Rail Traffic Requirements Engineering

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Abstract

The deregulation of the Swedish rail transport market and introduction of several operators competing for train paths has fundamentally affected the demands on the capacity allocation process. As a consequence this process is facing radical change in the near future. The demands and their consequences for the future are analysed in this paper.

The analysis proceeds from a set of identified requirements typically posed by rail transport customers and service operators. A simple mathematical framework in which these requirements can be formalised is defined and methods for conflict detection and resolution are discussed.

Keywords

Requirements engineering, rail traffic specification, rail infrastructure capacity application and allocation

1   Introduction

The deregulation of the Swedish rail transport market and introduction of several operators competing for train paths has fundamentally affected the demands on the capacity allocation process. As a consequence this process is facing radical change in the near future. The demands and their consequences for the future are analysed in this paper with the long term goal of achieving cost efficient, attractive and competitive rail transports.

Traditionally the principles for timetable planning was based on priority rankings made by monolithic organisations with access to all available data on costs of vehicle usage and personnel rotations. Transport demand was estimated from long term contracts with customers such as regional authorities and large cargo transport buyers. To a large extent political decisions influenced both prioritisations and investments in improved infrastructure.

With the introduction of several competing operators, Banverket Trafik, the authority responsible for slot allocation and time table planning in Sweden, is struggling with a much more complex process than a few years ago.

This paper describes, with some mathematical precision, the details of this problematic situation and gives indications of what type of technology could be used to support the planning process. It also identifies some open subproblems.

The analysis proceeds from a set of identified requirements typically posed by rail transport customers and service operators. A simple mathematical framework in which these requirements can be formalised is defined and methods for conflict detection and resolution are discussed.

2 Identified Requirements

The requirements and limiting factors of the train path allocation process arise from 4 main sources:

1. Customer requirements

2. Operators requirements

3. Connections and exchanges

4. Inherent and temporary capacity limits on infrastructure resources

When identifying and analysing a requirement we have tried to point out its original source and its most general form. E.g. most of the customer requirements are seen by the allocation body only through the operators applications which currently need not identify the transportation task served by a train requiring a particular path. We firmly believe that this situation has to change and that many customer requirements has to be made more explicit in the allocation process.

The exact form of the requirements listed in this section is preliminary and not yet fully analysed. The mathematical form of the requirements outlined in section 3 are also currently tentative. In particular certain requirements (e.g. vehicle and personnel rotations) have nonlinear form that can make conflict detection and resolution very difficult.

This is also the case for the scheduling constraints arising from the limited infrastructure capacity but these are not really part of the train path application and can be handled by the allocation body relatively independently from the operator and customer requirements. Some such limits are published as part of the network statement but identifying and resolving conflicts between trains that require the same infrastructure resources is still one of the most complex and time consuming task in time table planning.

In the case of the rotations it may be possible to characterise the requirement not with regard to a specific rotation but rather as some overall property of the timetable that tend to allow for efficient rotations. A similar approach was taken for personnel planning in [8] but to apply it to this domain clearly needs more work.

2.1 Customer requirements

Temporal requirements
Most customer requirements involve departures and arrivals at given locations in the rail network and path traversal durations for point to point transports. They generally has one of the forms:

1. Some event must happen *before*, *after* or *at* some particular moment in time

2. Some event must take place during a particular time interval

3. The temporal distance between two events must be of *at least*, *at most* or *exactly* a particular duration (e.g. rigid intervals between events of similar type)

4. The occurrence of several events of similar type must occur at fixed intervals (e.g. basic interval timetable)

5. Punctuality (i.e. requirements on the robustness of the timetable under indeterministic perturbations)

Temporal customer requirements are generally collected and synthesised into high level requirements by the transport operator.

Weight, length, and cargo requirements
For public rail transports the routes traversed by transports generally depend directly on customer requirements. That is not necessarily the case for goods transports whose route through the network may vary more widely but may instead be constrained by e.g. weight, length and security considerations.

Speed requirements
Fast passenger trains will in some cases require particular high speed corridors. Since it is for capacity reasons a bad idea to mix slow and fast traffic, slow goods traffic may be required to take alternate routes. If so, it must be made clear in the network statement which routes are primarily allocated to which type of traffic.

Conservative changes
The passenger traffic operators often advocate conservative changes between timetabling periods. It is debatable how real this demand is from the operators customers. However if the capacity allocation process should take this type of demands into consideration we need to formalise them and find ways to compare them to other and perhaps conflicting requirements.

