and Bundles

The meaning of the terms edge, route, line and bundle are defined in Figure 5.1. In the context of this thesis an edge is a single, double or quadruple track stretch of a railway line for long-distance services from one hub to another. A route is a (random) combination of several edges. A line – in contrast to a route – is a clearly defined route from a starting hub to an end hub. In its finished form, a line has properties such as a timetable or an interval. Finally, a bundle is a combination of lines grouped together for e.g. geographic or vehicle reasons.

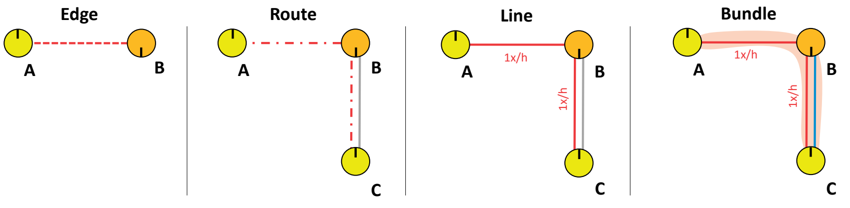


Figure 5.1: Definition of edge, route, line and bundle

While there is extensive literature on the creation of local bus or rail lines, bundle planning for the competitive tendering of public transport and especially long-distance transport is scarcely discussed. Bundle planning covers strategic network and line planning, passenger demand planning and operational planning of vehicle and duty scheduling.

The following discussion considers:

- A railway network for long-distance lines (IC or IR) including links to adjacent networks
- An ITF model for this network consisting of hubs and edges
- Demand-based intervals of ITF services on the edges

…and discusses in detail:

- Lines based on given edges and intervals
- Bundles consisting of lines
- A procedure primarily covering strategical and tactical planning.

5.2 Bundle Planning Methods

Bundle planning is based on line planning which is covered in literature in the fields of classification, objectives, methods and tools. Kepaptsoglou and Karlaftis (2009), Walter (2010) and Schöbel (2012) give an extensive overview about these fields. Methods are classified in conventional methods, mathematical procedures and heuristics (Kepaptsoglou and Karlaftis, 2009). For recent applications in long-distance passenger services see Weigand and Berschin (2019), who show how passenger numbers could be doubled with the implementation of the ITF (so-called "Deutschlandtakt") on the German Intercity-network. The tool CONNECT which was developed for designing long-distance lines in the US

(U.S. Department of Transportation, 2014) is a demand-oriented analytical tool for network design from scratch. The shortest path algorithm was used for forming long-distance services by Bussieck et al. (1996) and applied to the German IC-network (Hoffmann, 1997). Amstutz (2020) applies an integrated optimisation toolbox to redesign historically developed line and timetable variants for long-distance trains in Switzerland. While algorithm-based optimisation is becoming more and more popular with today's digital technologies, conventional analogue expert methods like the passenger flow oriented approaches of Sonntag (1979) or (Simonis, 1981) are more or less the methods currently used by experts.

Only a few examples for the creation of bundles for long-distance railway services exist as there are hardly any competitive tenders at this level in Europe. This is different at the level of local and regional passenger rail services, where tenders have taken place in many countries in recent decades. Literature usually covers these local and regional tenders. Therefore, expert interviews are essential to develop approaches for tendering STP bundles for long-distance railway services.

5.2.1 Bundle Concept

Bundles can be packages of geographic coherent lines or packages of timewise-combined lines (Figure 5.2). Bundles of STPs make it possible to form packages of relevant economic size. In contrast to the allocation of individual STPs, cherry-picking is prevented this way as well. Packages put together should therefore also include less attractive train slots at off-peak times.

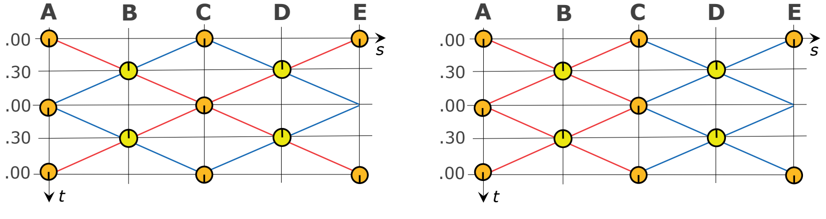


Figure 5.2: Timewise parallel bundles (left) and geographically split bundles (right)

In the following considerations, a network-wide ticket integration of all services is assumed. Therefore transfers to other RUs do not mean extra costs for passengers and do not result in a demand resistance.

5.2.2 Bundle Planning Approaches

Among currently applied bundle planning approaches for long-distance services, different objectives and boundary conditions can be identified as listed in Table 5.1.

Table 5.1: Bundle planning approaches

Country					
Approach	timetable	geography	capacity	region	direct connections, vehicle circulation
Objective	operational efficiency	cost-saving, geography-oriented	increase capacity utilisation	combining regional and interregional services	timetable
Boundary condition	timetable-oriented	terminus stations London, depots	size of packages	covered by one PTA	ITF

CZ – Timetable-oriented

The Czech Republic is one of the few countries in Europe that has already been tendering long-distance railway services in bundles. Janoš and Kříž (2019) describe a four-step-procedure that was iteratively developed based on an existing timetable and operation concept. The proposal aims for optimising operational efficiency.

Firstly, hubs and intervals are defined to calculate the minimum number of required vehicles. Secondly, peak-hour services are defined aiming for a minimum number of vehicles. Thirdly, operational efficiency is optimised considering refuelling, maintenance and cleaning. Fourthly, timetables in the evening hours are adapted in order to reduce the number of total working hours and vehicles.

The challenge in creating bundles was not to increase the number of required vehicles, even though long-distance lines were affected that originally also had regional transport functions. Based on conceptional timetables, vehicle requirements and costs were determined. Detailed vehicle scheduling concepts were developed attempting to expand the service and increase vehicle utilisation. Technical and operational aspects such as the time required for a vehicle turnaround at each station must be taken into account. In most cases, large increases in productivity could be achieved with the first tender. This can consequently no longer be expected in subsequent tenders (Janoš, 2019).

The actual size of bundles is often based on existing structures or contracts (Janoš, 2020b). The bundles awarded in the Czech Republic in 2019 covered about 2.0 to 6.0 million train kilometres with line lengths of 70 km to 430 km (Railjournal, 2018).

GB – Geography-oriented

The design of the original 25 franchises in 1995 was mostly based on former structures of British Rail. Those where developed before 1995 according to levels of service quality and geography (Intercity, regional railways and Network South East). Furthermore, the historic development of competing companies prior to nationalisation in 1923 shaped many franchises. The type of traction and terminus stations in London resulted in an obvious separation. After the year 2000, franchises were joined or redesigned to reduce the number of RUs and complexity in stations, resulting once more in geographically homogenous bundles. Infrastructure developments and timetable transitions were another reason to merge franchises. In the later redesign, objectives such as reducing costs for staff, economical size of fleets and depots with similar train types and avoiding remote locations were considered (Alexandersson, 2010; Nuttal, 2021).

This process resulted in franchises covering 3.0 up to 33.0 million train-km (Tomeš and Jandová, 2018). Brown (2013) suggested that bundles should rather be small and homogenous in terms of operations and rolling stock. While this contradicts the economies of scale, financial risks and administrative complexity can be reduced, which may encourage new market entrants.

ES – Capacity-oriented

In order to increase capacity utilisation of its high-speed network by 60%, the Spanish ministry for transport decided to tender services. PaPs were designed by the IM in order to be able to offer dense intervals and attractive connections on the three main routes of the country. The objective was to form three bundles of different size, which resulted in a dominant bundle covering 60% and two smaller bundles of 30% and 10% of the PaP. Each bundle covers PaPs of all of the three routes. While the biggest bundle was designed for an RU with sufficient resources, the smaller bundles were aimed at market entrants or low cost carriers with limited resources. The biggest bundle was awarded to the incumbent Renfe, the second biggest to the Treniatlia owned ILSA and the smallest one to Rielsfera, a subsidiary of the French incumbent SNCF (Montero and Melero, 2020).

SE – Authority-oriented

With the liberalisation in the 1990s railway services in Sweden were classified in four service categories and profitable and unprofitable services were identified. Besides unprofitable regional services and profitable long-distance services, interregional services were split into profitable and unprofitable lines (Alexandersson, 2010). While profitable services are open for any RUs interested, non-profitable services were tendered by the regional PTA. Regional and interregional services were tendered in bundles due to geography and area of responsibility of the authorities (Fröidh and Nelldal, 2015).

AT/CH/NL – Non-competition

In Austria, the Netherlands and Switzerland, long-distance services are directly awarded under a PSO regime (AT) or are self-sustaining within a network-wide concession (CH, NL). Therefore bundles for public tendering have not been designed yet, which is why the focus here is on line creation.

In **Austria,** non-profitable lines are directly awarded. They are primarily aligned to the requirements of the ITF and consider direct connections as well as homogenous passenger demand and train composition. In **Switzerland,** long-distance services are optimised for direct connections between important metropolitan and regional centres. The basic interval is an hourly frequency, an increase to a half-hourly frequency allows additional direct connections (Scherrer and Büchel, 2020). Furthermore, vehicle turnarounds, capacity of carparks in terminal-stations and international connections are taken into consideration. The **Dutch** Intercity network is strongly focused on passenger flows and end-to-end travel chains.

Criteria for bundle formation

According to Janoš (2020b) and Liebhart (2020a), the following criteria should be considered in bundle design:

- **Direct connections** reducing the number of transfers are important and bundle formation should not lead to a deterioration of existing services.
- Bundles should cover lines with the same **traction**. Long-distance services on main routes in Europe are usually electrified, however, Diesel- or hybrid traction on single lines influence the vehicle fleet.
- **Frequency** within a bundle should be as homogenous as possible amongst different sections.
- Lines should be combined to bundles in the same **geographical region.**
- **Operational aspects** like top speed, timetable and vehicle requirements should be homogenous.
- A similar **vehicle strategy** amongst the lines of a bundle is essential.
- An optimal **vehicle circulation** for an efficient operation should be considered.
- **Depot and infrastructure conditions** such as vehicle turnarounds must be taken into account.

5.3 Procedure Development

Based on the findings of line and bundle planning, target functions are identified. These can be divided into the three areas of transport planning, railway operations and demand modelling is visualised in Table 5.2.

5.3.1 Target Functions Bundle Planning

Transport Planning
Transport planning covers a large number of aspects that affect demand and railway operation. Two of these aspects are service intention and service availability, which are the contribution of public transport and therefore define the attractiveness to customers. Furthermore, the length of lines and size of bundles as well as the risk management have to be defined by transport planning.

- The **timetable concept** with interval and operation times has a significant impact on the volume of services and size of bundles.
- The creation of the **network layout** is a fundamental task of transport planning and represents the basis for line planning.
- The applied **line concepts** influence the shape of lines and bundles as well as the requirements for vehicles.
- The minimum and maximum **line length** influence the extent to which direct connections can be created. The same applies to the minimum and maximum **size of bundles**, which, depending on the size of the network, determines the number of bundles and thus has a significant influence on market accessibility.
- The **service availability** of the services to be tendered decisively defines the bundle size. The intended extent and interval of tendered services determine the traffic volume to be covered.
- **International connections** affect line formation considerably in medium-sized countries with cross-border passenger flows. The number of connections and their intervals need to be considered.
- The **risk management** determines whether the revenue risk remains with the RU or the PTA. If RUs bear the risk, the different yields of lines considerably affect the attractiveness of bundles.
- Bundle forming should consider amongst other parameters homogenous rolling stock, **homogenous geographic markets** and workshop locations.

Demand Modelling

Demand is the basis for strategic transport planning and can be separated into several target functions.

- Traffic relationships exist between individual traffic cells, hubs or markets in the form of **passenger flows**. These are described with an origin-destination matrix (OD matrix). Line planning aims to cover maximum passenger flows.
- Superimposed on each other, passenger flows result in the **passenger amount**. In the interest of an attractive offer and efficient service, the cross-section values are an important basis for planning and should be as homogenous as possible.
- Travel time is a decisive factor for the demand potential. In an ITF, the focus is therefore on the **minimum total travel time**. The total travel time consists of riding, transfer and waiting times.
- Attractive passenger services require direct long-distance services between the most important hubs of a network. In combination with smooth transfers to regional lines, an ITF can utilise its full potential. A **maximum number of direct connections** throughout the network should be aimed for.

Railway Operation

Railway operation is the joint implementation of transport planning and demand modelling. The main tools of railway operation are the timetable and vehicles. While the main features of the timetable are specified by the ITF, the requirements for vehicles result from infrastructure, railway operation and demand. Within a line or bundle, the requirements should be as homogeneous as possible.

- The **stopping pattern** defines the stops of a line and is an essential characteristic of a timetable. The ITF defines transfer hubs beforehand. It is part of the RU's unique selling proposition to decide which stops are served in addition to the hubs. These stops are not taken into consideration in the following line and bundle planning process.
- The **quality of railway operation** depends mainly on punctuality and quality of vehicles (IC or IR), both of which influence vehicle circulation and bundle composition.
- **Vehicle properties** such as vehicle traction and vehicle dynamics depend on the infrastructure. The requirements for vehicle dynamics are derived from the required edge riding times and the design of STP (chapter 4.3.3).
- Depending on the demand, the **passenger capacity of vehicles** results in the required number of vehicles per line.

- Closely linked to vehicle capacity is vehicle utilisation, which also results from the demand. RUs aim for a homogenous and **moderate vehicle utilisation** to enable economic operation and to have sufficient reserves in order to build up for passenger growth in the future.
- **Service facilities** must be available at end points of lines. The shunting of vehicles and servicing are basic requirements of railway operation.
- Workshops for rolling stock are needed for **light and heavy maintenance**.
- **Optimal vehicle circulation** is one of the core competences of a successful railway operation and has a significant influence on the size of the vehicle fleet. A detailed optimisation of vehicle circulation aiming for a minimum number of vehicles is the responsibility of the RU. However, to save costs it is crucial to consider it at this early planning stage.
- RUs aim for **cost-efficient operation**, which can be achieved best by an optimal vehicle circulation.

Table 5.2: Target functions for bundle planning

Transport planning	Line	Bundle
Timetable concept (interval and operation times)	x	-
Network layout	x	-
Line concepts	x	-
Line length and size of bundles	x	x
Service availability	x	-
International connections	x	x
Risk management	-	x
Homogenic geographic markets	-	x
Demand Modelling	**Line**	**Bundle**
Passenger flow	x	x
Passenger amount	x	-
Minimum travel time	x	-
Direct connections	x	x
Railway operation	**Line**	**Bundle**
Stopping pattern	x	-
Quality of railway operation (punctuality, quality of rolling stock)	x	(x)
Vehicle properties (traction, dynamics)	x	x
Homogenous vehicle capacity	x	-
Moderate vehicle utilisation	x	x
Service facilities	x	-
Light and heavy maintenance	x	x
Vehicle circulation	x	x
Cost efficient operation	x	-

These target functions have to be considered in line and bundle planning and need to be processed in a sensible sequence. Risk management can be considered in bundle forming; however, it primarily has to be included in the tendering process (chapter 6).

5.3.2 Sequence of Bundle Planning

In order to derive a reasonable sequence of bundle planning, target functions must be put into a logical sequence. Referring to planning sequences in railway operations (see chapter 1.5), it is recommendable to apply criteria in the following sequence:

- Firstly, strategic criteria like passenger flow, direct connections or consideration of international connections
- Secondly, tactical criteria like minimum travel time
- Thirdly, operational criteria like vehicle circulation

This order is useful in that otherwise operational arguments might largely be given lower priority than strategic arguments. Since tactical and operational arguments are more subtle, this is not the case in the order of strategic – tactical – operational arguments.

The same limiting factors are valid for strategic, tactical and operational arguments. Therefore, **limiting factors** have to be considered at the very beginning of the line and bundle forming process.

This is followed by **international connections** as those need to be planned on a long-term level and should not be modified later on. The modal share for railway transport of international connections is significantly lower than for domestic connections. However, in Austria 50% of all long-distance services are cross-border services.

In the next step, **demand** as the primary strategic argument in transport planning has to be considered. Herein the passenger flow is the primary strategic argument for line creation. Only within the framework of these passenger flows **direct connections** can be taken into account. In both arguments, domestic and cross-border relations must be considered.

Next follows **bundle design** as it needs to be done at a stage when improvements within bundles are still possible. Consequently, bundles shall be formed based on the **passenger flow**. Finally, tactical and operational arguments such as **service facilities** or vehicle **turnaround** are applied.

5.3.3 Suggested Method and Procedure for Bundle Planning

An approach for bundle planning is developed based on the presented target functions and by applying the proven methods of line planning. As network planning in the present case is already covered by the ITF, the optimisation of bundle forming focuses on the remaining target functions. For implementation, a strategic, heuristic, demand-based approach is chosen with subsequent manual optimisation. The procedure will be aligned to the partial line method of Simonis (1981) which is a demand-based approach and makes it possible to consider the derived target functions. The procedure aims to enable experts to create lines and bundles in a long-distance railway network in a simple, structured and practicable way in a relatively short time on the basis of a basic data set.

Based on these considerations, a multi-stage procedure is suggested (Table 5.3). The different stages cover aspects of demand modelling, railway operation and transport planning. From a given hub-edge model with service quality and interval, line bundles are created in eight steps:

1) Technical boundaries for the minimum and maximum line lengths and limits of size of bundles need to be set.
2) International connections play a major role in the line design of medium-sized countries. It is therefore necessary to identify relevant international connections and the respective intervals.
3) The line construction is defined by the strongest passenger flows in the network. Lines start at hubs and are formed using an Origin Destination matrix until all edges in the ITF network are covered.
4) For attractive travel chains as many hubs as possible should be directly connected. Therefore, the lines created need to be aligned to potential direct connections between important railway hubs, large cities, or administrative centres.
5) Bundles are formed by combining geographically connected lines and considering similar passenger amounts but also connectivity to workshops. Optimisation is done on a tactical and operational level in the subsequent steps.
6) Cross-sectional demand of lines should be homogenous in order to ensure economic train operation. A homogeneous vehicle fleet of the lines and bundles is aimed for.
7) Since light maintenance must be possible during operation, it is considered whether all lines reach hubs with workshops. Furthermore, the capacity of depots in the planned start and end hubs need to be reviewed.
8) Vehicle circulation is a strong indicator for an economic operation. Therefore, within lines and bundles, vehicle circulation is examined and checked for homogeneity and

plausibility. If necessary, operational tightening is carried out and finally the bundles are fixed.

Table 5.3: Line and bundle planning procedure

	Transport Planning	Demand Modelling	Railway Operation
Step 0 Service intention	Timetable concept Network layout Line concepts Service availability		Quality of railway operation
Step 1 Line length and size of bundles	Line length and size of bundles		
Step 2 International connections	International connections		
Step 3 Passenger flow		Passenger flow Minimum travel time	
Step 4 Direct connections		Direct connections	
Step 5 Bundle forming	Risk management Homogenous geographic markets		
Step 6 Passenger amount		Passenger amount	Homogenous vehicle capacity Moderate vehicle utilisation
Step 7 Service facilities			Service facilities Light and heavy maintenance
Step 8 Vehicle circulation			Vehicle circulation Cost efficient operation
Post tender award			Stopping pattern

5.4 System Train Path Bundle Procedure

The procedure for defining STP bundles is aligned to the target functions and sequence suggestion as described beforehand. Service intention described in Wieczorek (2006) and Caimi (2009) is crucial to timetable planning and calculating the traffic volume. Service intention has to be defined first and only then the eight-step bundle design procedure can begin. The parameters are chosen from different (ITF-aligned) railway networks, expert opinion and educated guesses.

In real networks, lines can be distinguished in national and international connections/lines. In the procedure and later on in the model network, they are described as network-wide connections and cross-border connections.

The **target functions** are written in bold face. The service intention and the steps of the STP bundle procedure are presented in the following format:

- Objectives of the relevant target functions
- Analysis of parameters
- Derived method and sequence for the procedure

5.4.1 Service Intention – Step 0

Objectives Step 0
The service intention represents the public transport offer and covers the definition of timetables, intervals and service quality. It needs to be defined before starting any time-table or bundle planning. The service intention covers the target functions **timetable concept**, **network layout**, **line concept**, **service availability**, **quality of railway operation** and **vehicle properties**.

Analysis Step 0
The STP bundle procedure is based on an ITF as described in chapter 2.4. The ITF defines arrival and departure times in hubs as well as edge riding times. The range of possible **intervals** in long-distance traffic, as well as the usual operating times, are derived from railway networks with an ITF or periodic service offers.

Long-distance IC services are the backbone for a network-wide ITF service. The demand-oriented offer should allow for an attractive network-wide frequency. In the Netherlands and Switzerland, Intercity services run in intervals of 15 up to 60 minutes with plans for even denser intervals of up to ten minutes (Bücher and Scherrer, 2019). The planning objective for the Swiss railway network foresees a maximum interval of 60 minutes on long-distance lines (BAV, 2017). In Austria, the interval of Intercity services strongly depends upon the line and ranges from four trains per hour on the Western Line (2019) to 120 minutes or more on less frequented relations (ÖBB-Personenverkehr AG, 2019a). This results in a range of intervals from **15 to 120 minutes**. For the purpose of the model, **30 to 60 minutes** are assumed as a reasonable basic interval for network-wide long-distance services. An interval of 60 minutes allows to easily reduce the interval to 120 minutes without sunk costs, as train crossings in a 60 minute interval happen in the hubs. This reduction can be used to offer additional slots of self-sustaining OA services.

Operation times of long-distance services depend on the type of relation and the direction of load. In Central Europe, long-distance connections start at about 4:00 to 6:00 in the morning and are kept up until 22:00 and 24:00 in the evening (Table 5.4). Off-peak services are partly covered by night trains. The assumptions are based on the first or last intercity trains leaving or arriving in the respective capital. This means that in other hubs in these countries, there could also be earlier or later trains. This results in an average operation time from **05:00 to 23:00** which amounts to 18 hours.

Table 5.4: Operation times and intervals in selected European countries

Parameter							
Operating hours [hh]	05-23	06-23	05-21	04-24	06-23	03-22	05-24
Source	ÖBB-Personenverkehr AG (2020)						

As stated above, bundle definition in railway systems is usually done within an existing railway network. Railway infrastructure has to be planned in the long-term, which is why **network layout** is assumed to be done beforehand. Hubs and lines of the network need to be known. If the network layout is not fixed beforehand, the network design has to be integrated into the bundle and line design process.

In existing railway networks, the network of routes is the framework for **line concepts**. This is different from road-based bus lines that are comparably free to choose varying streets to connect stops. As shown in Siegloch et al (1992) and Walter (2010) line planning uses different kinds of line types such as radial, tangential or circle lines to connect hubs and stops.

In reality, networks are typically historically grown and often experienced no continuous systematic planning.[19] As the construction of railway tracks is a complex and long-lasting

[19] Compare the systematic network planning of Riepl and Ghega the mid 19th century, opposed by an unsystematic planning of single lines in following decades analysed by Geyer (1954)and Reisinger (1997).

process and the design of railway networks is not the primary intention of this research, the focus is on the line design on a given network. Lines may serve parallel stretches, branch lines (splitting or combining of lines) or run in a circle. Hubs function as starting, turning and end points for lines.

As backbone of the ITF a **service availability** is required in terms of time and geography. This means that all lines of the long-distance network should offer at least an hourly interval throughout the day. Since long-distance services usually do not differ between working days and holidays these services are offered 365 days a year. Therefore, the service availability includes the volume of lines and bundles.

The **quality of railway operation** influences the attractiveness for customers. Specifications for punctuality and timetable stability as well as train types are relevant in route and bundle planning.

Punctuality is an important service feature and is the responsibility of the RU. However, respective parameters need to be defined beforehand in order to guarantee timetable stability. Those parameters are laid down in the network statement of the IM and include recovery time, minimal turnaround time and buffer times (see chapter 4.3.1). These parameters become relevant in vehicle circulation and later on for train path allocation. The recovery time has to be considered on the level of train paths. Turnaround and buffer times are discussed in chapter 5.4.9.

The **quality of rolling stock** can be defined in two gradations: Train types and Train equipment. The details of the train equipment have to be specified in the tender. Requirements for train equipment on Intercity and Interregio services cover e.g. accessibility and amenities like suitability for barrier-free travel, air-conditioning, passenger information systems, sanitary facilities, bicycle transport, catering area, first class area and multi-purpose area (Bmvit, 2018).

The train type plays a role in the line and bundle planning process when allocating lines and creating vehicle circulation. SCHIG's pre-announcement on the ÖBB transport services contract distinguishes between accelerated priority long-distance services, priority long-distance services, Interregio-services and night trains (Bmvit, 2018). For comparison, the competitive timetable for local transport tenders in Germany distinguishes between seven different categories from S-Bahn to Interregio (BAG SPNV, 2019). Internationally common train types are described in Walter (2016). As neither regional nor night trains are dealt with in this thesis, a distinction is subsequently made between the two quality levels Intercity (IC) and Interregio (IR).

These classifications depend upon the function of a line and are assigned accordingly. The functions may be interregional, national or international. In addition the number of passengers and line length are relevant. Train types, if relevant at all and not purely used for marketing purposes, can therefore only be assigned after the line and bundle formation process is finished.

Vehicle properties such as vehicle traction and vehicle dynamics are defined by the infrastructure. The vehicle traction depends on the type of infrastructure, while the requirements for vehicle dynamics are derived from the required edge riding times (see STP - chapter 4.3.3).

The traction type as well as the requirements for driving dynamics determine which vehicle (types) can be used. For RUs it is important that bundles consist of lines with homogeneous requirements. Especially in small bundles, the required vehicles should be homogenous. In large bundles it is easier to use a set of different vehicles (Liebhart, 2020a).

Most railway lines used for long-distance services are electrified. However, in Germany or Great Britain there are still long-distance lines operated with Diesel-traction. On the contrary, the variety of traction types in regional railway services is much larger. Five categories of traction are considered for tenders between 2019 and 2033 in Germany, namely Electro, Diesel, Diesel and Electro, Fuel Cell, Battery plus the category "*not yet defined*" (BAG SPNV, 2019).

The edge riding times of an ITF network result in minimum requirements regarding vehicle dynamics for trains (chapter 4.3.3). For Intercity services in ITF networks in medium-sized countries, top speeds of 160 – 250 km/h are required. High acceleration values allow for additional stops. For certain routes, the use of increased lateral acceleration or tilting trains may be necessary in order to be able to run the edge time. Most of these requirements can be met by standard high-quality long-distance vehicles (Fuit-Bosch, 2020).

Method Step 0

The inputs for *Step 0* Service Intention are listed in Table 5.5.

Table 5.5: Procedure inputs for service intention

Target function	Input	Characteristics
Timetable	ITF	hubs + edges + edge riding times are predefined; hubs function as starting, turning and end points for lines
	interval	15 – 60 minutes
	operation times	05:00-23:00; resulting in 18 h of operation; 18 departures and arrivals per hub per line (doubled in the event of half-hour-interval, halved at 120 min interval)
Network layout	hubs and lines	usually predefined; otherwise network design can be integrated into the line planning process
Line concepts	line types	parallel, branch and circle lines and variations
Service availability	all network, (half-)hourly services	18 (on some edges 36) STP per hour / direction; 7 days a week, 365 days/year; gives a basic offer in million train-km per year
Quality of railway operation	punctuality	7% recovery time, turning times, buffer times
	quality of rolling stock	Intercity (IC) or Interregio (IR)
Vehicle Properties	traction	Electro, Diesel or Hybrid; mostly Electro on long-distance routes
	vehicle type	Electrical Multiple Unit (EMU) or locomotive and waggons, sometimes tilting trains, V_{max} 160 – 250 km/h, high acceleration allows for adapted stopping pattern

The steps are described by a model network (Figure 5.3) which is further explained in chapter 5.5. The sequence for defining the service intention is depicted in Figure 5.4.

