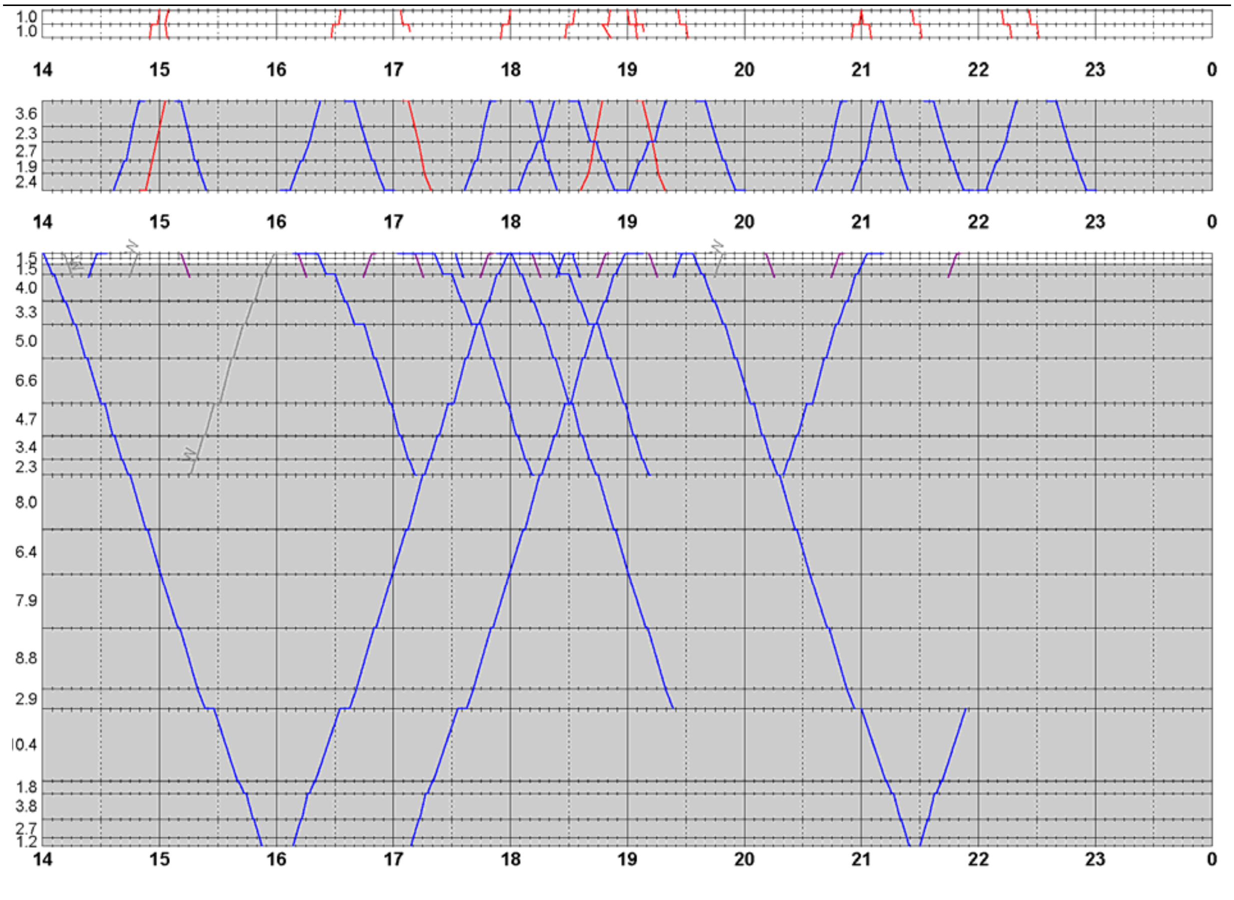

FROM THE RETICULAR DIAGRAM TO THE 24-HOURS TIMETABLE

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Abstract

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Several European countries operate their train services on the basis of a regular-interval timetable. Building such a timetable starts with defining a service backbone with a set of services that will form the future transport supply. Based on those services, the basic timetable framework is then built. This is generally done for a 2-hours time slice and becomes the fundamental "*raw material*" to build the final timetable. The basic framework is usually represented as a ***reticular diagram*** that shows the network topology and all the train paths defined by their arrival and departure minutes in all or main stations for a 60- or 120-minutes time interval, which is to be repeated throughout the day.

Thus, theoretically, to create the ***24-hours timetable*** for a normal working day comes down to repeat the basic framework throughout the day, and fine-tune the early morning and late night services. However, in many “real life” cases, the step from the reticular diagram to the 24-hours time table did not prove to be as simple as it might appear in theory. Cancelling some train paths in off-peak periods, modifying some train paths to meet local demands (and, thus, diverging from with the reticular diagram), bears consequences on the scheduled connections. This is the kind of issues encountered when taking the step to the 24-hours timetable.

The paper describes the intermediate steps leading from the design and interpretation of the reticular diagram to the eventual 24-hours timetable. It provides an in-depth analysis of the consequences the planner faces at every step of the procedure, e.g. the differences when considering a peak-period reticular diagram or an off-peak one, or the constraints created by higher priority train paths, such as those national ones, when building a regional timetable.