2.2 Operators requirements

The following resource requirements involve the resources managed by the traffic operator, mainly vehicles and personnel.

In the infrastructure capacity allocation process used today most of the following requirements are implicit and generally not made available to the allocation authority. Instead the traffic operator attempts to fulfil a requirement of this type by producing a request for infrastructure capacity that is so rigid that the resource requirement can be reliably estimated or limited. In almost every case the request takes the form of an assignment of fixed moments in time to a large number of time table events; in practise a finished timetable for the traffic of a single operator.

From the capacity allocators point of view it is highly undesirable if several operators states their demands in such a rigid format. There will almost inevitably be conflicts between the applications of the different operators and no indication of what type of resolution are then preferable. Interdependencies between individual trains in a single operator's

applications may also have to be guessed or reconstructed after explicit consultation with the operator. This is a very inefficient, error prone and slow process as it stands today.

We will argue that instead making the real requirements explicit will make it possible to use less rigid forms for the train path application for infrastructure. We will also argue that the use of less rigid forms of the application will simplify the allocation process and benefit all parties in the process.

Vehicle requirements

The most important vehicle requirements arise as a consequence of the operators management of their vehicles into a type of plan usually referred to as vehicle rotations. These consists of sequences of movements which are repeated after a characteristic interval. Each sequence of tasks is called a circuit since it generally describes a closed circuit of track link traversals performed by a set of vehicles. The properties of the vehicle rotations strongly influence the number of vehicles and the amount of service transports required by the plan. To produce plans that use the vehicle resources efficiently is one of the most decisive factors in the process of producing cost efficient, attractive and competitive rail transports.

Engine circuits   The engines (locomotives) is the most costly of the vehicle resource used by the operator. The cost of the use of the engines stems from a variety of sources. The most important are

- Capital or leasing costs

- Maintenance costs

In addition, since the current policy in Sweden is to bill the operators for infrastructure usage based on number of (actively used) vehicles and total distance travelled, infrastructure cost is also dependent on how the engines are used.

. Electricity is billed by type of train, distance and weight, as well as track fees, accident fee, diesel fee and some others. Cost for driver salaries also depend on the time spent on active and passive transports of engines.

The elementary operation connecting the planned individual movements of two trains using the same engine is called an (engine) turn. The local properties of the turns pose both hard and soft constraints on the arrival and departure events in the timetable. E.g. the arrival of the vehicle to a particular location has to precede its departure from the same location by a duration typical to the location and the involved vehicles. However, if the planned movements involve a service transport of the engine from one location to another, the duration required for the turn can be thought of as including adequate time for the service transport. This type of requirement can be modelled as hard limits on the duration between the arrival and departure events and some type of cost as a function of the distance from some ideal turn duration.

However more important than the duration of individual turns are overall (global) properties of a set of sequences of movements that characterise the repeatable patterns of the vehicle flow since the total duration and structure of each circuit determine the number of vehicles necessary to serve it and the amount of passive transport necessary to supply vehicles to the active transports.

It is possible to characterise the constraint on the timetable posed by a given circuit (see e.g. [4, 7]) but in reality there may be many alternative sets of circuits that gives

approximately the same cost so the requirements from the operator should ideally not consist of a fixed set of circuits but a limit on the cost of the best rotation for any given timetable.

Car flows For many types of transports the cost of car resource usage depends heavily on the engine circuits since the the cars follow the engine over large distances. On the other hand service transports of cars constitutes a significant fraction of the planned movements of the engines. This means that the car rotations can be seen as an *input* to the timetabling process. However if these requirements are not made explicit in the process, the exact rotations cannot be determined until the timetable has been fixed.

The requirement on the timetabling process posed by the management of cars takes the form of flow values for different types of cars on the links on the rail network. These flow values should be used to determine which service trains we need to run in order to supply the need for cars at particular times at various point in the network.

Once the service trains have been determined the car flow requirements are implicit in the requirements on the engine rotations provided that constraints on arrival and departure events of the engines also enforce the connections required by the cars.

Personnel requirements

Specific requirements on the timetable posed by the rotation of personnel are hardly used today. The personnel rotations and parings are invariably produced after the fact, i.e. for a given timetable. The duration of turns may, however, be influenced by generic characteristics of the personnel rotations such that a particular location is or is not suitable for particular type of break in the work schedule of e.g. a driver.