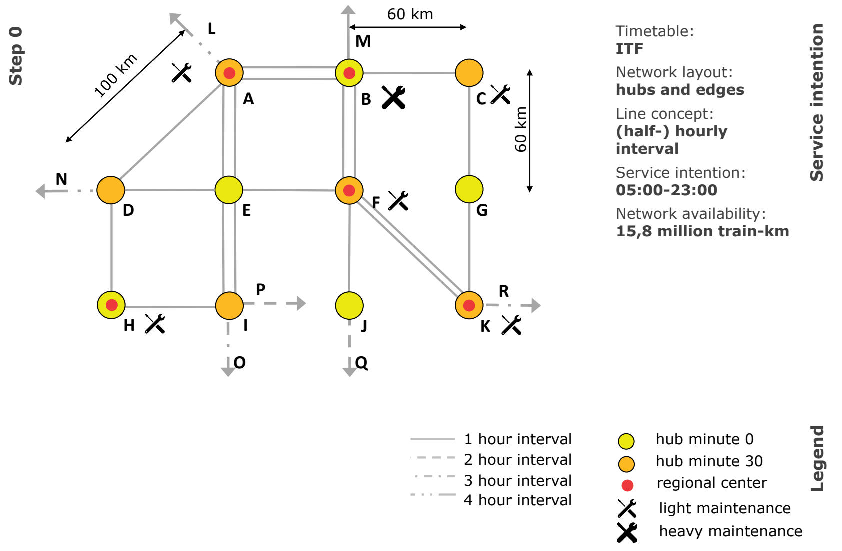


Figure 5.3: Model network step 0 – Definition of service intention

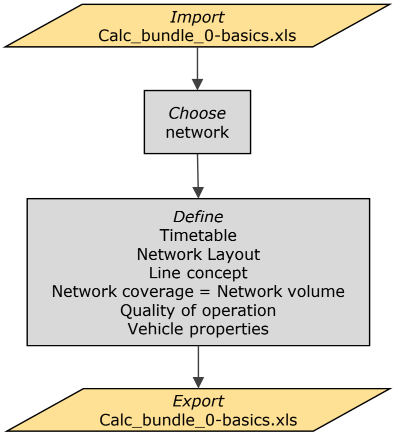


Figure 5.4: Sequence step 0

5.4.2 Line Length and Size of Bundles – Step 1

In order to provide limits for the creation of lines and bundles, the definition of the minimum and maximum **line lengths** and **bundle sizes** is necessary. The assumptions are based on empirical values from various networks and tendering processes in Europe.

Objectives Step 1

The minimum and maximum **line length** is strongly connected to the geography of a country and its railway network. In order to determine a minimum line length, the demarcation between regional and long-distance services has to be defined. For long-distance lines, it is difficult to define a general upper limit, as this strongly depends upon the network. Long connections can be the result, especially for international direct connections. In an ITF, the line length could be specified additionally so that a majority of the trains used can run the entire length of the line within the operating time. However, the minimum line length has to be defined anyway.

The **size of bundles** affects railway operation but also determines the number of bundles and the market accessibility. Small bundles represent a low market barrier; however, they might be unprofitable due to the economies of scale or the number of required vehicles might be too small. Large bundles allow for more flexibility within the bundle over a contract period. The size might also be influenced by the type of tendered services such as regional, mixed or long-distance services.

Analysis Step 1

The **minimum line length** of long-distance lines is defined differently amongst railway networks. Catharin and Gürtlich (2015) define long-distance services in Austria starting with a line length of 70 to 90 km and a travel time of 60 to 90 minutes. It is assumed that a return to the starting point is possible within one day. In Germany, regional transport services range up to a length of about 50 km or one hour travelling time (AEG, 2020). In Great Britain, long-distance services start about 80 km (Network Rail, 2013). In Switzerland, a functional definition is applied based on criteria like the connection of metropolitan centres or the fastest connection on an important relation. The shortest Intercity-lines in Switzerland are 50 to 74 km long (SBB CFF FFS, 2019). In the Czech Republic, the shortest tendered long-distance lines are 70 km.

Considering these approaches the minimum length of long-distance lines in an ITF network of a medium-sized country is assumed at 100 km, which is equivalent to a travel time of about 60 minutes.

Table 5.6: Minimum line length in long-distance passenger services

Minimum line length					
Long-distance services [km]	70-90*	50-74	>70	>50	>80
Long-distance services [min]	60-90*	45-60	-	>60	-
Source	Catharin and Gürtlich (2015)	SBB CFF FFS (2019)	Railjournal (2018)	AEG (2020)	Network Rail (2013)

* A return to the starting point on the same day has to be possible

The minimum line length could also be adjusted to allow a certain percentage of the vehicles to run the whole line length within the operating time.

The **maximum length of lines** is, as mentioned above, strongly dependent upon the network and whether the line is an international cross-network line or not. Furthermore, different train categories implicate different line lengths. As the focus here is on a network, the length of IR- and IC-lines shall be determined.

The longest IC line in the Netherlands is 240 km long (Treinreiziger, 2019), while in Germany the average travel distance of ICE-trains is 335 km (DB AG, 2019). The longest tendered lines in the Czech Republic so far were 430 km long (Railjournal, 2018). In Great Britain the longest through train runs for 1162 km, takes 13 hours and 15 minutes and has 33 stops (Jackson, 2020). See Table 5.7 for more details. The station spacing in Austria, Switzerland and Germany for IC services vary between 20 and 100 km and are between 10 and 50 km for IR services (Walter, 2019).

Table 5.7: Maximum line length of IC services

Parameter					
Min. station spacing IR [km]	20-50*	10-30	-	-	-
Min. station spacing IC [km]	50-100**	20-50	-	-	-
Max. length [km] from - to	700 Wien - Bregenz	370 Genève - St. Gallen	430 Praha - Jablunkov-Navsi	1160 Aberdeen - London - Pencance	240 Leeuwarden - Rotterdam
Corresponding travel time [hh:mm]	05:42	03:47	04:35	13:15	02:37
Sources	Walter (2019) ÖBB (2020)	Walter (2019) ÖBB (2020)	Railjournal (2018) ÖBB (2020)	Jackson (2020)	ÖBB (2020)

*common IC **accelerated IC

In comparison, high-speed services have, due to their network structure, higher top speeds and therefore wider station spacings. In France and Spain station spacings are, dependent on the service, between 100 and 200 km or even more (Walter, 2019).

As line length varies with the constellation of a network and top line speed, travel time should be taken into consideration. A useful upper limit depends, among other things, on travel distances and therefore on the purpose of the trip or the competing offers. A reasonable limit for travel time of an IC-service in a medium-sized ITF network is about four to six hours. If overlapping routes can be covered with one line, the acceptable travel time can also be longer.

However, longer lines potentially reduce timetable stability and can negatively affect vehicle utilisation. In the event that lines become too long in the design phase, they ought to be split for the sake of timetable stability (Weigand and Berschin, 2020).

The **size of bundles** in competitive tenders in long-distance and regional transport services has been varying considerably in recent years (Figure 5.5). The biggest bundle in competitive tenders can be found in Great Britain, where franchises have ranged from 3.3 to 33.0 million train-km in recent years (European Commission, 2019). However, the median size was 26.5 million train-km and the biggest tender was for 44.9 million train-km in the last decades. In Germany only regional services are tendered with a size of 0.1 up to

10.0 million train-km. However, there are also exceptions in the form of the S-Bahn networks that reach sizes of up to 26.0 million train-km (Nash et al., 2013) and even bigger bundles are projected to be formed by 2033 (BAG SPNV, 2019).

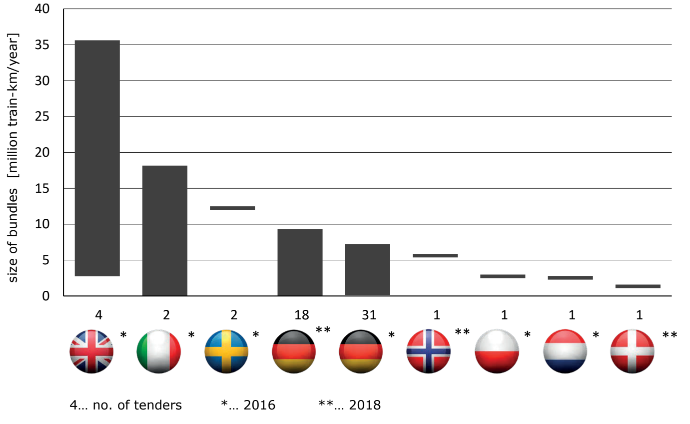


Figure 5.5: Band width of competitive tenders in 2016 and 2018 (European Commission, 2019, 2021)

To benefit from network economies or economies of scale it is required to reach an appropriate bundle size (Salesse, 2017). Although there are tenders for small bundles of 0.1-1.0 million train-km per year in regional rail services (Recker and Westenberger, 2015), these can hardly be operated economically because the share of overhead costs is too high (Winter, 2018). Bundle sizes in the subsegment of 0.1-1.0 million train-km can only be adequately supplied by (small) RUs that are already active in the market as an additional service (to secure their existence). In addition, a public transport authority (PTA) might be interested in experimenting with certain parameters or strategies on small bundles (Holzhey et al., 2011).

From an economic point of view, a volume of at least 2.0 million train-km is necessary in a tender competition that is open to new market participants to cover administration and overhead cost (Liebhart, 2020a). In the Czech Republic, several bundles with about 2.0 million train-km were tendered since small bundles were requested by the market. Given a thought-out coordination and cooperative RU, a market can still be flexible with smaller sized bundles (Janoš, 2020b). In Germany, about 75% of the market are tendered in bundle sizes of 3.0 to 10.0 million train-km (Recker and Westenberger, 2015).

Since vehicles are the biggest cost driver for RU, a **reasonable number of vehicles** is essential for an economic operation. A fleet of about 10-20 vehicles makes sense in terms of acquisition and maintenance. This allows for a customised acquisition process and economic maintenance in the context of economies of scale (Liebhart, 2020a). With this number of vehicles, a service volume of approximately 5.0 to 10.0 million train-km per year can be operated if a yearly mileage of 0.5 million train-km is assumed per vehicle (chapter 5.4.9).

In general, larger bundles can be operated more efficiently, they are more flexible and vehicle reserves are comparatively lower. However, large bundles require high financial investments and extensive administrative resources and can therefore represent a barrier to market entry. Advantages of larger volumes are a reduction of tendering processes and administration burden for the PTA, synergies and flexibility in operation (Holzhey et al., 2011). In addition, larger bundles often show operational advantages (Janoš, 2020b). The volume of franchises became bigger in Great Britain as the number of franchises decreased since 1995. However, these large inhomogeneous bundles are difficult to operate and require large scale resources from the RU as well as the PTAs (Brown, 2013; Liebhart, 2020a). On the contrary for (very) small bundles the opposite case may be possible. With tight maintenance, fewer reserve vehicles are needed, which can make efficient operation possible even in small bundles.

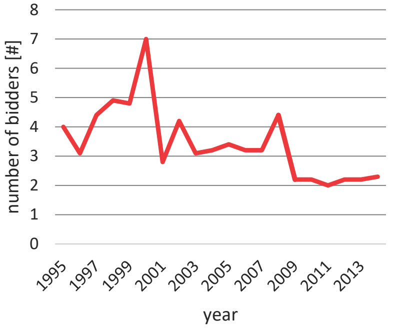
The question remains what a **useful bundle size** is. Recently awarded bundles for long-distance services in the Czech Republic cover 2.0 to 6.0 million train-km (Railjournal, 2018). In Sweden, PSO services were tendered with a size ranging from 0.8 to 6.3 million train-km, with a median of 2.6 million train-km (Nash et al., 2013). However, in 2018 two bundles with about 12.0 million train-km were awarded (European Commission, 2021). Experiences in the Czech Republic and Germany show that bundles of about 4.0 to 5.0 million train-km are a useful size (Liebhart, 2020a). However, most bundles have a volume below 10.0 million train-km as higher volumes become difficult to handle in terms of staff and financial resources (Seifert, 2020). Based on (BAG SPNV, 2019) it is calculated that 80% of the tenders in Germany are smaller than 8.0 million train-km.

Concluding, most tenders in European railway networks range from 2.0 to 10.0 million train-km, which is a recommendable size for bundles in regional railway services according to (Holzhey et al., 2011). Smaller lots are relatively time-consuming to award, less flexible and hardly ever profitable. In the case of larger lots, there is a risk that very few potential applicants compete, and incumbents or established RUs are therefore privileged. Even if long-distance rail services cover longer distances and have comparatively lower staff requirements, it can be assumed that these values do not deviate significantly.

Table 5.8: Relationship between bundle size and market accessibility

Type of bundles	Size of bundles [million train-km/year]	Number of bundles	Degree of market accessibility
Small	2.0 – 4.0	many	high
Medium	4.0 – 8.0	some	medium
Large	8.0 – 10.0	few	low

For a successful tender, a reasonable **number of competitors** is relevant. At least two competitors are required for a competition. Studies show that comparably small tenders (0.5-1.0 million train-km) attract many offers (Holzhey et al., 2011). In Germany the number of bidders decreased since 1997, with approximately three bidders per tender nowadays (Figure 5.6). According to (Recker and Westenberger, 2015), with increased bundle sizes the number of competitors slightly decreased (Figure 5.6). However, experiences in Great Britain show that RUs have to fight harder in order to get bundles and will bid more aggressively when bundle sizes get larger (Brown, 2013).



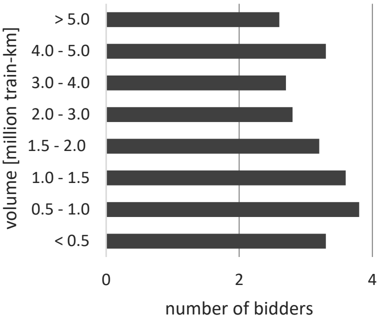


Figure 5.6: Number of bidders in competitive tenders in Germany from 1997 up to 2014 (left) and number of bidders according to bundle size (right)

Method Step 1

Long-distance lines are assumed to cover a length of at least 70 km, otherwise these lines are usually classified as regional lines or serve as branch lines. The minimum line length for IR services is assumed with two edges, which is about 60 minutes travel time and a distance of 120 km. For Intercity services the minimum length is assumed with three edges, which is about 90 minutes travel time and a distance of 180 km. The travel time on a line should ideally be a full divisor of the operation hours to optimise vehicle flows.

Since long lines might have negative impacts on timetable stability, the line length in an ITF network should be limited. The length from the hub with the highest demand to the hub farthest away should have a maximum length of no more than half the network length (Table 5.9 and Figure 5.7). The size of railway bundles is assumed to cover a range from 2.0 to 10.0 million train-km.

As the complexity of a bundle is not mainly connected to its size, the type of services and vehicles should be as homogenous as possible. Within this band width, smaller bundles can be designed to allow for a low market barrier. However, if operationally useful larger bundles allow for more flexibility and efficient operation.

Table 5.9: Definition of minimal travel time and maximal line length

Type	Distance [km]	Edges [-]	Travel time [min]	Comments
Interregio min.	120	2	60	beyond: regional services
Intercity min.	180	3	90	beyond: Interregio-services
Intercity max.	-	-	-	<50% of edges of network
Further assumptions	travel time and line length depending on hub-edge model = edge time*n; shorter than two edges = branch line			

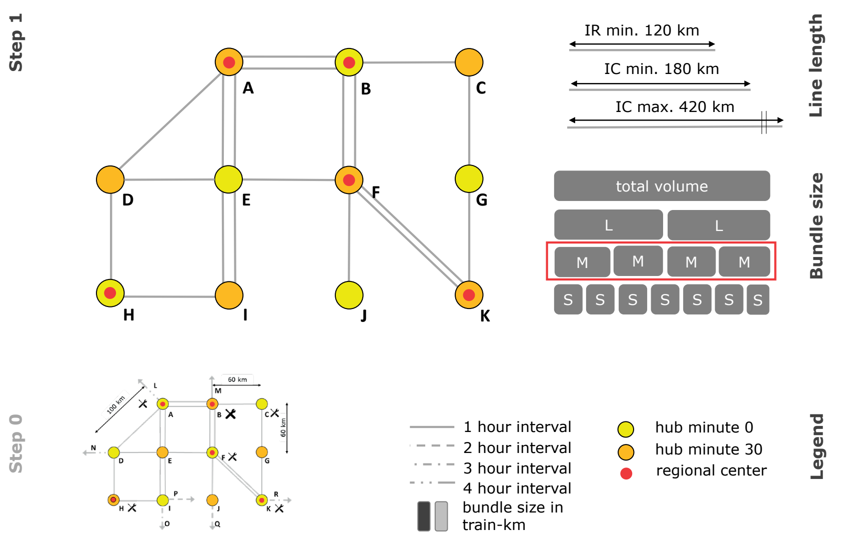


Figure 5.7: Step 1 – Definition of min./max. line lengths and bundle sizes

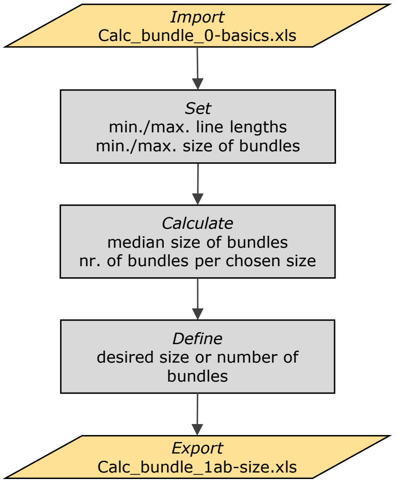


Figure 5.8: Sequence step 1

5.4.3 International Connections - Step 2

Objectives Step 2

Cross-border services connected to ITF services affect line forming considerably. Therefore, it has to be defined which **international connections** are relevant in the bundle forming process.

Analysis Step 2

International connections have high relevance in small and medium-sized countries as their railway networks are usually closely connected to neighbouring countries. An ITF is usually designed based on the international railway network, this was also shown by Bahn 2000 in Switzerland (Meiner, 2019). In the Czech Republic about 30%, and in Austria close to 50%, of passenger traffic in pass-km is international (European Commission, 2019). About every second long-distance train in Austria is a cross-border services (ÖBB-Personenverkehr AG, 2020). To improve the ridership on international lines efforts are being made for Europe-wide direct connections (Scheuer, 2020) and a Europe-wide coordinated ITF system (Scherrer and Büchel, 2020). Coordination of international train services is rather complex, as they have to be prioritised in train path allocation according to European and national law (see chapter 3.1). Therefore, it makes sense to integrate these services in the planning process at an early stage.

Due to higher production costs, international daytime services can often only be financed as extensions of national services (Arx et al., 2018). While national and international long-distance services in Switzerland and Germany are operated exclusively as self-sustaining services, most of these services in Austria and the Czech Republic are operated under a PSO regime. As international connections usually do not generate profits on the international level, they have to represent a business case in the national sections. In the case of the Wien-Zürich Railjet, profits are only made on the Wien-Salzburg section, while the sections Salzburg-Buchs run under PSO and Buchs-Zürich is integrated into the concession of SBB (Arx et al., 2018). However, this also means that these connections must be integrated into the national timetables and tariff systems, otherwise financing becomes even more difficult. Not integrating international services in the national timetable results in less attractive connections with more transfers and longer waiting times. Thus in long routes with several operators involved, reliability and comfort for customers are reduced (Arx et al., 2018). However, nationally extended international connections are prone to delays and as a result may cause delays in the national network (Graffagnino, 2019). Therefore, in Switzerland they have to wait for another clocked train path if they miss the ITF route. The interval and integration in the timetable has to be defined carefully. To avoid subsequent delays, sufficient transfer times and turn-over times need to be considered (Uttenthaler, 2019).

The combination of national with international services is important. They need to be integrated into the national ITF system and its rules. A cross-border coordination of timetabling and traffic management is crucial for attractive services with high stability (PRIME, 2015). The integration can be done by extensions of the national lines (Graz-Praha/Berlin) or splitting of national services (Wien – Wien Flughafen/Budapest, Wien – Innsbruck/Zürich). The specific route will be determined on the basis of passenger flows (*step 3*).

The present concept assumes that the train paths will be awarded within the framework of a PSO contract. Therefore it has to be clarified whether international services can be included in a PSO scheme from a strategic and technical perspective or whether they should be left out. If cross-border services are considered, the interval and function of these services have to be defined. It can be distinguished between relations serving a hub and transit functions. International services can be integrated into the tendering process but could also be tendered separately. If tendered separately is has to be decided if these lines should be considered in the subsequent planning process. The tendering of international services is further discussed in chapter 6.1.1.

International services usually represent attractive direct connections between major hubs with a travel time of four to six hours (Arx et al., 2018). These services run between two or more countries. From a network perspective, international connections can be adjusted towards one hub or run across the network primarily linking hubs in other networks (transit service).

The interval of international connections depends on the demand and the relevance of direct connections according to transport planning. If there is no clear main or transit relation, an interval parting on different lines should be taken into account. However, the connections of the cross-border edge will be defined in *step 4*. In addition, cross-border lines outside the ITF scheme are possible as self-sustaining services. Furthermore, it has to be decided whether single connections should be left to non-integrated OA services (Figure 5.9).

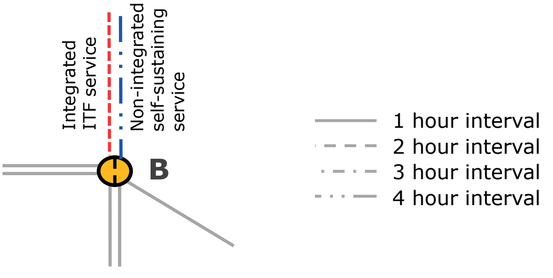


Figure 5.9: Integration of cross-border services

Method Step 2

To consider **international connections** in the planning process, relevant edges have to be identified first (Figure 5.10 and Figure 5.11). Cross-border edges are considered if demand is sufficient and/or direct connections make sense in terms of transport planning. Furthermore, compatibility with integration in the suggested ITF and PSO tendering scheme has to be ensured.

If an edge is considered, passenger relations to hubs or transit functions and the interval of the service have to be identified. The interval has to be defined taking into account if self-sustaining services complement the clocked offer. Once the number and interval of international connections is defined the additional volume of train-km to be considered in the line and bundle design can be calculated.

The routing of international lines is done, as for national lines, according to the passenger flow in *step 3* and is then reconsidered according to direct connections (*step 4*). If a splitting of a connection is considered on more than one line, this is done at the very end of the process (*step 8*).

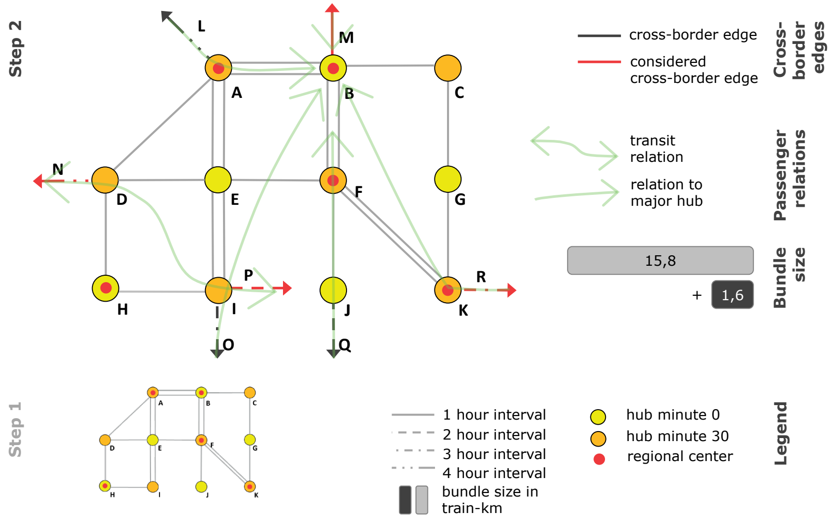


Figure 5.10: Step 2 – Consideration of international connections

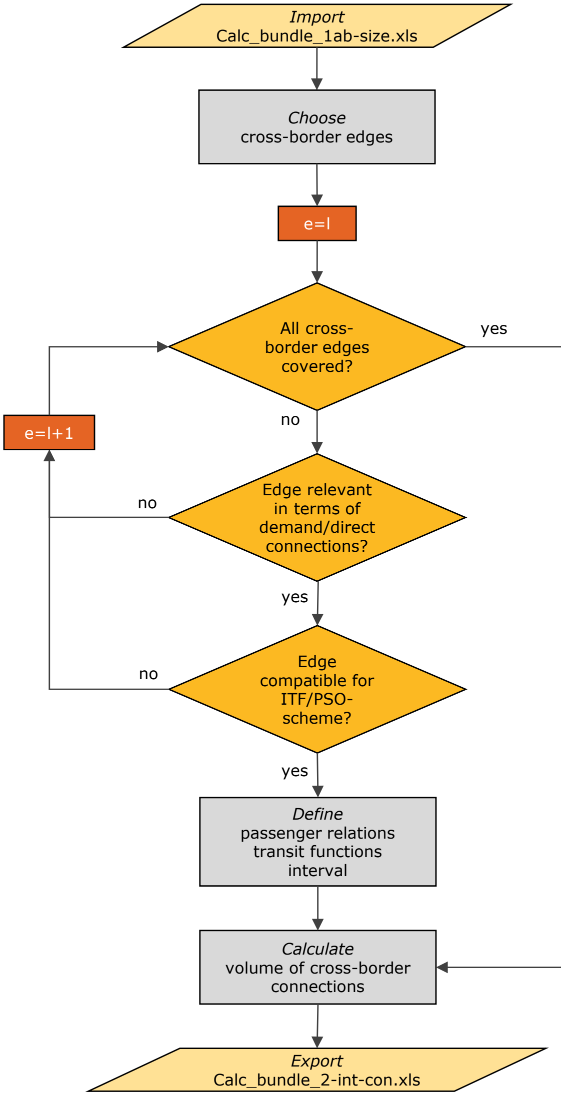


Figure 5.11: Sequence step 2

5.4.4 Passenger Flow – Step 3

Objectives Step 3

Demand is the strongest argument for strategic line and bundle planning**. Passenger flows** in the network have to be calculated on an OD matrix. Lines should be created along these passenger flows considering the **minimum total travel time** and the minimum and maximum **line length** as defined in step 1. Cross-network edges are included in line construction, however, with lower priority than edges within the network.

Analysis Step 3

Demand relations exist between individual traffic cells or hubs in the form of **passenger flows**. Therefore, in this thesis a passenger flow describes the amount of passenger travelling between a certain relation. The term is not to be confused with passengers boarding or alighting.

Passenger flows are described with the help of an OD matrix, which are based on:

- Real-world data (e.g. countings or mobile phone data)
- Calculated data (e.g. model based on data or assumptions)

In this thesis the bundle procedure is based on an OD matrix filled with data calculated with Lill's law of travelling. Lill's law of travelling describes the distance-relevant passenger potential of railway line changes and is used in the adapted form of Mayrhofer (1991). The railway affinity factor which defines the attractiveness of railway connections as a function of travel speed and distance is used according to (Smoliner and Walter, 2019). Janoš and Kříž (2018a) show that this gravity model can be set up by defining inhabitants of the hubs in the railway network.

The developed procedure for line design is a heuristic approach based on the aforementioned progressive procedure by Simonis (chapter 5.2). While this approach has been developed decades ago it is still suitable for expert procedures and used in practise. It is a demand-based approach depicting passenger flows. The strongest passenger flow along the minimum travel time defines the through-service (Bücher and Scherrer, 2019). In the next steps, the derived line network is steadily optimised by the objectives of direct connections, homogenous passenger numbers, availability of service facilities and optimisation of vehicle circulation (*step 4* to *8*).

As suggested by Simonis (1981), line constructions start in the hub with the strongest passenger flow to another hub. The line is formed to the other hub by adding one edge after the other. This is done along the edges with the strongest passenger flow. In an ITF network connected edges need to be assigned to the same interval group. If edges of the network represent e.g. a half-hourly interval, the correct combination of edges has to be ensured (Figure 5.12). Different interval groups allow for more direct connections, however, connectivity among each other in the hubs needs to be considered. Among services of the same interval group, transfer times are minimal (less than ten minutes). To other interval groups, transfers take longer.