Finally, a methodology to manage the difficulties when establishing the 24-hours timetable is presented, aiming to ensure a highly regular timetable as outcome.

Keywords

Regular-interval timetable, coordinated regular interval timetable, timetable regularity

1. Introduction

A coordinated regular timetable (or clock-face timetable) as it is being set up in an increasing number of countries, is based on a reticular diagram out of which a “24 hours timetable” is then designed. This step consists, in theory, in repeating the framework throughout a standard working day’s service duration. Although seemingly simple in the elaboration process of the annual timetable, this is a crucial step leading from "theoretical" planning down to the real schedule. This is all about the transition from a systematic to a "customized" solution, adapted to « real life » cases.

Going from the reticular diagram to the 24 hours timetable comes with a certain amount of significant adaptations that may have consequences on the operation of the coordinated regular timetable as a whole. Some of these adaptations have no consequences on the quality of the service, such as the train path's start or end station, or changes in the stopping pattern, at the very beginning or very end of the operational range. Others will significantly affect the quality of the planned services or the connections. In this paper, we focus on the latter and describe the typology of these modifications as well as their consequences, the causes and the possible solutions.

2. Building a regular-interval timetable

Going from the reticular diagram to 24 hours timetable is only a first step in the whole process of elaborating a complete timetable. It is thus important, to state the context and recall the basic characteristics and elements constituting a regular interval timetable as well as the general process of timetable building.

The following paragraphs (2.1 and 2.2) are largely taken up from [8] which can be considered as the theoretical foundation of this paper.

2.1 Some definitions

A coordinated regular timetable is based on a certain amount of elements which assemble gradually from the simplest to the most complex, and are briefly presented below.

2.1.1 Services

A ***service*** is composed by:

- a directional path in the network (defined by its origin, destination, and route),
- a stopping pattern (defining in which intermediate stations the train stops and for how long),
- a commercial identity, which may be related with
    - travel time objectives,
    - choice of rolling stock assigned to this particular mission,
    - fare policy,
    - package of extra services, etc.

In most cases, each service has a dual one, running in the opposite direction and with the same characteristics. Actually, a service matches the commercial vision of the operator: to provide a given transport supply on a route for a defined market segment.

2.1.2 Structure

Building a ***structured timetable*** comes to keep the service typology under control, i.e. [6]:

- to provide a finite (and not too large) number of services, which insures that the transport supply remains readable for the customers and the operators as well;
- to define fairly distinct services, that are easily identifiable; supplying a range of products that are easy to identify makes consumer choices simple (and helps improving the marketing, too);

- to assign each particular train to a given service (by avoiding planning "outlier" trains, that are hard to recognize by both customers and operators and which degrade the readability of the whole transport supply).

A structured timetable is not necessarily based on regular intervals. Customers are still forced to consult the full timetable, although they can easily sort between fast, local, high-speed, etc.

2.1.3 Regular-interval timateble

A ***regular-interval timetable*** is a structured one and, what is more, with successive identical services planned at fixed time intervals [6]; services are periodical, and the time interval is the period. Theoretically, periodicity may not be the same for various services although, to fully benefit from the systematic properties of the principle, periods are usually unique or integer multiples of a basic time interval.

2.1.4 Coordinated (clock-face) timetable

A ***coordinated regular timetable*** (or ***clock-face timetable***) is a regular-interval timetable that obeys to three additional constraints [6]:

- a common axis of symmetry for all the lines in the network,
- balanced transport supply in opposite directions,
- scheduled and guaranteed transfers in major stations.

The major conceptual difference is that regular-interval timetable can be defined at the line level, while a coordinated regular timetable covers a whole network.