The problem to generate personnel rotations and pairings for a given timetable on railways is considered difficult compared with e.g. air transports and the total cost of personnel is perhaps even higher than that for vehicles. It would, therefore, be desirable to capture and enforce properties of timetables that allow for creation of efficient personnel rotations. Other work on this problem by the authors of this report include [2, 8].

Prioritisation

Prioritisation between different parts of the traffic of a single operator has traditionally not been part of the train path application since this has already been handled in the timetable proposed by the operator. When generalising the application format to allow for more flexibility explicit prioritisation become a very important part of the requirements of the operator.

Variable capacity and alternate train paths

The cargo operators plan for traffic which should be able to accommodate varying customer demands which are largely unknown at the time of capacity allocation. To ascertain that they can supply this demand they traditionally apply for sufficient capacity to accommodate a maximum estimated demand, i.e. a total capacity allocation that they in practise seldom use. A particularly intriguing example of this is the case where the operator applies for three train paths for a particular route but expect to simultaneously use at most two of them.

This is highly undesirable from the capacity allocators point of view and ongoing discussion indicate that this procedure will be depreciated in the near future. Nevertheless the need is certainly real and should be handled in the way that best serves all involved parties. We have not yet attempted to formalise this type of requirement but acknowledge the need to do so in an efficient fashion.

2.3 Connections and exchanges

These requirements occur both as customer requirements and from how the operators organise the flow of goods through the rail network. We have chosen here to treat them separately from the customer and operator requirements since they generally have a very specific form. The following main types have been identified:

- Connections to other transport systems, e.g. at harbours, airports and bus terminals

- Exchange of travellers or goods between transports organised by

  - the same operator
  - another operator

- Attachment or detachment of cars arising from traveller or goods flows

These requirements take the form of either

1. Limits on the duration between arrival and departure events

2. A minimum overlap between two durations, e.g. stop times of two trains at a particular location

3. The existence of departure for a particular destination within a particular duration from a given arrival at e.g. the same location

4. That the occurrence of an event take place at any of a set of alternative intervals, e.g. connection with regular departures at a harbour

2.4 Infrastructure constraints

For the applicant, the demands on infrastructure is a function of his other requirements. These requirements have traditionally been on a low level, i.e. in many cases on signal block level. But since the requirements on infrastructure stems from more high-level requirements such as interchanges and departure and arrival times at stations and shunting yards, it may be the case that the application should be made on a more abstract level, regarding the *actual* requirements on the infrastructure. This needs further investigation.

Track capacity
The infrastructure requirements for tracks is simply that track capacity is never exceeded. What the capacity of a particular stretch of track is, however, is far from trivial to determine. See also [6].

Single track (bidirectional traffic)   Track capacity for single track lines is generally given on signalling block level and the capacity is always at most one, i.e. a maximum of *one* train at a time on one particular block. The capacity may be further reduced in cases of very short blocks or due to limits in the signalling system so that a train traversing a particular block may in fact use capacity of several adjacent blocks

The capacity of longer stretches of single track depend to a very large extent on the rhythm of traffic direction changes and relative speeds of the involved trains. It has been argued that it is pointless to estimate the capacity of longer stretches of single track without also considering a particular class of traffic pattern. See e.g. [1].

Double tracks (unidirectional traffic)   The low level requirement on double tracks is the same as for singe track but since traffic is unidirectional the capacity of longer stretches of track may often be approximated using a temporal headway that depends only on block traversal times and on the speed difference of the involved trains.

Station capacity

There are requirements on the stations, e.g. some platforms are dedicated to some operators, some platforms are for traffic going through the station, etc. However, most of the requirements on station capacity are solved once the timetable is made, when the actual arrival and departure times are known.

Meeting stations are handled in the time tabling process, but there are seldom explicit requirements on these. There may however be implicit requirements, such as train lengths and weight in the sense that heavy trains may have difficulties to start uphill.

In general it would be desirable to let some type of uniform measure on the capacity of stations and other localised resources such as shunting yards to influence the time tabling process.

3   Mathematical formalisation of the requirements

3.1   Elementary concepts

The basis of the form we have chosen to express the requirements use a number of elementary concepts of which the most basic is an *event* in the timetable. The most common events are *departures* and *arrivals* of travellers, cargo, personnel, trains and vehicles at *locations*. Events are momentary and lack duration. *Durations* are modelled as the temporal distances between events.