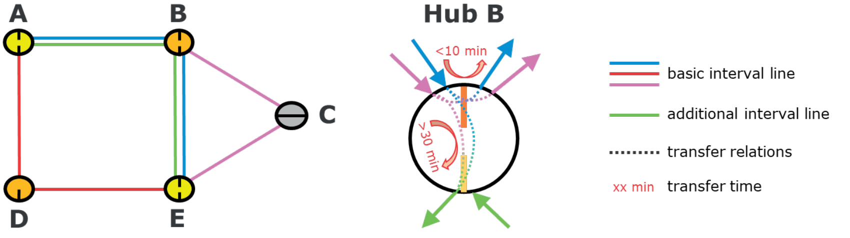


Figure 5.12: Transfer times among different interval groups

As long lines often suffer under inhomogeneous capacity utilisation (Amstutz, 2020), the passenger flow-oriented line construction should not result in line lengths close to the maximum line length (*step 1*). When long routes make sense in terms of attractive direct connections, the routes will be adapted in *step 4*.

Method Step 3

As line construction is done according to passenger flows, an OD matrix for all hubs in the network and virtual hubs for cross-border edges is calculated based on Lill's law of travelling. Input parameters are inhabitants of hubs, the length of edges and the railway affinity factor. Alternatively, when available, any OD matrix covering all hubs can be used.

The line construction starts at the hub with the strongest passenger flow and continuous along the strongest OD pair of this hub (Figure 5.13). The route is formed by adding adjacent edges within the same interval group one after another aiming for the minimum total travel time. If several routes offer the same travel time, the route along the strongest passenger flow is chosen. If alternative edges have equal passenger flows, the edge with the higher passenger flow on the consecutive edge is chosen (Figure 5.13).

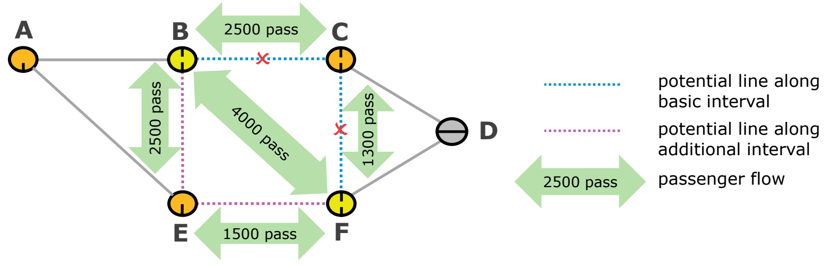


Figure 5.13: Line construction along strongest passenger flow

If one OD pair can be connected on two parallel routes via a basic interval or an additional interval, the line should be assigned to the additional interval group (Figure 5.14). Edges with the basic interval have usually more options to connect.

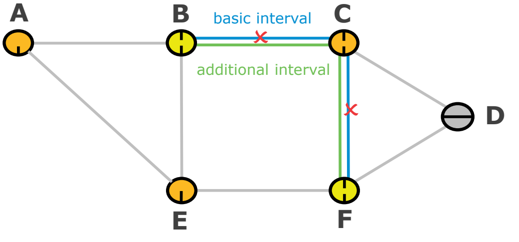


Figure 5.14: Line construction in case of parallel edges

The line construction ends when the maximum line length is reached as defined in *step 3* or a hub can be reached faster via another line combination. The travel time of the resulting line has to be at least the minimum total travel time (Figure 5.15). Cross-border edges are equivalently considered in this process.

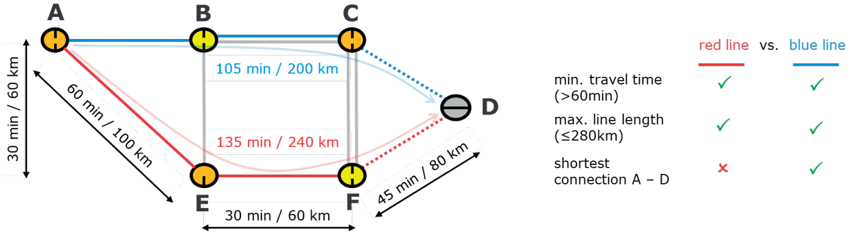


Figure 5.15: Definition of line ends

If the first line is finished the next line starts at the hub that has the highest uncovered passenger flows. This scheme continuous until all edges of the network are occupied with lines. If single edges are left they are assigned as a branch line to existing lines according to the strongest OD pair of the single line.

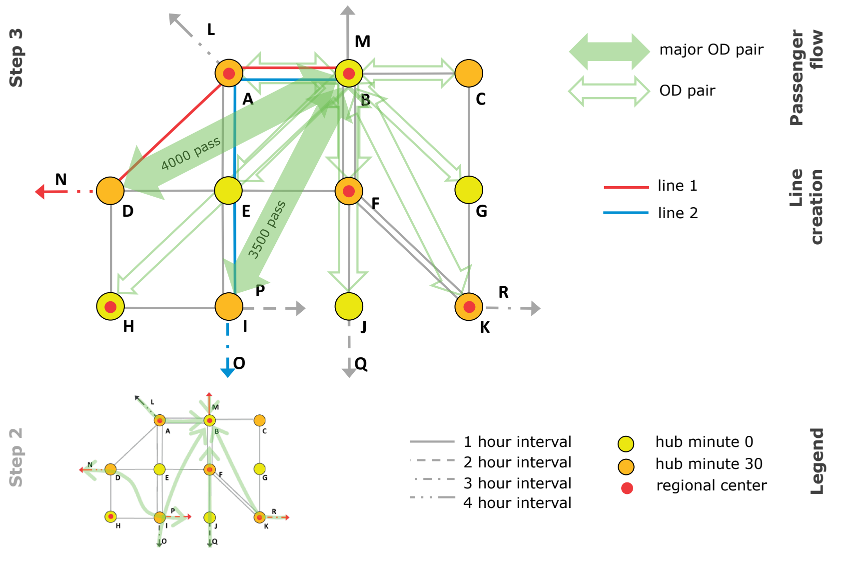


Figure 5.16: Step 3 – Line creation according to passenger flows

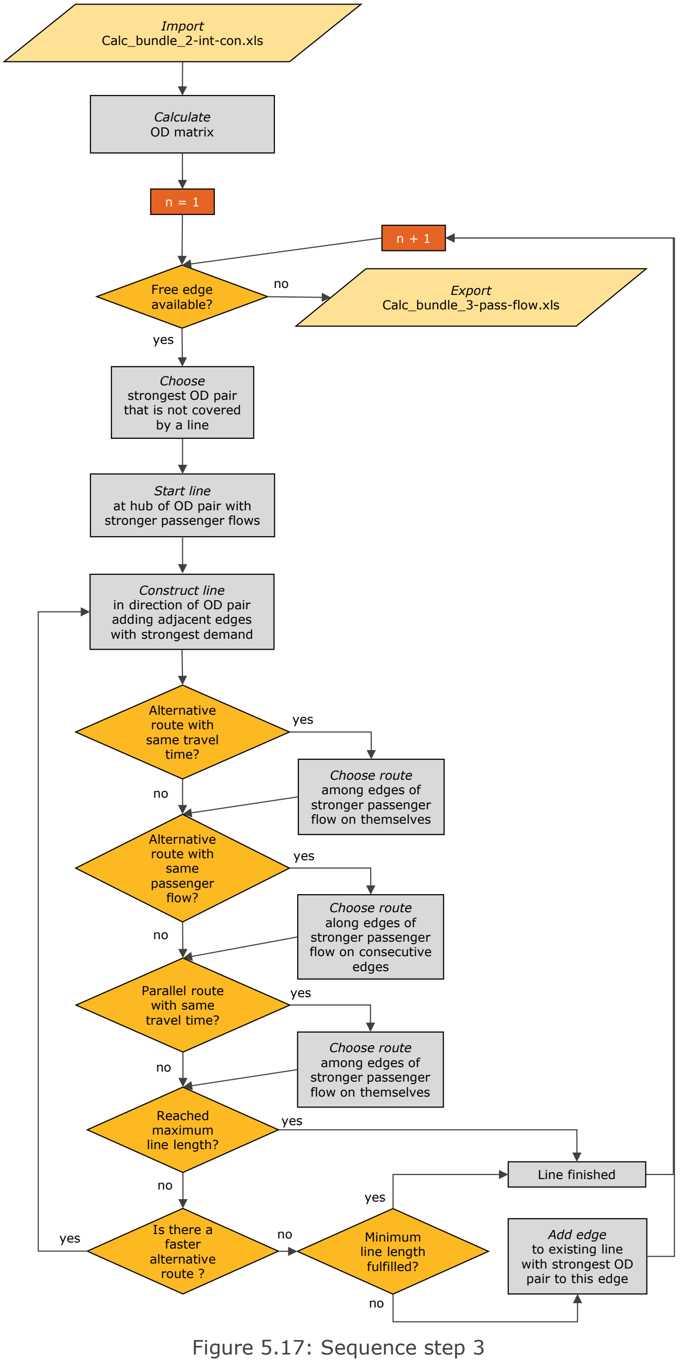


Figure 5.17: Sequence step 3

5.4.5 Direct Connections – Step 4

Objectives Step 4

The constructed lines in *step 3* shall be optimised in order **to maximise the number of direct connections** among the most important hubs of the network. In combination with smooth transfers to regional lines an ITF can utilise its full potential. Lines should be adapted in order to offer as many direct connections as possible from the hubs to the capital or to regional centres. Furthermore, the potential of direct connections from cross-border edges to important hubs should be considered.

Analysis Step 4

Direct connections are perceived attractive, especially for passengers in long-distance services and are desirable from a transport policy perspective too. Relevant relations for direct connections can be the accessibility of the capital or of other administrative or regional centres (U.S. Department of Transportation, 2014). In addition, special importance is paid to international connections (Uttenthaler, 2019).

As a benchmark, the direct connections to the capitals in ITF-oriented railway networks are compared. In Switzerland, almost all hubs have direct connections to the capital city Bern and the largest metropolitan area Zürich (SBB CFF FFS, 2019). In Austria and the Czech Republic, most hubs have direct connections to the capitals Wien and Praha. However, in the Netherlands many hubs do not have a direct connection to Amsterdam or Den Haag. Due to the geographical structure of the country, the IC network in the Netherlands is atypical for most other countries and can rather be compared to a suburban railway network. It can be derived that in principle a connection from all hubs to the capital should be aimed for. A single changeover would be acceptable, a second changeover should be avoided in a medium-sized country (Brezina and Knoflacher, 2014).

Since railway networks in Austria, Switzerland and the Czech Republic offer a high number of direct connections, this high level should not be considerably reduced by tendered PSO. However, Amstutz (2020) showed that an optimisation of existing long-distance networks along the objectives of maximising frequency, minimising travel time and minimising number of transfers would result in fewer direct connections.

A high priority of direct connections strongly shapes the line design and leaves little room for other optimisations. For this reason, the number of direct connections and the resulting optimisation must be defined carefully. Providing direct connections from every hub to the capital is difficult in larger networks and will conflict with the maximal line length and other constraints. In this context the assignment of routes to interval groups is a limiting factor as certain direct connections cannot be offered in the same interval group (Figure 5.12). Although the criterion of direct connections is a crucial one, it makes sense to allow transfers in a certain extent in order to also apply other optimisation criteria such as homogeneous vehicle deployment or vehicle circulation.

Cross-border edges should be connected to one line or split amongst different lines to allow for a maximum number of international direct connections. A fixed through connection of one line on a cross-border edge could be counterproductive. Direct international connections can be maintained by switching direct connections at hubs as shown in Figure 5.18 (Buschbacher and Kasparovsky, 2020). In the case of cross-border edges with few connections daily, it must be considered that a direct connection is beneficial for a disproportionately smaller number of passengers than an interregional hourly connection. Therefore, lines primarily should be aligned to the main passenger flow and lines with higher intervals. However, single through connections should be offered on less frequented lines to raise the proportion of direct connections.

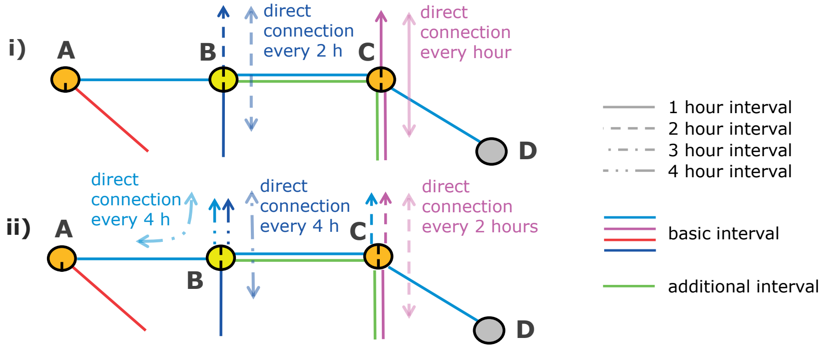


Figure 5.18: Possibilities to link international connections to national lines

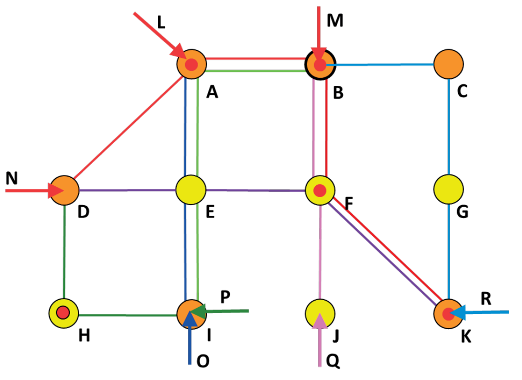
Method Step 4

First, the target level of direct connections has to be defined. Three levels of direct connections describe the extent of direct connections in four relation categories (Table 5.10). These categories are hub – capital, hub – administrative centre, cross-border edge – capital and cross-border edge – cross-border edge. For the sake of simplicity, the category hub – administrative centre will not be discussed further.

Table 5.10: Level of direct connections

Level	Hub – Capital	Hub – Administrative centre	Cross-border edge – Capital	Cross-border edge – Cross-border edge
0	direct connection			
1	max. 1 transfer			
2	max. 2 transfers			

Then, based on the line network derived from *step 3*, the number of direct connections from all hubs to the capital, from cross-border edges to the capital and transit relations have to be evaluated (Figure 5.20 and Figure 5.21). The level of direct connections can be quantitatively assessed by dividing all transfers on a certain kind of relation by number of required transfers. In Figure 5.19 his ratio is calculated for the relations hub – capital, capital – cross-border-edge and in-between cross-border-edges.



No. of Transfers Relation	2	1	0	Sum of trans-fers	Ratio
Hubs – Capital	0	1	9	1	
Hubs – Abroad	0	1	4	1	
Abroad – Abroad	0	2	0	2	
Sum of relations		**17**		**4**	**24%**

Figure 5.19: Calculation of percentage of transfers within the model network shown

The derived network from *step 3* has to be critically judged in terms of the aimed level of direct connections. If the aimed level of direct connections is not fulfilled, edges should be reassigned amongst the lines in order to raise the overall level of direct connections in the network and towards cross-border edges. Intervals and parallel routes must be taken into account. If no clear improvement in the network can be reached by exchanging edges, the derived line constellation from *step 3* should be left unchanged.

On relations where the aimed level of direct connections is not reached, a direct connection along the "shortest path" (minimum total travel time) shall be identified. If possible, edges should be exchanged between lines to construct this direct connection. In case a new line can be formed on two alternatives with the same travel time the edges along the stronger passenger flow should be chosen. If the resulting new line implies losing other direct connections, this approach should be discarded.

The connections from cross-border edges to the capital or on transit routes should also be examined with this approach. After all relations have been checked, the number of direct connections should be higher than at the beginning, otherwise the assignments are to be discarded and the initial network from *step 3* is to be pursued further.

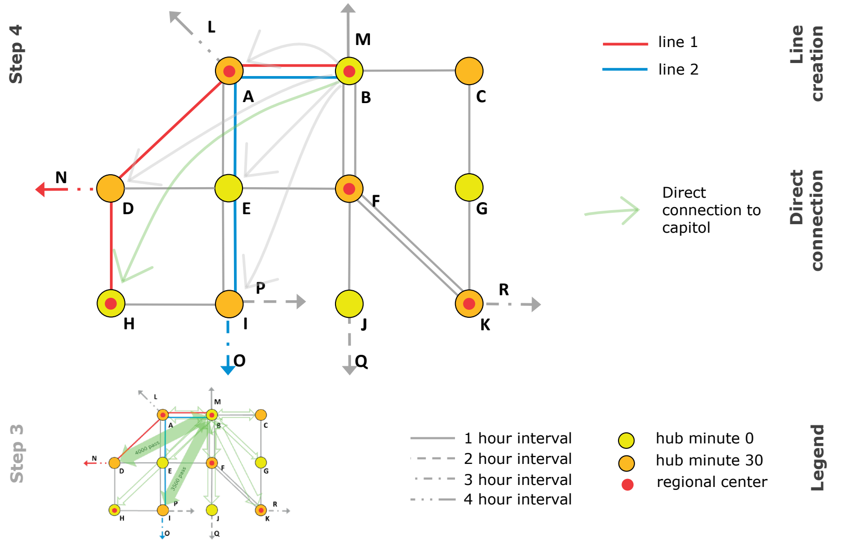


Figure 5.20: Step 4 – Realigning along direct connections

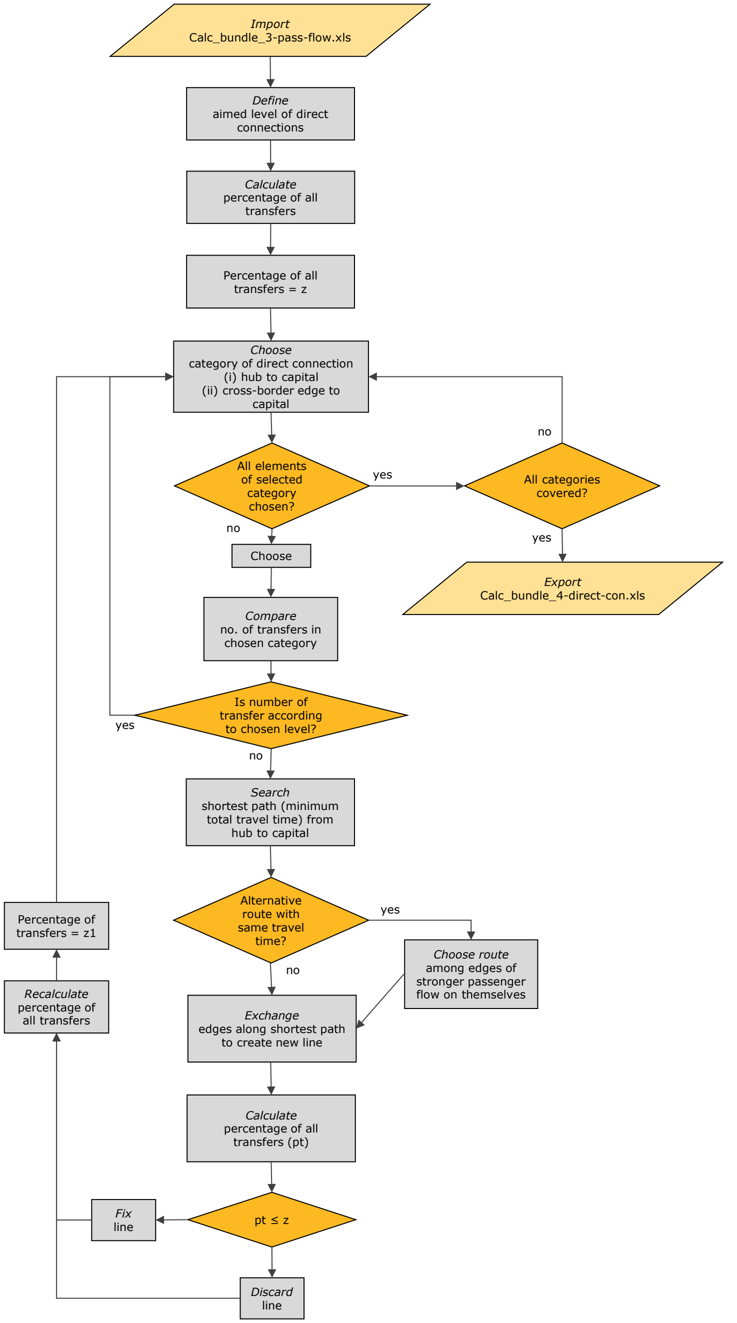


Figure 5.21: Sequence step 4

5.4.6 Bundle Forming – Step 5

Objectives Step 5

Lines constructed in step 3 and 4 should be combined considering criteria like **geographic markets**, **vehicle properties/traction**, **maintenance locations** and profit of lines. The distribution of train-km should be relatively even amongst the resulting bundles. Furthermore, the minimum and maximum size of bundles defined in step 1 have to be considered.

Analysis Step 5

The most important boundary condition in the creation of bundles is a homogeneous fleet (Müller, 2020). This allows the RU to operate cost-effectively and ensure flexibility in terms of vehicle and staff scheduling. Furthermore, vehicle traction, vehicle type and quality type (IC/IR) have to be considered. Different traction types in a bundle mean significant additional costs for the RU in terms of workshops, personnel, etc. and should be avoided as far as possible. The same applies for different vehicle types resulting from vehicle requirements or parameters. This is also valid for the quality classes IC and IR. Homogenous vehicle types, vehicle capacity as well as traction were relevant parameters in long distance tenders in the Czech Republic (Janoš and Kříž, 2019).

Strong arguments in bundle design are **homogenic geographic markets** (Fröidh and Nelldal, 2015). Geographic cohesion allows for a more economical operation because locations for workshops and personnel can be combined amongst different lines in a bundle. Furthermore, this allows a close cooperation between the operator and the local transport planning authorities and stakeholders as well as establishing a regional brand with strong brand loyalty (Brown, 2013).

On parallel routes, synergy effects in terms of vehicles, personnel and marketing can be achieved with the same RU. In contrast, competition can be pushed when two different companies operate on one route. Since in the proposed PSO tenders the timetable is largely predetermined and ticket integration is required (see chapter 6), this might be less interesting. While this issue must ultimately be resolved by transport planning, a combination of parallel lines in the same bundle is subsequently pursued according to the idea of homogeneous geographic markets.

Workshops play an important role in the disposition of railway operations. Workshop locations for **light and heavy maintenance** are considered in detail in *step 7*. All lines in a bundle should be connected to a workshop for light maintenance. Ideally, all bundles are also connected to a workshop for heavy maintenance. This makes it possible to bring vehicles to a workshop in a coordinated rotation within the bundle.

When forming bundles, the option of combining lines to form longer direct connections along passenger flows should be considered. While transfers are optimised in an ITF regardless of the RU, longer direct connections with the same RU can be achieved with thought-trough combinations of lines. With regard to *step 8*, such a through connection can already be planned in advance.

As the lines of a network usually have different **yields**, this can have a significant impact on attractiveness of bundles in the awarding procedure. High-yield routes can compensate for low-yield routes. If RUs bear the revenue risk, they will have a substantial interest in bundles which include high-yield routes. If the potential yield of the lines in the network is known, bundles should be arranged in such a way that yields are balanced.

Among these considerations, the principles regarding line length, number of bundles and bundle size mentioned in *step 1* have to be considered.

Method Step 5

Transport planning determines the target number of bundles which implies the bundle size. The bundles should be of evenly distributed volume (*step 1*). Lines are combined to bundles considering the minimum and maximum bundle size according to *step 1* (Figure 5.22 and Figure 5.23). Furthermore, the following arguments are to be considered:

- Firstly, lines of homogenous rolling stock requirements (traction, vehicle type, type of service) should be combined.
- Secondly, lines are arranged to form geographically homogenous markets.
- Thirdly, parallel routes are combined in the same bundle in order to achieve synergy effects.
- Fourthly, lines are combined according to passenger flow.
- Fifthly, the connection of every bundle to a workshop for light maintenance is evaluated and modified if necessary. Ideally, also a workshop for heavy maintenance is touched by at least one line.

Steps 2 to *5* are iterative and are best solved based on expert experience. Alternatively this step could be implemented in a sophisticated algorithm which is not covered in this thesis.

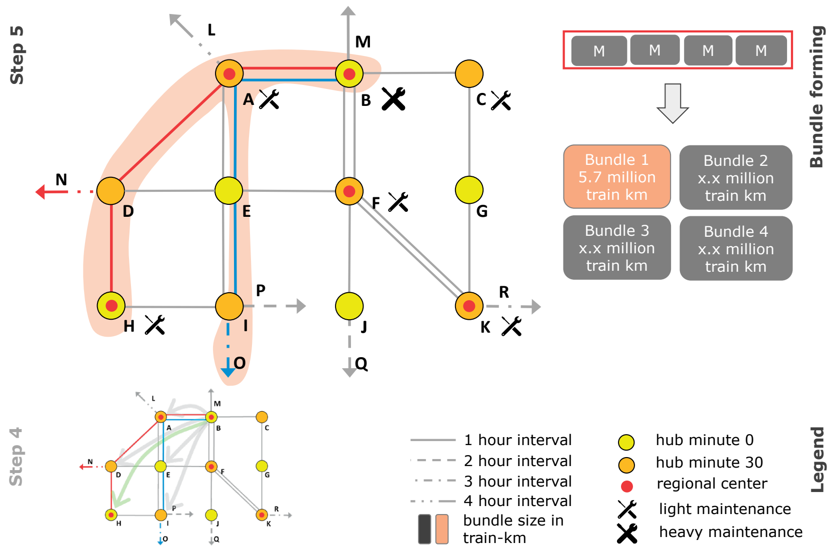


Figure 5.22: Step 5 – Bundle forming

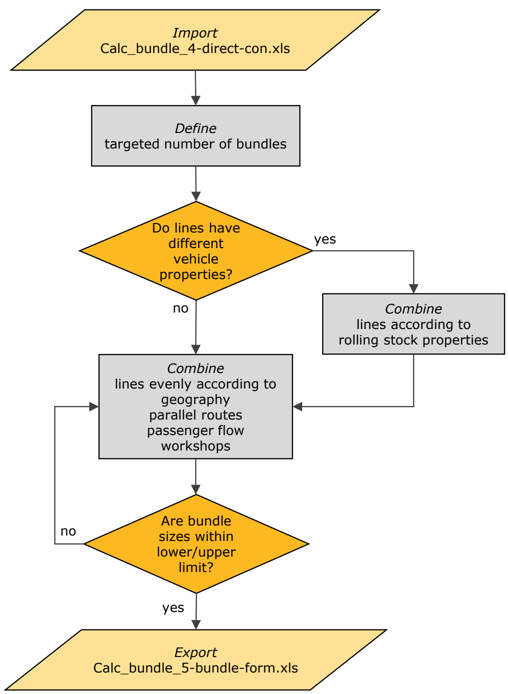


Figure 5.23: Sequence step 5

5.4.7 Passenger Amount – Step 6

Objectives Step 6

The **passenger amount** on the edges should be calculated by assuming **vehicle capacities**. The **vehicle utilisation** can then be derived and the required type of service per line (IC or IR services) can be determined. In addition, a need for double traction should be identified.

Analysis Step 6

According to the lines constructed in the steps before, the passenger flows between the different hubs can be superimposed. This results in the **passenger amount** on the edges (Figure 5.24).

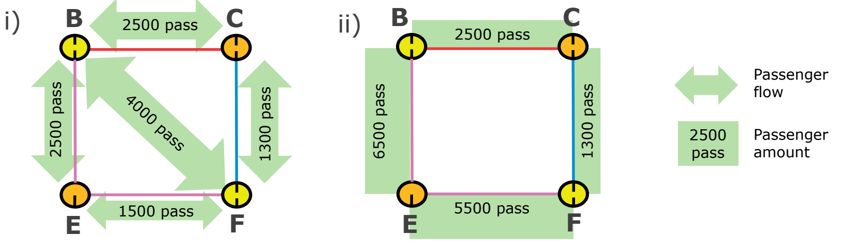


Figure 5.24: Passenger flow (i) superimposed to passenger amount per edge (ii)

On the basis of the passenger amount, the **vehicle capacity** can be assigned. Based on a comparison of several long-distance trains in the DACH region (Table 5.11) the seating capacity for Intercity-services is about 400 seats and for Interregio-services approximately 250 seats. Accordingly, passenger capacity varies significantly between 200 and 800 seats. As a standard capacity about 400 seats can be assumed.

