Train Slots: A Proposal for Open Access Railways

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Abstract
This paper seeks a concept to include fixed-interval paths with manageable train slots to satisfy the flexible needs of freight traffic in a strict fixed-interval passenger timetable. The primary method is constituted by literature review and theoretical slot construction. The terms timetable and railway operation are specified and illustrated. Different levels of timetables will be discussed and further developed. Two concepts, slots and pulses, are described together with precondition and modelling to accomplish a mixed timetable level for flexible freight traffic and fixed passenger traffic. Finally, a comparison of the timetable levels with the rail freight corridor Rhine-Alpine is presented. In conclusion, three points for further research are made, and an experiment is suggested to validate the result in the future.

Keywords
railway operation, railway timetable, timetable path, timetable slot, transit layer

1 Introduction

Timetables are a vital component in satisfying transport needs in railway systems. This paper discusses timetable concepts and their dependencies on railway operation. It is part of an ongoing study about how to determine infrastructure from a given timetable. In Scheidt (2018), an approach in layers was presented to reduce the solution space for the transition between infrastructure and timetable. Two layers contain timetable information to organise traffic on the infrastructure: the transit and the transport layers. The transit layer contains the paths, and the transport layer contains the rail services that use the paths. While there is a suitable model for the transport layer, there is no viable model description for the transit layer.

The current lack of the model results from the representation of the variability of train movements in combination with the actuality of the operational disposition. The variability of train movements was the focus of several works. Pöhle (2016) points out that different interval and stopping patterns need to be taken into consideration for the operating varieties. Medeossi, Longo, and Fabris (2011) extends the standard blocking time with performance parameters to include these variations. Hertel and Steckel (1992) illustrates that these parameters also vary significantly between passenger and freight trains. Roos (2006) introduces a dispatching concept to dispatch trains through a junction. Caimi et al. (2009) shows that compensation zones can help to stabilise variations in a train movement along a line section before the train enters a junction. However, typical timetables from the field of operations research form the conditions of the railway operation inadequately. The impact on the railway operation and the ability to guide traffic flow have to be considered to develop timetable concepts further.

The conditions of railway operation include that planned train movements have different probabilities for how they occur. Passenger trains will most likely run as planned, whereas freight trains can have a shifting occurrence. The reaction from railway operation is to use dispatching extensively for freight trains while trying to enable passenger trains to be as punctual as possible. The dual nature of traffic, together with the planning of train archetypes for timetables, shape the problem set that railway operation has to overcome. This leads to the research question (Q_0): How to handle variations in the traffic mix with a timetable as a working base for railway operation?

The goal is to evaluate the impact of timetable concepts down to specific train movements on routes and tracks. Several subquestions can be formulated. The following three questions were used to guide the answer:

(Q_1) Are there different kinds of timetables, and can they be structured?

(Q_2) What is railway operation, and how does a timetable affect it?

(Q_3) What types of paths in a timetable can be used to accommodate variations?

The principal method consists of a literature review and the theoretical construction of train movements. The goal of the construction is to identify use cases for operators. These use cases have to be visualised in such a way as to improve the ability of an operator to capture the situation. A proposed timetable with new types of paths has to be able to contain the duality of the traffic without favouring one over the other.

This analysis will describe what will be necessary for such a timetable to be included in the previously mentioned layer model and to enhance planning without capacity impact on the infrastructure. The main result is a formulation for the specifications and data required for the transit layer and the impact on the transport layer. The specifications result from the connection between timetables and railway operation, and to comprehend the connection further, both terms must be specified.

This paper is structured as follows: Section 2 describes and defines the relation of railway operation and timetables. In Section 3 categories including the need for further development are concluded from current timetables and the timetable life cycle. From there, concepts for line segments (Section 4) and junctions (Section 5) are formed into a future timetable category and followed by the preconditions for such a timetable category in Section 6. Finally, an exemplary use case is indicated in Section 7; followed by the conclusion.

2 Timetable and Railway Operation

A timetable is the sum of all planned train movements. The planning of the train movements is known as scheduling and is considered a large field for operations research. Scheduling has to fulfil requirements such as synchronising between trains, preventing severe congestion including deadlocks (stability) and being without conflict (feasibility). The requirements are satisfied by the structure of the timetable. For instance, to prevent severe congestion, the allocated timetable capacity is usually less than the actual line capacity (Pachl 2018, p. 179).

The timetable presents access rights to the infrastructure by means of the timetable authority. Furthermore, it also has to provide a working base for railway operations (Pachl 2018, p. 27). Different views on the fully scheduled timetable are used to fulfil traffic demands by passengers or freight and guide the traffic flow by the operators (see Figure 1).

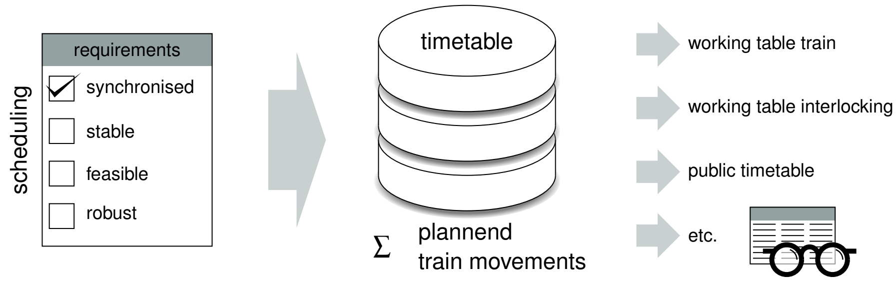


Figure 1: Requirements and views of a timetable.