Events may be required to occur at, before and/or after particular fixed moments in time. We regard these as *properties of events*. The occurrences of events may also be limited by the occurrences of other events. The simplest such case is a binary *relation between events* requiring e.g. an event to take place only after another event. In general relations may be non-binary and arbitrarily complex to verify and enforce.

Since the requirements of the operators are typically expressed on events on repetitive cyclic schedules (weekly) the linear inequalities ($\leq$ and $>$) used below will be used to define higher level concepts more suitable for requirements engineering in section 3.4.

3.2   Basic mathematical properties and relations

We conjecture that most of the above mentioned requirements can be expressed or approximated by using only the basic properties and relations listed below where x, y and $y_0, \ldots, y_n$ are variables denoting the time point of the occurrence of an event in the timetable and $c_0, \ldots, c_n$ are fixed time points and $d_0, \ldots, d_n$ fixed durations. These relations form the basis, while we expect the actual train path application to be stated on a higher level and in

a syntactically richer language, which facilitates interpretation and understanding. Section 3.4 will define a selection of such high level constructs and indicate the general direction we envision the development of such a specification language to take.

Occurrence of an event before and/or after fixed times

$$x \leq c_0$$
$$c_0 \leq x$$
$$c_0 \leq x \leq c_1$$

Upper and/or lower bounds on duration between two events

$$x - y \leq d_0$$
$$d_0 \leq x - y$$
$$d_0 \leq x - y \leq d_1$$

Occurrence of an event within interval defined by two other events

$$y_0 + d_0 \leq x \leq y_1 + d_1$$

Existence of one or more events within an interval defined by another event

$$\exists y_{i_0} \ldots \exists y_{i_k} \left(d_0 \leq x - y_{i_0} \leq d_1 \wedge \cdots \wedge d_0 \leq x - y_{i_k} \leq d_1 \right)$$

where x is the occurrence of a particular event (e.g. a departure from a particular location l) and $y_1, \ldots, y_n$ are a number of events that are candidates (e.g. arrivals at l) to enter into a linear relation with x. The condition enforce that a minimum number k of the n candidates occurs within an interval defined by the event x and two parameters d_0 and d_1. This is useful to give abstract requirements on vehicle or personnel circuits, e.g. to state that there must exist at least one arrival y_0 from a particular location that can supply a vehicle to be used by a planned departure x. It is not yet clear how difficult such a condition would be to maintain in the time tabling process and if it would suit the operators to state their requirements in this form.

Weights on properties and relations   All relations above may be extended to handle costs associated with breaking them. This makes more sense and is easier to implement using a OR-based approach than one based on constraint programming.

3.3   Notes on scheduling constraints for track and station resources

Hard limits on infrastructure capacity are generally specified in the network statement but for planning purposes they must also be expressed as low level disjunctive constraints on the individual infrastructure resources. These so called *scheduling constraints* are very hard to satisfy and are perhaps the main reason why timetabling is inherently difficult.

These constraints are not strictly part of the operator and user requirements but are rather *limits* that the allocation authority must handle in its internal process. They *do* complicate the process of capacity allocation since it is difficult to determine if any of the user requirements are in conflict with the infrastructure resource limits but they do not *directly* enter into the negotiation between operator and capacity allocator. For a technical introduction to models used for infrastructure resource scheduling in the train domain, see [5].

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3.4 Mapping requirements to the primitives

This section attempts to bridge the gap between the general mathematical primitives in section 3 and the requirements identified in section 2. Note that this material only concerns the requirements in the train path application. There is also a need to combine the train path applications, stated in the expressions below, with the infrastructure description to get the material that is actually going to be used in the timetabling design. Also note that the syntax used here is a mathematical one and the actual syntax to be used in a train path application will probably be somewhat different.

Note that even though some of the relations given below may be implemented as collections of simple before/after relations, this high level formulation makes it easier for the timetable constructor to see the overall structure of the requirement rather than having to reconstruct it from collections of its low level components.

Notation

In the following we will use the following general notation:

l denotes a location, e.g. stations, important points, etc

d denotes a departure time, d_i denotes the departure of train i from its origin, d_i^l denotes the departure of train i from location l

a denotes an arrival time, a_i denotes the arrival of train i to its destination, a_i^l denotes the arrival of train i to location l

e denotes the time of an arbitrary event, generally either an arrival or a departure

$c_i, \underline{c}, \bar{c}$ denote constants used e.g. to represent durations between events and lower and/or upper bounds for time points and durations

Requirements on individual trains

Trains should have the data given in table 1 (note that we include only the requirements passed from the operator relevant to a time table planning). The list is partly based on the results in [3].