Table 5.11: Capacity of long-distance trains in the DACH-region

Type of service	Manufacturer	Type	Length [m]	Seating capacity [#]
IR	Bombardier	Talent 3 (6 car)	100	300
IC	Siemens	Railjet (7 car)	200	404-442
IC	Siemens	ICE T (7 car)	200	381
IR	Siemens	DML (3 parts)	75	244-259
IC	Stadler	KISS (6 car)	100	501
IC	Stadler	Giruno (11 car)	200	422
Assumption				**400**

The theoretical maximum vehicle capacity per edge (18 services per day) in both directions for an IC with 400 seats and an IR with 200 seats are shown in Table 5.12. As the utilisation of trains in the peak hours should not be higher than 80% (VDV, 2018) the values are assumed with 11.520 passengers for IC and 5.760 passengers for IR services.

Table 5.12: Daily capacity of IC and IR services

Type of service	Seat capacity	No. of directions	Service intention	Theoretical capacity/ day	Consid-ered capacity/ day
IC	400	2	18	14.400	11.520
IR	200	2	18	7.200	5.760

As long-distance services are discussed, only the seating capacity is considered. The capacity could be higher if standees are taken into account, however, this should solely be done for rush hours close to metropolitan centres and not network-wide. Capacity for bikes or people with reduced mobility is not covered.

PTAs and RUs aim for a **moderate vehicle utilisation** to enable economic operation and to have sufficient reserves for peak hours, extraordinarily high passenger volumes and passenger growth. Along a line, the vehicle utilisation during the day should not be too inhomogeneous. Otherwise the vehicle might be underutilised for too big a portion of its circulation and therefore cost-inefficient. The percentage between the weakest edge and the strongest edge along a line should not be higher than 30% for PSO services. For self-sustaining services, this value should be 40% or higher (Posch, 2020). If the utilisation exceeds 100% on one edge of a line, double traction has to be arranged for the peak hours. If the utilisation is 150% the double traction is required in peak hours (about half of the day). If it is higher than 200% a parallel route should be considered in the next steps.

Table 5.13: Vehicle utilisation and suggested service type

Vehicle utilisation	Service type
>5.700 pass	IR
<5.700 pass	IC
>100%	IC
>150%	IC partly double-traction
>200%	IC parallel line

In order to make vehicle utilisation more homogenous, edges can be switched between the lines. If there are several lines with small passenger amounts, which generally designed for lower demand edges, IR services can, if required, relieve IC services. If necessary, Interregio services can be combined into a separate bundle. When redesigning lines they can be split at hubs, continuing in two different directions. To split vehicles in more than two directions multiple-traction train sets would be required, for which splitting in the hub would take too long. Above a certain passenger flow direct connections have priority over line adaptations for homogenous vehicle utilisation.

Method Step 6

Based on the lines constructed in the steps before, the passenger amount on the edges is calculated (Figure 5.25 and Figure 5.26). Then IC and IR services are assigned to the lines based on the passenger amount and the vehicle capacity. Consequently, the vehicle utilisation is calculated. If the vehicle utilisation of different sections along a line differs more than 40%, edges are changed between the lines to make the utilisation more balanced.

In case IC-lines have more than 100% utilisation, double traction is partly required. If it is higher than 150% it is required throughout the day. If it is higher than 200%, an additional route should be considered on this edge.

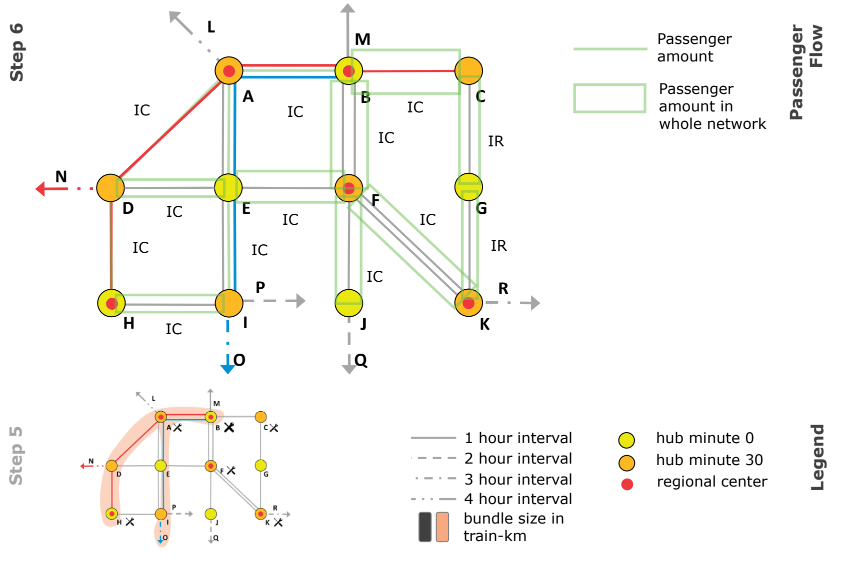


Figure 5.25: Step 6 - Adapting lines according to passenger amount

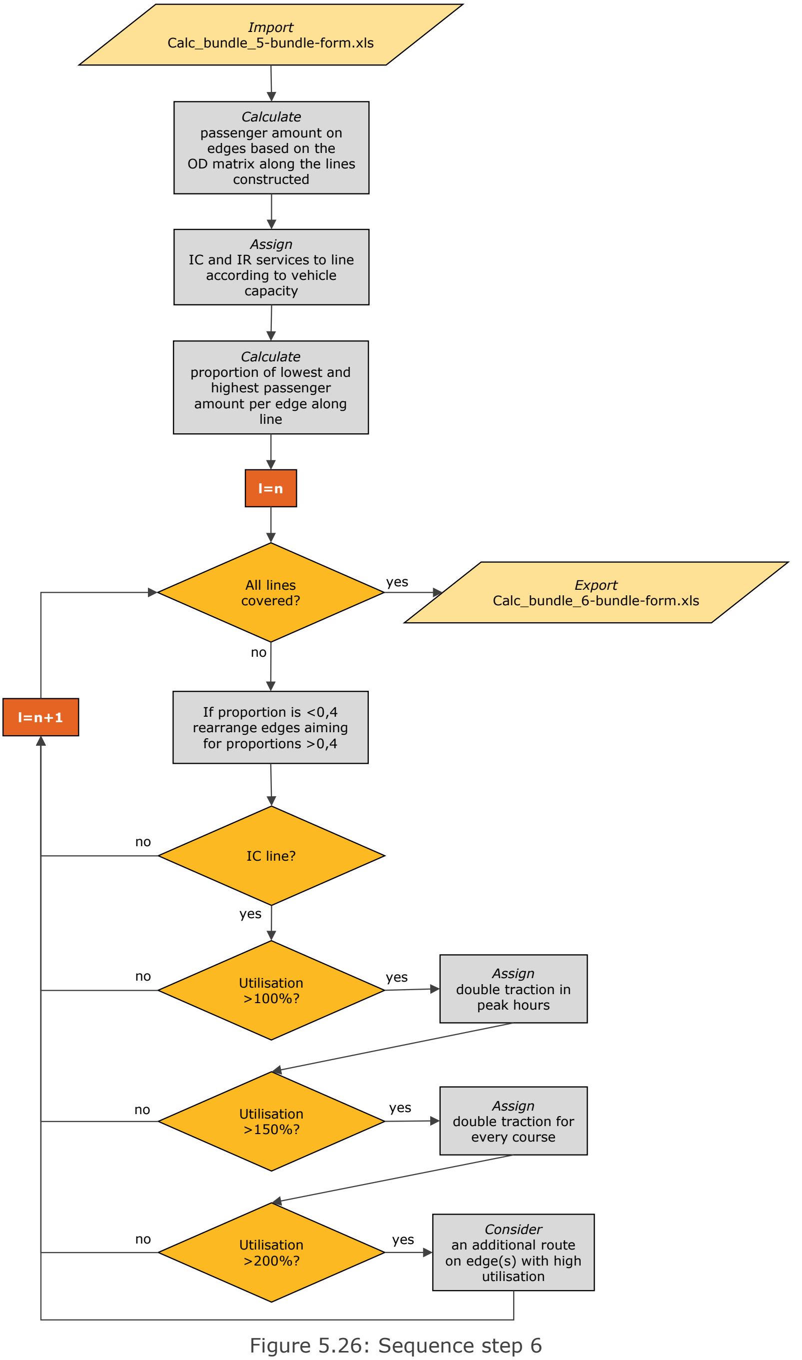


Figure 5.26: Sequence step 6

5.4.8 Service Facilities – Step 7

Objectives Step 7

For railway operation service facilities and **workshops for light and heavy maintenance** are needed at the endpoints or along lines. Service facilities cover servicing, parking, cleaning and refuelling. While light maintenance needs to be done frequently, heavy maintenance is done in intervals of several months up to years and can be carried out decentral. The listed services are an essential basis for vehicle circulation and therefore have to be covered before vehicle circulation is fixed. For this reason, locations of service facilities and workshops have to be handled in the line and bundle optimisation process in order to ensure operational efficiency (Janoš and Kříž, 2019).

Analysis Step 7

According to Directive 2012/34/EU and the EisbG, the IM has to supply, if existing, a non-discriminatory access to service facilities like:

- *"marshalling yards and train formation facilities, including shunting facilities*
- *storage sidings*
- *maintenance facilities, with the exception of heavy maintenance facilities dedicated to high-speed trains or to other types of rolling stock requiring specific facilities;*
- *other technical facilities, including cleaning and washing facilities;*
- *refuelling facilities and supply of fuel in these facilities"*

Additional services that can be offered by IM include for example pre-heating for passenger trains. Furthermore, ancillary services like heavy maintenance, facilities for high-speed trains or specific facilities for other types of rolling stock can be offered by the IM (2012/34/EU).

The availability of service facilities and **workshops** is laid down in the network statement of the IM and is evaluated for hubs in the Austrian network the potentially serve as line start or end point. Most services are available in ITF hubs which can be considered as the end of a line (ÖBB-Infrastruktur AG, 2020a) as shown in Table 5.14. While **light maintenance** is provided in most hubs, especially **heavy maintenance** is often restricted to a few locations in a network.

Table 5.14: Availability of service facilities in Austria (ÖBB-Infrastruktur AG, 2020a)

	Short turnaround		Long turnaround						
Hub	Cleaning	Board service	Sanitary	Heating	Exterior cleaning	De-icing	Shunting	Light maintenance	Heavy maintenance
Wien	x	x	x	x	x	x	x	x	x
Linz	x	x	x	x	x	-	x	x	-
Salzburg	x	x	x	x	-	-	x	x	-
Innsbruck	x	x	x	x	x	-	x	x	-
Feldkirch	x	x	-	x	-	-	x	-	-
Bregenz	x	x	x	-	x	-	x	x	-
Graz	x	x	x	x	x	-	x	x	-
Klagenfurt	x	x	x	x	-	-	x	-	-
Villach	x	x	x	x	x	-	x	x	-

Light maintenance needs to be done frequently, therefore at least one workshop is needed along a line. For high-speed lines (V_{max} > 160 km/h) special services like an anti-ice system are required which can only be found in certain hubs. Therefore, services with high speeds should touch or end in hubs with heavy maintenance.

The type of required services strongly depends on the maintenance demand of the rolling stock used. EMUs have different maintenance intervals than locomotive and waggon trains. In addition, there are varying service requirements amongst different types of EMU (Liebhart, 2020a).

According to Directive 2012/34/EU, **heavy maintenance** is "*work that is not carried out routinely as part of day-to-day operations and requires the vehicle to be removed from service.”* Ideally at least one line of a bundle touches a workshop for heavy maintenance so vehicles can rotate internally to reach the workshop when necessary (Fuit-Bosch, 2019). Essentially, every vehicle should stay in a hub with main service facilities approximately once a week. Service can be done overnight or on the subsequent days (Uttenthaler, 2019). A change of Intercity-vehicles within a bundle is common. However, with modern EMUs, many services can be done overnight when the vehicle is not in use – even heavy maintenance such as the change of boogies (Posch, 2020).

In larger bundles the availability of heavy maintenance facilities increases. Maintenance can be done more flexibly by exchanging vehicles among the lines of a network. Alternatively, heavy maintenance is done outside the bundle or is outsourced. However, this requires unproductive empty trips. Workshops at the central hub in a network with several lines crossing that can be used by several RUs are most efficient (Liebhart, 2020a).

Although workshops are often exclusively built for a service contract in regional services (Fuit-Bosch, 2019), existing locations are assumed to be used in the following. If workshops for light maintenance are not available along a line or heavy maintenance within the bundle, an exchange of edges should be considered. However, the aforementioned criteria have to be taken into account. Ideally, as many lines as possible should reach the main workshop for heavy maintenance.

Method Step 7
Service facilities and light maintenance should be available along every line, workshops for heavy maintenance are optional.

Firstly, lines are checked whether they touch hubs for light and heavy maintenance (Figure 5.27 and Figure 5.28). If this is not the case it has to be checked whether these are provided within the same bundle. A change of vehicles within a bundle is only possible for vehicles of the same service quality and has to be recorded as a requirement for vehicle circulation. If an access within the same bundle is not possible, the line has to be adapted.

Secondly, lines are checked whether if they touch a hub with a workshop for heavy maintenance. It is sufficient if at least one line of a bundle per class of vehicles / vehicle properties touches such a workshop. If this is possible this has to be recorded as a requirement for vehicle circulation. If a workshop for heavy maintenance cannot be reached, the line might need to be adapted in case that does not counteract other considerations of the optimisation process. Otherwise the missing access has to be stated and included in the tender documents.

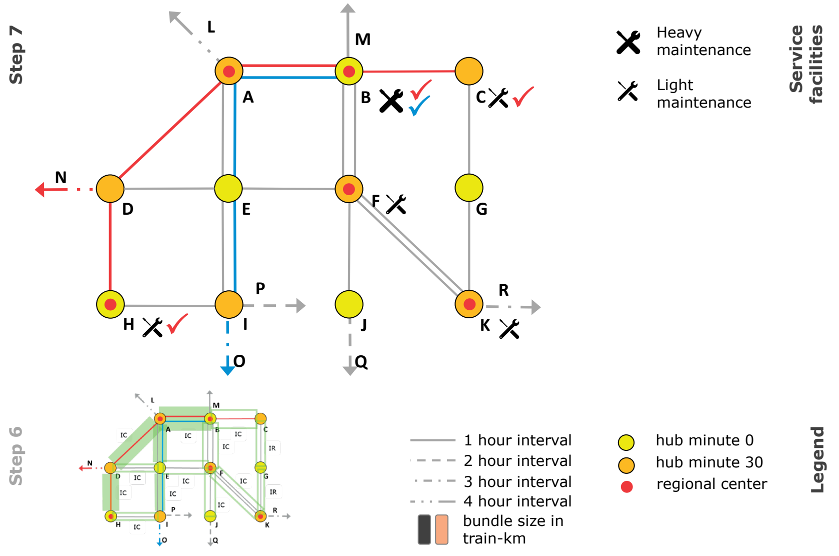


Figure 5.27: Step 7 – Accessibility to service facilities

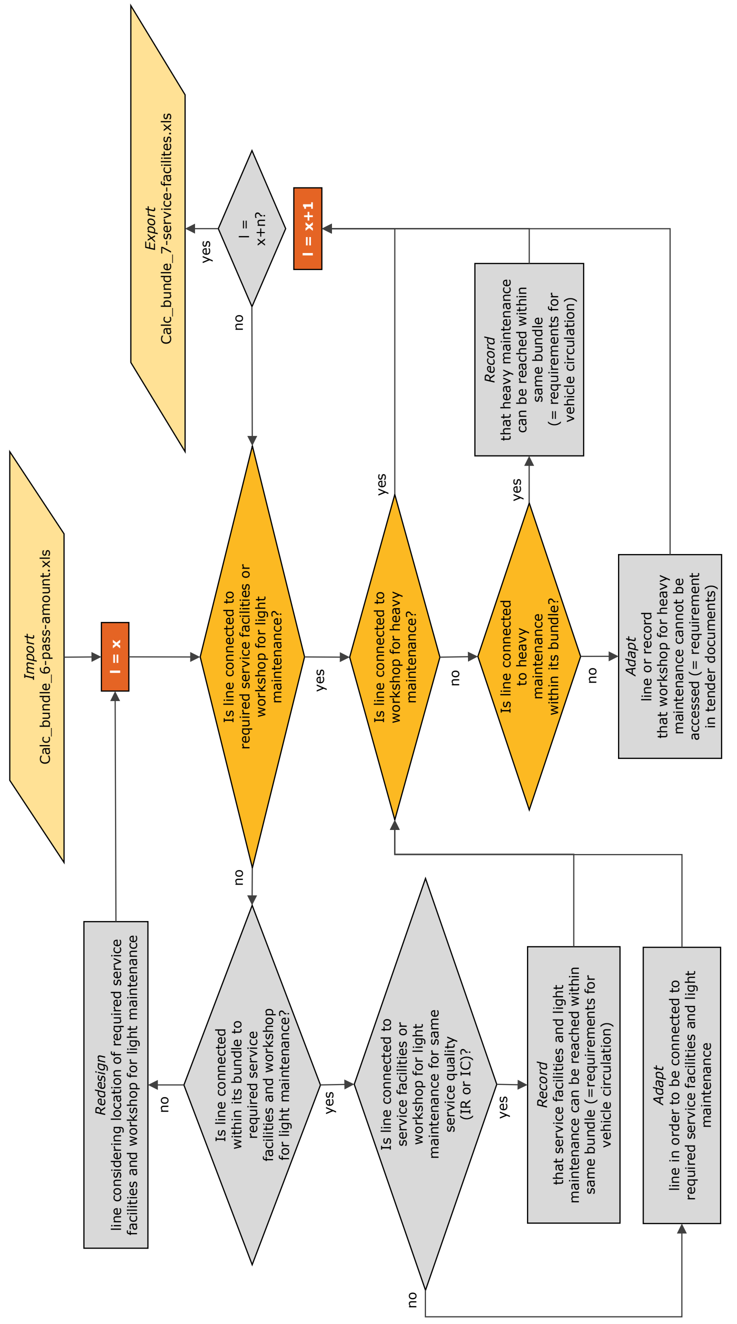


Figure 5.28: Sequence step 7

5.4.9 Vehicle Circulation – Step 8

Objectives Step 8

The optimisation of **vehicle circulation** aims for a minimum number of vehicles and a high mileage. When designing a vehicle circulation, parameters like set-up-times, buffer times and smooth turnarounds have to be considered. While a detailed vehicle optimisation can be done best by RUs once a bundle is awarded, a strategic vehicle optimisation is essential before the tendering process (Fuit-Bosch, 2020).

RUs aim for **cost-efficient operation** which is ultimately beneficial for the taxpayer in a competitive bidding offer. Besides a reduction of maintenance, capital costs and overhead, this can be best achieved by reducing the number of vehicles as this consequently reduces staff and energy costs. This can be achieved with an optimal vehicle circulation.

Analysis Step 8

The daily **vehicle utilisation** can be limited by maximum mileage, maximum operation hours, the timetable or maintenance intervals. Most modern rolling stock have a high availability and the daily mileage results primarily results from the timetable and vehicle circulation. Approaches for the calculation, organisation and optimisation of railway vehicle utilisation can be found in Maróti (2006), Liebchen (2008), Liao et al. (2021), Vojtek et al. (2019) or in Janoš and Kříž (2018b) for public bus transport.

The mileage and operation times depend on timetable, travel time and rolling stock. A preliminary rough estimate can be made that highly utilised vehicles on conventional railway lines do mileages of approximately 2,000 up to 2,500 km per day (Liebhart, 2020a). Over a year, these figures are lower due to maintenance and repairs (Figure 5.29).

In Austria, values of 800 km (Rechnungshof, 2015) up to 1.400 (ÖBB-Personenverkehr AG, 2019b) per day as annual average are reported for vehicles in long-distance services. It is assumed that loco and waggon trains do less mileage per day than EMUs, as locos and waggons have different maintenance intervals (Liebhart, 2020a). High-speed vehicles are able to run approximately 1.300 up to 2.500 km per day (Handelsblatt, 2013).

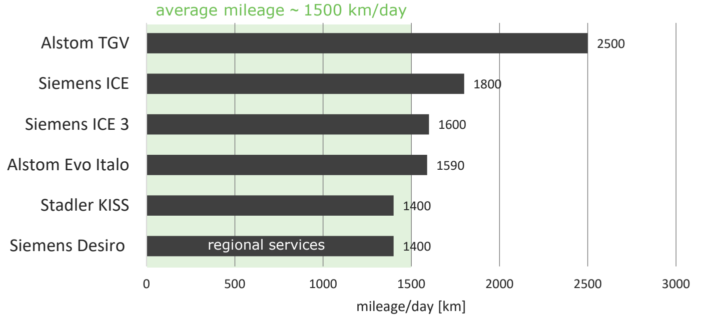


Figure 5.29: Daily mileage of selected vehicles in European railway networks based on about 300 working days annually[20]

In the following it is assumed that the average mileage is 1.500 km per vehicle per day, resulting in 0.5 million train-km per year. The mileage of vehicles is crucial to determine the number of vehicles needed. Furthermore, the number of extra vehicles is relevant which depends on the economic motivation of an operator. While timetable stability is crucial for an operator under PSO to fulfil quality criteria, an operator of self-sustaining services might focus on optimal vehicle utilisation and minimising the number of reserve vehicles (Posch, 2020). Therefore OA operators (and PSO operators which lack extra vehicles for whatever reason) have about 0 to 10% extra vehicles during rush hour. Maintenance has to be done in off-peak hours or overnight (Posch, 2020). For a stable operation, fulfilling high quality standards of a PSO contract, a **vehicle reserve** of 10% to 20% is recommendable according to Uttenthaler (2019) and Janoš (2020b).

Table 5.15 shows the required number of vehicles for different bundle sizes assuming an average daily mileage of 1.500 km and a vehicle reserve of 20%.

Table 5.15: Number of vehicles per bundle size

	Small bundle	Medium-sized bundle	Large bundle
Volume [million train-km]	2.0	6.0	10.0
Demand vehicles [-]	5	14	22

Assumptions: average daily mileage of 1500 km, 365 days of operation, 20% vehicle reserve

[20] TGV: Handelsblatt (2013), ICE: FIS (2017), ICE 3/Velaro: Reuss (2004), Siemens Mobility (2021), Alstom Evo Italia: Italo (2019), Stadler KISS: ÖBB-Personenverkehr AG (2019b), Railjet with 1116: Rechnungshof (2015)

The systematic approach of ITF networks allows for a systematic optimisation of vehicle turnaround times at the termini. Ideally, the round trip results from the ITF, so attention must be paid to optimal round trips when designing the timetable. In a given ITF, optimisation can then only be done in a limited scope (Uttenthaler, 2019).

In order to minimise the number of vehicles, the vehicle utilisation should be high and turnarounds should be as short as possible. However, long-running services require time buffers in termini to ensure timetable stability. Table 5.16 distinguishes between short, medium and long turnarounds.

Table 5.16: Turnaround times for IC-services

Turnaround	Short	Medium	Long
Time [min]	5-10	10-30	>30
Vehicle utilisation	high	medium	low
Services	none	sufficient	sufficient
Time buffer	critical	sufficient	stable
Suggested line length [min]	short (<300)	medium (<420)	long (>420)
Examples	Airport Wien (ÖBB): 6 min	Wien Westbahnhof (Westbahn): 26 min	Salzburg (Westbahn): 44 min Innsbruck (ÖBB): 66 min

Short turnarounds allow for an optimal vehicle utilisation. In ITF hubs the train in the opposite direction leaves the hub five to six minutes after the arrival of the first train. The minimum turnaround time is defined in the network statement and depends on the train length. In order to guarantee a high level of operational stability during short turns, extra vehicles can be kept available at strategic points of the network, as is the case with the SBB in Switzerland (Weigand and Berschin, 2019). However, this option can be considered unprofitable for a competing company (Liebhart, 2020a).

Medium turnarounds allow for cleaning and loading activities (catering) to be carried out. Medium turnarounds present an optima between vehicle utilisation and buffer times and are therefore recommended as long as the lines served are not too long (Liebhart, 2020a). Depending on the line length, it is suggested to have vehicle circulations contain medium turnarounds on every second occasion.

Long turnaround times are ineffective in terms of vehicle utilisation and might increase the number of required vehicles per line. On the other hand, long turnaround times increase timetable stability and are suggested for long-running lines on every second occasion.

In order to determine when medium and long turnarounds make sense, it is assumed to include a run-length-dependent time buffer at the line end point. This time buffer could be e.g. 5% of the running time. If the calculated value is higher than 30 minutes at the turnaround, a long turnaround is suggested at least at every second occasion of a vehicle circulation.

Depending on the line constellation, different **vehicle utilisation** rates are the result. The vehicle utilisation can be defined as the ratio of the actual journey time to the theoretically possible journey time. If the vehicle utilisation on a line is below 80%, a line adaptation or extension as well as combination of lines can be considered. Various options are possible:

- Since longer lines usually have higher vehicle utilisation, changing single edges or a combination of lines can help to increase vehicle utilisation as well. The number of required vehicles can be reduced, for example, if a short IR line is combined with a long IC line.
- Additional connections can be offered. All or some services of a line can be extended along further edges in the network or on cross-border edges according to the passenger flow. This extension of lines can be done within the PSO. Extensions of clocked long-distance services are found for example in the extension of the Graz – Wien service to Flughafen Wien, the Graz – Praha service to Berlin or the Salzburg – Wien service to Bratislava (ÖBB-Personenverkehr AG, 2020). If the RU is free to offer such services, appropriate contractual arrangements need to be made.
- Lines with low vehicle utilisation can be merged with lines of a very high vehicle utilisation.
- In the event of double traction, lines can be split, e.g. offering additional services on cross-border hubs (e.g. Railjet Wien Hbf – Salzburg is split to München and Bregenz; Railjet Salzburg – Wien Hbf is split to Wien Flughafen and Budapest (ÖBB-Personenverkehr AG, 2020).

Method Step 8

First the minimum number of vehicles per line and bundle is calculated (Figure 5.30 and Figure 5.31). Lines can be adapted to allow for a smoother vehicle circulation with the following measures:

- Check whether combinations of lines make sense in terms of passenger flows and direct connections.
- Reduce vehicles by changing assignment of IR/IC lines (longer IC lines are cheaper than short IC + IR lines).

- Add services on national or cross-border edges if applicable with interval. In case of double traction, trains can be split to offer additional direct connections (if intervals fit).

This results in the final line and bundle constellation.