The operation control of an operator is considered a part of the railway operation. Railway operation can be described as a collection of processes and functions with a focus on enabling train runs (see Figure 2). To do so, the operator observes the current operational status and places the movement requests for a train according to the dispatching rules in compliance with the timetable authority from the working timetable.

Consequently, the timetable plays an essential role in railway operation. The operator is the second tier in preventing deadlocks and coordinates the current train movements within the normal fluctuation in operation by amending the train order, if necessary. The operator can also remove the bonding between fast and slow trains by slowing down the fast one in the event of extensive disruptions and, therefore, increase the usable capacity (Pachl 2018, p. 181). He can also improve synchronisation between trains by adapting their priorities. Disruption management by the operator plays an essential part in the efficiency and effectiveness of the real-time rescheduling and in compensating the disruption. For this, the operator needs freedom of action in the timetable contributed by margins.

There are several methods to integrate margins for railway operation in a timetable. A widely adopted one is documented by the UIC in the leaflets code 406 and code 451 (UIC 2000; UIC 2004). These codes suggest adding margins to a train run for circumstances like general recovery, hub margins, or track work (see Figure 3c). The UIC codes distinguish between different types of passenger or freight traffic and different types of infrastructure. However, these codes do not consider that at the time of planning the margins, little is known about the freight traffic as opposed to the passenger traffic. Nevertheless, the very essence of competitive freight traffic is that it is flexible, it cannot be planned like passenger traffic, and it should be regarded differently in the UIC codes. Consequently, a timetable should satisfy the different environments of well-planned passenger traffic and flexible freight traffic.

In timetables, path requests are used to coordinate the use of a timetable's resources, and there are two poles of path requests on open-access railways. One pole consists of path requests with known properties that can be defined as long-term. These requests are typically for paths for passenger trains with fixed-interval timetables. The other pole consists of ad-hoc traffic in need of paths where properties are only known on short notice. These requests come mainly from freight operators, where the business model depends on flexibility. These two poles represent the contradictory nature a timetable has to overcome: to generate ad-hoc paths for short-term freight trains and still enable long-term fixed-interval paths. From the point of view of railway operation, the main challenge is to provide the opposite of a compact timetable, with ample margins for dispatching.

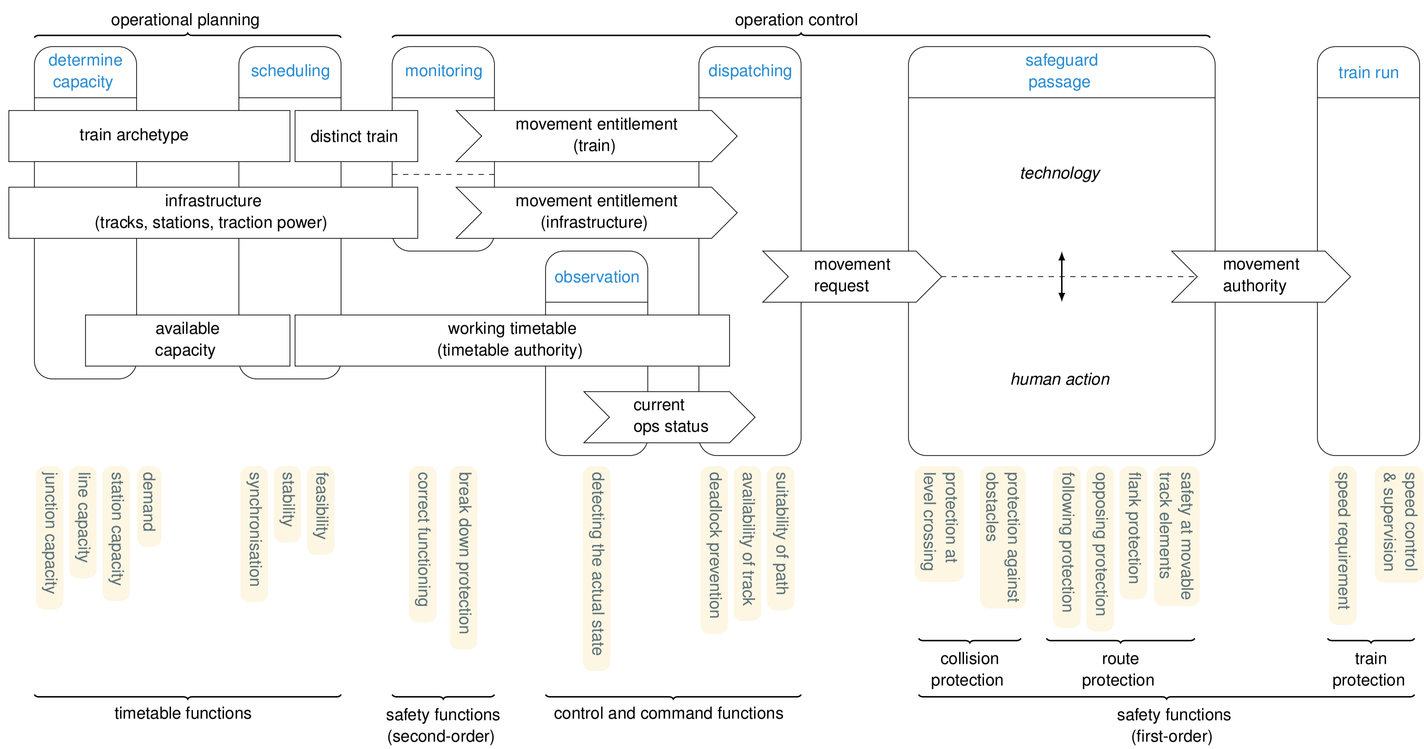
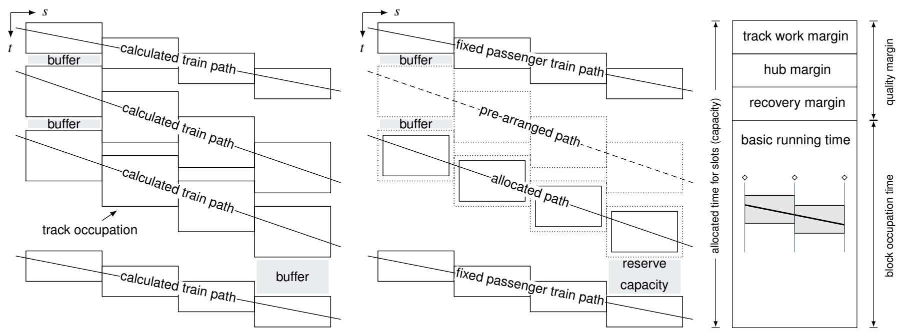