The event requirements ER in table 1 should, for traceability, take the form of a pair: $\langle id, r \rangle$ where id is a unique identification number for the requirement, and r is a property or relation that can be translated into one of the basic relations described in section 3.2. Table 2 gives some sample relations, many of which have been proposed or discussed in [3].

By the first four relations in table 2 it is possible to state both shifts and delays of departure and arrival times. The 5:th, 6:th and 7:th relation are example of relations that are more expressive and may be used to state quality requirements on the transport. Note that the allocation body may well pose its own restrictions for e.g. minimum shift departure and traversal times between given locations for each type of transport. The allocation body can thereby enforce a minimum amount of slack suitable to the priority of each type of transport. This possibility was as far as we know first suggested in [3] and was in fact implemented in a limited form in the network statement of Banverket during 2004.

Table 1: Requirements on trains

FIELD	NAME	DESCRIPTION
i	Train id	Unique identification of transportation task.
D	Days	The days of the week that the train should leave.
TT	Train type	Determines speed limits, braking capacity, etc.
TD	Train data	Other data relevant for timetable planning (e.g. length, weight, etc).
CP	Class priority	Priority according to classification of transportation task (see [3]).
OP	Operator priority	The operator's stated priority.
PT	Periodic timetable	Set of pairs, $\langle j, o \rangle$ where j is a train id and o is an offset in minutes from the departure of i.
RR	Route requirement	A sequence $\langle l_0, \dots l_{m_i} \rangle$ of "via" locations which the train i must pass.
ER	Event requirements	Requirements on departure and arrival events along the route of the train. Only events at locations specified in RR may be used.

Table 2: Sample event requirements

NAME	EXPRESSION	DESCRIPTION
Max shift departure	$\underline{c} \leq d^l \leq \bar{c}$	Maximum shift of departure, for the transport to be of commercial value. Limits may be omitted.
Max shift arrival	$\underline{c} \leq a^l \leq \bar{c}$	Maximum shift of arrival, for the transport to be of commercial value. Limits may be omitted.
Preferred departure	$\underline{c} \leq d^l \leq \bar{c}$	Preferred departure window, in which all time points are equally good
Preferred arrival	$\underline{c} \leq a^l \leq c$	Preferred arrival, in which all time points are equally good
Min/Max duration	$\underline{c} \leq a^{l_j} - d^{l_k} \leq \bar{c}$	Restriction on the duration between a departure and an arrival event
Accumulated traversal time	$\underline{c} \leq \Sigma_{j=1}^{m_i} a^{l_j} - d^{l_{j-1}} \leq \bar{c}$	Restriction on the accumulated traversal time for a train i
Accumulated stopping time	$\underline{c} \leq \Sigma_{j=0}^{m_1 - 1} d^{l_j} - a^{l_j} \leq \bar{c}$	Restriction of the accumulated stopping/waiting time for a train

Table 3: Requirements on relations between trains

Field	Name	Description
id	Identification	Unique identification for requirement
AT	Type	Association type (e.g. driver connection, passenger flow, etc).
PC	Priority class	Priority class, based on how valuable the association is (e.g. amount and value of goods, number of passengers, etc).
T	Trains	Vector of trains, i.e. events are referred to by the index of the train in this vector.
ER	Constraint	Set of event relations that should be fulfilled

Relations between distinct trains

Relations (associations) between events for distinct trains should contain the data given in table 3. Note that requirements on a train in relation to some external (not track-bound) transports could also be given as relations in this sense.

Each ER should for traceability take the form $\langle id, r \rangle$ where r takes one of the forms described below. The mathematical formulation is given in table 4.

It is important to note that, for most of the requirements addressing transportation flows (passenger or cargo), the requirements are stated inside the planning period (typically a week), while for some of the requirements addressing resource requirements (circuit and sequence), the requirements are actually posed over several consecutive instances of the planning period.

In the following (and table 4), t_i and t_j denotes train identifiers in T.