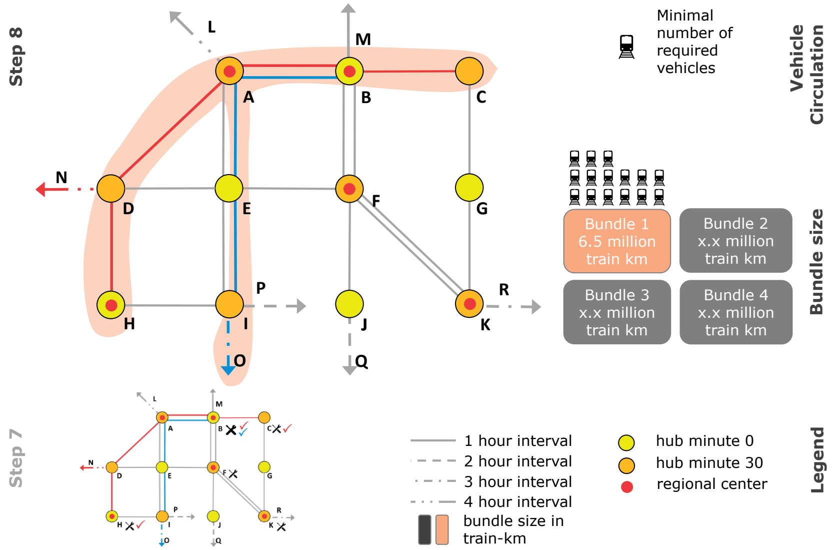


Figure 5.30: Step 8 – Calculating and optimising vehicle circulation

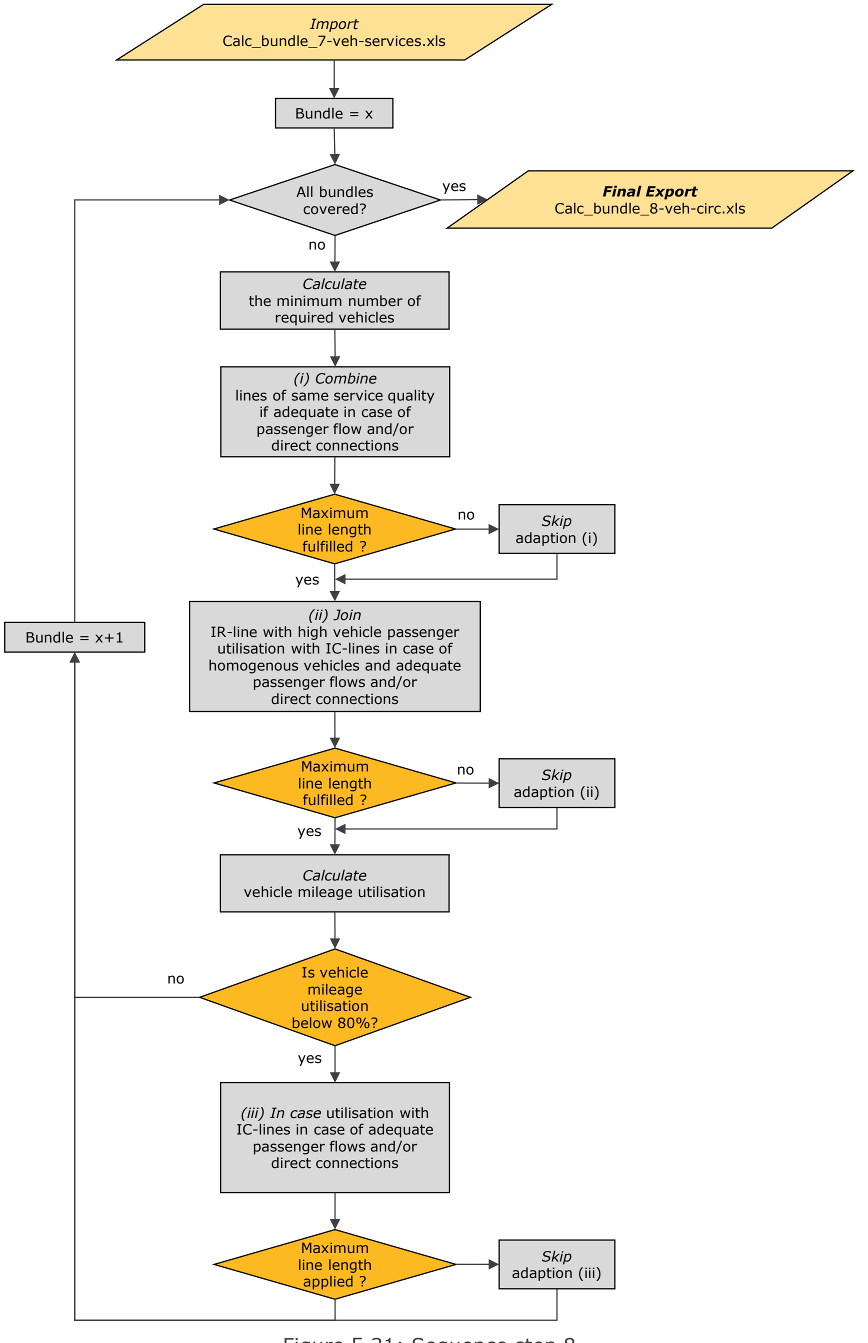


Figure 5.31: Sequence step 8

5.5 Application in a Model Network

The procedure developed is applied to and validated upon a model network. The objectives of the application are to:

- Check functionality of the line and bundle planning process
- Evaluate the suggested band width of parameters
- Review the concept and sequence of the suggested procedure
- Validate results of the model network with a sensitivity analysis

A hub-edge model as shown in chapter 5.4 representing realistic characteristics of a medium-sized country is designed as a model network. Its size allows for a large number of possible line and bundle combinations, but is still easy to handle in a manual process. The following parameters are given:

- Service intention (interval, service availability)
- Passenger flow
- Cross-border connections (synonymously used as international connections)
- Location of workshops
- Relevance of hubs

5.5.1 Structure of the Model Network and Service Intention

The model network which is shown in Figure 5.32 was designed featuring the following properties:

Geography
The properties are supposed to represent a long-distance rail network of a medium-sized country with strong international connections. The model network consists of 10 hubs and 14 edges. The basic edge length is 60 km with an edge riding time of 30 minutes. Some edges (e.g. AD) are 100 km with an edge riding time of 60 minutes, assuming that these lines have a lower top line speed. One hub is defined as capital, and various other hubs as regional centres.

Service Intention
The basic interval is one hour. On some edges an interval of half an hour is foreseen to cover a higher demand close to the main hub (capital). On these edges, two STPs per hour are required and two lines run along these edges (e.g. AB and BA). The hubs are served at .00 or .30. In the event of a half-hour-interval, both hub times are served.

The service availability foresees network-wide IC services from 05:00 to 23:00. This results in a basic service offer of 15.77 million train-km per year in the whole network.

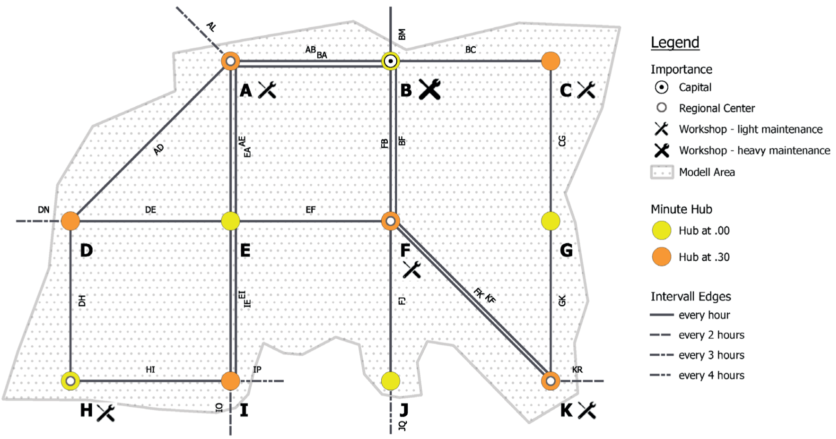


Figure 5.32: Model network

International Connections

Frequent cross-border connections represent common circumstances in medium-sized European countries. Passenger flows from abroad to the main hubs are considered as well as transit connections. To calculate the demand potential of cross-border edges, a virtual hub on the end of these edges is assumed. The length of all cross-border edges for demand calculation is 60 km. The length of cross-border edges relevant for bundle forming is considered from the last hub in the model network to the border, which is between 10 to 40 km.

Location of workshops

While workshops for light maintenance are required on a regular basis and are found throughout the network, a workshop for heavy maintenance is seldomly required and is found in the capital only.

5.5.2 Assumptions for a Moderate Scenario

The values of each parameter of the model network can be varied within certain band widths. Here, a standard case with moderately pronounced parameters is assumed. The full range of parameters of the model is shown in the sensitivity analysis (chapter 5.5.4).

Line Length and Bundle Size

Line lengths of at least 120 km and bundle sizes of 2.0 to 10.0 million train-km are considered. According to the network size the maximum line length is 420 km.

International Connections

On every international edge, IC services are offered with four to eighteen services a day. International direct connections are requested towards hubs in the network, some have transit functions between hubs outside the network (Table 5.17). These relations result in further 1.58 million train-km per year. International connections are connected to the basic interval.

Table 5.17: Model network – international connections

Cross-border edge	Consid-ered	Services per day	Relation capital		Transit route		Volume [million train-km per year]
			Yes/No	Hub	Yes/No	Relation	
AL	yes	6	yes	B	yes	AL-KR	0.11
BM	yes	18	yes	B	no	-	0.53
DN	yes	6	no	0	yes	DN-IP	0.13
IO	yes	9	yes	B	no	-	0.33
IP	yes	4	no	0	yes	IP-DN	0.06
JQ	yes	4	yes	F	no	-	0.03
KR	yes	9	yes	B	yes	KR-AL	0.39
Sum	7						**1.58**

Demand

The inhabitants of the hubs are assumed as shown in Table 5.18. The OD matrix is calculated with Lill's law of travelling (chapter 5.4.4). This results in moderate demand flows, represented by the passenger numbers per day.

Table 5.18: OD matrix of the model network for moderate demand

demand		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
	inhabitants	120 000	320 000	90 000	110 000	40 000	80 000	20 000	50 000	130 000	50 000	110 000	40 000	50 000	50 000	80 000	20 000	20 000	50 000
A	120 000		4 175	2 055	2 422	522	1 826	203	839	2 968	507	904	522	1 142	839	812	203	114	243
B	320 000	4 175		3 131	4 920	2 435	2 783	1 218	1 096	3 518	3 044	4 920	2 435	1 740	1 096	1 218	304	541	1 096
C	90 000	2 055	3 131		678	304	1 370	196	182	557	381	1 884	304	856	182	219	55	86	381
D	110 000	2 422	4 920	678		478	1 674	89	598	2 721	465	829	372	377	598	744	186	105	223
E	40 000	522	2 435	304	478		348	38	381	565	381	615	304	169	381	609	152	68	137
F	80 000	1 826	2 783	1 370	1 674	348		224	338	1 979	435	1 614	271	761	338	541	135	304	559
G	20 000	203	1 218	196	89	38	224		27	79	68	239	38	85	41	34	8	16	190
H	50 000	839	1 096	182	598	381	338	27		707	119	223	137	101	476	761	190	30	67
I	130 000	2 968	3 518	557	2 721	565	1 979	79	707		550	979	440	309	550	1 131	283	124	263
J	50 000	507	3 044	381	465	381	435	68	119	550		769	95	211	119	190	48	109	171
K	110 000	904	4 920	1 884	829	615	1 614	239	223	979	769		178	377	223	357	89	151	598
L	40 000	522	2 435	304	372	304	271	38	137	440	95	178		169	137	152	38	24	54
M	50 000	1 142	1 740	856	377	169	761	85	101	309	211	377	169		101	122	30	48	101
N	50 000	839	1 096	182	598	381	338	41	476	550	119	223	137	101		190	48	30	67
O	80 000	812	1 218	219	744	609	541	34	761	1 131	190	357	152	122	190		304	49	107
P	20 000	203	304	55	186	152	135	8	190	283	48	89	38	30	48	304		12	27
Q	20 000	114	541	86	105	68	304	16	30	124	109	151	24	48	30	49	12		41
R	50 000	243	1 096	381	223	137	559	190	67	263	171	598	54	101	67	107	27	41	

Direct Connections

Direct connections are ranked medium to high. Therefore, a maximum of one transfer from any hub to the main hub and on international connections is aimed for (Figure 5.33):

- All cities have direct connections to the capital (B)
- Some cross-border edges have direct connections to the capital (AL, BM, IO, JQ, KR)
- Some cross-border edges have transit functions (AL-KR, DN-IP)

Bundle Formation

To attract several competitors, the size of bundles should not be too big (<10.0 million train-km). In addition, the size of the resulting bundles should not be too small in order to derive bundle sizes which are economically interesting (2.0 – 10.0 million train-km, see chapter 5.4.6). Therefore, four bundles of similar size shall be formed (~4.0 – 5.0 million train-km).

Vehicle Circulation

As arrivals and departures happen around .00 or .30, medium turnarounds are only possible with intervals of half an hour.

5.5.3 Results Model Network

With the above-described parameters, lines are constructed based on the 8-step bundle design procedure. The passenger flow is adjusted to the lines in a path matrix (Table 5.19).

Table 5.19: Model network – path matrix

paths		A	B	C	D	E	F	M	N	O	P	Q	R
	inhabitants	120 000	320 000	90 000	110 000	40 000	80 000	50 000	50 000	80 000	20 000	20 000	50 000
A	120 000		BA	ABBC	AEDE	EA	ABBF	ABBM	ABADDN	AEEIIO	AEEIIP	ABBFFJJQ	ABBCCGGKKR
B	320 000	AB		BC	ABAD	BAEA	FB	BM	ABAEDE	ABAEEIIO	ABAEEIIP	BFFJJQ	BCCGGKKR
C	90 000	ABBC	BC		BCABAEDE	BCABAE	BCBF	BCBM	BCABADDN	BCABAEEIIO	BCABAEEIIP	BCBFFJJQ	CGGKKR
D	110 000	AD	ABAD	BCABAD		DE	DEEF	DEAEABBM	DN	DHHIIO	DHHIIP	DEEFFJJQ	DEEFFKKR
E	40 000	AE	BAEA	BCABAE	DE		EF	AEABBM	DEDN	EIIO	EIIP	EFFJJQ	EFKFKR
F	80 000	BAFB	BF	BCBF	DEEF	EF		BFBM	EFDEDN	EFEIIO	EFEIIP	FJJQ	KFKR
G	20 000	ABBCCG	BCCG	CG	ADABBCCG	AEABBCCG	FKGK	CGBCBM	CGBCABADDN	GKFKEFEIIO	GKFKEFEIIP	GKFKFJJQ	GKKR
H	50 000	ADDH	ABADDH	BCABADDH	DH	DEDH	EFDEDH	EIAEABBM	DHDN	HIIO	HIIP	DHDEEFFJJQ	DHDEEFFKKR
I	130 000	EAIE	BAEAIE	BCABAEEI	DHHI	EI	EFEI	EIEFBFBM	HIDHDN	IO	IP	EIEFFJJQ	EIEFKFKR
J	50 000	ABBFFJ	BFFJ	BCBFFJ	DEEFFJ	EFFJ	FJ	FJBFBM	FJEFDEDN	FJEFEIIO	FJEFEIIP	JQ	FJKFKR
K	110 000	ABBCCGGK	FBKF	CGGK	DEEFFK	EFFK	FK	FKBFBM	FKEFDEDN	FKEFEIIO	FKEFEIIP	FKFJJQ	KR
L	40 000	AL	ABAL	BCABAL	ADAL	EAAL	BFABAL	iABABM	ALADDN	ALAEEIO	ALAEEIP	ALABBFFJJQ	ALBAFBKFKR
M	50 000	ABBM	BM	BCBM	ADABBM	AEABBM	BFBM		BMABADDN	BMBFEFEIIO	BMBFEFEIIP	BMBFFJJQ	BMBCCGGKKR
N	50 000	ADDN	ABADDN	BCABADDN	DN	DEDN	EFDEDN	BMABADDN		DNDHHIIO	DNDHHIIP	DNDEEFFJJQ	DNDEEFKFKR
O	80 000	AEEIIO	ABAEEIIO	BCABAEEIIO	DHHIIO	EIIO	EFEIIO	ABAEEIIO	DNDHHIIO		IOIP	IOEIEFFJJQ	IOEIEFKFKR
P	20 000	AEEIIP	ABAEEIIP	BCABAEEIIP	DHHIIP	EIIP	EFEIIP	BMBFEFEIIP	DNDHHIIP	IOIP		IPEIEFFJJQ	IPEIEFKFKR
Q	20 000	ABBFFJJQ	BFFJJQ	BCBFFJJQ	DEEFFJJQ	EFFJJQ	FJJQ	BMBFFJJQ	DNDEEFFJJQ	IOEIEFFJJQ	IPEIEFFJJQ		JQFJKFKR
R	50 000	AEEFFKKR	BCCGGKKR	CGGKKR	DEEFFKKR	EFKFKR	KFKR	BMBCCGGKKR	DNDEEFKFKR	JOFJKFKR	IPEIEFKFKR	JQFJFKKR	

With the given parameters seven IC lines and four bundles are constructed with a total volume of 17.34 million train-km per year (Figure 5.34).

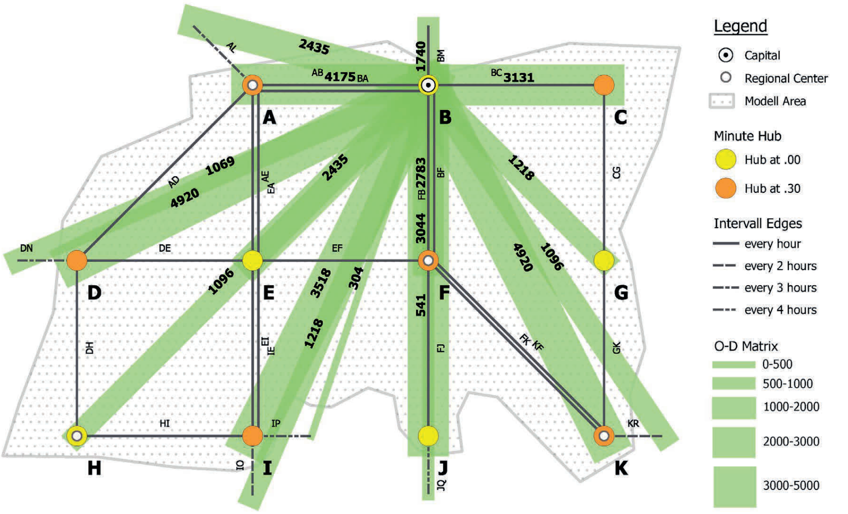


Figure 5.33: Model network – passenger flows for moderate demand

The passenger flow according to the chosen lines shows about 300 to 4900 passengers per day towards the capital B (Figure 5.33). The resulting lines and bundles are shown in Figure 5.34.

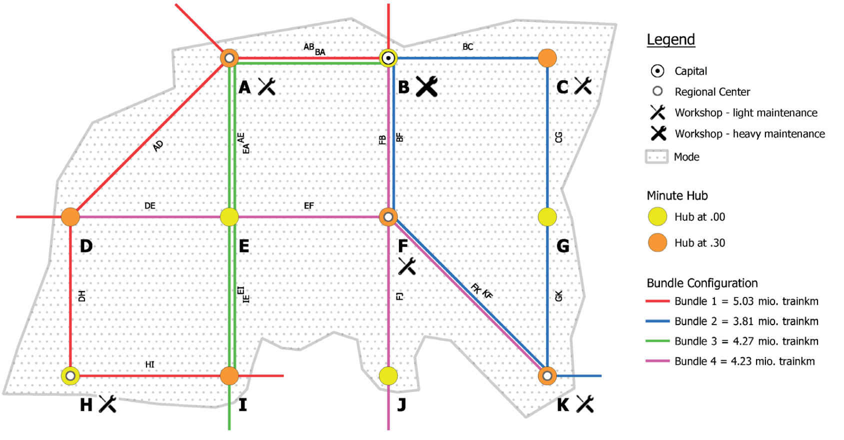


Figure 5.34: Bundles in model network with "medium" parameters

A demand of 46 vehicles was calculated, including double-traction on four lines.

5.5.4 Sensitivity Analysis Model Network

The sensitivity analysis aims to verify the procedure of the model and to show the effects of varying parameters. A set of parameters was designed and calculated for 27 different cases. The set of parameters for every step is listed in Table 5.20. To limit the cases to be calculated there is no variation done in *steps 6* to *8*.

Table 5.20: Model network – set of parameters

Step	1 Size of a) lines b) bundles	2 International connection		3 Passenger flow		4 Direct connections		5 Bundle forming	
	a) lines b) bundles	relevance	no. and interval	railway affine relations	range [km]	transfers to capital	no. of transfers	size of bundles	no. of bundles
Variation of parameters	moderate	minor	4	short	80	often	2	small	8
		moderate	7	medium	120	medium	1	medium	4
		intense	7	long	200	minimum	0	large	2

Variations of Parameter Set

To verify the results of the procedure, the effects of parameter adjustments were examined in a sensitivity analysis. The intensity of the international connections, the strength of demand, the frequency of transfers between certain relations and the number of bundles were varied in three steps. In 27 variations, the stability of the results was shown under changing assumptions.

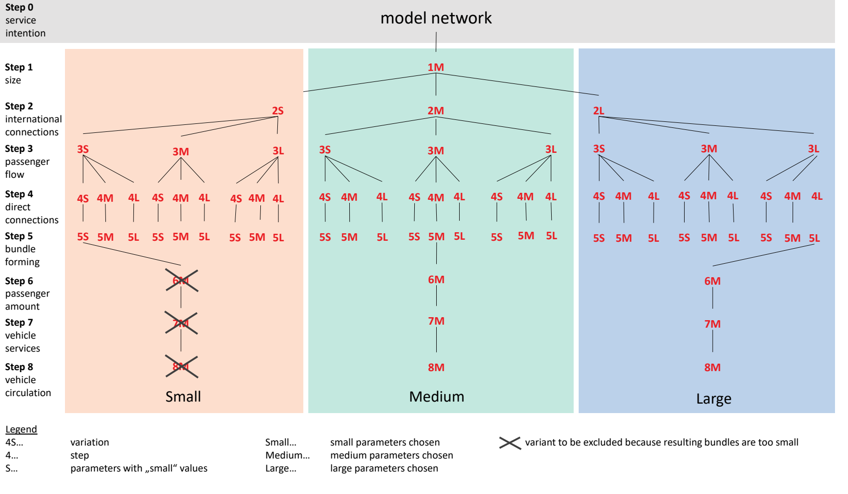


Figure 5.35: Number and allocation of variations

Since “small” parameters (left pillar in Figure 5.35) lead to bundles sizes smaller than 2.0 million train-km per year, this solution is not recommended and not therefore not calculated.

Evaluation of Parameters

Besides the number of passengers in a network (based on inhabitants of the hubs) which are not varied, the strongest influence is triggered by the strengths of passenger flows, the weighting of direct connections and desired size of bundle.

The scattering of demand intensity results in varying degrees of passenger flows (Figure 5.36). Depending on the targeted number of bundles, different bundle sizes result in the example network with a fluctuation range of approximately 2.0 million train-km (Figure 5.37). The number of transfer operations is reduced with an increased focus on direct connections (Figure 5.38). However, the avoidance of transfer operations on all main routes is caused by two boundary conditions such as maximum line length or demand-oriented line formation.

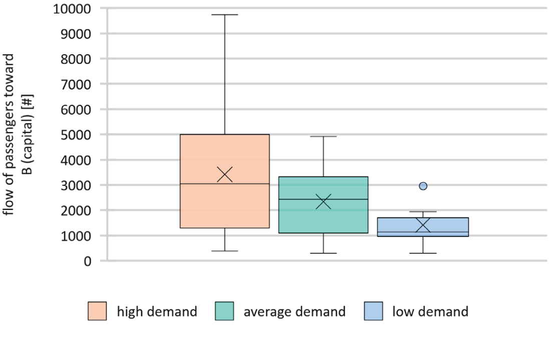


Figure 5.36: Passenger flow towards the main hub in the network depending on the demand intensity

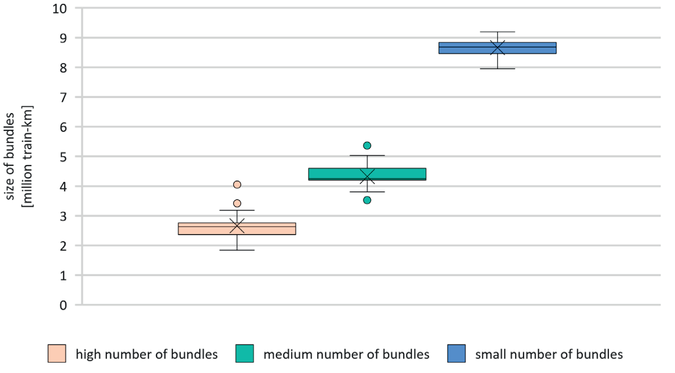


Figure 5.37: Size bundles depending on targeted number of bundles

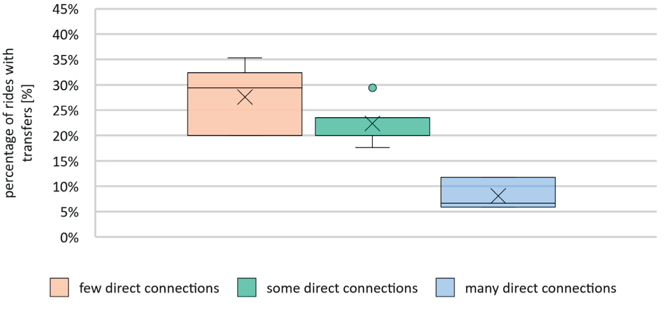


Figure 5.38: Proportion of transfers for all ways in the network depending on the targeted direct connections

Reliability of the Model

The line and bundle configurations determined after varying the input parameters hardly differ (Figure 5.39). The variation of demand intensity described above leads only to slightly different line configurations, which confirms the stability of the results.

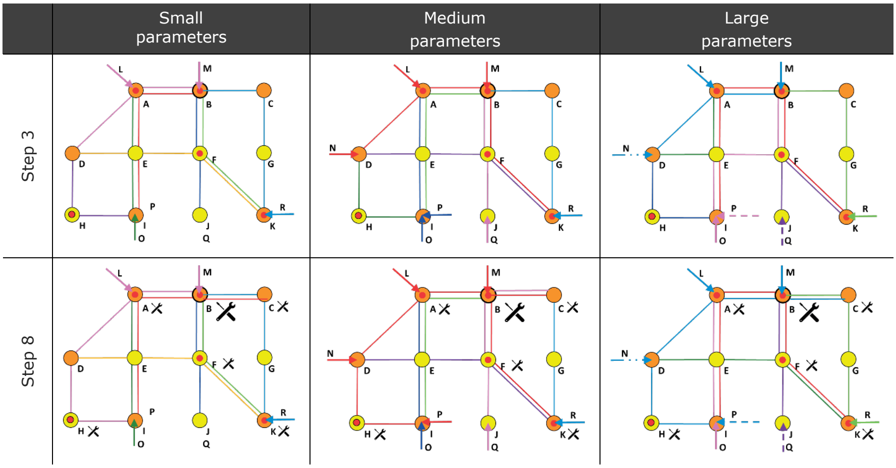


Figure 5.39: Line and bundle configuration after step 5 and step 8 for different parameters chosen

For further verification of process and parameters, an application to real networks such as the Austrian long-distance transport network is recommended.

6

Tendering of System Train Path Bundles

The approach for system train paths presented in chapter 2.6 foresees the competitive tendering of STP bundles. A competitive PSO tendering is suggested, however, several tendering options shall be discussed here. Furthermore, institutions involved in the process and the steps and sequences of a tendering procedure are presented.

6.1 Competitive Tendering

A PSO for railway passenger services can either be structured as direct award or as competitive award according to Regulation 1370/2007/EU. Competitive tendering of PSO has to be done in a fair, transparent and non-discriminatory way (1370/2007/EC) and is going to be mandatory according to Regulation 2338/2016/EU from 2023 onwards. Direct awards are consequently only allowed if permitted by national law and under the following conditions:

- Inhouse awards
- Low volumes
- Under certain circumstances as emergency awards

The benefits of competitive tendering compared to direct awards such as a cost-decrease are stated to be manifold for the stakeholders involved. Lower costs make it possible to raise the number of services, service quality is expected to increase and the commitment of (local) competent authorities and public transport authorities (PTAs) should be pushed as shown by Brown (2013). The costs and revenues for competitive tendered PSO services are analysed in chapter 6.3.2. However, there are also disadvantages to the tendering process. Punctuality and timetable stability could decrease due to lesser trained market participants and changing requirements. The number of bidders often decreases over time as shown in chapter 5.4.2 (Scherp, 2018).

The most important goals and tasks in a competitive tendering process are:

(i) Definition of tasks and resources
(ii) Integration of local stakeholders – to respond to regional needs and the specific situation of a network
(iii) Communication with political and social stakeholders
(iv) Definition of the tendering procedure and contract duration
(v) Risk management – Definition of gross or net cost contract
(vi) Estimation of budget constraints, costs, incentives and revenues
(vii) Definition of scope/service intention
(viii) Definition of objective tendering documents and awarding criteria
(ix) Time management – Definition of a realistic timeline
(x) Quality management – Definition of quality standards and monitoring
(xi) Facilitation of access to all important means of production
(xii) Doing test pilots with less complex bundles

The definition of tasks, resources, procedures and contract duration are discussed in chapter 6.1.1. In chapter 6.2 the definition of a realistic timeline is covered. The difference for net and gross cost contracts is touched in chapter 6.3.1. For an extensive overview of all tasks crucial for competitive tendering see Brown (2013), Schaaffkamp and Karl (2018), Gast and Autengruber (2019) and Scherp (2018).