Figure 2: Process map of railway operation (Scheidt et al. 2018). Getting more specific from left (macroscopic network) to right (single train run).



(a) Level 1 timetable. (b) Level 2 timetable. (c) Timetable margins (based on UIC 2000; UIC 2004).

Figure 3: Timetable categories and margins

3 Timetable Categories

There are different timetable categories, as railway operation happens in a diverse environment which differs in requirements for the timetable. For some networks, a timetable can be optional. This form can be encountered in the tram system: A timetable still has a purpose for passengers, but it is not needed to prevent deadlocks or severe congestions. This characteristic is due to the comparatively simple network, which is usually not deadlock-prone. A timetable can be categorised into several levels to distinguish between the properties and relevance of different timetable concepts (see Figure 3). Level 0 shows the cases in which timetables are optional.

Level 1 encompasses classic timetables for railway systems (see Figure 3a). Here, the timetable helps with coordinating over an extensive network. In many cases, a timetable may also serve essential safety functions. This type of timetable consists of individual calculated paths. If there are temporary restrictions on the network, paths may require reconstruction. Such Level 1 timetables have existed in Europe for decades and come with a mutually agreed life cycle (RNE 2014). In a Level 1 timetable, all calculated paths have to be included in the scheduling phase, which is closed before a yearly timetable takes over and ends with the timetable handover. This procedure favours the long-term planning of paths and does not favour short-term path requests.

In Level 2, European Union legislation enforced a regulation to overcome favouritism (EU 2010). Here, a timetable consists of common calculated paths for long-term traffic and particular pre-arranged paths for likely traffic (see Figure 3b). The timetable life cycle is amended and includes regular path requests, which have to be made at least eight months in advance of the timetable period. The ad-hoc request phase starts two months before a yearly timetable takes over and ends with the timetable handover (see Figure 4). The timetable also includes reserve capacity to further enable ad-hoc traffic. The organisational structure to manage path request and methods for scheduling can be inherited from Level 1. The operation of such a Level 2 timetable raises questions about how to cope with used or unused paths for operators. Operators have to identify reserve capacity that will not be used for

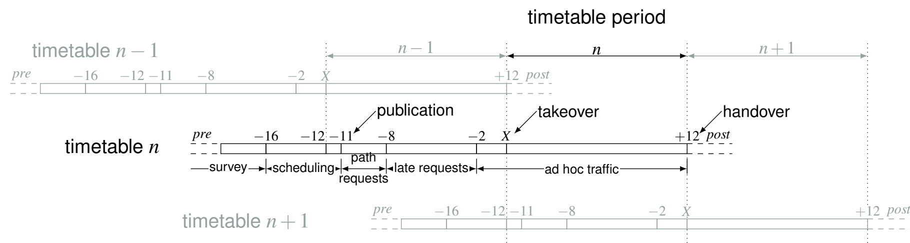


Figure 4: Timetable life cycle (based on RNE 2014).

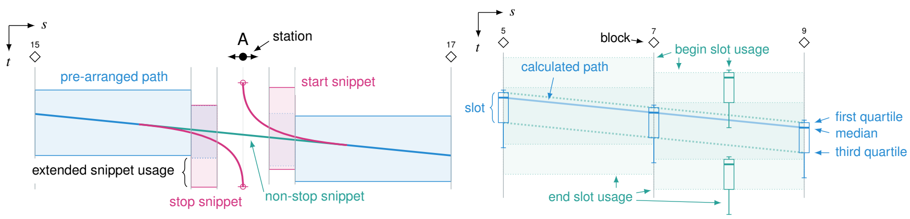
ad-hoc traffic so they can use it for dispatching. They could have to identify trains running with the same train number but different destinations or vice versa.

Currently, the answer to the question mentioned above is to project the Level 2 timetable to a Level 1 timetable in small time slices since most of the railway operation management systems predate the EU legislation. However, if the Level 2 timetable, as a working basis for railway operation, can provide information about the actual use of pre-arranged paths and reserve capacity, there could be the aptitude to predict and reduce route conflicts. This provided information could have an impact on train priorities, dispatching rules, and real-time rescheduling, disturbance, and disruption management.