2.2 The steps leading to a regular-interval timetable

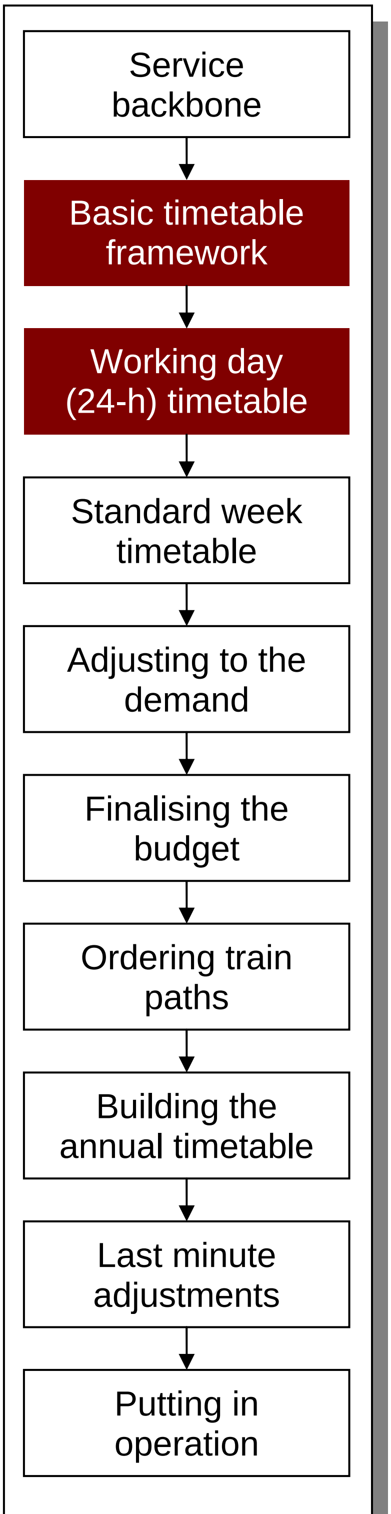

Figure 1: Step-by-step process

The process (Figure 1) that leads from an initial "idea" of the service to its materialization as a timetable is a step-by-step approach [7] with several intermediate milestones, more or less formal validations, and a heavy need for arbitration.

The first step is to define the fundamental structure of the future transport supply as a more or less abstract set of services (Figure 2).

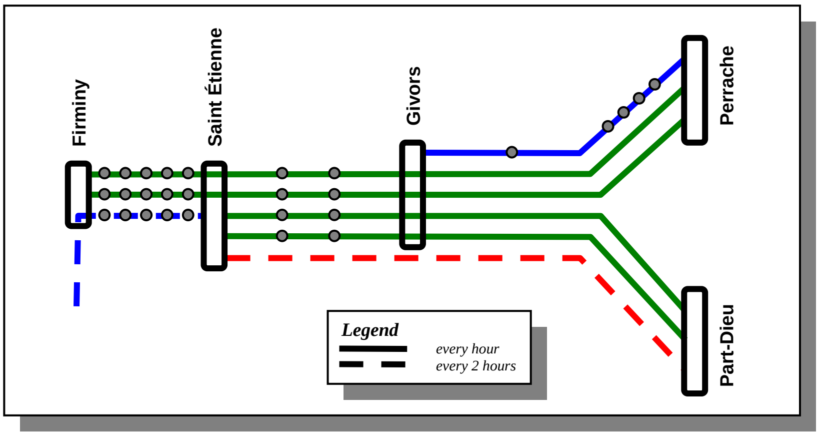

Figure 2: The services backbone

Building the basic timetable framework is the second step. This is generally done for a 2-hours time slice and becomes the fundamental raw material used to build the final timetable. Often, the best way to represent the basic framework is a reticular diagram that shows the network topology. Each line represents a train path able to be repeated every hour, or every two hours (Figure 3). A reticular diagram should be conflict-free, compatible with the rolling stock resources, and ensuring that all technical movements are possible.

The third step is to design, line by line, the 24-hours timetable for a standard working day. This is more than repeating the basic framework 7 or 8 times. Planners should also include extra freight train paths, include possible track possessions for maintenance work, set the early morning and late night services, possibly alleviating off-peak services, and adding extra train paths in peak periods if needed. The usual representation of this timetable for each rail line is a time-space diagram.

To build the weekly timetable, planners use the standard working day timetable; they may also need to design extra timetables for the weekend. Finally, the annual timetable takes also into account special days, holidays or events of low or unique occurrence with special demand patterns.

At this stage, the detailed estimation of the cost of the future system becomes possible. Due to cost restrictions, fine adjustment of the project may be required. Formal procedures are launched to ensure project funding. The actual process includes several loops and feedbacks that are specific to both the location and the institutional context.