Overlap $o(\langle t_1, \ldots, t_n \rangle, \underline{c}, \bar{c}, l)$ Overlap between trains $t_i, \ldots, t_n$, the overlap between any pair of trains should be at least $\underline{c}$ and at most $\bar{c}$, at location l. This can be used to e.g. state two way passenger flows at a station p. Note that this relation also implies a restriction on the duration of the stop at l for each train in $\langle t_1, \ldots, t_n \rangle$.

Some overlap $v(\langle t_1, \ldots, t_k \rangle, \langle t_{k+1}, \ldots, t_n \rangle, \underline{c}, \bar{c}, l)$ States that at least 1 train in the first set and 1 train in the second set must have a overlap (see [9]). This relation is much harder to handle efficiently, and should probably be avoided initially (must be investigated thoroughly). This may be used to state regular transitive connections with limited waiting times in e.g. urban areas.

Before $b(t_0, \langle t_1, \ldots, t_n \rangle, \underline{c}, \bar{c}, l)$ Train t_0 should arrive at location l at least $\underline{c}$ and at most $\bar{c}$ minutes before the departure of any trains in $\langle t_1, \ldots, t_n \rangle$. This can be used to state typical shunting relations or one-way passenger flows.

After $a(t_0, \langle t_1, \ldots, t_n \rangle, \underline{c}, \bar{c}, l)$ Train t_0 should depart from location l at $\underline{c}$ and at most $\bar{c}$ minutes after the arrival of any train in $\langle t_1, \ldots, t_n \rangle$. This can also be used to state typical shunting relations or one way passenger flows.

Connections, $s(\langle t_0, \ldots, t_n \rangle, \langle c_1, \ldots, c_n \rangle, \langle l_1, \ldots, l_n \rangle, k)$ The trains $t_0, \ldots t_n$ should arrive and depart in sequence at each location $l_1 \ldots l_n$, with a delay of at least $c_1 \ldots c_n$ in

Table 4: Nonlocal requirements

NAME	NOTATION	MAPPING TO PRIMITIVE CONSTRAINTS
Overlap	$o(\langle t_0, \ldots, t_n \rangle, \underline{c}, \bar{c}, l)$	$\underline{c} \leq d^l_{t_i} - a^l_{t_j} \leq \bar{c}$ for all $0 \leq i, j \leq n$.
Some overlap	$v(\langle t_0, \ldots, t_{k-1} \rangle, \langle t_k, \ldots, t_n \rangle, \underline{c}, \bar{c}, l)$	$\exists i j (0 \leq i < k \leq j \leq n \wedge o(\langle t_i, t_j \rangle, \underline{c}, \bar{c}, l))$
Before	$b(t_0, \langle t_1, \ldots, t_n \rangle, \underline{c}, \bar{c}, l)$	$\underline{c} \leq a^l_i - d^l_0 \leq \bar{c}$ for all $1 < i \leq n$
After	$a(t_0, \langle t_1, \ldots, t_n \rangle, \underline{c}, \bar{c}, l)$	$\underline{c} \leq d^l_0 - a^l_i \leq \bar{c}$ for all $1 < i \leq n$
Connections	$s(\langle t_0, \ldots, t_n \rangle, \langle c_1, \ldots, c_n \rangle, \langle l_1, \ldots, l_n \rangle, k)$	$a^{l_i}_{t_{i-1}} + c_i \leq d^{l_i}_{t_i}$ for all $0 < i \leq n$
Circuit	$c(\langle t_0, \ldots, t_n \rangle, \langle c_0, \ldots, c_n \rangle, \langle l_0, \ldots, l_n \rangle, k)$	$a^{l_i}_{t_{i-1}} + c_i \leq d^{l_i}_{t_i}$ for all $0 < i \leq n$ and $0 \leq a^{l_0}_n \leq d^{l_0}_0 - kZ$ where Z is the length of a period in time units and k, the length of the circuit in periods

between. l_i may be any location where both t_{i-1} and t_i passes. This means that l_i and l_{i+1} are not necessarily consecutive on the line, but that the "transportation flow" shifts train at each consecutive l_i. It is an error if two consecutive trains t_{i-1} and t_i do not have the location l_i in their respective route requirements (see table 1). This may be used to state a flow of goods or passengers trough a sequence of connections.

Circuit $c(\langle t_0, \ldots, t_n \rangle, \langle c_0, \ldots, c_n \rangle, \langle l_0, \ldots, l_n \rangle, k)$ Similar to s above, except that the trains $t_0 \ldots t_n$ should be in closed sequence (loop), with a gap of at least c_i in between and repeated after a fixed number k of periods of duration Z (typically a week). This may be used to specify e.g. an engine or personnel circuit.