4 Line Section Slots

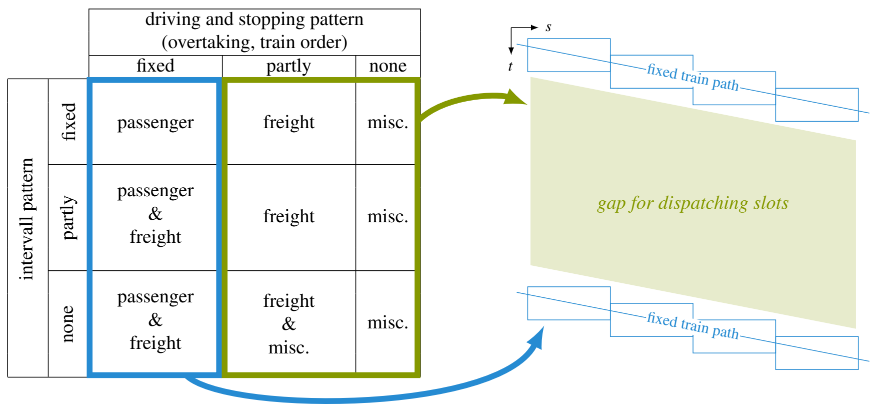
The Level 2 timetable has to work with a train archetype since little is known about the trains during the scheduling phase in the timetable lifecycle (Weigand and Heppe 2013, p. 460). These train archetypes could be depicted as cohorts composed of actuals trains from the past. There will be regional differences, and, therefore, the cohorts are best collected subsidiarily. However, cohorts can be an access impediment and will, therefore, need a legal structure to ensure neutrality between infrastructure managers and railway undertakers. Performance parameters can be used to retain the cohorts (Medeossi, Longo, and Fabris 2011). Boxplots can be used to simplify handling in railway operation. The 50% (median) and the 80% (third) quantiles have proven to be useful for representing a time slot for a pre-arranged path (Schittenhelm and Richter 2009, p. 12). There will be different needs for quantiles depending on the archetype train. To distinguish between a regular pre-arranged path and a pre-arranged path with quantiles, here, the terms train slot or slot is used (see Figure 5b).

Pöhle (2016, p. 68) shows that different intervals and stopping patterns need to be considered for railway operation, and these two patterns can be attributed again into fixed, partly fixed, and non-existing patterns. Although this leads to nine types of path classifications (see Figure 6a), two concepts can be used to accommodate them: classical fixed train paths and slots. The fixed train paths create a gap in a timetable, which can be used to arrange slots. Instead of filling the gap between the fixed train paths with pre-arranged paths, the gap can be kept open for dispatching and preferably provide further information for the operator regarding how to use the gap efficiently. The concept of a dispatching gap, together with railway operation management for slots, is an advancement to a Level 3 timetable (see Figure 6b). Other concepts for arranging and allocating these slots are needed to take full advantage of slots within the free capacity.



(a) Pre-arranged path with snippets at a station. (b) Slot, calculated path, and boxplot.

Figure 5: Slots and snippets.



(a) Classifications of paths for central Europe. (b) Level 3 timetable.

Figure 6: Paths classifications and their accommodation in a Level 3 timetable.

The concepts required for arranging and allocating slots are:

1. Slot parameters for train archetypes to fit distinct trains.
2. A slot must fit several train run events, like acceleration, deceleration, and non-stop train run.
3. Dispatching rules for train archetypes to grant and organise timetable authority.
4. Differences between lines and junctions for the arrangement of slots.
5. Dispatching rules for traffic jams and matching distinct trains to their train archetypes.

A solution to the obstacle to fitting several train run events (like acceleration, braking, and non-stop drive through stations) into slots has been presented by Pöhle (2016, p. 68). He describes the solution as snippets, where each snippet represents one possible train run event (see Figure 5a). Snippets will increase the blocking time usage compared to a non-stop train run. The increase should not impede the recommendation from UIC code 406 that it is not to exceed more than 60% to 85% for occupation time against a time window (UIC 2004, p. 19). The extended blocking time usage by snippets, together with the cohorts of the slots, could be seen as a kind of buffer time under the UIC code 406.

