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How regular is a regular-interval timetable? Theoretical foundations and assessment methodology

(STRC Topic: Highway and railway engineering)

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Abstract

Several European countries operate their train services on the basis of a regular-interval timetable. Those who do not, are gradually coming to this type of operation, too. Initially, choice of regular-interval timetable was mostly addressing operational concerns. Systematic operations help both increasing the network throughput, and smoothing the day-to-day tasks of the personnel. Separation between infrastructure management and train operations, induced by the European Union since the early 90s, and the future opening of the rail services to competition, pushes more and more infrastructure managers to operate their network on regular-interval timetable. Thus, the interest of measuring the degree of regularity.

The paper defines the different steps needed for going from conventional operations to fully coordinated regular-interval timetable (the so-called clock-face timetable). It shows the advantages for both the operators and the passengers, but also the limits and drawbacks of the approach.

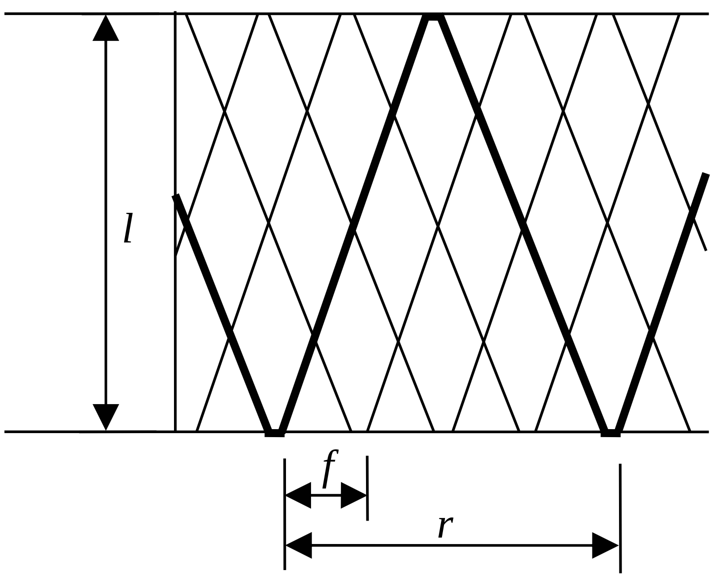
Then, based on those definitions, a methodology is developed to measure and assess the regularity of a timetable, on a line and over a full-scale network. This is because, in practice, implementation of a perfectly regular timetable is not possible and, perhaps, neither desirable. Constraints related to demand or to resources lead to cancel train paths during off-peak periods or to provide extra stops or longer dwell times and slower travel time during peak hours, for instance.

More specifically, the paper presents a methodology for determining the interval used to evaluate and compare reference and actual timetables, per train class and by corridors. Tolerances in measuring are extensively dealt with. A structure index is also defined. The developed methodology has been used to develop assessment software, which is presented in another paper (by Tron et Tzieropoulos), and applied to the French Rhône-Alpes Region's 2008 timetable. Finally, some general provisions to improve timetable regularity are given.

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

History

Traditionally, operation of metro, urban and - more generally - shuttle public transport lines has been based on a regular-interval timetable. That is, headway between services running in the same direction was set to a constant value, which depends on the demand level and the unit capacity of the vehicle/vessel/train.



Let be:

l: line length [km]

f: the time interval between services [h]

c_u: the unit capacity of a vehicle/vessel/train-set [pass]

K: the carrying flow (line capacity) [pass/h]

Then:

$$f = \frac{c_u}{K}$$

(NB: Substitute **passengers** by **tons** for freight operations)

Figure 1: Fundamental structure of a regular-interval timetable (space - time diagram)

Towards the last quarter of the 20th century, several European rail networks started applying the principle of regular-interval timetable to national services and at a network level, expecting gains in system productivity and network capacity that are induced by systematic operations ([2], [5][1]).

More recently, EU regulations required the separation of infrastructure management and train operations, to promote competition between train operating companies. This evolution adds an extra advantage to timetable planning based on regular intervals between successive identical services, in that it makes it possible for the infrastructure managers to "sell" in the market identical train paths differentiated only by their departure time. Infrastructure managers can thus eschew the risk of being reproached to favour one train operating company over the others [8].

Definitions

Daily operation of railways is based on a timetable, which basically sets departure and arrival times for all trains and for every serviced station. By planning similar trains at regular time intervals, railways aim to produce orderly services and offer them systematically. We came up with a set of nested definitions that, like a Lego construction, start with basic ones and combine them to build more complex ones.