6.1.1 Tendering Options

The following variants are conceivable for the competitive awarding of STP bundles:

- Concession
- Franchise
- Public Service Obligation (PSO)
- Train Path Catalogue
- Cost-oriented scheme using Track Access Charges (TACs)
- Auction or Raffle

In a competitive tendering process a concession, a franchise or a PSO are similar options as they represent a timewise and geographically precisely defined set of train paths which is granted support payments or exclusive rights. Often these options cannot be clearly distinguished and are sometimes used synonymously. In this thesis, the terms are defined as follows. A **concession** is meant as an exclusive right for all long-distance service in a certain part of the network or the whole network without receiving subsidies. In a **franchise** long-distance services are grouped together on certain lines or regions which - depending on the bundle - receive subsidies or pay premia and are given preferential treatment over other long-distance services. Technically a **PSO** is the tool to grant an exclusive right or a subsidy. Here, a PSO covers the provision of transport services on a specific line or in a region without having exclusive rights. As a rule, this covers transport services that are not provided commercially by the market to this extent or in this quality and therefore receive subsidies. In a **train path catalogue** all system train paths are predefined and offered to interested RUs, the costs of these train paths could be gradational according to the demand and the desired steering effect. **TACs** for integrated STPs would be raised, while charges for train paths like point-to-point services could be lowered. This gives commercial OA operators the option to acquire cheaper train paths outside the ITF. If TACs for STPs are higher, compensation payments for PSO services using this TACs have to be raised as well. When using TACs, STPs bundles are difficult to implement as this raises the question, whether an RU can be obliged to run all services of a bundle over several years. With a train path catalogue, lines can be specified but not bundles. The formation of STP bundles is preferable for an **auction or a raffle system** to prevent cherry picking and to provide a network-wide availability of services. Considering these options, STP bundles have to be operated on a self-sustaining basis, only when using franchises or PSO contracts a subsidy can be awarded.

A detailed discussion of these tendering options can be found in Smoliner et al. (2018c). These findings and further inputs from Brown (2013), Berschin et al. (2019), Knauff (2019) and (Seifert, 2020) are summarised in Table 6.1.

Legal Considerations of Tendering Options

As stated in Directive 2014/23/EU, awarding a **concession** means transferring the exclusive right to operate services in a respective segment to an RU without granting subsidies. The financial risk is to be borne by the RU (Gast and Autengruber, 2019). The term "concession" is used with differing meanings in § 14 and 16 of the Austrian EisbG, for example, as a transport concession, also known as transport permit. For detailed explanations and delimitations of the term concession see Pöschl (2017).

However, Directive 2016/2370/EU permits exclusive rights solely if the economic equilibrium of a public service contract were compromised by additional services. While competition is supposed to break up monopolies, concessions promote them and would largely hinder self-sustaining OA services to enter the market and thus not foster competition (Winter, 2018).

Franchises are a similar to concessions in that they convey exclusive rights which, as described above, are compatible with EU law in exceptional cases only. While a concession is usually acquired, i.e. the RU applies for it and may pay a fee. However, a concession is not usually linked to subsidies and often awarded on a network-wide basis. Franchises can be purchased for a subsidy (e.g. PSO) or may pay a premium to the awarding body and are often limited to sections of the network.

The franchise concept in GB shows that self-sustaining OA services can only be established as a niche product (Tomeš et al., 2016). Since RUs are obliged to take the revenue risk, they are exposed to macroeconomic uncertainty (Brown, 2013). This can also be the case in PSO net cost contracts (chapter 6.3.2). Economical turbulences such as the Covid-19 pandemic can lead to financial problems and have in some cases, even collapsed franchises. Therefore, it is expected that the ongoing William's review will suggest a system of concessions which is supposed to be more flexible in times of crises and more stable for the financial situation of the RUs (Jackson, 2020).

The awarding of exclusive rights or compensation payments to an operator have to be conducted within the framework of a **PSO** (1370/2007/EC). In the case of concessions and franchises, this concerns the exclusive rights. However, in most cases, PSO contracts determine compensation payments to cover non-commercial services. A competitive PSO award of STP bundles allows for a detailed description and control of the service provision as well as a higher level of quality management (Knauff, 2019).

When using **train path catalogues,** a priority catalogue has to be defined in the event of multiple requests of the same train paths. The RU that orders most train paths, the longest train paths or the densest interval, etc. should be awarded the contract. However, this method poses a potential barrier to market entry for small competitors.

While **TACs** should cover costs that are directly related to railway operation (wear and tear), mark-ups are an extra charge that the market can bear. They are intended to compensate for wear and tear (2012/34/EU), an implementation as a control mechanism is a complex model (Berschin et al., 2019). According to Art. 32, Directive 2012/34/EU, TACs should be the same for the same type of services, therefore it is difficult to justify that TACs are higher for STPs than for other train paths (Segalla, 2002). For this reason mark-ups are not suitable to distinguish between PSO and OA services or ITF services.

Table 6.1: Characteristics of tendering options for STP or STP bundles

	Franchise	Concession	PSO	Train Path Catalogue	TAC	Auction/ Raffle
Competition						
Exclusive rights	✓	✗	✗	✗	✗	✗
Additional self-sustaining services possible	~	✗	✓	✓	✓	✓
Factor of market accessibility	Volume of franchise	Volume of concession	Volume of PSO	Criteria of priority catalogue	Criteria of priority catalogue	Price in auction, un-predictable
Service availability/stability						
Options of packages	Part of the network / STP bundles	Network / Part of the network / STP bundles	STP bundles	Routes / STP bundles	Routes / Sections of routes	STP bundles
All STP in network covered?	✓	✓	✓	~ Not guaranteed	~ Not guaranteed	~ Not guaranteed
Planning stability	>1 year	>1 year	>1 year	1 year	1 year	>1 year
Financial						
Subsidies required?	~ Subsidy or premium	✗ Self-sustaining	~ Subsidy or premium	✗ Self-sustaining, PSO for non-covered STP	~ Self-sustaining, Refund for PSO	✗ Self-sustaining, PSO for non-covered STP
Tendering procedure						
Specifications in tendering possible?	✓	✓	✓	~	✗	✗
Objective procedure / Criteria	✓	✓	✓	✓	~ Only in pre-qualification	~ Only in pre-qualification
Challenges in awarding				Priority catalogue in case of multiple requests	Priority catalogue in case of multiple requests	Sufficient + homogenous demand required
Contract management						
Integrated ticketing on long-distance level required	✓	✗	✓	✓	✓	✓
Coordination with other services	✓	✓	✓	✗	✗	✗
Quality assessment	✓	✓	✓	✗	✗	✗
Applications						
Examples in long-distance services	GB	CH: IC+IR network NL: IC network	AT CZ	CH: Freight	-	in train path allocation (exceptional cases): DE, SE

An **auction** or a **raffle** of train paths is basically not considered in Directive 2012/34/EU and is difficult to align with the Union Law (Segalla, 2004). There is evidence that this only works if there is a large amount of homogenous train path requests. Compared to other network industries such as telecommunication, railway networks have a so-called “scarce capacity” with a limited number of train paths. Selling train paths at high prices in an auction may exclude small competitors. Furthermore, market accessibility is seen to be guaranteed best by easily understandable and predictable structures, which is not the case in an auction-based system (Tanner and Mitusch, 2011).

The chosen option partly depends on the granularity of the network where services should be implemented:

- A concession can cover an entire network or parts of the network, while
- Franchises or PSOs can cover networks, parts of a network or train path bundles.
- A train path catalogue, track access charges (TACs), an auction or a raffle can be based on single routes or route sections.

Recommendation of Tendering Option

The tendering options are evaluated by taking into account the long-term predictability, network availability, market accessibility and legal feasibility (Table 6.2).

The market accessibility of the different options depends on the respective conditions. An auction seems to have a low entry barrier, however, with financially strong RUs in the market (incumbents), prices may become unaffordable for smaller RUs.

In contrast, franchises, concessions or PSO contracts of large volume may be impossible to afford for smaller RUs. Furthermore, self-sustaining OA services are not possible for all options as described above. A PSO allows different RUs to take part in the competitive tendering and additional self-sustaining OA services are possible, the only condition being that Open Access services do not affect STPs. PSO contracts could also be a stable financial basis for commercial operators. With unused rolling stock or to optimise vehicle utilisation these RUs could offer additional commercial services (Buschbacher and Kasparovsky, 2020).

For STP bundles which are tendered with a franchise, concession, or PSO contracts, it is assumed that all bundles will be taken by the incumbent or competitors and as a result the whole network will be covered. As STPs in a train path catalogue, with TACs, or auction/raffle have to be operated on a self-sustaining basis, economically less attractive bundles might not be requested. These services then have to be covered by a PSO.

Train path catalogues and TACs can only be awarded on a yearly basis, therefore the long-term predictability of these services is very limited while franchises, concessions or PSO contracts are usually awarded for five years or longer. STP bundles which are awarded in auctions or raffles can be granted for several years, however, self-sustaining services are volatile and may be cancelled after a few years.

From a legal perspective the implementation of systems based on auctions or raffles, TACs, franchises or concessions is (partly) not compatible with EU and national law. PSO contracts and train path catalogues are legally feasible without having to make adjustments to the current jurisdiction.

Taking these arguments into account, the awarding of STP bundles as PSO appears to be the most suitable option. However, the payment of subsidies for services that could be operated as self-sustaining services seems questionable under an economic perspective. Depending on the economic attractiveness of bundles, subsidies have to be paid but also premiums can be expected. Economically attractive bundles may be able to generate premiums as is the case in Great Britain as shown in Figure 6.9. However, if premiums are received for a PSO it becomes difficult to give RUs incentives. In such cases the introduction of penalty payments can become relevant (Winter, 2018). Economically less attractive bundles will require compensation payments as is the case in Austria and the Czech Republic for most long-distance lines.

Table 6.2: Evaluation of tendering options

	Franchise	Concession	PSO	Train Path Catalogue	TACs	Auction/ Raffle
Market accessibility	✓*	~	✓*	✓	~	~
All STPs in network covered?	✓**	✓**	✓**	~ Not guaranteed	~ Not guaranteed	~ Not guaranteed
Long-term predictability	✓	✓	✓	✗	✗	~/✗
Legal feasibility	~/✗	~/✗	✓	✓	✗	~/✗

* if size is not too big | ** if offered at market conditions and applicants can be expected

Tendering Procedure

A PSO can be tendered in an invitational competition, an open or a closed procedure. In a closed procedure, interested parties have to hand in participation applications. The procedure consists of two up to three steps (Gast and Autengruber, 2019). Due to the size of

STP bundles and an expectedly low number of participants, an open procedure is recommended.

Negotiation procedures and competitive biddings are frequently used for open tendering procedures, and often combined. In a negotiation procedure an indicative offer is delivered, which is the basis for further negotiations which allow the RU to contribute its creative and cost-saving input in coordination with the client.

In competitive biddings, the performance potential of a bidder is requested. Often this procedure is applied as part of a two-stage process (Fuit-Bosch, 2020). Market consultation and negotiation procedures have been used e.g. in the Czech Republic (Janoš and Kříž, 2019), while competitive tendering is applied for franchises in GB or tenders on a regional level.

If there is only one bidder, the authority may start negotiations with this applicant, according to Regulation 1370/2007/EU, if:

- this applicant proved to be able to deliver
- no artificial narrowing of parameters and
- no reasonable alternative exists

For the tendering of several bundles it is important to design bundles as a package that makes it possible to form lot prices. If several bundles are tendered the maximum number of bundles a bidder may be awarded has to be defined (Gast and Autengruber, 2019). Once the decision is made to tender STP bundles this needs to be published in the appropriate media. In addition, it is recommendable to include an explanation of the process and the boundary conditions in the network statement in the sense of transparent and fair communication.

Contract Duration

PSO contracts for rail services may be awarded for up to 15 years according to Regulation 1370/2007/EU. Under certain circumstances like investments for rolling stock or the geographical situation, contracts may be extended by 50% of their length. This results in a maximum duration of 22.5 years (1370/2007/EC). The actual length of contracts has to be designed carefully and is often limited to several years. Later on, longer contracts are usually awarded. From the RU's point of view, longer contracts are preferable in order to spread the amortisation over a longer period of time (Scherp, 2018). Brown (2013) suggests contracts for at least seven and up to ten years with the possibility of extension for three and up to five years. Winter (2018) suggests a duration of at least ten years due to depreciation of cost-intensive investments like rolling stock. Figure 6.1 shows PSO contract durations throughout the EU.

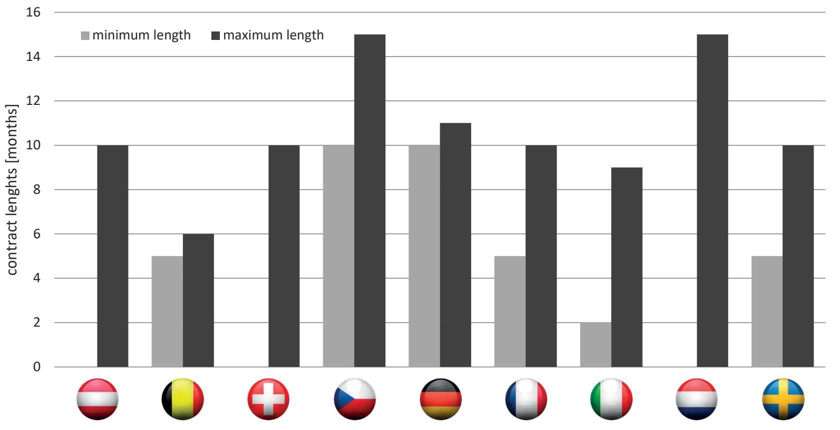


Figure 6.1: Overview of PSO contract duration throughout the EU (Caramello-Álvarez, 2017)

Table 6.3 shows the duration of selected competitively tendered contracts in Europe ranging from 3 up to 15 years.

Table 6.3: Duration of selected competitive tenders in Europe

Parameter					
Tendering procedure	PSO	PSO	PSO	franchise	franchise
Segment	IC/IR	regional	high-speed	R/IR/IC	R/IR
Contract duration [yy]	lately 3-10, others 8-15	2-15, now more often 10-15 due to investments	10	mostly 10-15, others 1-30	lately 5-8 with option for extension, others 1-3
Source	Janoš (2019)	Nash et al. (2013)	Montero and Melero (2020)	Baldwin et al. (2012)	Scherp (2018)

International Connections

The integration of international lines poses a particular challenge in the awarding process. International connections can be tendered (i) requiring a cooperation with another railway across the border, (ii) by cross-border tendering or (iii) by excluding the line from the tender to find a separate solution.

In option (i) the tendering documents need to clarify that services to the next hub abroad should be offered in cooperation with a foreign RU, or are done on a commercial basis. This scheme was applied for a service running from the Czech Republic to Slovakia. The RU was obliged by the Czech transport ministry to run a service into Slovakia. The Slovakian ministry ordered the service on the Slovak territory under the condition of cooperation with the Slovak incumbent ZSSK (Janoš, 2020b). Additional examples are regional railway services tendered by VOR[21] between Retz in Austria and Znojmo in the Czech Republic. For this connection, the RU must ensure that cross-border services are offered. The RU is free to do so at its own expense or in cooperation with other RUs.

A cross-border tender according to option (ii) is done between the regions of Bavaria in Germany and Tyrol in Austria for the bundle Werdenfels (Beltle, 2020). Another common tender between Bavaria and the Czech Republic is planned on relations with strong passenger flows (Janoš, 2020b).

If the other two options are not feasible another possibility is (iii) to tender cross-border lines separately (Uttenthaler, 2019).

Awarding Criteria

The awarding criteria in a competitive tendering should primarily consider which applicant in the tendering process requires the lowest subsidy or promises a premium. Furthermore, quality factors (Brown, 2013), earliest possible start of operation, social criteria and sustainable goals should be considered (Montero and Melero, 2020).

6.1.2 Implementation and Institutions of the Suggested Procedure

The implementation of STP bundles tendered as PSO should be embedded in the existing structures of timetabling, network planning and train path allocation. It requires a close collaboration between several institutions according to Smoliner and Marschnig (2020):

- An institution for **demand estimation**,
- a **competent authority** being responsible in close cooperation with
- the **public transport authority** for timetabling, network design, design of STP bundles and PSO awarding,
- an **infrastructure manager** in charge of infrastructure design, system train path design and train slot allocation,
- a **regulator** and (if needed) **courts** to clarify disputes.

[21] VOR is short for German "Verkehrsverbund Ost-Region"

System train paths are, on the one hand the tool to guarantee ITF services in the yearly timetable, but they also function as a planning tool for the development of the target timetable as well as the network development plan. The planning competences have to be clearly allocated and are described in the following, with the exception of transport planning which is an upstream step that is not dealt with here. As the role of regulators and courts is not directly affected by the presented procedure, it is not further discussed in this thesis either. Finger and Messulam (2015a) discuss the important role of a strong regulator in liberalised railway networks.

Given these considerations, the following planning procedure is suggested as illustrated in Figure 6.2:

- The **demand estimation** is done by an institution for transport planning as basis for the identification of the service intention.
- The **service intention** is determined by the public transport authority in close coordination with the competent authority.
- The **target timetable** representing the service intention has to be designed by the public transport authority according to the demand and by considering the concept of STPs.
- The strategic **network development plan** is based on the target timetable.
- Based on a long-term target timetable and the network development plan, a sound **infrastructure** is designed by the IM.
- Based on the given infrastructure and the target timetable, **system train paths** for passenger services are designed by the IM.
- These train paths are arranged into **STP bundles** and are consequently awarded to RUs by the public transport authority.
- Those **RUs** who have been awarded the STP bundles **request STPs** in the annual timetable allocation process according to their specific rolling stock characteristics and stopping pattern.
- Finally, the optimal number of **feasible train slots** not interfering with system train paths is **allocated** by the IM resulting in the network timetable.
- If competitors **file a protest** against the tendering process or a **train path conflict** occurs, the regulator or the respective court are consulted.

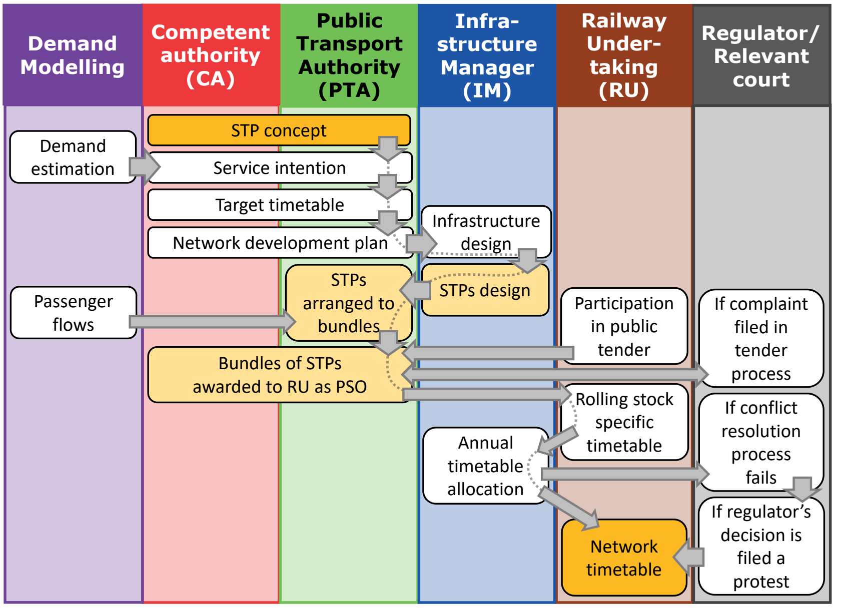


Figure 6.2: Stakeholders in the STP bundle procedure

Competent Authority (CA)

The competent authority (CA) is the administrative unit responsible for the respective railway network (Segalla, 2004). In the case of a long-distance railway network, this is usually the ministry in charge of the railway network.

The core tasks in the implementation of STP bundles are:

- Define service intention
- Define system train path concept
- Design target timetable
- Define network development plan

The CA works closely together with the sub-ordinated public transport authority (PTA) and the infrastructure manager (IM). Qualified and sufficient personnel at the CA and PTA is highly relevant to a transparent implementation of the procedure. Comprehensive network and system knowledge of demand and operational requirements are needed. The definition of the service intention, the network-wide target timetable and the network development plan need to be defined on the network-wide demand estimation provided by transport planning. These tasks include the strategic design of passenger services in terms of lines, hubs, edge riding times, transfers and intervals (Burgdorf et al., 2019).

In the tendering process the CA has to publish market information, a pre-publication and the tender documents. If rolling stock is not provided by the RU, the availability of vehicles has to be provided by the CA as mentioned in chapter 6.3 (Scherp, 2018).

Public Transport Authority (PTA)

The PTA is an independent body closely linked to the competent authority. In Austria this is the SCHIG mbH, given that resources for the competitive tendering procedure are provided.

The core tasks of the PTA, in addition to the aforementioned tasks closely coordinated with the CA, are:

- Design of the target timetable
- Design of the network development plan
- Design of STP bundles
- Awarding of STP bundles as PSO

The tendering of competitive PSO contracts is a long-lasting and time-consuming process, especially if this is done for the first time (Krummheuer, 2014). Further tasks are ticket integration (chapter 6.3.1) and quality management of PSO contracts. The role and different forms of public transport authorities are described in Krummheuer (2014), Alexandersson et al. (2018) and Herfurth (2019). These studies focus on the level of urban and regional transport; however, these findings are useful for long-distance services as well.[22]

Infrastructure Manager (IM)

The tasks of the IM are:

- Design infrastructure
- Design system train paths
- Allocate train paths

The IM needs to efficiently plan capacity according to the strategy of the owner of the infrastructure. This strategy is based on a long-term network development plan. The underlying target timetable is based upon the concept of system train paths. The IM provides

[22] The predecessor of public transport authorities in 19th century London was the Railway Clearing House which coordinated the operation of several RUs; Bagwell: The Railway Clearing House in the British Economy in Schivelbusch (2002).

and manages the railway network. The **train path allocation** continues to be one of the central tasks of the IM (2012/34/EU). In addition, the IM is responsible for the **design of STPs** as described in chapter 4. Here, the used vehicle parameters or model vehicles have to be chosen carefully in coordination with the PTA to prevent the preferential treatment of an RU and to ensure a fair and non-discriminatory procedure (Burgdorf et al., 2019).

In order to guarantee the most independent planning possible for system train paths and train path allocation in general, it is conceivable to outsource this to an independent body such as the Swiss capacity allocation body TVS[23] (Trassenvergabestelle, 2021) or VPE in Hungary (Rail Capacity Allocation Office, 2021).

6.2 Steps and Sequence of the Tendering Process

6.2.1 Steps of the Tendering Process

The steps of a PSO tendering process (Figure 6.3) are analysed in the following, based on expert interviews.

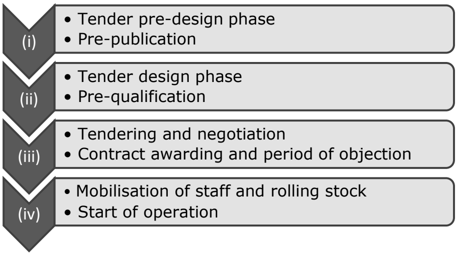


Figure 6.3: Steps of a PSO tendering process

The benchmark of different tendering procedures is presented in Figure 6.4. The analysis is based on:

- The tender of a regional bus bundle and two directly awarded regional railway bundles in Styria, Austria (Walter, 2020)
- One competitively awarded regional cross-border bundle in Austria and Germany (Beltle, 2020)
- Long-distance railway bundles tendered in negotiation procedures (Janoš, 2020b)
- The timeline for franchising in the UK (Department for Transport, 2017)

[23] TVS in German short for „Trassenvergabestelle"

In addition, expert opinions[24] from Austria (Liebhart, 2020b), Germany (Fuit-Bosch, 2020; Seifert, 2020) and on a European level (Kummer et al., 2013) are included.

Tender Pre-design Phase

In the tender pre-design phase, the type of award, the form of contract and its content must be specified. Timetables, volume of the transport services, rolling stock specifications and quality standards need to be specified in order to be able to prepare the tender documents (Beltle, 2020). Furthermore, start of operation and duration of the contract have to be determined according to Art. 7-2, Regulation 1370/2007/EU. These points must already be known at this stage for the pre-notification and can only be changed afterwards to a limited extent. This process includes the coordination between the stakeholders and takes about eight months (Beltle, 2020) up to several years (Walter, 2020). If the tendering of railway operation, rolling stock, servicing and/or maintenance is to be carried out separately, this must be determined at this stage (Fuit-Bosch, 2019).

Pre-Publication

According to Regulation 1370/2007/EU, a pre-notification about the planned tender has to be published in the Official Journal of the European Union at least one year before *"the launch of the invitation to tender procedure or one year before the direct award"* (1370/2007/EC). The following content is required:

- Contact of competent authority
- Type of award
- Services and area covered
- Starting date and duration of the contract

Furthermore, transparency and a non-discriminatory handling of the procedure is crucial (Kramer and Hinrichsen, 2018). A pre-publication is not necessary in the event of inhouse awards, if the contract volume is below 50.000 km per year or under certain circumstances as emergency awards (1370/2007/EC, 2007). A missing pre-publication does not automatically lead to a cancellation of the tender, provided that equivalence, effectiveness and equal treatment are respected in the procedure (Gast and Autengruber, 2019). However, to guarantee a fair procedure a pre-publication is recommended by Casati (2020) and Janoš (2020b).

[24] Longstanding employees of Public Transport Authorities, consultants and scientific researches.

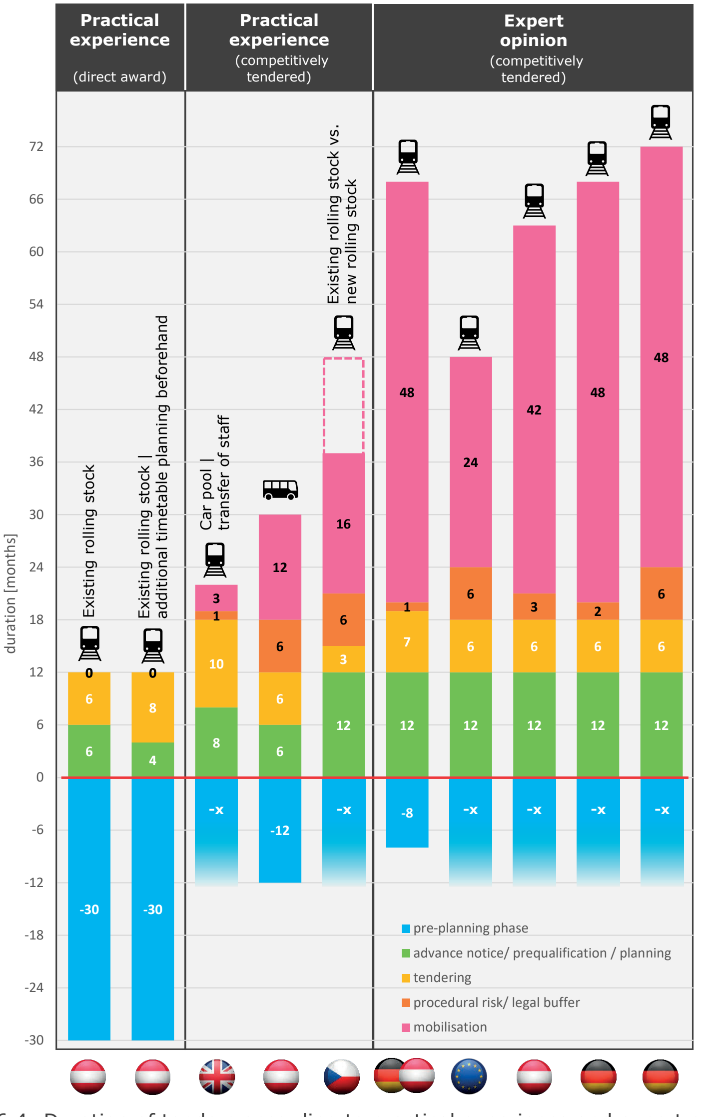


Figure 6.4: Duration of tenders according to practical experience and expert opinions

Tender Design Phase

The tender design phase is set after the pre-publication. The requirements that were developed in the tender pre-design phase are now specified in detail and the tendering documents are established. In addition, further coordination processes are taken between the (political) stakeholders (Casati, 2020). This step ideally takes place in the period between pre-publication and publication and lasts about one year (Janoš, 2020b; Seifert, 2020).