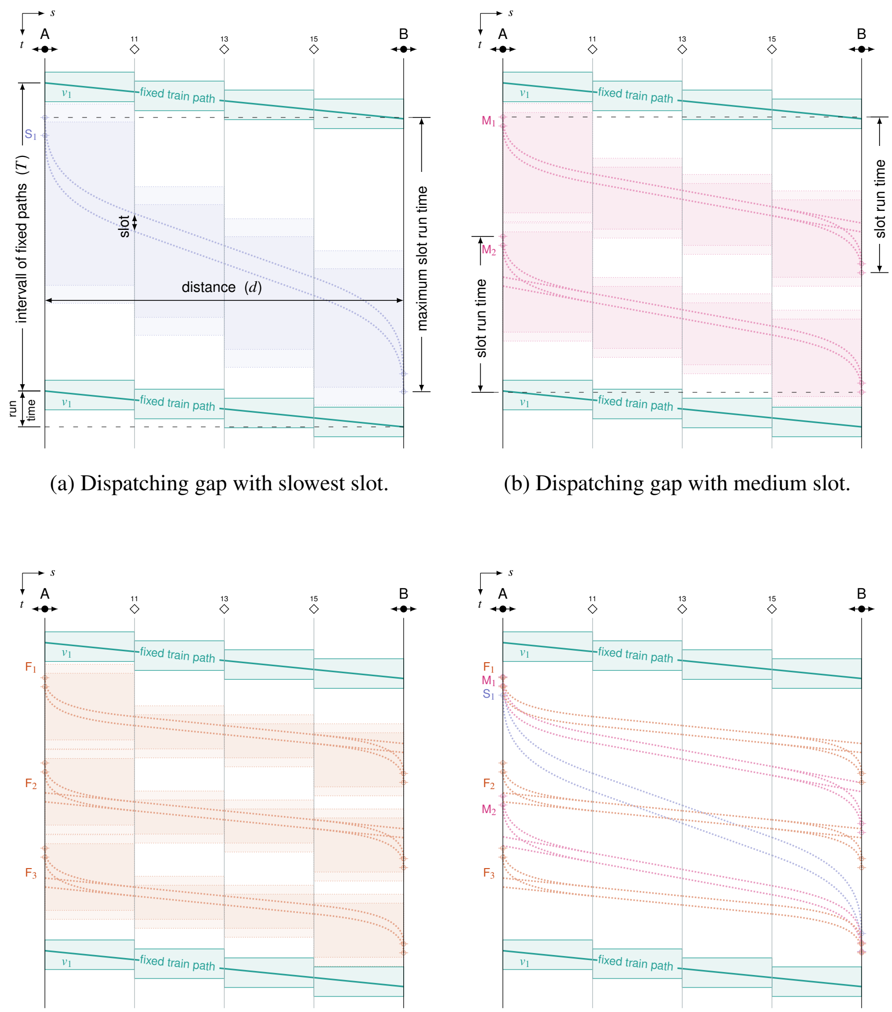
The utilisation of the dispatching gap depends on various factors, such as the snippets, the distance between two stations, the interval between two fixed paths, the slot cohorts, and the run time of the slot (see Figure 7a). The snippets can be used to include different slots with a different driving regime into the dispatching gap. A fast train can vacate the second station early, which permits a second or a third train with the same properties to pass through the line (see Figure 7b and 7c). Slots are supposed to overlap and include a mechanism for preclusion through dispatching rules to utilise the dispatching gap fully. For example, the preclusion mechanism will disable the medium and fast slot if the slow one is used; however, it could permit a combination of a medium and a fast slot (see Figure 7).

It is necessary to consider different numbers of slots for different traffic times during a day in railway operation and hence alter the dispatching gap. Traffic schemes can be used to control the number of available slots per scheme by adapting the size of the dispatching gap and, therefore, be suitable for an adaptable number of fixed train paths. The number of fixed train paths can be increased or decreased for peak traffic times since the passenger traffic usually follows a characteristic pattern (see Figure 8). Similar kinds of traffic schemes can also be implemented for temporal restrictions to automate timetable generation in cases of track work or incidents where the capacity must be restricted, assuming alternative lines with spare capacity.

5 Junction Pulses

Infrastructure limitations have to be considered to utilise the dispatching gap further. For the utilisation, dispatching rules must differentiate between line sections and junctions. Line sections are parts of a network where trains cannot change their order, and signalling is merely used for spacing the trains (i.e., block signals). Junctions are parts of the network where turnouts require interlocking systems with routes. A junction usually stretches from a route signal to the route clearing points. If the junction is signalled bidirectional, the junction can be extended between the opposing route signals for easy recognition. The junction may be called interlocking limit in conformity to North American railway operation rules. The reason to differentiate between line sections and junctions is due to the different properties and restraints in railway operation. A line section can be viewed as a queue that can be used by trains in accordance to blocking time theory, and the trains will only interact with trains on the same line sections in sequence. Junctions, on the other hand, introduce restrictions not only on the sequence of trains but also on the simultaneity of trains in multiple line sections. Consequently, a network with stations and lines can be fragmented into junctions and line sections (see Figure 9a and 9b). Furthermore, a network can be modelled for dispatching rules and a Level 3 timetable into a timetable network equivalent (see Figure 9c).

Line sections can be accommodated with slots. However, bare slots will only partially work for junctions, since slots only account for sequences. Slots have to be supplemented to consider simultanous restraints of junctions during railway operation. Railway operation restraints for junctions are similar to an interlocking matrix (see top of Figure 10a). Two opposing trains will cause railway operation states of restriction on each train: wait/release, pull-in/pull-out, counter movement, and route crossing. The wait/release restriction forces



(a) Dispatching gap with slowest slot.

(b) Dispatching gap with medium slot.

(c) Dispatching gap with fastest slot.

(d) Preclusion for different slots by dispatching.

Figure 7: Utilisation of dispatching gap with slots.

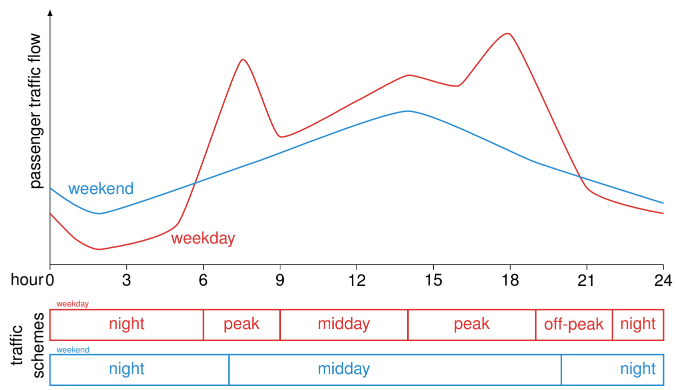


Figure 8: Traffic times and schemes in relation to the traffic flow for a timetable (fictitious).