[1] Numbers between brackets point to the reference list at the end of the paper.

In this context, a ***service*** is composed by [7]:

- 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 who 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 service on a route for a defined market segment.

Building a ***structured timetable*** comes to keep the service typology under control, i.e. [7]:

- to provide a finite (and not too high) number of services, which insures that the transport supply remains readable for customers and 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. The customer is still forced to consult the full timetable, although she can easily sort between fast, local, high-speed, etc.

A ***regular-interval timetable*** is a structured one and, what is more, with successive identical services planned at fixed time intervals [7]; 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.

The time interval may be of any value, and for shuttle services - where the vessel capacity cannot be easily modified - it reflects the round trip time on the route, or an integer fraction of it (Figure 1). In those cases, customers still need to consult the timetable, unless they make an extra memory effort. Where the vessel capacity can be adjusted (and this is generally possible with train sets), interval between services may be set to a round value, 60 minutes, for instance. In this last case, a customer only needs to remember the departure minute of her train: if it is 12, for instance, for the train leaving for town X, she knows she has a train available at 7:12, 8:12, 9:12, and so on.

A ***coordinated regular timetable*** (or ***clock-face timetable***) is a regular-interval timetable that fulfils three additional constraints [7]:

- 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 is defined at the line level, while a coordinated regular timetable covers a whole network.

Properties, advantages and drawbacks

Several properties are linked to the periodicity of regular-interval timetables. All services being periodical means that any particular operational task is also reproduced periodically: entering or leaving a station, train crossings, overtaking, all events occur periodically. If a conflict appears during timetable construction, it also occurs in every period; on the other hand, once it is solved, it is solved for good. Timetable planners can work out problems on an elementary time slice, the ***basic framework***, which equals the period. The basic framework is then repeated throughout the ***daily operational range*** (from, let us say, 6 a.m. to 10 p.m.).

Particular issues stem out of the periodicity, too: bottlenecks are located in particular points of the network instead of being split randomly across it. Requirements in infrastructure enhancement are located in particular spots and may become useless if ever the timetable structure changes. In cases of coordinated timetables, capacity is particularly stressed in major stations where all trains must enter and leave almost simultaneously to ensure transfers. Stringent requirements on uniformity (especially for the rolling stock) may also be seen by some companies as tremendously hard to achieve.

Regular-interval and coordinated timetables bear advantages in two fields: the technical operations, and the transport policy. Among the technicalities, one should mention besides easiness of planning the fact that systematization of operations alleviates most operational tasks, which both alleviates the workload on the ground and improves indirectly safety. Experience shows, also, gains in productivity thanks to a more rational use of resources and, namely, the rolling stock.

From a transport policy point of view, regular-interval timetable ensures time coverage of service through the day. Customers have the certainty that any given service is available at any moment. Coordinated timetables extend geographically the service coverage: by making it possible to transfer in main stations from any origin to all possible directions, passengers now that it is possible to reach "any" point in the territory, much like using their private cars.

Designing a regular-interval timetable

Timetables are usually built by highly specialised technical teams that have an extensive and detailed knowledge of the infrastructure internals, the rolling stock capabilities and limits, and the operational procedures. However, the timetable itself is the final "product" of a network and, as such, it is essentially the translation of the producing company's commercial strategy. Similarities are frequent with industrial productions, although in railways there are some quite critical differences, too.

Rail network production is a monopolistic process, without competition. Most often, customers (i.e. train operators or public authorities) are paramount in defining the service basics, that is, the transport policy. Thus, several players are involved in the game: infrastructure manager, train operating company, public authorities (sometimes several ones with conflicting objectives), and - possibly - lobbies.