Some of the relations in table 4 are illustrated by the figures 1 and 2.

When implementing a support system that can take advantage of these relations, they may be used differently depending on e.g if an operation research approach or a constraint programming approach is taken. In the case of a constraint programming approach, these relations are ideal for forming so called global constraints, i.e. encapsulated specialised algorithms that take advantage of the explicit structure between the used parameters and variables. In an operations research approach, they will be mapped onto linear equations, and since the basic equations (with the exception of those discussed in section 3.2) are linear such a mapping exists. All relations in table 4 can be mapped as described in the fourth column, except perhaps the relation *exists overlap* which includes an existence statement. However, the paper [9] describes how this has been done for the CADANS software used in the Netherlands, which may be applicable here also.
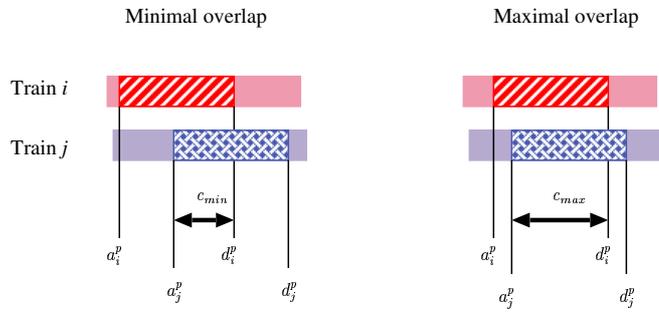
Figure 1: An example of an overlap relation between two trains at a station, with restrictions of the minimum and maximum duration of the overlap. The background boxes denotes the possible slack.
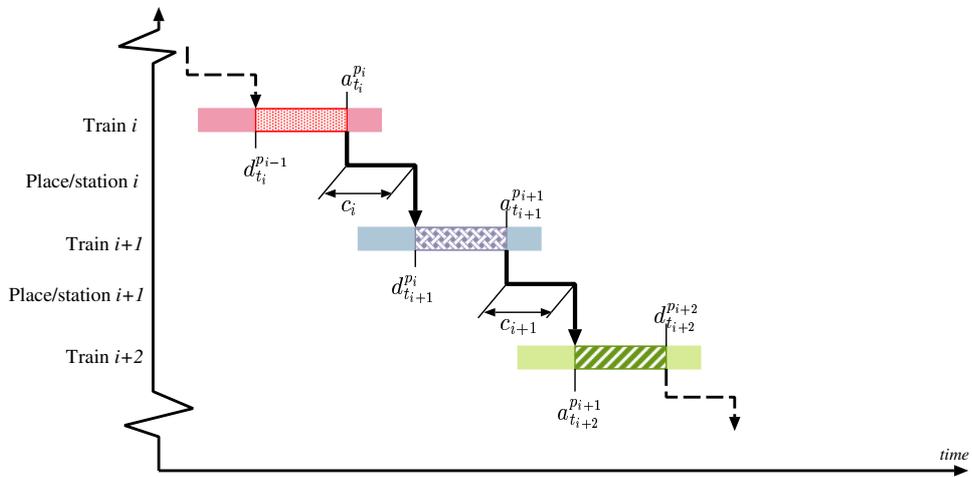

Figure 2: A (part of) a sequence of connections. The shadowed boxes denotes the slack for each train.

If an operations research approach is taken, these relations, despite being mapped on primitive linear relations, works as a communication media between the operator and the allocation body. These high level relations expresses in a more comprehensive way, what the operator wants really to achieve.

4 Conclusions and future work

We have reported an investigation of typical requirements on the rail traffic from the operator and end users point of view and analysed the mathematical properties of these requirements. Furthermore we have outlined the general design and desirable properties of a formal language used to specify these requirements.

Using this analysis we intend to specify and implement a decision support tool for handling several and possibly conflicting applications for infrastructure in a way that both benefits the operators and end users of the transport service and can be used to support the implementation, e.g. prioritisation policies. For such a tool and the allocation process to be efficient, in the context of many operators competing for infrastructure capacity, it is necessary to make the real requirements more explicit than in the rigid application formats that have been used up till now.

We intend the work reported here to be a first step in this direction and in the longer term to fundamentally revise the process of infrastructure capacity application and allocation.

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