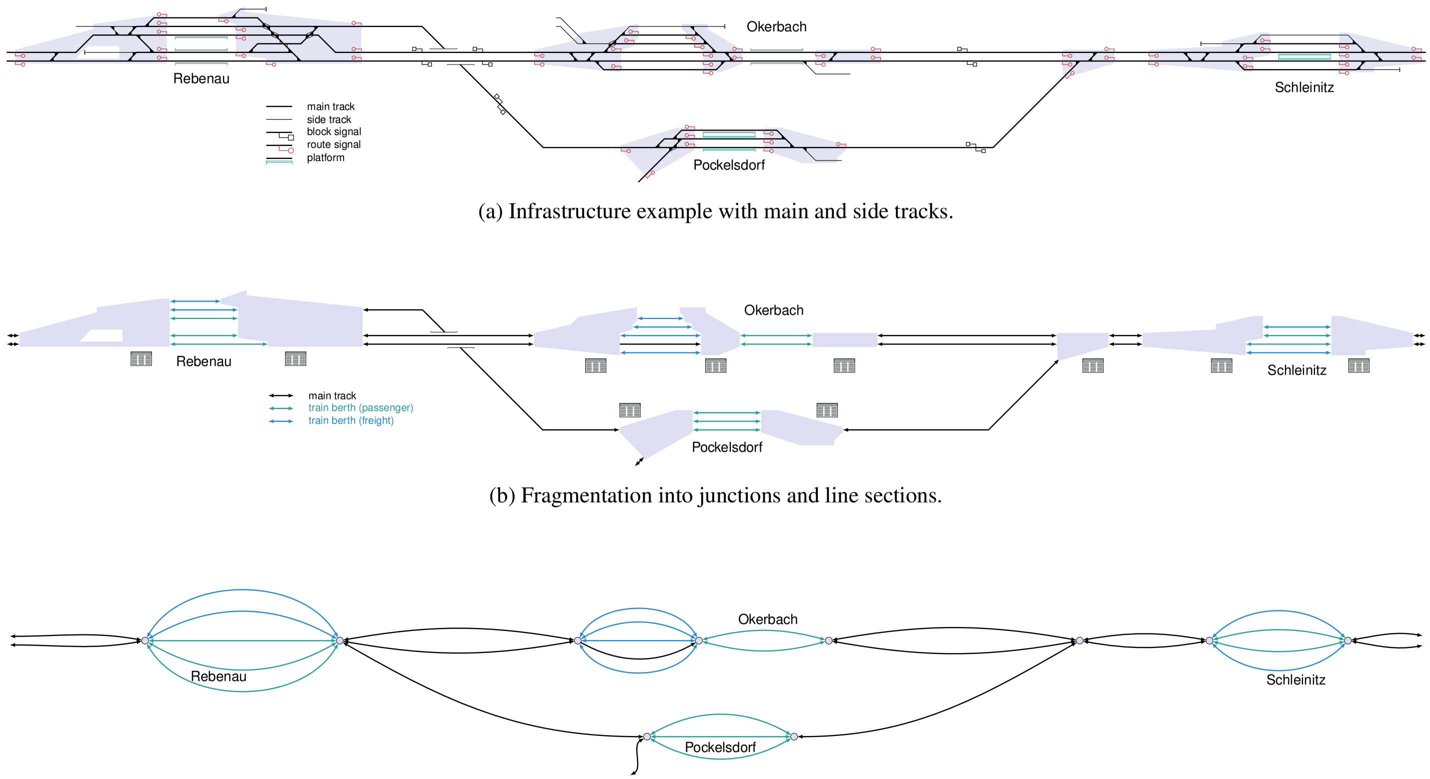
one train to wait until the other has released a track. Compared to an interlocking matrix, the railway operation restraint matrix will not be symmetric with the wait/release restriction. The pull-in restriction terms the dependency of trains if they share the same path after a turnout. The pull-out restriction applies if the trains separate their path. The combination of pull-out and pull-in restrictions at two succeeding junctions could lead to an overtaking manoeuvre. The counter movement restriction is the preliminary stage of a deadlock and has to be avoided. The involved trains for the route-crossing restriction have to be coordinated to not occur at the same time.

A junction can be parted into discrete time tranches to simplify the solution set for the coordination of the restrictions. Roos (2006) introduces the concept of pulses laid upon the junction, and describes pulses as a form of screening regarding possible train runs to reduce the solution set for the scheduling process. The achievement is a smaller solution set for regularly running trains through the junction with pulses. These pulses can be used to match trains quickly and patch them through a junction without, or with limited, conflicts with other trains. Pulses enable a relatively clear possibility for arranging slots. The combination of the railway operation restriction matrix, together with slots in pulses, resemble a possible way to provide tools for dispatching and scheduling for a Level 3 timetable for junctions.