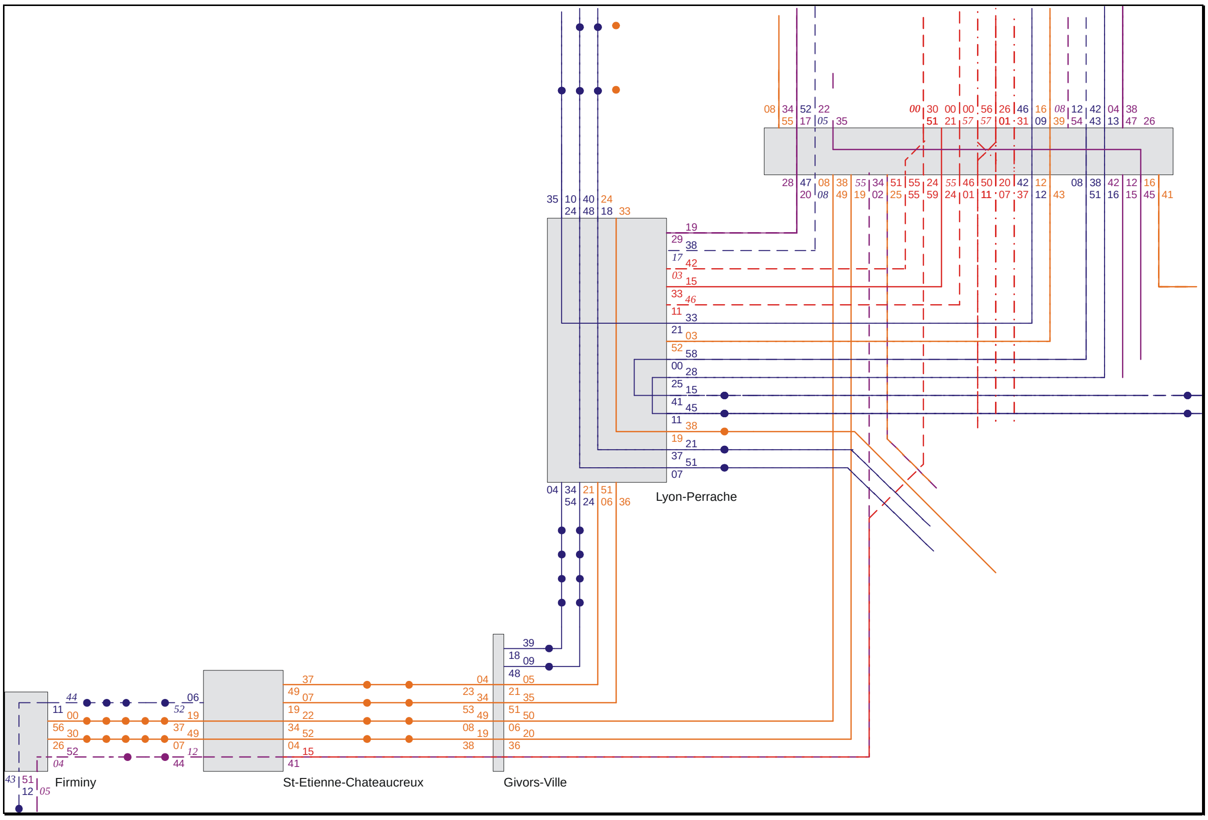

Figure 3: Reticular diagram

The last steps leading from ordering the train paths to the actual operation need not to be detailed in this paper, though it may result in further slight adjustments of train paths that further degrade the service regularity.

2.3 Possible interpretations of the reticular diagram

The reticular diagram is the key element on the road from the initial planning to the actual timetable. However, two uses of the reticular diagram are possible when building the 24 hours timetable.

For links intended to be operated with a dense service, providing a continuous transport supply over the whole operational range, the reticular diagram represents the standard timetable for one (or two) typical hours. It is repeated throughout the day, with some minor exceptions, mainly at the beginning and at the end of operations, or with additional (reinforcement) train paths during peak periods. In this case the reticular can be considered as an off-peak hour timetable.

In other cases, the reticular diagram is considered as a catalog out of witch the train paths are activated at a given times. This is particularly the case of links with low demand levels that justify the activation of full set of train paths only during peak periods. In this case, the reticular diagram is considered as a peak hour timetable or a train path catalog.

2.4 Stakeholders and planning levels

Beyond the general planning stages, an additional characteristic of the timetable planning is the multiplicity of involved stakeholders and levels of planning.

The timetable planning involves three main stakeholders: the infrastructure manager (IM), one or several railway companies (RC), and the organizing authority (OA) (i.e. regional or national public bodies), each having objectives and priorities that can be radically different, even contradictory. Locus of responsibilities and the planning organization depend on the particular national context. Nevertheless, timetable planning is a multi-actor process.

Moreover, timetable planning is a multi-layer process, done at various levels, from a high priority level (high speed links, long national and international services, etc.) generally managed at a national level, to lower priority levels (interregional, regional, local services, etc.) that usually reflect the transport policy set by the local authorities. The precise definition of the various levels as well as their span and the way they interact depend on the institutional context. Nevertheless, the high level traffic has, generally speaking, priority on the lower level one when it comes to the network capacity allocation. This is justified by stringer constraints attached to the high level, stemming from the route length and the interactions with numerous national and regional services. The high priority train paths are the "structuring" ones that become a constraint for all the lower levels services.

Furthermore, freight traffic should also be taken into account. Usually, freight services are planned separately and must be assigned a sufficient capacity share. Some freight trains have very long and often international routes; however, they enter the planning process with a lower priority than for most of the passenger services. This is also because they show greater flexibility in travel times, stopping duration and operational range (many freight trains will be operated at night when there is no or only little passenger activity).

3. Source and causes of difficulties

To put in place the 24 hours timetable implies taking into account operational constraints and specific requirements which could not, or only partially, be counted for during the design of the reticular diagram.

Some of these constraints or requirements like regular maintenance works, (or already scheduled heavy infrastructure maintenance) or early morning and late evening adjustments are inevitable and will not be discussed further on. We will rather focus on two important issues:

- Problems that raise due to train paths not strictly adhering to the reticular diagram
- Problems resulting from the reticular diagram's definition itself

The first category raise when building the 24 hours timetable. The second one can already occur while designing the reticular diagram, but difficulties increase sharply during the 24 hours timetable building process. Furthermore, the two categories are not completely independent. For example, a not ideally designed reticular diagram will more likely encompass modified train paths.

