A model for the evaluation of basic interval timetables and their effects on the carrying capacity of the stations

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Introduction

The basic question in this research is: does the basic interval timetable allow the full utilisation of the railway infrastructures?
The importance of this question is progressively increased by the extension of the timetables market resulted from the application of the European Directive 440/91 concerning the separation between infrastructure and trains owners.
Coming to the key topic it is well known that the main peculiarity of the basic interval timetable is the synchronism of the connections at the nodes of the network (interchange stations).
Moreover, the basic interval timetable is mnemonic and homogenous and its articulation is only related with the different train classes (Inter-city, inter-regions, regional, etc.); at the same time the manoeuvres at the stations are reduced and the rolling stock is intensively employed.
Nevertheless the resulting timetable structure is rigid: departure times are periodic and travel times are symmetric, each destination may be reached by changing trains theoretically without the help of a timetable book for the trip planning.
The optimisation of a basic interval timetable is based on the research of the minimum waiting times at the stations and the optimisation processes are usually faced with the linear programming with variables consisting on continuous and whole numbers, whose practical applications are usually fairly complex.
In the present paper a procedure for the analysis of possible alternative basic interval timetables for a complex railway network based on a combinatorial procedure is presented. It is based on a simulation routine building up a set of possible network timetables on the basis of:
   i) the travel times calculation on the network links;
   ii) the correspondence to be granted in a set of stations;
   iii) the operational rules to be respected (headway, movements compatibility within the stations, etc.).
The quality of the alternative timetables is measured by means of the typical synthetic indicator (mean waiting time at the stations).
Anyway, the specific aim of the present work is the study of the interaction of the basic interval timetables with the carrying capacity of the stations.
In fact, from the explication of this interaction it is possible to identify useful elements in order to answer the initial question about the full utilisation of the infrastructure carrying capacity.
The problem may be theoretically faced by means of synthetic, analytical or simulation models.
Due to the need of detailed input data for the simulation models and the often complex use of its results, the effects of different timetable structures may be more effectively evaluated by means of specifically upgraded synthetic and analytical models.
The whole procedure has been applied at a case study consisting on an extended network (about 2000 km) in the central Italy.

2. Basic interval timetable concepts

The well known key concepts of the basic interval timetable are:
- continuous, regular and periodic repetition during the whole service period \(RT\) (normally with a period of 30 to 120 minutes for inter-city services and lower for urban or sub-urban services);
- symmetric structure with the same running times on the line and waiting times at the stations (including the train crossing on the single track lines), resulting in quite strong operation constraints;
- symmetric cycle in each node with arrival and departure times complementary to the period (e.g. a train leaving at the minute \(x\) from A arrive to A at the minute \(RT-x\)), that allow to ensure all the possible correspondences.

3. Mathematical model

The proposed methodology is based on a timetable simulator producing, at the end of each interaction, a timetable structure compatible with the constraints imposed by infrastructure and operation.

In fact the circulation on a line or in a station require the corresponding infrastructure occupation and interdiction for a time related to the distance between the trains and the line/station sections release.

In figures 1 and 2 the circulation on double and single track lines with occupied and interdicted areas (on a space-time diagram) are represented.

In figure 3 an example of the train distance constraints is represented (\(d\) is the time distance between the trains and \(s\) is the maximum blocks section length):

\[ X_{a,j+1} - X_{a,j} > d \]  \hspace{1cm} (1)

Figure 1: circulation constraints on a double track line station
The various timetable structures are obtained by the random definition, within the period, of the departure time from the node representing the network origin; this procedure allow the generation of a wide set of timetable structure, also for the more simple networks. In order to define the optimal timetable within a set of possible structures, at the same time limited and statistically representative, the iterations number is limited by an interval defined for an indicator related to the passenger waiting times. Once the selected timetables set is defined, it is possible to identify the structure more respondent to the specific objectives (e.g. minimum waiting time in all the nodes, minimum waiting time in a set of strategic nodes, etc.). The model steps are summarised in the figure 4 flowchart.
The basic database is organised in matrices containing graphs, running times of various trains and correspondence nodes.

The simulation model produces the trains timetable and calculates the single waiting times at the stations for correspondence.

The Mean Waiting Time (MWT) is a synthetic output parameter, which allows to compare alternative timetable structures.

A further useful output parameter is the Mean value of the MWT calculated on the iterations carried out (MMWT), which allows to investigate the stability of the results and to determine the minimum Number of iterations (N) capable to reduce the Confidence Interval (CI) of its Variance (V) within the limit of the Maximum Tolerated Error (MTE) for a defined Reliability Level (RL).
4. Model application

In order to test the validity of the proposed model an application to a case study represented by a network in the central Italy, limited by the nodes of Bologna, Pescara and Roma (figure 5), has been developed [1].