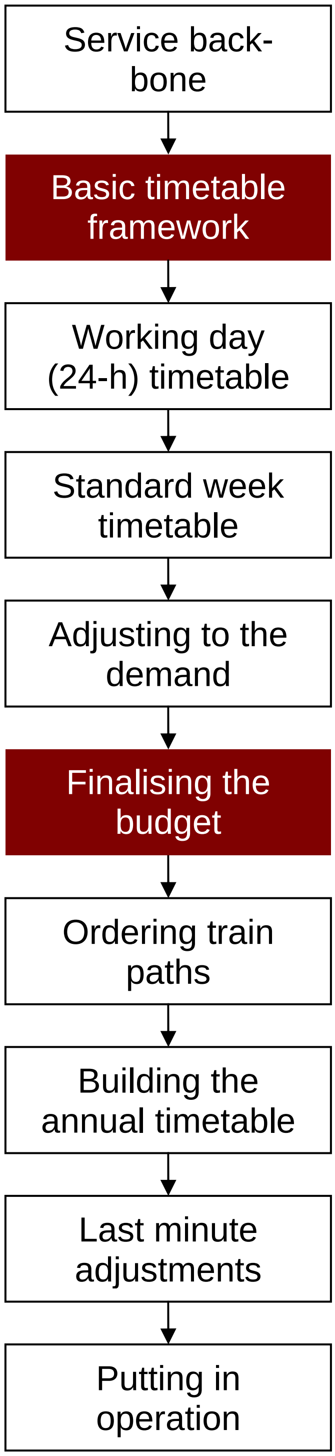


Figure 2: Step-by-step process

The process (Figure 2) that leads from an initial "idea" of the service to its materialization as a timetable is a step-by-step approach [8] 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 3).

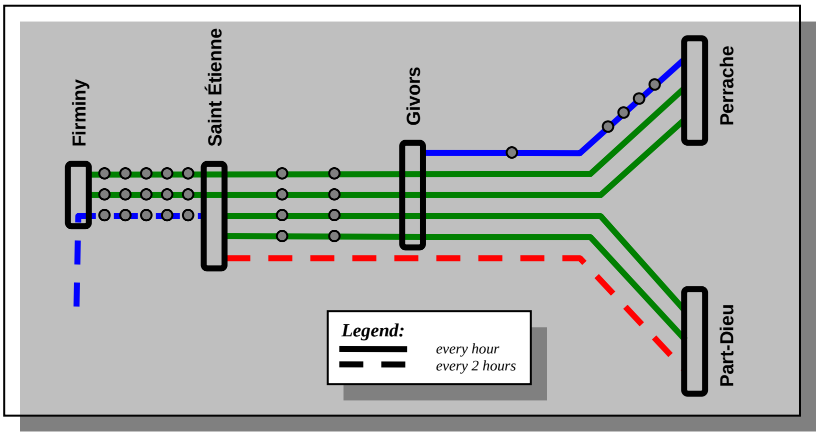


Figure 3: The services backbone

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 4). 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 and should also possible design timetables for the weekend days and/or standard holidays. Finally, the annual timetable takes also into account special days or events that usually of low or unique occurrence throughout the year and that correspond to special demand patterns.

At this stage, 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.