3.1 Issues related with diversions from the reticular diagram

A reticular diagram should contain all the train paths to be operated in the final timetable. Nevertheless, exceptions do occur in some cases and affect the timetable operation as a whole. The panel of the possible, occasional reticular diagram modifications is pretty large. It can affect:

- high priority train paths,
- as well as lower priority train paths.

Diversions from the regular pattern of the reticular diagram may occur in:

- the stopping pattern (adding or removing intermediate stops)
- the travel time (e.g. because of a less performing rolling stock)
- the departure and arrival time (time shifting of the planned train path with all the other characteristics remaining unchanged)
- planned train split and merge in selected stations

Finally, selective cancellation of train paths (mainly during off-peak periods due to budgetary concerns) can also be seen as belonging to the "non-respect of the reticular diagram" category, as this breaks the requirement for continuity of service of a regular interval timetable. However, this case has some particular characteristics and will therefore be treated separately.

3.1.1 Modifying higher or lower level train paths

Consequences of diversions from the reticular diagram differ if they are due to higher or lower level train paths.

To simplify what follows, we will consider only two priority levels. A high priority, structuring level (e.g.: international, national and high speed trains) and a low priority level (e.g. regional and interregional trains). The whole analysis can easily be transposed to a multi-level situation.

When a train path diverges from the reticular, that only affects train paths of the same or the lower category. This is by design as, for a given level, train paths of higher level are seen as constraints. Modification of a train path is not acceptable if it induces modifications on higher level ones. The whole design process comes to first allocate capacity to the highest level services, then go down with the lower levels. Lower level services are planned knowing the higher level scheduled ones.

As a consequence, high level train paths bear a huge set of dependencies, not only within same level paths (for granting connections), but also with lower level services that act as feeders. Any change applied on a high level train path generates a huge volume of impacts on several lower level services that have been designed taking into account the higher level scheduling.

When there is enough spare capacity, those impacts can be dealt with by adapting the other trains paths, in a way to avoid major consequences. However, in most cases, margins for modifying train paths (or the planned transfer times) are low and not capable to fully absorb variations of the structuring train paths.

3.1.2 Consequences of diversions from the reticular diagram

Diversions from the originally planned reticular diagram will have consequences on:

- the service itself
- other train paths impacted by these modifications.

For the modified train path itself, the possible consequences may be:

- Loss of regularity (identical arrival and departure minutes every hour), which is one of the goals of a regular timetable
- The impossibility to grant transfers or the deterioration of their quality (e.g. because of longer transfer times)
- The loss of symmetry in train split and merging operations. Any asymmetry may reduce the capacity in one direction, or result in train paths that are possible in one direction but impossible in the opposite one.

As already stated, diversion of a train path can impact other train paths, and induce modifications to the latter. The most extreme consequence is when other train paths become infeasible and need to be deleted. This may occur when there is no sufficient capacity left for a lower train path after the modification of a higher level one.

3.1.3 Causes of reticular diagram diversions

There may be various sources of diversion from the reticular diagram that depend also on the priority level (high or low) of the train path. For every modification we will list the most common cause(s) but without having the pretention of being exhaustive.

Modifications on stopping patterns

Modifications of the stopping pattern, by adding or removing intermediate stops on a given service or by changing the dwell time, may have different causes depending on the priority level.

Diversions on **high level train paths** may be caused by:

- Demands for extra stops on high level trains issued by regional authorities
- A legal obligation to provide given performances or direct links

In minor regions, where high level trains usually do not stop, and are linked to major centres by connecting links that require transfers, local authorities may ask, mostly for political or prestige reasons, to provide, at given moments, direct connections that are not originally included in the reticular diagram. It is not without interest to notice that, very often, such demands are in contradiction with the local transport policy and have negative consequences on the local transport supply, of which local politicians are not always aware. This is because planning of higher and lower level train paths occurs sequentially in time and is done by different teams. Consequently, local authorities often don't measure sufficiently the consequences of their "special requests".

In some cases, legal obligations, especially when local authorities contribute to infrastructure investment, may exist when constructing a new (high speed) line. These legal obligations may consist in minimum travel time objectives or in a certain number of daily direct links for a given station. For example, in France the DAM (Dossier d'Approbation Ministériel) will fix, before the construction of new LGVs (High speed lines), a frame for the future services that will have to be respected afterwards. This frame may be impossible to realize with one single service (e.g. the minimum time target can only be achieved with no intermediate stops and, at the same time, there is also a compulsory minimum number of intermediate stops to be made daily). As a result, the most frequent service will be used to build the reticular diagram, but the 24 hours timetable will include several exceptions with the inevitable consequences on the lower level trains.

Diversions on low **level train paths** may be caused by:

- Unique needs for different stopping patterns
- The compensation of some “service losses” due to the transition from a “custom made” timetable to a regular interval timetable.

An example for unique change of stopping pattern is the case of stations that are only used to access a school. In that case some trains may stop there exceptionally, shortly before and after the classes’ start and end.