There are two kinds of pulses: common and concurrent (see Figure 10). The mutual exclusion characterises common pulses: only one train can use one pulse. Concurrent pulses can enable more than one train run depending on the railway operation restriction matrix. Figure 10b shows such concurrent pulses: trains 2–5 and 4–1 can run simultaneously while train 3–4 has to wait for the next pulse. Routes via the diverging track of a turnout usually run at a lower speed; therefore, train run 3–4 needs a little more time than the slot envisaged but stays within the limit of the slot.

6 Level 3 Timetable Preconditions

Trains will have to stay as punctual as possible to concatenate slots from line sections and pulses from junctions. Compensation zones could be included in the line sections to add further margins and ensure punctuality. Compensation zones add flexibility of the speed profile in line sections to ensure punctuality at condensation zones like junctions (Caimi et al.

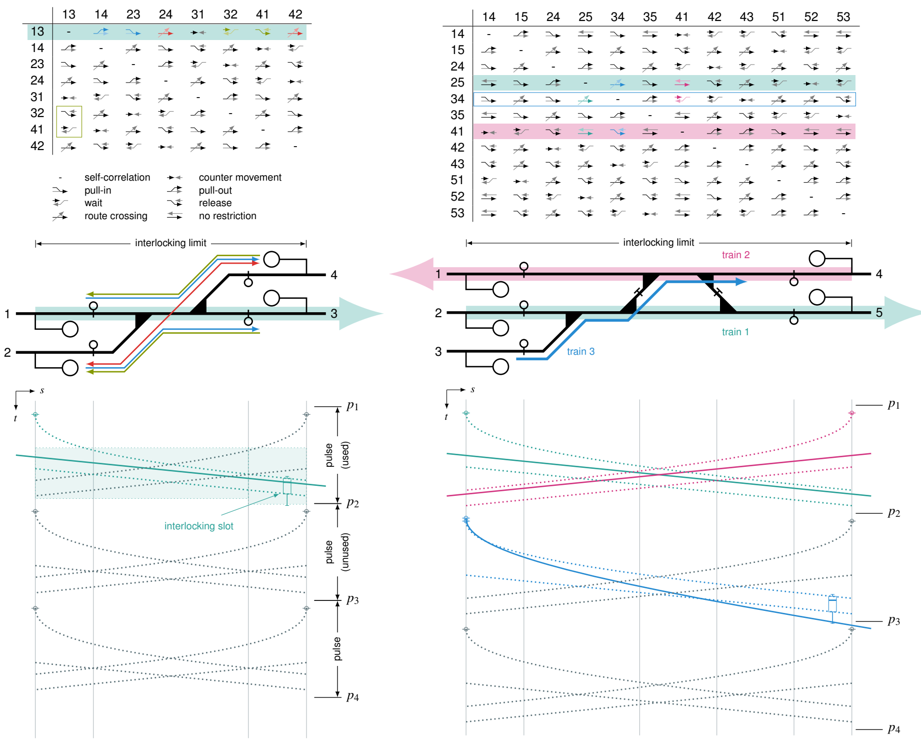


(a) Infrastructure example with main and side tracks.

(b) Fragmentation into junctions and line sections.

(c) Timetable network equivalent.

Figure 9: Example for fragmentation of lines with/without platforms, junction with turnouts.



(a) Common interlocking pulses. (b) Concurrent interlocking pulses.

Figure 10: Pulses at interlocking limits with slots.

2009). Compensation zones will work under the assumption that a train is fitting a slot but still needs a greater degree of freedom for driving.

If a train does not match the properties of a slot, an operator will require means to ensure the quality of a timetable. These means could be to reallocate the train to a different slot type or to demand a change of the train properties, for instance, an additional power unit or a split of the train. Track facilities are required to change the train properties. Facilities for railway operation to react to the current operational status is one of the preconditions for a functioning Level 3 timetable. Other preconditions are:

1. not all slots can be booked to have spare capacity available following UIC code 406; therefore, capacity management for selling rights of usage is required;

2. availability of train berths in front of condensation zones or other bottlenecks (infrastructure for queuing at erratic network parts);

3. sidings or other facilities as a waiting area in order to use the next suitable or the booked slot;

4. alternative lines with spare capacity as a bypass;

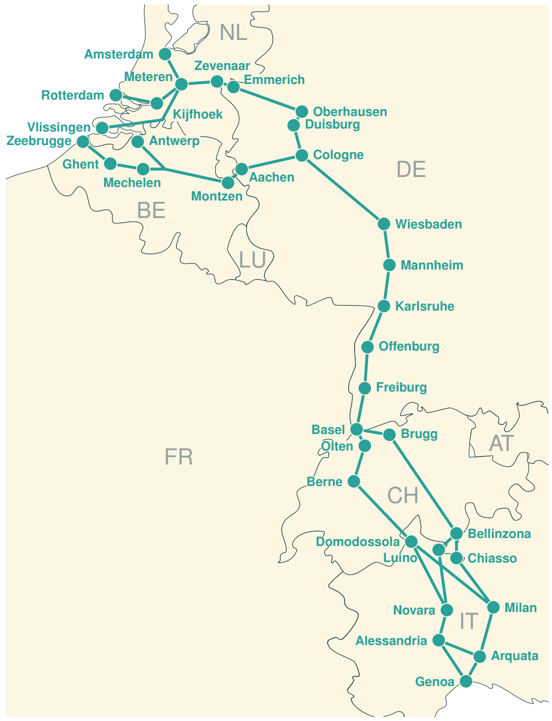


Figure 11: Rail freight corridor Rhine-Alpine.