The main lines included in the network are:
- Roma – Orte – Firenze – Bologna (double track);
- Orte – Falconara (partially single track);
- Bologna – Falconara – Ancona – Pescara (double track);
- Pescara – Roma (single track).

The considered basic interval services are:
- first level Intercity trains Roma – Bologna;
- second level Intercity trains Roma – Firenze and Roma – Ancona;
- interregional trains Bologna – Pescara and Roma – Pescara.

The model has been applied to four different scenarios (timetable structures) with increasing demand level on the network and corresponding trains frequency on the lines.

For the stability analysis a $MTE$ of 1 minute and a $RL$ of 98% have been considered.
The results of the application are summarised in Table A.

Table A: results of model application to the case study network

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<tbody>
<tr>
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<td>60</td>
<td>60</td>
<td>76</td>
<td>35.8</td>
<td>28.7</td>
</tr>
<tr>
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<td>30</td>
<td>60</td>
<td>75</td>
<td>32.7</td>
<td>23.7</td>
</tr>
<tr>
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<td>60</td>
<td>50</td>
<td>30.8</td>
<td>26.2</td>
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<tr>
<td>T4</td>
<td>30</td>
<td>30</td>
<td>38</td>
<td>24.3</td>
<td>19.9</td>
</tr>
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The minimum $MWT$ decrease progressively with the increase of trains frequency, with the single exception of T3 structure, which results not effective. The number of iterations required to reach the solutions stability decreases with the increase of frequency too.

In figure 6 the trend of $MMWT$ during the simulation is shown: the process stops when the $CI$ verification is satisfied.

5. Effects on stations carrying capacity
The problem has been approached by comparing the residual carrying capacity of one station with the different timetable structures. The residual carrying capacity has been evaluated by means of the models proposed by Potthoff [4] and Giuliani, Malavasi, Ricci [2].

The first is a synthetic model based on the generalisation of the carrying capacity evaluation method developed for a simple node occupied by a train once for a time $T$ to a complex node contemporary occupied by a Mean Number of trains:

$$MN = T N^2 / \Sigma (NI NJ)$$

(2)

Where $TN$ is the total number of trains running in the station during the reference period $RT$ and $NI$ and $NJ$ are the number of trains running on the incompatible routes.

The $MN$ trains occupy the routes for the Mean Time

$$MT = \Sigma (NI NJ TIJ) / \Sigma (NI NJ)$$

(3)

Where $TIJ$ are the single interdiction times of the route $I$ on the route $J$.

The probability of train arrivals during the analysed period is supposed constant. The residual carrying capacity may be expressed by the index:

$$RCC' = [RT - TN MT / MN + \Sigma (NI NJ TIJ^2) / 2 RT] / RT$$

(4)
The second model is a more analytical one based on the construction of occupation and interdiction diagrams based on an assigned timetable for each station route and on the identification of the residual windows of Free Time (FT) available for the circulation of additional trains. The aggregate expression of the residual carrying capacity index is in this case:

$$RCC'' = \frac{RT - \sum (FTK)}{RT}$$  \hspace{1cm} (5)

Where the summation is extended to all the $K$ windows available for the circulation of an additional train.

In figure 7 the values of residual capacity obtained for a transit station with the two models for various traffic density (frequency of trains on the connected lines) are reported.

**Figure 7: residual carrying capacity of a transit station for various traffic density**

The residual carrying capacity with the basic interval timetable is moderately higher than with a different (not cyclic) timetable structure. Moreover, the differences between the results obtained by means of the two carrying capacity models are limited for the case of the basic interval timetable, because the hypothesis of constant probability of the trains (typical of the synthetic model) suites well with the regular trains distribution during the analysed period, which is a peculiarity of the cyclic timetables themselves.

**6. Final Remarks**

The main result of the present research is the set up and the case study application of an extensive and effective simulation procedure for the analysis of basic interval timetables, with the specific aims to:

i) optimise the correspondence at the stations;

ii) verify the effects on the carrying capacity of the stations.
This second issue provides a contribution to answer the key initial question concerning the full utilisation of the infrastructure. Nevertheless the research activity in this field is still open and the ongoing developments are particularly oriented to:

i) the extension of the input–output sensitivity analysis (e.g. the calculation of the running times on the lines and in the stations);

ii) the assessment of the stations carrying capacity with different cyclic timetable structures (e.g. with progressively increasing frequency);

iii) the application to more connected networks, including a larger amount of correspondence nodes;

iv) the evaluation of the carrying capacity for different station lay-outs (e.g. terminal stations).

References