When going from a “custom made” timetable to a regular one, the services' typology is reduced to a finite, small number of services. Inevitably there are some stations that will be daily serviced more and others that will experience a service reduction. To compensate this reduction, some trains, mostly during peak-hours, may do additional stops in those stations.

Travel time modifications

If the travel time changes are caused by a difference in the stopping pattern, the causes are those listed above.

The most common travel time variation other cause is the use of a different, less performing, rolling stock, which make it impossible to run with the travel time scheduled in the reticular diagram. The reticular diagram should be designed either for a rolling stock that is available during the whole operational range or for the slowest rolling stock that will be used on a given link. However, mostly for prestige reasons, this is not always the case.

Time shifting of the train path

A time shift of a train path can have two main causes:

- The adaptation to a modification of another train path it interacts with
- To meet a specific local time requirement

If a train path has to grant transfers with a train path that is modified itself, it may be necessary to shift the full path. This is especially the case when a low level train has to grant a transfer to a high level train.

Time shifting may also be done to meet specific local requirements, e.g. when a train has to arrive in time for the classes’ start, it may be necessary to run the regular train path a few minutes earlier.

Train merging and split

In some cases, multiple unit train-sets are split in a station to end their journey at two different destinations. On their way back, trains are then merged in the same station. These operations require a longer stop to perform the splitting/merging operations. It may happen though, that at a given hour, the train doesn't split or that it merges/splits with another train, and that results in significant changes in station dwell time. Very often, those changes do not occur at the same time slice for the two opposite directions. The consequence is a loss of symmetry.

The usual causes for these changes are basically the same that lead to a difference in stopping patterns: the desire to make some links faster or transfer-less.

3.1.4 Cancelling low-demand off-peak services

In a coordinated regular timetable, the services are supposed to be repeated every hour throughout the whole operational range; thus the planned transfers are granted every hour. However, on some less important lines or links, mainly for budgetary reasons or due to very low demand levels, repetition is not perfect, with some train paths not running during off-peak.

Besides the loss of supply continuity for the customer, things start to become complicated when several such low supply lines (or services) come together at one station and must grant connections between them. It may happen that the set of the train paths that should be run to grant connections is not the one that corresponds to the demand pattern. The dilemma here is either to break the connections, or to not run the most "useful" train paths. Usually, in such cases, lack of coordination and “network thinking” lead to the sacrifice of the connections. The ideal would be to provide a larger volume of train paths than those necessary to grant the transfers or the local supply, which goes against the budgetary concerns.

3.2 Issues related with the design of the reticular diagram

Issues arise also by the very design of the high level reticular diagram. Mostly, those issues are related to some lack of coordination between services that may still be acceptable at the higher level, but create significant difficulties down the path, when it comes to plan lower level services or to build the 24-hours timetable. Two cases will be mentioned here:

- A network effect, where by combining two perfectly regular high level structures, we end up with the impossibility to design an acceptable structure for the lower level services.
- The philosophy of the "train path menu" (called "catalogue de sillons" in French), that results in a reticular high level diagram including several train paths that cannot be operated at the same time but that must be taken into account when building the “lover

priority" part of the reticular diagram. A particularly pernicious variation of this philosophy is when the reticular diagram is designed with several options for the same high level path.

3.2.1 Incompatibilities at he high level reticular diagram

Description and consequences

A high level reticular diagram may exhibit inconsistencies at the lower levels when it is build with components that are perfectly structured but ill-coordinated. As shown in Figure 4, in the area between Cannes and Nice there is one TGV service with a regular 30 minutes interval, and a second one (with TGVs coming from another origin than the first service) with a 60 minutes regular interval. Those services enter the area in such a way that the second TGV service is placed slightly before the first TGV service.

The high level reticular diagram that results out of the combination of those 2, perfectly regular services, makes it impossible to design a structured low level 15-minutes interval service for the regional trains. A 30-minutes structure is still possible, but a 15-minutes interval is only possible in one out of two 30-minutes time slice.