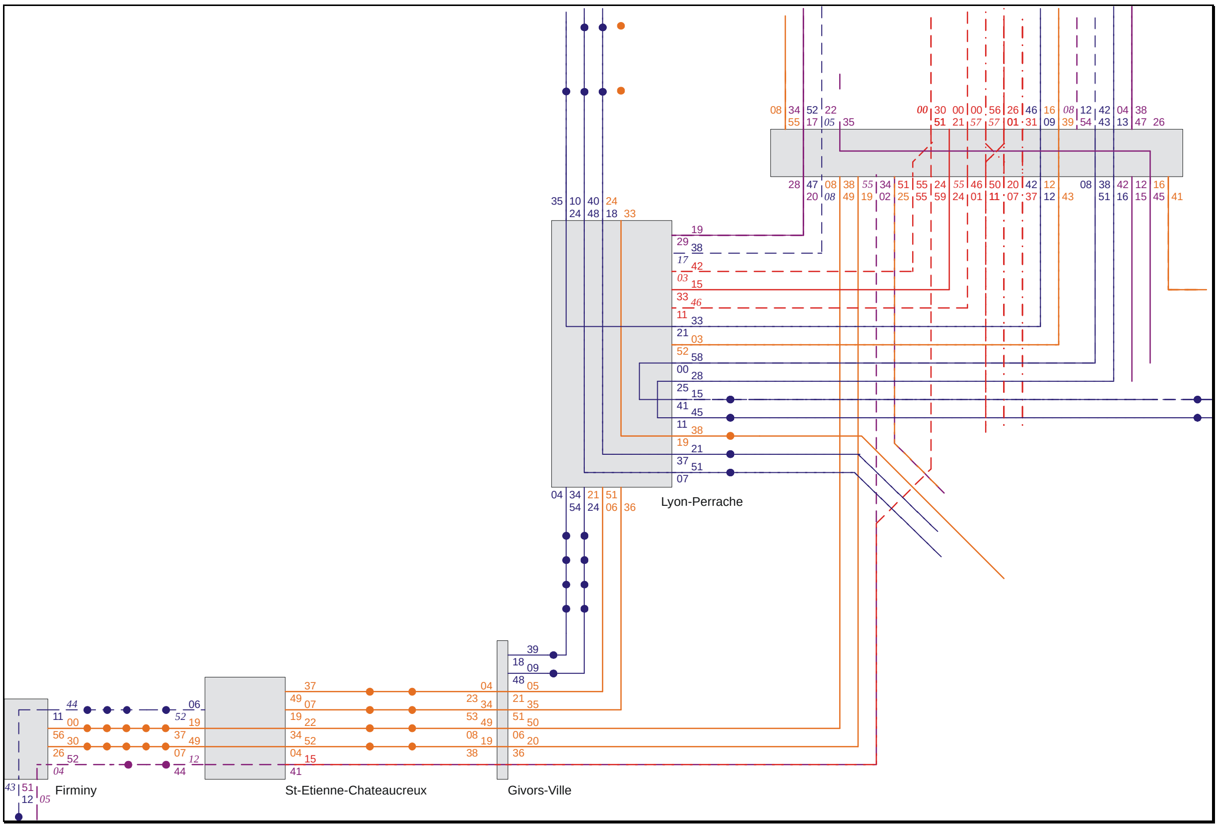


Figure 4: Reticular diagram

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

Setting-up assessment indicators

LITEP-EPFL has developed a methodology to assess the regularity of real timetables [7]. Two main indexes have been defined and can be further developed to capture structural differences among timetables:

- a ***structure index***, reflecting how well the different services comply with the service backbone;
- a ***regularity index***, reflecting how well the final timetable complies with the periodicity defined in the basic framework.

Analysis of a real timetable may show:

A) Regular train paths belonging to a given service, planned at regular time intervals
   a) produced by strictly replicating the train path of the reticular diagram, or
   b) being "loose" copies of the initial service, i.e. exhibiting slight differences either in travel times or in servicing intermediate stations

B) Gaps in regularity, i.e. missing train paths that should exist according to the periodicity of the service

C) Train paths belonging to a given service, but planned at irregular time intervals
   a) strictly complying (travel times and stopping patterns) with the service definition, or
   b) loosely replicating the initial service (with slight differences in travel times or stopping pattern)

D) Outliers, i.e. train paths that cannot be traced back to a given service, and which can be further distinguished depending their planning time as:
   a) within the normal operational range, or as
   b) at the fringe of the operational range, i.e. very early in the morning or very late in the evening (first and last trains)

Strict compliance with the service backbone or with the regularity (periodicity) is self-explained. To assess loose compliance or not compliance at all, one needs to define tolerance rules. Whenever differences lay within the tolerance thresholds, compliance is qualified as loose. If a given train path transgresses any tolerance rule, it is qualified as outlier.

The tolerance mechanism is composed by rules and values. Here is an example [1]:

- [0 min; + 4 min] interval for the departure time at the origin of the service
- [-4 min; +2 min] interval for the arrival time at the end station of the service
- no more than 1 extra stop or 1 stop less in intermediate stations compared to the service definition

In applying the methodology, setting tolerance thresholds should be left to the user. The set of rules, itself, should be fixed [6].

Assessment methodology

The assessment methodology is quite sequential. It involves 6 steps [7].

1) Set up a reference reticular diagram

This will be the reference frame in comparison with which assessment of compliance will be done. The reticular diagram includes implicitly full information on the service backbone, which makes it possible to compute both indexes: structure and regularity.

For a given timetable, the underlying reticular diagram may be known or not. In the latter case, some previous analysis is needed to reverse engineer the basic framework of an existing timetable, which may involve some arbitrary decisions.

2) Set up the tolerance thresholds

That may be as simple as accepting the default values shown in the previous section.

3) Define the O/D relations that will be used in computing the indexes

This means actually that the user needs, somehow, to model the network as a set of lines. This is largely arbitrary and reflects the user's view of the network. Subjectivity here is an unavoidable part of the game. Our experience shows, however, that analysts with fair knowledge of the network come up with pretty close, often identical solutions.