Pre-Qualification

A pre-qualification phase makes it possible to pre-select potential RUs according to references, capacities or other criteria. In Great Britain a "*pre-qualification questionnaire (PQQ) passport for rail franchising*" is used (Department for Transport, 2017). Interested RUs have to register via this procedure at least half a year before the invitation to tender is launched (Department for Transport, 2017). This phase helps to speed up the actual tender process. If several bundles are being tendered, a dynamic procurement process makes it possible to do the pre-registration only once (Casati, 2020). The registered RUs are then invited for each single tender.

Tender and Negotiation

One year after the pre-publication, the tender documents are published. After a consultation phase the deadline for submitting tenders is set and followed by the contract assessment and finally the contract award. For this step a duration from three months Janoš (2020b) up to 10 months (Department for Transport, 2017) is recommended.

Contract Awarding and Period of Objection

The contract awarding can be done as soon as the PTA comes to a decision about the winner. For legal appeals in Austria, a ruling by the Federal Administrative Court has to be issued within six weeks. Appeals can be lodged with the Supreme Administrative Court. The period of objection, including a legal threshold for a review procedure in the event of procedural deficiencies, lasts about one month (Beltle, 2020) up to six months (Seifert, 2020).

Mobilisation of Staff and Rolling Stock

It is recommendable to start with the mobilisation once the contract is awarded and legal files are clarified (Beltle, 2020). The term "mobilisation" describes the time-intensive acquisition of staff, rolling stock and other resources.

The duration of the procurement process depends on the strategy for rolling stock chosen by the competent authority. This procedure was originally done by RUs themselves, however, Art. 5a, Regulation 1370/2007/EU allows competent authorities to support the process. The options that require different time periods for the provision of rolling stock are explained in chapter 6.3.1.

As rolling stock is usually tailored to the needs of an RU and the specific requirements of a railway network, the acquisition process of new vehicles can take two and up to four years

(Müller, 2020). When ordering new transport equipment, lengthy vehicle registration tests are to be expected. Acquisition times shorter than two years can only be realised with the use (and redesign) of existing rolling stock (Fuit-Bosch, 2020).

Staff such as train drivers, conductors, controllers and operational planners have to be hired at last one year in advance to allow for intensive training and to guarantee a stable transfer of operations (Fuit-Bosch, 2019). The timing here is essential in order to not hire personnel too late and risk running out of staff, but also not too early for economic reasons (Janoš, 2020a).

The process of mobilisation can be shortened as shown in Great Britain where almost all staff has to be transferred to a new franchise holder (Department for Transport, 2021). Rolling stock is usually leased from rolling stock operators (Dillon et al., 2015). Furthermore, changes regarding service offers do not have to be made when a franchise starts operating, but can be made over the course of one to two years thereafter (Nuttal, 2021).

Start of Operation

Due to the complexity of railway operation, the start of operation has turned out to be a very critical moment in the procurement process. On the one hand, there are the challenges of having all the components required for railway operation such as rolling stock and staff ready in time, on the other hand, the operation can only be tested to a limited extent under real conditions. This often leads to delays and an unstable operation in the initial period, especially when new rolling stock and staff are involved (Seifert, 2020). Usually the European timetable change in the second week of December is chosen for the start of new operations.

6.2.2 Suggested Timeline and Sequence

A realistic timeline is a key component of a successful tendering procedure of PSO contracts for railway services. If several bundles are to be tendered in a network, the sequence of the different steps is crucial for an efficient resource allocation and to achieve best possible network-wide demand effect.

Suggested Timeline

According to the boundary conditions such as acquisition of rolling stock and staff, the process lasts for at least 3.0 as much as 4.5 years. Delays due to legal files or delayed delivery of rolling stock may further extent the procedure (Scherp, 2018). Competitive tendering with new rolling stock takes at least four years, but more likely about six years. Shorter procedure times can only be achieved by using existing vehicles or carpools. The following sequence is suggested for an optimal tendering procedure as shown in Figure 6.5:

- A pre-tender phase of at least one year is required for sufficient planning of the bundles and preparing the documents for pre-publication.
- The pre-publication is done one year ahead of the start of the tender in order to ensure a transparent and fair process.
- In the following tender design phase, detailed planning, consultation of stakeholders and preparation of tender documents is carried out.
- In a parallel dynamic procurement system, RUs are registered.
- The tender and consulting phase lasts six months.
- The contract awarding is followed by a period of possible objection lasting three additional months.
- Then the mobilisation process for rolling stock and staff starts. Assuming new rolling stock is required, this process takes four years.
- Finally, the start of operation phase is reached.

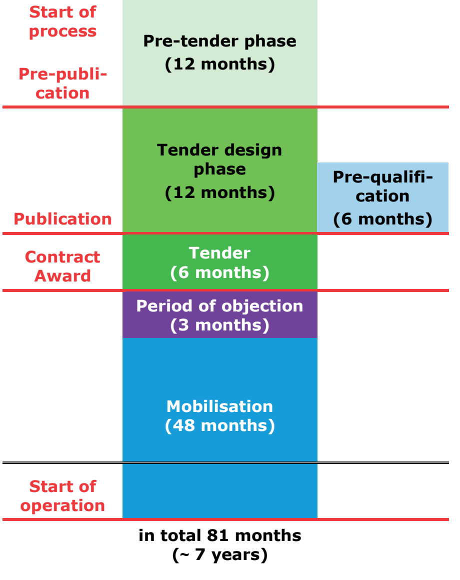


Figure 6.5: Steps in a tendering process

Suggested Sequence

A speedy process from tendering to commissioning all bundles can be achieved with "parallel tendering".

Theoretically a simultaneous start of operation of several bundles seems recommendable, however, could also be problematic. The start of operation of various bundles at the same time is critical, as RUs require the same resources in the mobilisation phase in a contested market. Furthermore, the simultaneous start of operation could be problematic as well, as delayed rolling stock or problems with staff acquisition often lead to chaos in the first phase after the start of operation. Most start of operations after competitive tenders in Germany were delayed or lead to significant timetable interruptions (Liebhart, 2020b). Therefore, a realistic timetable with buffers and test pilots is crucial (Fuit-Bosch, 2019) and a stepwise arrangement can be advisable.

Furthermore, major timetable changes (e.g. following infrastructure developments) can be implemented best with a start of operation at the same time for all bundles. However, risks easily outweigh advantages if resources are blocked due to several ongoing procedures at the same time.

Delayed or shifted tendering procedures allow RUs to participate in several tenders at the same time. This can be resource intensive but raises the chance of winning one of the tenders (Seifert, 2020). RUs not successful in the first tender might try harder in the next tender (Fuit-Bosch, 2020). With shifted procedures, administration and RUs can use the gained knowledge in the next tender (Beltle, 2020). Nevertheless, this leads to a shifted start of operation and a period of transformation. Such a transformation is suboptimal for customers, but seems more realistic in large networks (Fuit-Bosch, 2020; Liebhart, 2020b) The start of operation should be coordinated with the timetable change and therefore be one year.

Based on the experiences of the above-mentioned experts, the different options are compared in Figure 6.6. If several bundles are tendered it is recommended to start stepwise for an efficient use of resources and knowledge transfer. Various experiences show that this allows for a more homogenous workload for the administration, but also for RU and manufacturers (Seifert, 2020). As the start of operations for a bundle usually means a lot of uncertainty, a stepwise start is suggested.

In the event of infrastructure openings and major timetable changes a combined start of operation can be realised with adjusted rolling stock strategies (Figure 6.7). If three bundles start at the same time, one bundle could use new vehicles at the very beginning, for one bundle a vehicle pool of existing vehicles that only needs to be redesigned is provided and in one bundle existing rolling stock is accepted for the first few years of operation. However, strategies need to be developed in order to ensure a stable start of operation for all bundles at the same time.

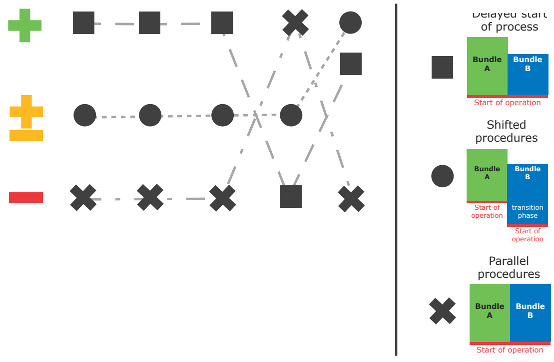


Figure 6.6: Evaluation of various time-wise arrangements of different bundles

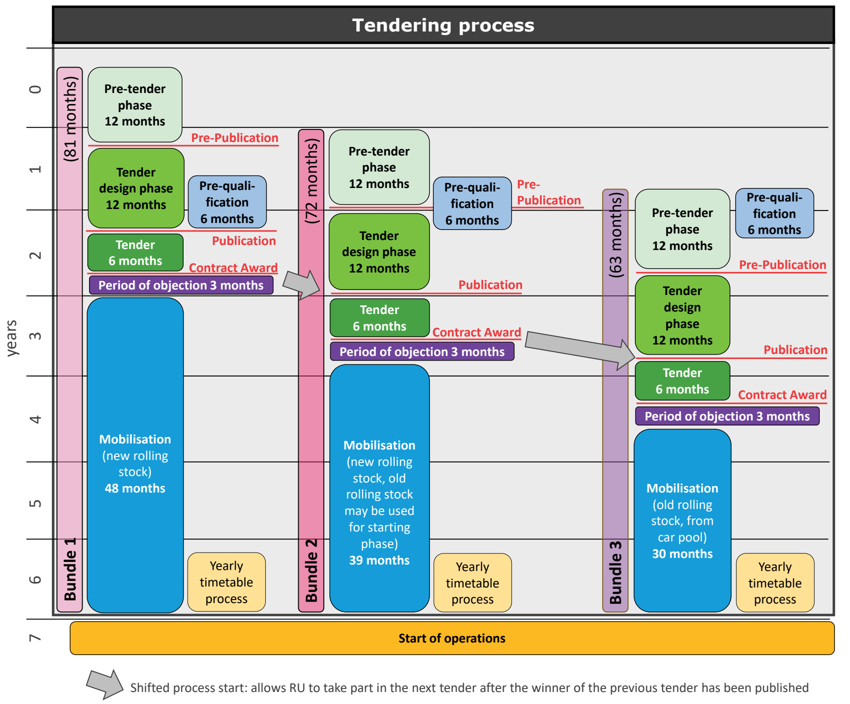


Figure 6.7: Suggested sequence for tendering process

6.3 Further Aspects of Tendering

For the successful tendering and operation of PSOs rolling stock acquisition, revenue and risk management and integrated ticketing are essential. These aspects are only covered briefly in this thesis, for further information consult the sources cited.

6.3.1 Rolling Stock Acquisition

As the procurement of rolling stock is cost-intensive and life span last for about 30 years, several acquisition strategies have been developed to foster competition. The challenges of competition in the capital-intensive railway market are clearly evident here (Winter, 2018). In addition, in small bundles cost-efficient minimum order quantities are not reached. Therefore, Art. 5a, Regulation 1370/2007/EU allows competent authorities to support RUs to ensure an "*effective and non-discriminatory access to suitable rolling stock*" (1370/2007/EC). The following options are listed in the regulation:

- Competent authority buys rolling stock
- Competent authority gives guarantee
- Purchase of rolling stock after end of contract by the PTA
- Create a pool of rolling stock

Further options not listed in the regulation are:

- Takeover of existing vehicles by the new RU
- Acceptance of existing vehicles for the first period of the contract (Janoš, 2020b)

Furthermore, these options can be used to speed up tendering procedures and start different bundles simultaneously. In addition to the classic acquisition of new vehicles, the re-use of existing vehicles and the creation of vehicle pools could be particularly relevant.

A carpool can be filled with new and existing rolling stock. Additional vehicles should be considered to allow for short-term adaptations of the timetable, as strategic reserve or to operate self-sustaining services (Buschbacher and Kasparovsky, 2020). A car pool also gives the competent authority the opportunity to pursue a uniform procurement strategy despite the presence of several competitors (Berschin et al., 2019).

If existing rolling stock is allowed in a tender, incumbents may be in advantage and it might be difficult for competitors to purchase respective vehicles in a short period of time (Fuit-Bosch, 2020). However, if no special vehicles are required for a tender it can be assumed that competitors are able to purchase comparable rolling stock as well. To avoid such a situation the competent authority could buy existing vehicles from the incumbent and park them in an independent carpool where the operator of the bundle can lease them. This would guarantee efficient use of taxpayer money and provide suitable rolling stock fast (Fuit-Bosch, 2020).

International examples for car pools and their advantages and disadvantages are discussed in Dillon et al. (2015) and Alexandersson et al. (2018). Lünser (2020) describes a hybrid variant of rolling stock funding by the competent authority and carpools at the example of the VRR[25]. Some PTAs allow RUs to choose between several option of rolling stock acquisition. The model of VRR also gives small market participants a fair chance to participate in the competition. However, this approach can lead to higher costs in the overall system.

6.3.2 Revenues and Risk Management

The allocation of revenues and risk management play an essential role in the design of a PSO contract and depend on cost recovery and risk allocation among competent authority and RU.

The **cost recovery** for long-distance services is dependent on revenues, production costs and any possible subsidies. The expense coverage in urban railway services by farebox revenue ranges from 30% to 80% (Wong, 2019). For long-distance services, this factor can be assumed to be higher on attractive routes but not across the whole network. As shown in Figure 6.8 long-distance services in the Swiss network are cross-subsidised amongst profitable and non-profitable routes. A similar distribution can be expected in Austria, which is why only bundle constellations that yield profits are unlikely.

Besides staff and overhead, the production costs are highly dependent on debt service for rolling stock and track access charges (TACs, see chapter 2.5.1), while energy costs in the railway sector are equal to all RUs if provided by the IM. As described above there are various options to handle financing of rolling stock. Furthermore, TACs are a significant factor as railway infrastructure is highly cost-intensive (Mitusch, 2019). The production costs and therefore the amount of compensation, is dependent on the amount of TACs (see chapter 2.5.1).

[25] In German: Verkehrsverbund Rhein-Ruhr

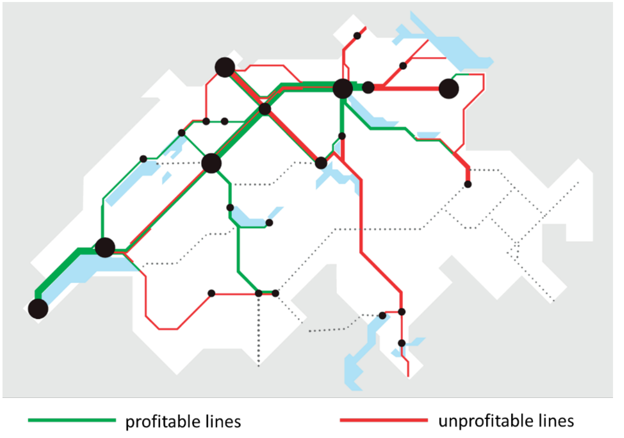


Figure 6.8: Profitable and non-profitable routes in Switzerland (SBB CFF FFS, 2018)

PSO compensation in countries with primarily direct awarding like France is higher than in countries with all or most tenders being competitively awarded like Sweden or Germany (Figure 6.9). On unprofitable lines, RUs will need subsidies for cost recovery, while RUs might pay a premium in some bundles that include profitable lines (Berschin et al., 2019). In Great Britain, for instance, some franchises even pay premiums for serving PSOs. In 2013, eight franchises paid premiums while ten received subsidies (Temple, 2015). This results in a country-wide average compensation of about 0 euros (European Commission, 2019, 2021).

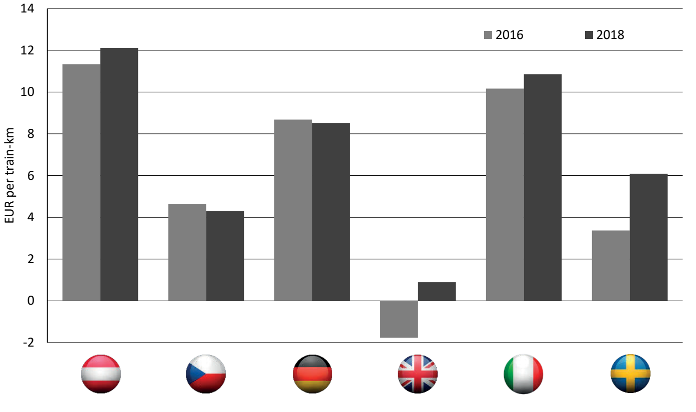


Figure 6.9: Average PSO compensation according to RMMS 2018 (European Commission, 2019) and RMMS 2020 (European Commission, 2021)

Risk management describes with which contractual partner assumes the revenue risk. In gross cost contracts, the competent authority covers the revenue risk and is responsible for marketing and sales. In a net cost contract, the RU receives the revenues and therefore has more motivation to improve its quality. However, if revenues are lower than expected, the RU has to cover the loss, which can lead to severe financial problems for the RU.

In literature, gross and net cost contracts especially in urban and regional public transport networks are covered. Stanley and van de Velde (2008) the revenue allocation for gross cost and net cost contracts. Brown (2013) outlines out how the type of contract defines the role of the competent authority and the RU. Finger (2017) suggests gross cost contracts for strong regional entities and net cost contracts for RUs that are entrusted with planning. Furthermore, Brown (2013) describes the cap and collar principle that was in force in GB with shifting risks to the government for a certain part of the risk. This scheme is not used anymore as it lead to overoptimistic bids and there was no incentive for a higher revenue at a certain point. Wong (2019) argues that there is a global growth of gross cost and management contracts and a move away from contract incentives. Furthermore, the correlation of network design and contract design is described. Characteristics of gross and net cost contracts based on literature and interviews with experts mentioned in chapter 6.2.1 are presented in Table 6.4.

Table 6.4: Characteristics of gross cost and net cost contracts

	Gross cost contract	Net gross contract
Charge of financial risk	competent authority	RU
Marketing and sales	competent authority	RU
Role of competent authority	strong	weak
Price formation	competent authority	RU
Incentive for RU	(✓) (bonus/penalty)	✓
Stability in economic turbulences	✓	✗
Revenue management	✗	✓
Number of competitors	higher	lower

Since the development of revenues is difficult to estimate when a network is tendered for the first time, experts recommend to initially introduce gross cost contracts (Scherp, 2018). These contracts are easier to manage and a switch from a gross cost contract to a net cost contract can be done faster than the other way around (Fuit-Bosch, 2019; Wong, 2019).

A gross cost contract with incentives combines both types, which is generally positive, however, difficult to implement (Seifert, 2020). The cause of an increased demand can often not be attributed to one reason only. Reasons such as travel time, transfer options or interval of services cannot be influenced by the operator alone (Wong, 2019). Furthermore, the scope for incentives is usually too small to generate passenger growth (Walter, 2020).

If competition in a network is supposed to be fostered, gross cost contracts with incentives or net cost contracts are recommendable. For long-distance services, only net cost contracts allow for revenue management, which is an important tool to steer homogenous vehicle utilisation. However, the risk of overestimated revenues remains and, like a certain distribution of revenues or an intensive commitment of the RU, should be considered (Mund, 2020).

6.3.3 Ticket Integration

Ticket integration is a prerequisite of a closely linked public transport system if several long-distance and regional operators serve the same hub. This is the only way to ensure easy and cheap travelling for passengers if several operators are active in a network. Berschin et al. (2019) argue that integrated ticket tariffs and sales are the basis for an attractive ITF. A single ticket for several operators with integrated tariffs is therefore crucial.

The fourth railway package (Scordemaglia and Katsarova, 2016) facilitates the introduction of an integrated ticket in long-distance services; an analysis is presented in Maffii et al. (2012). According to Directive 2012/34/EU, Member States can force RUs to participate in integrated ticketing and information. Furthermore, an authority can be enabled to establish such a system (2012/34/EU).

Legal Implementation
From a legal point of view, experts agree that integrated ticketing can be implemented best by a "General Rule" according to Regulation 1370/2007/EU (Mund, 2020). The general rule makes it possible to prescribe measures to all services in a given area under the jurisdiction of one authority in a non-discriminatory way (1370/2007/EC). This allows the competent authority to grant a compensation payment when imposing general maximum tariffs (Kramer and Hinrichsen, 2018). A discussion on the general rule can be found in Gast and Autengruber (2019).

The implementation of an integrated ticketing amongst others is a complex task in terms of accounting. Differences occur regarding individual tickets and network tickets. Regardless of this, a generally accepted basic tariff (to cover parallel journeys) and the establishment of a ticket portal are required. This basic tariff can be imposed via the state or agreed upon via an industry association or a PTA. Ideally, a basic tariff still leaves room for revenue or capacity management, nevertheless to keep a balance remains difficult (Mund, 2020).

Individual tickets

- The implementation of individual tickets is easier, because a single journey can be attributed more easily depending on the RU used.
- Following this logic a ticket for single journeys is easier to implement than a ticket for a certain area or a zone tariff (Mund, 2020).
- However, the commonly used tool of distance dependent price degression makes long travels with the service of one RU attractive. If several RUs are used for the same distance and several single tickets have to be bought, the overall price increases for the customer. However, through ticketing covering gap revenues, is an essential task that PTAs are already doing today.

Network tickets

- The accounting of network tickets is complex as single journeys and passenger numbers are unknown.
- Nevertheless, various approaches were developed in order to overcome this issue (Mund, 2020).

For the introduction of an integrated ticketing further aspects have to be considered. **Ticket prices** need to be regulated in order to achieve moderate price increases. This can be linked to conditions such as a requirement to offer a certain number of saver tickets like it is done in Switzerland (Mund, 2020). In countries with a strong incumbent prices are usually oriented along the ticket prices of the incumbent (Burgdorf et al., 2019; Schienen-Control GmbH, 2019)

Tickets available and **accepted by all RUs** in a market (PSO and self-sustaining OA services) are important. In addition, dedicated tickets and products of single RUs should be allowed. Integrated tickets are interesting for self-sustaining OA services as well, as this allows access to a network-wide ticket retailing (Temple, 2015).

Revenue management is essential in order to achieve a homogenous vehicle utilisation, which is usually difficult to realise in an ITF. Even in Switzerland, which boasts high passenger numbers, only about 30% of seats in long-distance services are booked. In contrast, in Germany, Italy and France this value is above 50% (Weigand and Berschin, 2020).

In a network with frequent **international connections,** the handling of cross-border tickets is highly relevant, as these represent a significant proportion of the income of RUs which are active in international markets (Mund, 2020).

International Examples
On an international level several countries apply ticket and tariff integration.

In **Great Britain,** a nationwide ticketing retail system is implemented with RU selling shared as well as individual tickets. A complex mechanism provides for accounting, prices are regulated and may be raised by double the inflation rate per year (which is frequently used, leading to significant price increases over several years). The system grants benefits for customers and is easily accessible for new operators (Temple, 2015).

In **Switzerland,** the "Generalabo" covers almost all modes of public transport in the country. The ticket price is set by the Federal Office of Transport (BAV[26]), while an independent ticket reseller is owned by the Federation of Transport Companies and Associations (Alliance Swiss Pass, 2021). Price increases are done in consultation with the BAV and are often linked to the requirement of a certain number of saver tickets (Mund, 2020).

A unified fare system across the rail network with tariff integration is applied in the **Czech Republic** called OneTicket (Ministry of Transport of the Czech Republic and CENDIS, 2021). The tickets are integrated in the system in terms of time, space and tariff. This means tickets are accepted without being bound to specific trains among all operators (Janoš and Kříž, 2019). For long-distance services under a PSO the acceptance of all tickets is mandatory, regional and SOA services can participate on a voluntary basis. In long-distance services, RUs may also apply their own tariffs; fares interavailable amongst all operators have to be accepted. The tariff is set by the ministry of transport and is based on the ticket prices of the incumbent CD, including a surplus. Revenue allocation is handled through a clearing house. Fares for regional services are determined by the regions individually (Janoš, 2020b).

In **Sweden,** regional PTAs decide on the prices for tickets and travel cards on a political basis. Concessionaires on regional networks are exempted, however, the monthly ticket may not compete with the equivalent offer of the PTA (Alexandersson et al., 2018).

A current example of ticket integration is the emergency award of long-distance services **in Austria** between Wien and Salzburg during the Covid-19 pandemic. In order to maintain frequent intervals, the railway undertakings ÖBB PV and Westbahn, which usually operate

[26] In German: Bundesamt für Verkehr

self-sustaining services on this route, were granted an emergency PSO award. The payment of compensation was linked to ticket acceptance, as well as requirements regarding frequency and interval (Briginshaw, 2020).

Furthermore, in Austria currently (2021) discussions are ongoing how the so-called "1-2-3 Ticket" can be implemented as a network ticket for all kinds of public transport. It is agreed upon that the so-called One Mobility GmbH will be founded as a common ticket shop of several RUs and PTAs (Österreichisches Parlament, 2021). The former ticket shop of the incumbent ÖBB will be transformed to an independent ticket portal (Ungerboeck, 2020).

7 Conclusion

7.1 Key Findings

Problem Statement

The Integrated Periodic Timetable (ITF) requests long-term and cost-intensive infrastructure development based on strategic long-term timetable development. This is difficult to combine with volatile short-term planning of self-sustaining services in liberalised railway markets. In Austria about 30% of the railway infrastructure investments are spent on ITF-relevant projects. Therefore, an infrastructure utilisation according to the principles of an ITF is not only efficient but also sustainable. However, the current legislation does not guarantee an optimal network-wide utilisation. Slot allocation of long-distance trains can have negative effects on the regional network as well as transfers.

Approach

This doctoral thesis provides an integrated approach to combining timetabling, infrastructure development and train path allocation in a liberalised railway market. In order to combine competition and ITF at the level of long-distance services, the competitive awarding of system train path bundles as Public Service Obligations is proposed. System train paths need to be designed by the infrastructure manager beforehand according to the target timetable and the infrastructure parameters. The design and competitive tendering of system train path bundles is done preferably by a public transport authority. Further train slots for self-sustaining services which do not interfere with system train paths may be allocated by the infrastructure manager (Figure 7.1).

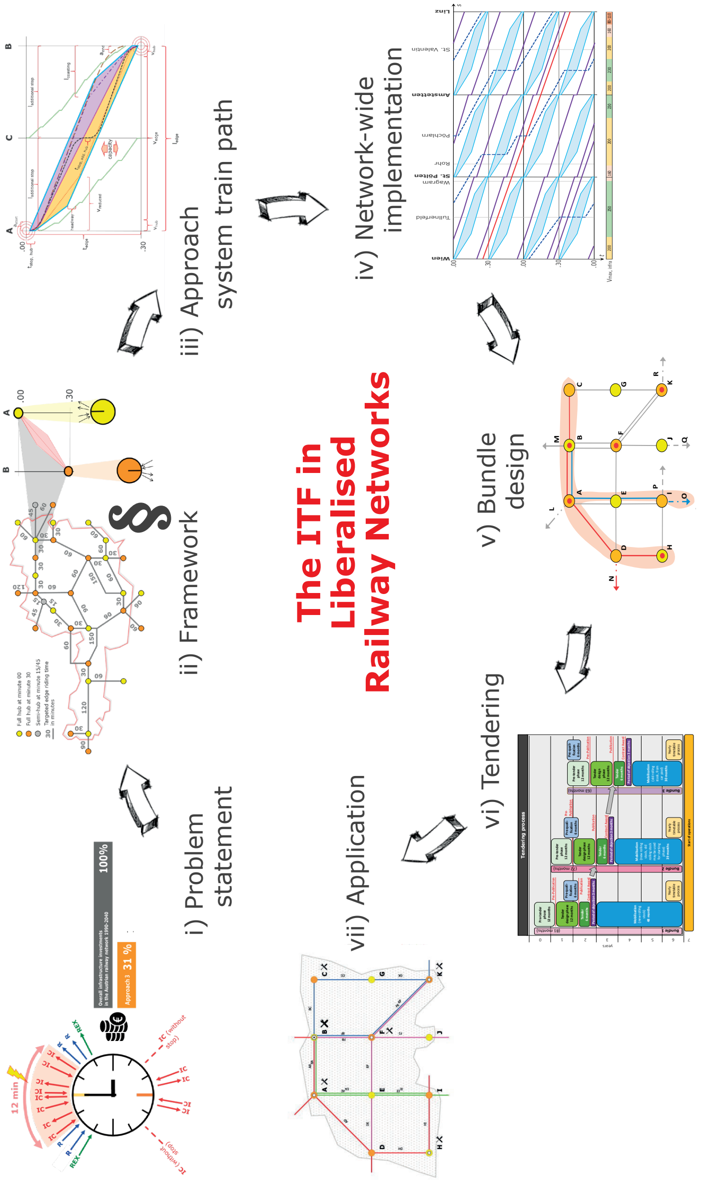


Figure 7.1: Overview of the approach for system train path bundles

This scheme guarantees an optimal network-wide implementation of the ITF according to the framework of the EU legislation. It allows for a high network-wide customer benefit and an efficient utilisation of infrastructure that is aligned to the ITF. Competition, if regulated and coordinated with long-term timetabling and infrastructure development, is beneficial for customers by increasing the number and quality of services as well as lowering ticket prices.