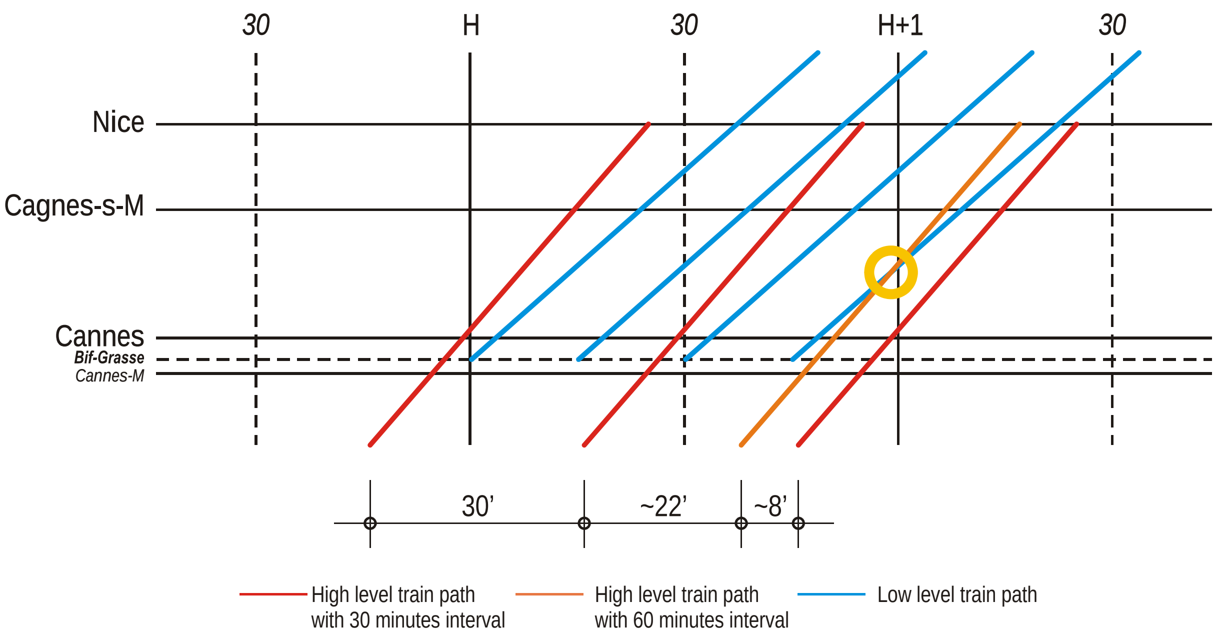

Figure 4: Collision between high and low level structure

This issue is exacerbated during 24-hours timetable planning, as both the 60-minutes interval TGV and the 15-minutes interval regional services are only needed during peak-periods, Off-peak 15-minutes regional services are still possible (but unneeded), as the 60-minutes TGV service is not run during off-peak.

Causes

The main cause lies in the insufficient coordination both between independent high level services and between the different planning levels. This case highlights the need for feedback loops between higher and lower level design of the services.

3.2.2 Including options on train paths within a reticular diagram

Description and consequences

To provide extra flexibility for services, reticular diagrams have been designed with several, mutually exclusive variations for the same service. The train operator is given the choice to select a particular option among those presented in the diagram.

Figure 5 shows the reticular diagram for the high level train paths between Dijon and Mulhouse. The main part of this link will be run on the new high speed line. But the accesses to the Dijon and Mulhouse stations use the conventional lines, interacting thus with the lower level trains.

This example shows very well the multiplicity of possible train paths. More precisely, there are four possible train paths between Dijon and Mulhouse but only two of them may run in the same time. However, when designing the low level services, the available capacity is restricted by all four train paths. Such a saturation of the reticular diagram with high level train paths, whilst way less trains will actually run, reduces significantly the possibilities for the lower level planning.

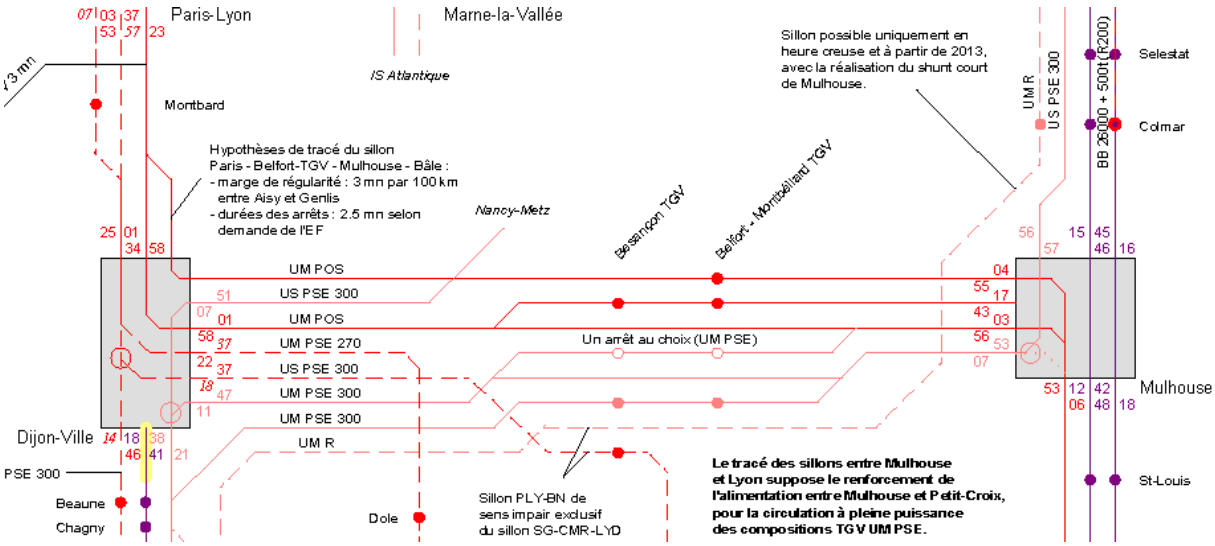

Figure 5: Excerpt of the high level reticular diagram for the Rhin-Rhône line (source : RFF)

When building the 24 hours timetable, the impossibility of activating simultaneously all of the train paths leads:

- on one hand to a large amount of spare capacity which can't be used for the lower level,
- on the other hand, to a highly irregular and imperfect low level supply as it is highly restricted by the high level's variations.