Knowledge of the service backbone may help, as some diametric lines in the reticular diagram may result from operational consideration and do not necessarily reflect functional objectives. Moreover, users may assign a weight on each line, to take into account volume of demand, or the strategic role that plays a given line.

4) Define the operational range for each O/D relation

A thumb rule may be that the operational range starts at the time of the first departure of a train path that belongs to a regular-interval planned service, and ends at the time of the last arrival at destination of a train path belonging also to a regular-interval planned service. Implementation for such a rule may be automated provided that assignment of a train path to a given service is also automated.

Alternately, and depending on the design of operations, the operational range may also be a fixed time interval, let us say from 6 a.m. to 8 p.m. Ideally, operational range should not be shorter than 13 hours.

5) For each O/D relation and for every train path included within its operational range, assign and label; identify also the missing train paths within a service

As seen in the previous section, we may have 4 labels for train paths:

- A, train paths belonging to a service planned at regular time intervals
- B, missing train paths that would exist if a service was planned at regular intervals
- C, train paths that can be assigned to a service, but not planned at regular intervals
- D, outliers that cannot be traced back to a service

Based on this qualification of train paths, we can define:

- a ***regularity index*** as been the ratio $$RI = \frac{A}{A+B}$$

- a ***structure index*** as been the ratio $$SI = \frac{A+C}{A+C+D}$$

- and, possibly, a reinforcement rate with the ratio[2] $$RR = \frac{C}{A}$$

Depending on the tolerance thresholds, measured regularity and structure may be strict (with 0 tolerance) or loose (with some tolerance allowed), as seen in the previous section.

6) Synthesize and present the results for the whole network

Both regularity and structure indexes may be computed for a line and for a service. In what it is proposed, there is already a first aggregation: indexes are computed for the full set of services on a given O/D relation. The issue of further aggregating the results

[2] If this particular ratio exceeds 50%, we face a methodological question: Are we really dealing with extra train paths aimed to enhance peak period services, or is it an imperfectly filled regularity planned at half the supposed time interval?

to end up with a unique index value for the whole network is left open. The development team feels that such an additional aggregation will result in unacceptable information loss and that it is actually purposeless. Transport policy makers are sufficiently aware and capable of analysing results on a per line basis; providing a unique performance indicator offers no significant gains in making an overall assessment of the situation.

Structure and regularity: usage, interpretations and limits of the methodology

The use and the interpretation of the developed indexes may be explained by means of some examples. To maintain clarity in the following examples, we deal with a line offering a single service. Graphically, both indexes may be represented using 2 parallel gauges (Figure 5).