5. a feedback system for overcrowded lines to modify the future timetable or induce infrastructure enhancements;
6. information management regarding reservation information for actual usage of slots and a dispatching handling system of allocated slots.

Slots, pulses, dispatching gaps and traffic schemes can be integrated into the timetable life cycle currently endorsed by RNE (2014) with these preconditions.

7 Example Corridor Rhine-Alpine

Rail freight corridor Rhine-Alpine (RFC-RA) was created to achieve the goals of the EU 2010. The RFC-RA represents the idea of Level 2 timetable and can hold as an example for the timetable categories from Level 1 to Level 3. The RFC-RA covers railway operation from the Netherlands, Belgium, Germany, Switzerland and Italy (see Figure 11). Their primary purpose is to provide a one-stop shop for path requests for freight trains crossing at least one border along the corridor. They use a path coordination system to manage and allocate path requests for pre-arranged paths and reserve capacity (RFC-RA 2018a).

The path requests for pre-arranged paths have to be submitted at least two months before the start of the timetable period to follow the timetable's life cycle (see Figure 4). After two months, the reserve capacity will be used for the path requests. The objective of the RFC-RA could be achieved with a Level 1 timetable, but this would mean higher organisational expenses for those railway undertakings using the corridor to book their paths ahead of time. Slots, on the other hand, would mean no difference between path requests for pre-arranged paths and path requests for reserve capacity. The fact that there is a difference can be illustrated by network conditions: if a freight train wants to leave Rotterdam in the direction of the German border, it will get a suitable path for the Betuweroute relatively quickly since it is the only freight route in a homogenous traffic mix. If the same freight train wants to leave Mannheim in any direction, it will matter whether the train has a path or will use reserve capacity because the train will have to share the frequently used network with competing trains in a diverse traffic mix.

The RFC-RA uses data collection from railway undertakings in the last timetable period to form a train archetype. The data collection is done via a spreadsheet called ”Expression of Needs” and takes parameters from reference-rolling stock (see RFC-RA 2018b). With the reference-rolling stock, the RFC-RA constructs or allows the construction of parts of pre-arranged paths along the corridor. Data management for trains from the past and procedures for forming cohorts need to be enhanced to further develop the formation of train archetypes for automation and building slots for the corridor.

As shown in section 2, the slots or pre-arranged paths have an impact on railway operation. Therefore, feedback is needed on which path is booked and which is freely available for dispatching. Different infrastructure managers do the railway operation of the RFC-RA in each country, and the booking of the paths are made via the Path Coordination System of RailNetEurope. If the path request is issued in a timely matter (see Figure 4), the railway operation for these paths can be based on the actual usage. However, there are many parties and management systems in various stages involved and, therefore, the consistency and availability of timetable data for the operator can be further improved to gain benefits in dispatching.

Alternative lines are essential for dispatching and slot in a Level 3 timetable. Consequently, the construction or expansion for a second line between Cologne and Basel was created, as the need for alternative lines was recognised for the RFC-RA (see Figure 11). The importance was even further stressed at the collapse of a tunnel during construction in Rastatt (between Karlsruhe and Offenburg) in August 2017. The collapse disrupted the corridor and alternative lines where not suitably equipped to absorb the resulting detour traffic.

8 Conclusion and Further Research

In summary, properties and concepts of timetables can be arranged in levels. This paper proposes timetable levels from 0 to 3, where Level 3 is an advancement to integrate the ad-hoc paths for short-term freight trains. The integration is devised by introducing a dispatching gap between long-term, fixed-interval paths. The dispatching gap needs to be managed and blended into the railway operation to enable the benefit of flexibility for freight trains. For junctions and line sections, different approaches must be used to utilise the dispatching gap. Slots can be used for the line sections and pulses can be used for junctions. Railway operational restrictions at junctions can be stated as a restriction matrix.

Encapsulating infrastructure restraints for railway operation, together with a timetable level with flexible slots, can help to formulate input data to determine infrastructure. Moreover, it will provide a further step for determining infrastructure from a given timetable. This paper also provides further analysis for the transit and transport layer of Scheidt (2018).

Further research is required since slots and pulses for the dispatching gap are only a concept. There are several opportunities to enhance the concept further:

1. Train archetypes form the basis of slots and are crucial for the usability of real trains. Therefore, the estimation of quantiles for each train archetype and line section needs to be further investigated.
2. Dispatching rules for the preclusion of slots and the handling of mismatching trains to their slots should be examined.
3. The impact of the capacity usage of slots compared to the UIC code 406 or other methods can be further reviewed.

It could prove difficult to verify the improvement to a Level 3 timetable for freight traffic experimentally with real trains. Two comparable line sections with railway operators willing to test the Level 2 timetable against a Level 3 timetable would be required. However, current railway operation management systems work in a critical environment where safety is the priority and the time for the development of features for these systems is elongated, which leaves only railway laboratories at universities for the validation of the model concept. Real train data for the train archetypes will be the limiting factor for the transfer of the results from railway laboratories to actual railway operation apart from the artificial interaction with a railway operation management system in a laboratory.

In the future, a level 3 timetable could simplify ad hoc scheduling. A train could immediately be given a conflict-free route based on the real time situation, in which all involved dispatchers and interlockings would know this train. Possibly across infrastructure manager borders, too; a prerequisite is a networked, digital train path management system, which combines operational planning and control (see Figure 2). This is easier said than done: interfaces between components within and between operators as well as suitable algorithms for processing are required.

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