Innovation

The concept of system train paths has not been used for network-wide timetabling in a liberalised railway market in the European Union so far. The applied approach fulfils the requirements of the ITF and is flexible enough to reflect the vehicle characteristics of different railway undertakings. The procedure shows how an ITF and self-sustaining services can be implemented in accordance with EU legislation. This non-discriminatory approach enables infrastructure managers to effectively utilise the cost-intensive infrastructure. Long-term strategic infrastructure development and efficient ITF timetabling is supported.

Competitive network-wide tenders have scarcely been used so far in the long-distance passenger railway market in Europe. The methodology of using a PSO tendering of system train path bundles will allow new market entrants to gain attractive market shares. Niche segments will be open for self-sustaining services. This methodology is of special interest to policy-makers, as infrastructure development costs billions of taxpayer money, especially in countries which align their railway network according to the requirements of an ITF. Customers benefit from systematic timetables with clear structures and smooth network transfers. Self-sustaining services remain possible as long as they do not conflict with system train paths.

7.2 Suggested Procedure

Law

A logic is derived on how PSO tendering of system train path bundles can be implemented in accordance with the current EU legislation. With a minor adjustment of the allocation criteria in the network statement (SNNB) of ÖBB-Infrastruktur AG, the prioritised allocation of system train paths can be ensured, with reference to the constraints of the ITF:

- Firstly, STPs will allow the ITF to be implemented in the best possible way and thus ensure that the infrastructure which is aligned to the ITF is used effectively. The importance of the ITF and the corresponding infrastructure development is clearly emphasised in both the SNNB (chapter 4.4.1.2) and the EisbG (§ 55a Abs. 2). From this alone, a significant constraint can be derived to consider STPs before other train path requests.

- Secondly, it is advisable to award STP bundles in the form of a competitive PSO tender, where every licensed RU is free to apply. If the winner of a competitive tendered STP bundle requests the respective STP, a non-discriminating allocation in accordance with the principle of equal treatment is guaranteed. The winner of the tender is contractually required to order STPs, which further strengthens the argument of the ITF being a constraint for the train path request.
- Thirdly, PSO services are already to be given preference in the allocation of train paths.

System Train Path Definition

A parallelogram-shape of system train paths guarantees transfers in the hubs and offers a certain flexibility to railway undertakings in designing their individual timetable in detail. The system train path can be defined by applying a standard form (Figure 7.2) or by calculating relevant train paths or so-called riding profiles as upper and lower limit.

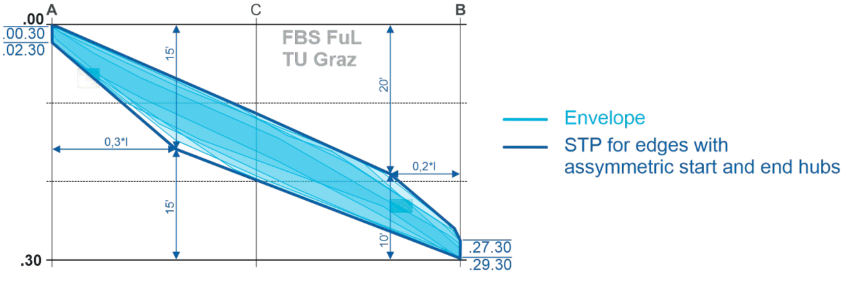


Figure 7.2: Standard form of the system train path

The practical suitability of system train paths can be proven by means of application on several edges in the Austrian long-distance railway network. Compared to current timetables the capacity of lines is not reduced by system train paths. Individually designed train paths for self-sustaining passenger services as well as regional and freight services are allocated as far as they do not interfere with system train paths.

System Train Path Bundles

The competitive tendering of system train path bundles as PSO ensures equal treatment of RUs and at the same time creates the basis for prioritisation in train path allocation. An eight-step procedure was developed for forming lines and bundles in an ITF railway network. The steps considered and their sequence are shown in Table 7.1.

Table 7.1: Procedure for defining system train paths

	Transport Planning	Demand Modelling	Railway Operation
Step 0 Service intention	Timetable concept; Network layout; Line concepts; Service availability		Quality of railway operation
Step 1 Line length and size of bundles	Line length and size of bundles		
Step 2 International connections	International connections		
Step 3 Passenger flow		Passenger flow; Minimum travel time	
Step 4 Direct connections		Direct connections	
Step 5 Bundle forming	Risk management; Homogenous geographic markets		
Step 6 Passenger amount		Passenger amount	Homogenous vehicle capacity; Moderate vehicle utilisation
Step 7 Service facilities			Service facilities; Light and heavy maintenance
Step 8 Vehicle circulation			Vehicle circulation; Cost efficient operation
Post tender award			Stopping pattern

The procedure for the formation of system train path bundles was applied in a model network showing plausible results, which were confirmed by a sensitivity analysis.

Administration
System train paths will be designed network-wide by infrastructure managers. An independent railway agency designs lines and bundles with these system train paths. The system train path bundles are then tendered by the Public Transport Authority. A timeframe of four to six years is suggested for the process of competitive tendering.

7.3 Outlook

This doctoral thesis describes the current status of railway competition in 2021. Beside the unforeseeable consequences of the Covid-19 pandemic on the public transport sector, the pressure for more competition and more self-sustaining operators are expected to make the content of this thesis even more relevant. Therefore, it would be worthwhile to do further research that in this paper could not be focused on, at least not in sufficient depth.

Further Developments and Relevance
Due to climate initiatives and ongoing infrastructure development resulting in shorter travel times and more capacity on many routes, the demand for railway services will most probably increase. This will bring new competitors into the market and make further routes relevant to self-sustaining services.

System train paths will gain more and more relevance in long-term (ITF) timetabling as uncoordinated train path requests are difficult to manage in highly frequented railway networks. System train paths are already used for passenger services in Switzerland and freight services in Germany. It is expected that further infrastructure managers will follow this example.

Competitive tendering will be mandatory as of 2023 for most railway services according to Regulation 2338/2016/EU. Therefore procedures for tendering PSO-services will become more and more relevant.

Further Research
Since this thesis was not written by an expert in legal questions, it might be worthwhile to have the **legal issues** examined in detail by a lawyer.

System train paths have been investigated on the assumption of single train paths in the interval of half an hour or one hour. The case of **parallel system train paths** running a few minutes after each other, which may occur in highly frequented hubs, should be investigated further.

The application of the suggested bundle forming procedure could be done more user-friendly by integrating the methodology in a **software**. While some steps undoubtedly require expert knowledge, some steps could be automatised and processing could be accelerated.

By applying the model to **real-world networks** the methodology could be proven and parameters verified. This would make it possible to improve the procedure.

As the tender of railway services will gain more importance in the upcoming years an in-depth analysis of past and on-going **tender procedures** would be useful. This could help to develop the suggested sequence and relevant process of tendering even further.

Ticket and tariff integration are highly relevant topics independent from the chosen from of competition or tendering. Further analyses should be done on the topics raised regarding **ticket integration** and **revenue and risk management**.

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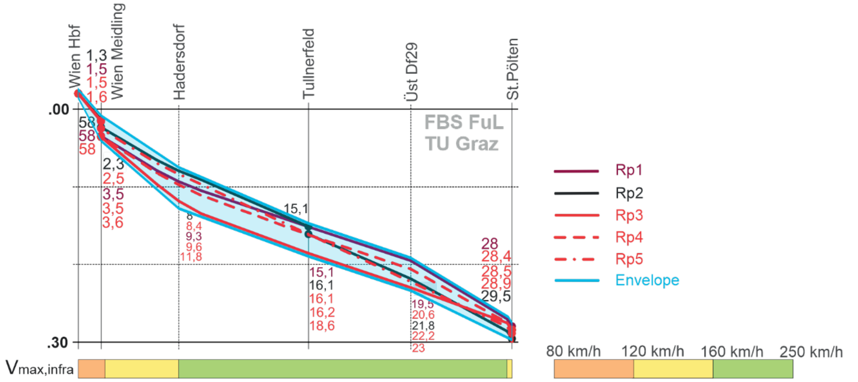
System Train Paths – Western Line

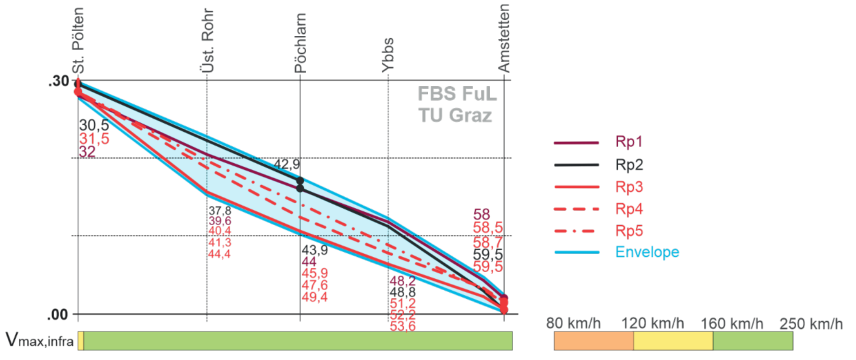
Wien –St. Pölten



Riding profile	Rolling stock	Signature	$V_{max, vehicle}$ [km/h]	reduced $V_{max, infra}$ in certain sections [km/h]	Recovery time	Coasting	Buffer time [min]
Rp1	Loco and waggon	▬▬ (purple solid)	230	-	10%	yes	3.2
Rp2	EMU I	▬▬ (black solid)	200	-	10%	yes	1.9
Rp3	EMU IIa	▬▬ (red solid)	230	100 (Wien Hbf – Hadersdorf)	10%	yes	0.0
Rp4	EMU IIb	▬ ▬ (red dashed)	230	140 (Wien Hbf –Tullnerfeld)	10%	yes	2.4
Rp5	EMU IIc	▬ · · (red dash-dot)	230	160 (Wien Hbf – St. Pölten)	7%	no	0.0

Annex 1: STP edge Wien Hbf – St. Pölten

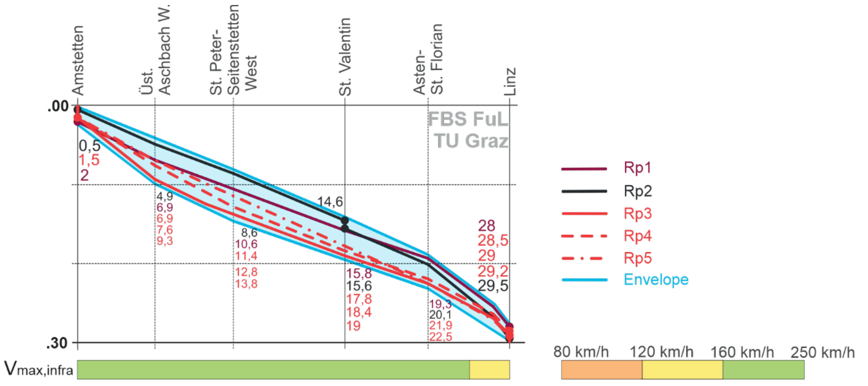
St. Pölten – Amstetten



Riding profile	Rolling stock	Signature	$V_{max, vehicle}$ [km/h]	reduced $V_{max, infra}$ in certain sections [km/h]	Recovery time	Coasting	Buffer time [min]
Rp1	Loco and waggon	solid purple line	230	-	10%	yes	4.1
Rp2	EMU I	solid black line	200	-	10%	yes	4.5
Rp3	EMU IIa	solid red line	230	100 (St. Pölten – Überleitstelle Rohr)	10%	no	0.0
Rp4	EMU IIb	dashed red line	230	140 (St. Pölten – Pöchlarnf)	10%	yes	0.3
Rp5	EMU IIc	dash-dot red line	230	160 (St. Pölten – Amstetten)	10%	no	0.0

Annex 2: STP edge St. Pölten – Amstetten

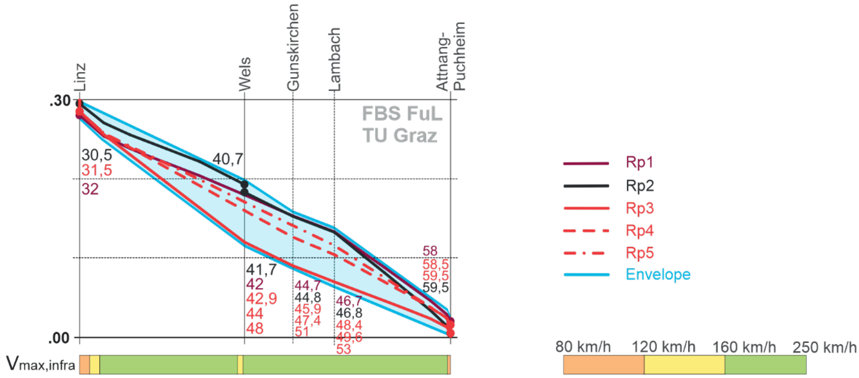
Amstetten – Linz



Riding profile	Rolling stock	Signature	$V_{max, vehicle}$ [km/h]	reduced $V_{max, infra}$ in certain sections [km/h]	Recovery time	Coasting	Buffer time [min]
Rp1	Loco and waggon	(solid purple line)	230	-	10%	yes	2.2
Rp2	EMU I	(solid black line)	200	-	10%	yes	2.8
Rp3	EMU IIa	(solid red line)	230	100 (Amstetten – Üst. Aschbach W.)	10%	no	0.0
Rp4	EMU IIb	(dashed red line)	230	140 (St. Pölten – St. Valentin)	10%	yes	0.1
Rp5	EMU IIc	(dash-dot red line)	230	160 (St. Pölten – Linz)	7%	no	0.0

Annex 3: STP edge Amstetten – Linz

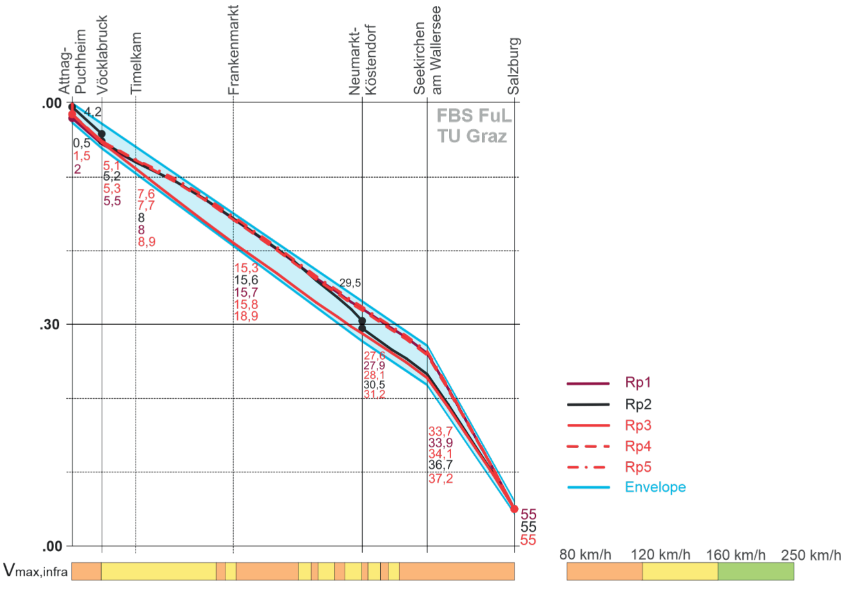
Linz – Attnang-Puchheim



Riding profile	Rolling stock	Signature	$V_{max,\ vehicle}$ [km/h]	reduced $V_{max,\ infra}$ in certain sections [km/h]	Recovery time	Coasting	Buffer time [min]
Rp1	Loco and waggon		230	-	10%	yes	4.9
Rp2	EMU I		200	-	10%	yes	6.3
Rp3	EMU IIa		230	100 (Linz – Wels)	10%	no	0.0
Rp4	EMU IIb		230	140 (Linz – Gunskirchen)	10%	yes	2.4
Rp5	EMU IIc		230	160 (Linz – Attnang-Puchheim)	10%	yes	2.4

Annex 4: STP edge Linz – Attnang-Puchheim

Attnang-Puchheim – Salzburg

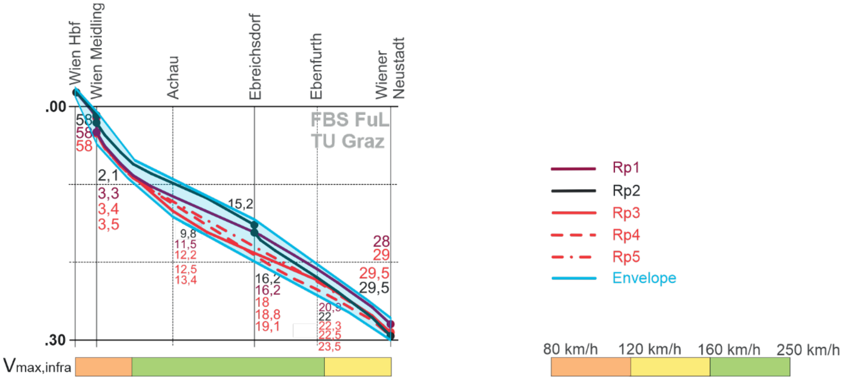


Riding profile	Rolling stock	Signature	$V_{max, vehicle}$ [km/h]	reduced $V_{max, infra}$ in certain sections [km/h]	Recovery time	Coasting	Buffer time [min]
Rp1	Loco and waggon	———	230	-	10%	yes	11.5
Rp2	EMU I	———	200	-	10%	yes	8.6
Rp3	EMU IIa	———	230	100 (Attnang-Puchheim – Frankenmarkt)	10%	yes	8.1
Rp4	EMU IIb	– –	230	140 (Attnang-Puchheim – Neumarkt-Köstendorf)	10%	yes	11.2
Rp5	EMU IIc	– · –	230	160 (Attnang-Puchheim – Salzburg)	10%	yes	11.7

Annex 5: STP edge Attnang-Puchheim – Salzburg

System Train Paths – Southern Line

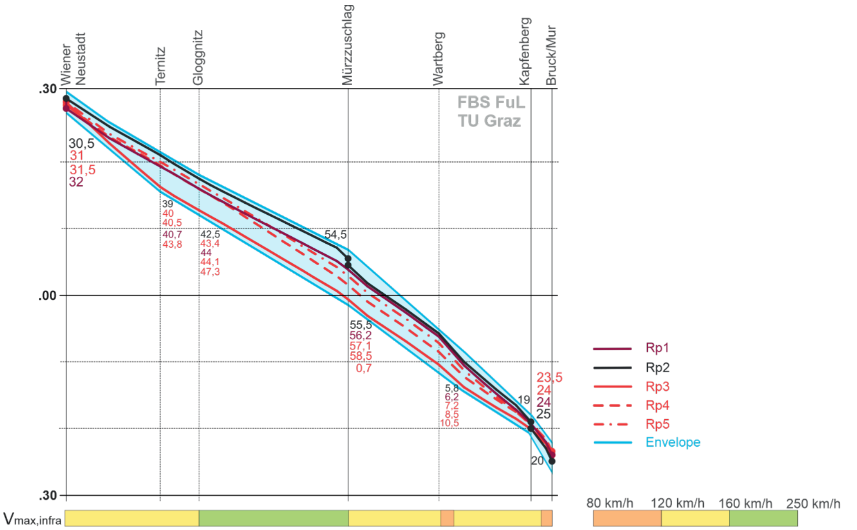
Wien – Wiener Neustadt



Riding profile	Rolling stock	Signature	$V_{max,\ vehicle}$ [km/h]	reduced $V_{max,\ infra}$ in certain sections [km/h]	Recovery time	Coasting	Buffer time [min]
Rp1	Loco and waggon	solid line	230	-	10%	yes	2.6
Rp2	EMU I	solid line	200	-	10%	yes	3.2
Rp3	EMU IIa	solid line	230	100 (Wien Hbf – Achau)	10%	yes	0.7
Rp4	EMU IIb	dashed line	230	140 (Wien Hbf – Ebreichsdorf)	10%	yes	0.2
Rp5	EMU IIc	dash-dot line	230	160 (Wien Hbf – Wiener Neustadt)	10%	yes	0.7

Annex 6: STP edge Wien Hbf – Wiener Neustadt

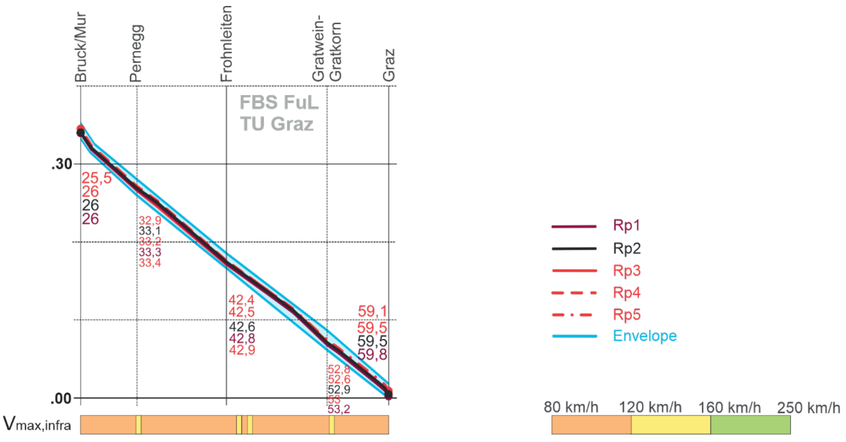
Wiener Neustadt – Bruck/Mur



Riding profile	Rolling stock	Signature	$V_{max,\ vehicle}$ [km/h]	reduced $V_{max\ ,\ infra}$ in certain sections [km/h]	Recovery time	Coasting	Buffer time [min]
Rp1	Loco and waggon		230	-	10%	yes	3.9
Rp2	EMU I		200	-	10%	yes	3.7
Rp3	EMU IIa		230	100 (Wiener Neustadt – Ternitz)	7%	no	0.0
Rp4	EMU IIb		230	140 (Wiener Neustadt – Mürz-zuschlag)	7%	yes	1.2
Rp5	EMU IIc		230	160 (Wiener Neustadt – Bruck/Mur)	10%	yes	2.9

Annex 7: STP edge Wiener Neustadt – Bruck/Mur

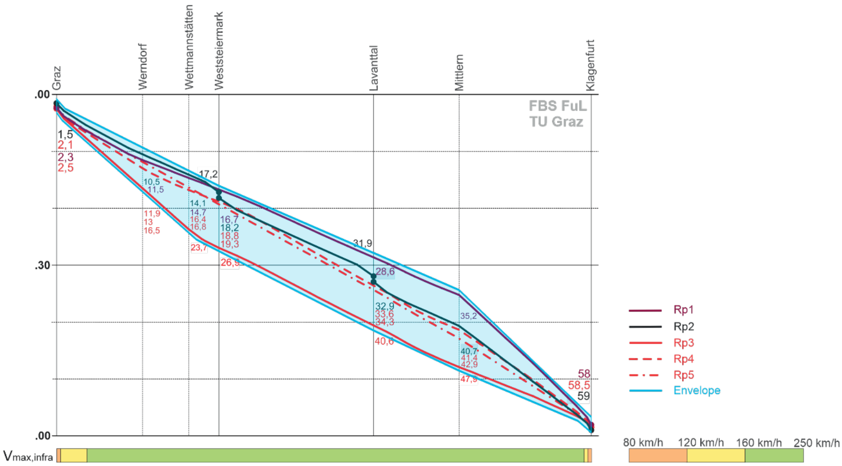
Bruck/Mur – Graz



Riding profile	Rolling stock	Signature	$V_{max,\ vehicle}$ [km/h]	reduced $V_{max\ ,\ infra}$ in certain sections [km/h]	Recovery time	Coasting	Buffer time [min]
Rp1	Loco and waggon		230	-	10%	no	0.0
Rp2	EMU I		200	-	10%	no	0.0
Rp3	EMU IIa		230	100 (Bruck/Mur – Pernegg)	7%	no	0.0
Rp4	EMU IIb		230	140 (Bruck/Mur – Graz)	10%	no	0.0
Rp5	EMU IIc		230	160 (Bruck/Mur – Graz)	7%	no	0.0

Annex 8: STP edge Bruck/Mur – Graz

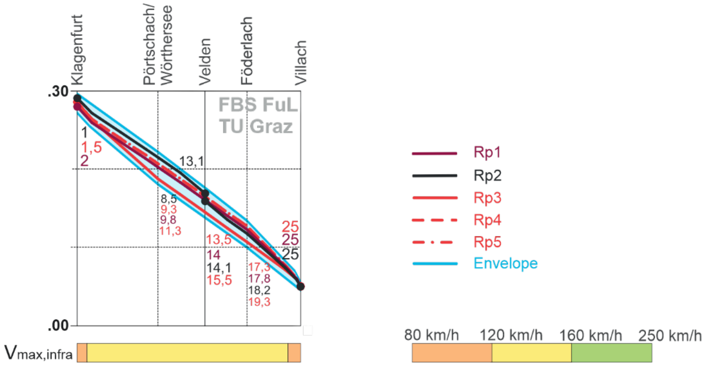
Graz – Klagenfurt



Riding profile	Rolling stock	Signature	$V_{max, vehicle}$ [km/h]	reduced $V_{max, infra}$ in certain sections [km/h]	Recovery time	Coasting	Buffer time [min]
Rp1	Loco and waggon	▬▬ (solid purple)	230	-	10%	yes	12.5
Rp2	EMU I	▬▬ (solid black)	200	-	10%	yes	7.2
Rp3	EMU IIa	▬▬ (solid red)	230	100 (Graz – Wettmannstätten)	10%	yes	0.2
Rp4	EMU IIb	▬ ▬ (dashed red)	230	140 (Graz – Werndorf)	10%	yes	6.7
Rp5	EMU IIc	▬ ▪ ▪ (dash-dot red)	230	160 (Graz – Klagenfurt)	10%	yes	2.1

Annex 9: STP edge Graz – Klagenfurt

Klagenfurt – Villach



Riding profile	Rolling stock	Signature	$V_{max, vehicle}$ [km/h]	reduced $V_{max, infra}$ in certain sections [km/h]	Recovery time	Coasting	Buffer time [min]
Rp1	Loco and waggon	▬▬ (solid purple)	230	-	10%	yes	1.8
Rp2	EMU I	▬▬ (solid black)	200	-	10%	yes	1.3
Rp3	EMU IIa	▬▬ (solid red)	230	100 (Klagenfurt – Pörtschach/Wörthersee)	10%	yes	0.2
Rp4	EMU IIb	▬ ▬ (dashed red)	230	140 (Klagenfurt – Villach)	10%	yes	2.2
Rp5	EMU IIc	▬ · · (dash-dot red)	230	160 (Klagenfurt – Villach)	10%	yes	2.2

Annex 10: Klagenfurt – Villach

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