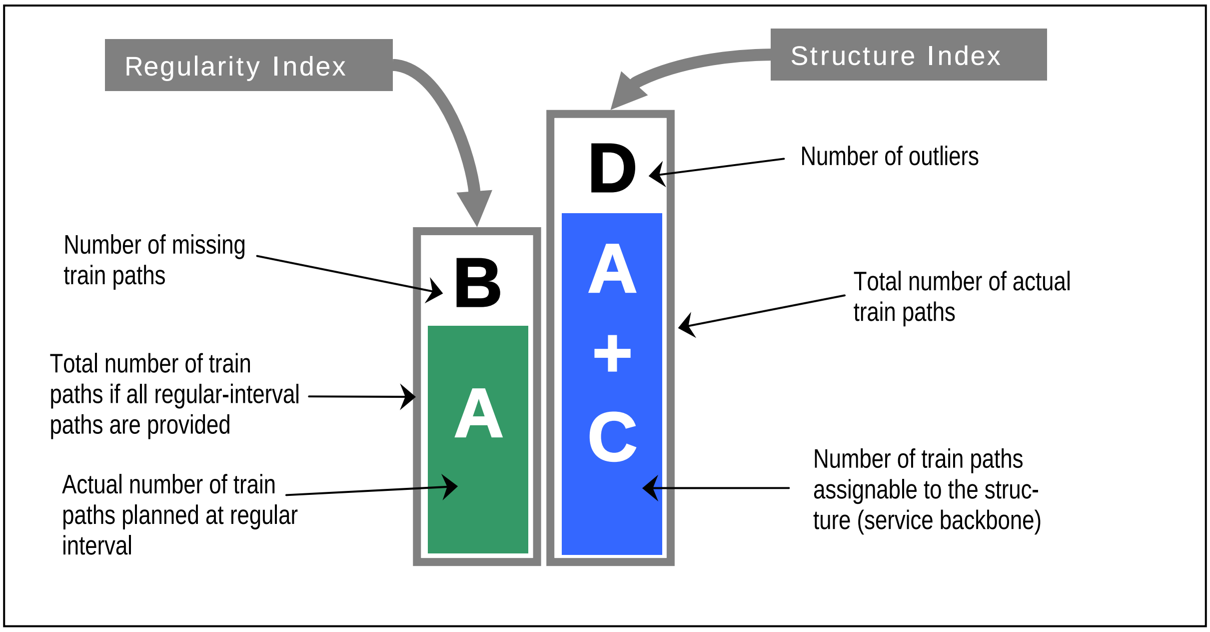


Figure 5: Reading key for the regularity and structure indexes

Timetables perfectly complying with the regular-interval principle exhibit both indexes at 100%. By cancelling 2 off-peak train paths (at 10 a.m. and 3 p.m.), the regularity index drops to 86%, but the timetable structure index is still 100% (Figure 6).

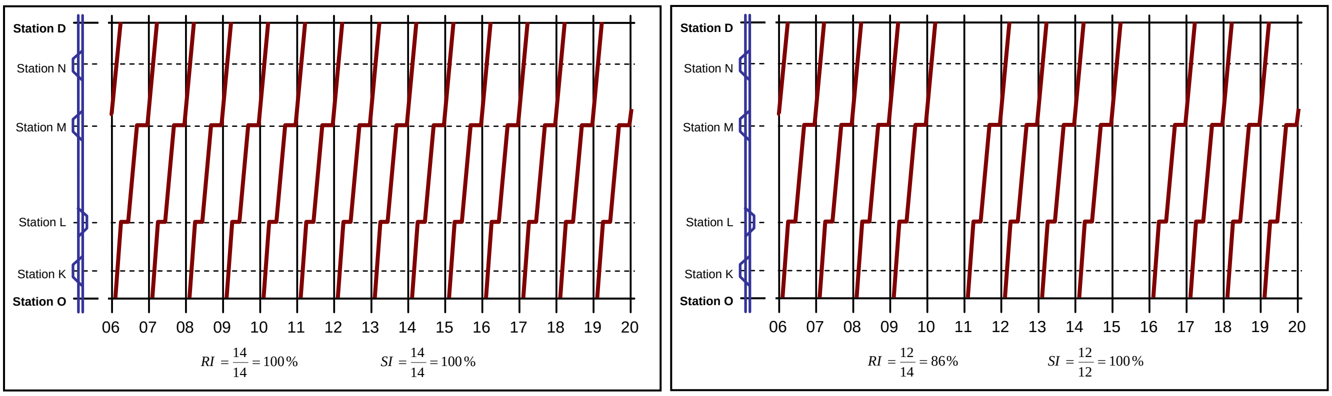


Figure 6: Effect of cancelling of 2 off-peak train paths

Adding extra trains to enhance peak-period service (at 6:30 and 7:30 a.m., and 4:30 and 5:30 p.m.) produces no change in any of those 2 indexes (Figure 7). The reinforcement rate, however, jumps from 0% to 33%.