As a consequence, the low level services that could be planned in this case look more like a "custom made" than a real regular service structure.

Causes

Like in the previously described case, the main cause is a lack of coordination between the different planning levels. If there is no limit to the capacity share that can be allocated to higher level services and no coordination between high and low level planning, the lower level may end with a service hardly compatible to the needs.

Two more possible causes are the same than those presented in section 3.1.3:

- Demands for extra stops on high level trains issued by regional authorities
- A legal obligation to provide given performances or direct links

The difference being that, instead of having some exceptions to the reticular in the 24 hours timetable, the exceptions become part of the reticular diagram. The consequences on the lower level train paths, however, can be significant.

4. Summing it up and recommendations

As shown in the previous chapter, the reasons for difficulties when building the 24 hours timetable as well as their causes are various. The following table sums up the main identified consequences and causes:

Problem	Causes	Possible Consequences	
Diversions from the reticular diagram	- Fulfilling local demands incompatible with the low level service - Legal obligations - Heterogeneity of rolling stock - Modifications to another train path	On “high level” train paths	- Loss of regularity - Impossibility to grant transfers - Asymmetry of train paths
	- Fulfilling local demands - Compensating supply losses - Heterogeneity of rolling stock - Modifications on a high level train path	On “low level” train paths	- Loss of regularity - Impossibility to grant transfers - Asymmetry of train paths - Suppression of train paths
Reducing service in off-peak periods	- Lack of coordination between OAs - Insufficient budgetary resources	On “high level” train paths	- Impossibility to grant transfers - Loss of regularity
	-	On “low level” train paths	
Structural incompatibilities in the reticular diagram		On “high level” train paths	-
	- Lack of coordination between high and low level planning - No restrictions in capacity usage	On “low level” train paths	- Impossibility to build the desired supply structure
Reticular diagram providing train paths with options	- Legal obligations - Fulfilling local demands - No restrictions in capacity usage	On “high level” train paths	- Loss of regularity - Impossibility to grant transfers
	- Lack of coordination between high and low level planning - No restrictions in capacity usage - Need to adapt to the high level supply	On “low level” train paths	- Loss of capacity - Impossibility to build the desired supply structure - Impossibility to grant transfers - Heavy regularity losses

Summing it up one can say that the large majority of the problems encountered when building the 24 hours time table come from contradictorily demands by local authorities and from a lack of planning coordination between lower and high level services.

The undisputed priority in capacity allocation that is given to high level train paths, without corrective feedback loops, may become a major source for loss of quality on the lower level Generally speaking, two aspects are essential for an efficient timetable planning:

- Strict respect of the regularity principle becomes more and more important as we climb up the priority level; diversions from the reticular diagram for high-speed and long-route trains should be completely avoided.
- When building a coordinated regular timetable in a complex network, “network thinking” is essential. At every stage of planning, the consequences of decisions on lower level train paths should be taken into account.

Obviously, it is not that simple to materialize these two points in a system that it is locked in a decades-long culture of custom made solutions. However some concrete actions can be undertaken:

A **better coordination of the high level and low level planning with the local authorities** can make it easier to point out contradictory demands and will help reducing the exceptions on higher level services. In a coordinated regular time table, granted transfers in main stations provide high quality transport supply even for customers whose origin and destination have no direct links and, therefore, punctual exceptions become pointless.

The high level services planning should **make a restricted use of the capacity** and leave enough spare capacity for lower level services. Although it is normal that high level services get priority in capacity allocation, i. e., they are planned first and other services are planned subsequently, this does not mean that high level services have limitless access to the infrastructure capacity. The situation is similar to what one can have in a canteen: the first in line will be allowed to choose the best meal but not to take more than he needs, with nothing left for those behind. This particularly means that reticular diagrams including options on train paths should be avoided as much as possible.

A **regular interval train path should have priority on any other non-regular train path**, regardless from its level. This means that modifications on high level train paths are only possible when compatible with the existing non-modified regular interval train-paths, including the lower level train paths. This will ensure that local transportation supply is not scrambled by changes on interacting trains.

There is need for iteration between high and low level planning. The high level services' structure determines greatly the ones for lower level services. Feedback loops must exist to promote a global system optimization. This will not necessarily resolve all structural incompatibilities, but will help finding solutions when it is still possible.

The reticular diagram should only contain train paths that are feasible at all time. Designing the reticular diagram with the fastest possible rolling stock, whilst the latter is not available to cover the full operational range, should not be acceptable. The rolling stock availability should be organized in order to ensure constant travel times for all services.

These actions may help reducing significantly the problems encountered when it comes to the building of the 24-hours timetable (and also the reticular diagram design itself). A coordinated regular timetable is a system ill-adapted to exceptions. Any possible action aiming to reduce exceptions should seriously be considered and promoted.

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