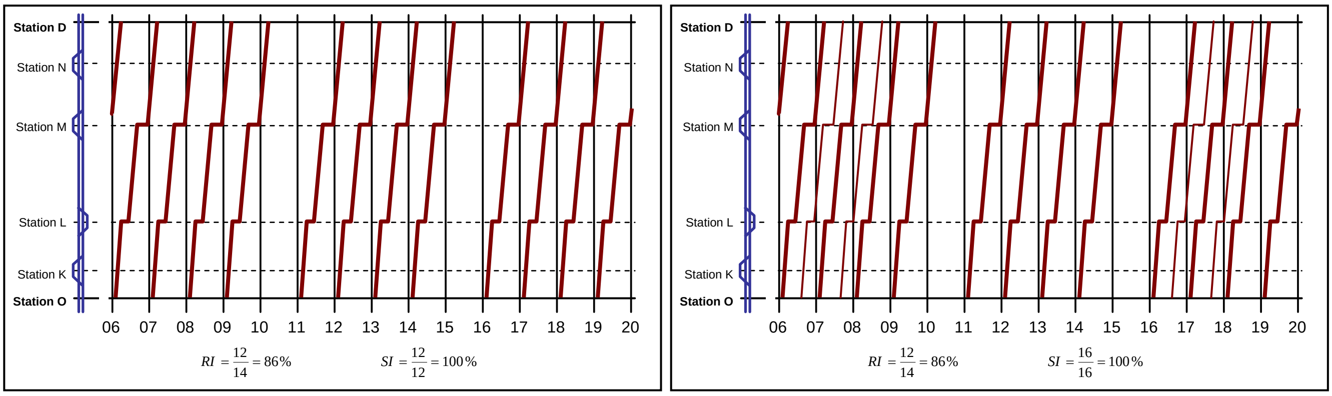


Figure 7: Effect of adding 4 train paths for extra peak services

Now, if those 4 extra trains provide additional stops to stations K and N, they don't comply with the structure anymore. That results in a drop of the structure index to 75% level (Figure 8).

This last case highlights one of the limits of the methodology. Actually, the 4 extra train paths, as designed in Figure 8, are identical and can be assigned to a new service (i.e. local trains as compared to the initial fast trains service). Counting them as outliers falsely reduces the structure index.

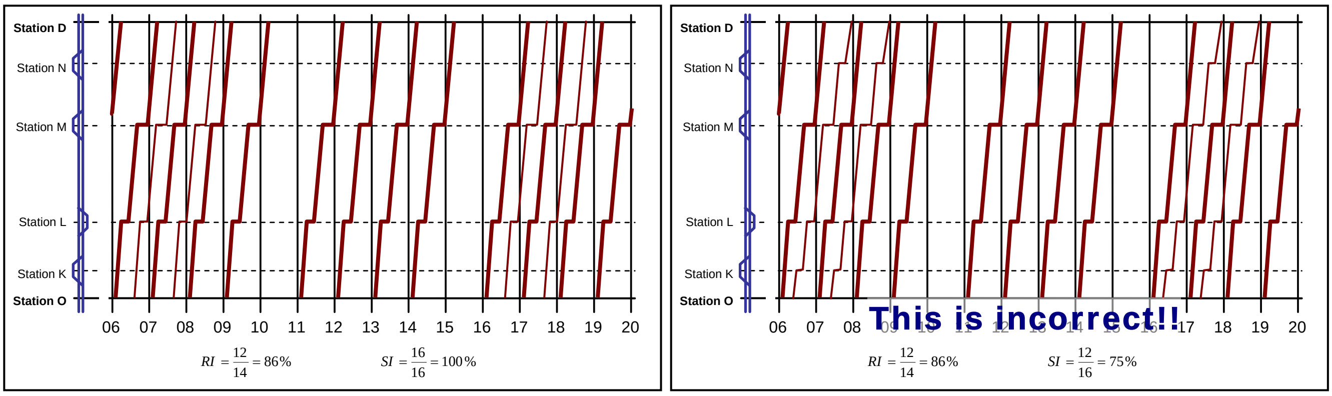


Figure 8: Effect of falsely taking into account 4 extra trains

What is really at stake here is that a second service has been added to the timetable, although, as it is restricted in peak periods only, with very low regularity (providing only 4 out of the 14 possible train paths). Counting correctly its effect should cause a drop to the regularity index and not to the structure one. By counting those 4 extra trains as a second service, the regularity index drops indeed to 57% (12+4 planned trains for a possible total of 14+14 train paths), while the structure index remains at 100% (Figure 9).

The issue raised here is related to the arbitrary identification of the services. Preventing it in this particular case is easy enough: one needs only to be systematic in service identification while reverse-engineering the service backbone. The software package presented in [6] does precisely this. However, in most complex cases and with the tolerance thresholds set to non-zero values, the issue is harder to settle, and user's decisions here are critical.

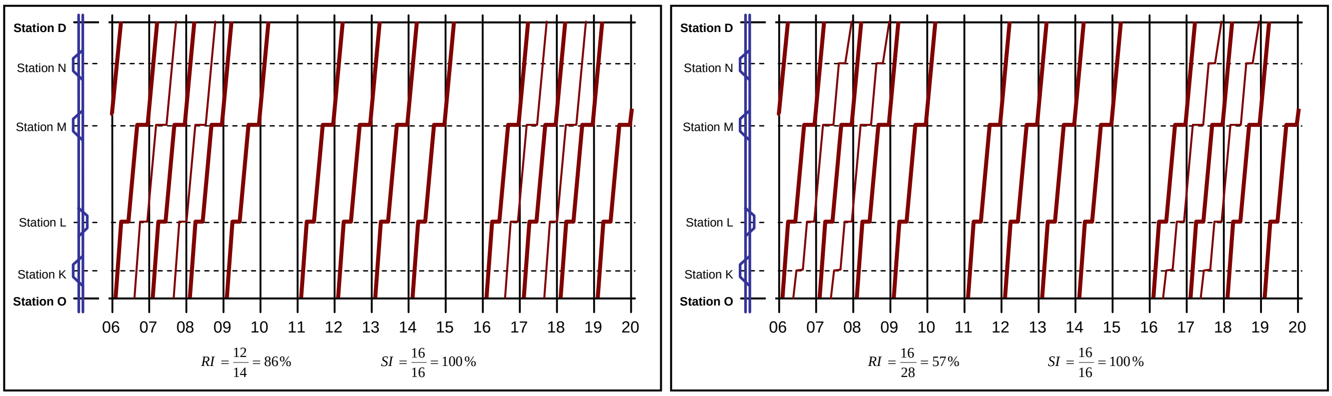


Figure 9: Correctly taking into account the effect of introducing 4 extra identical train paths

The case would have been different if the 4 extra train paths were real outliers, i.e. each one providing a unique service (Figure 10).

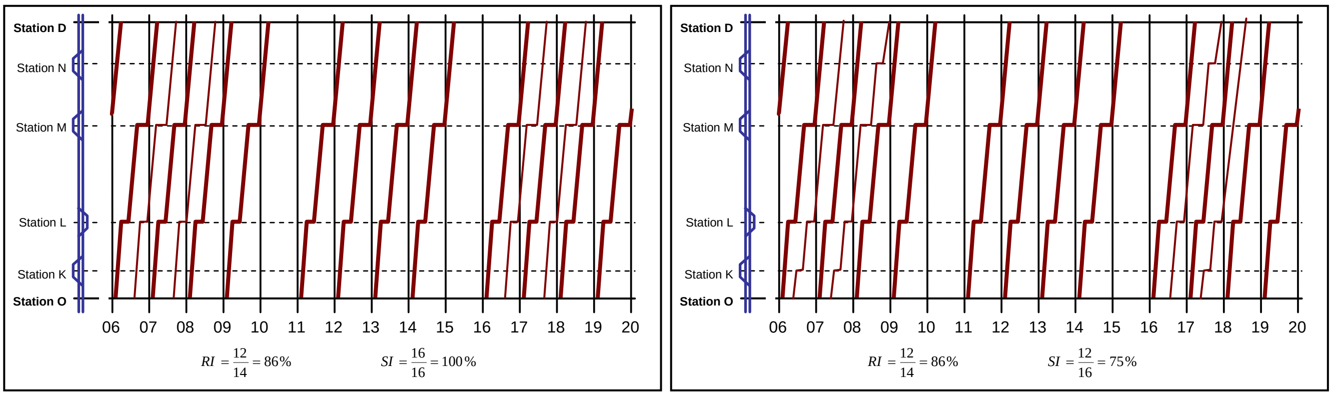


Figure 10: Effect of introducing 4 "real" outliers

Conclusions

Assessing the regularity of a real-life timetable is quite an important issue. As already mentioned, providing seamless presence of the railways services is a core objective for a regular-interval timetable. Users should trust the system and be sure that the service is available, all day long, without having to go through reading and decoding timetables. Breaches in regularity reduce the system's trustworthiness: customers need consulting the timetable prior to using the services.

Real life constraints however result in a more-or-less distorted application of the fundamental regularity that is initially conveyed by the basic timetable framework. Actual timetable often display some irregularities. It is important for the transport authority to assess how well the initial objective of regularity has been achieved through its actual implementation in the operational timetable. Here lies the interest of providing a general methodology to fast and efficiently measure the regularity.

The developed methodology aims to be eventually implemented in an operational tool, to make those assessments practical. Policy makers can use it to assess in which extend their objectives have been completed and, also, to be able to compare alternatives.

To be able to set up the methodology, and to design the subsequent tool, the developing team had first to go through a systematic effort of definitions, by taking again the theoretical foundations of the so-called "clock-face timetable". There are some limits, inherent to the methodology, that reflect limits due to those very definitions: at which point a given train path stops being an outlier and becomes member of a train family that provide systematic but scarce (some trains a day) service? There is not an undisputed way to settle this issue, which eventually requires expert user's involvement.

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