A multi-objective programming model for timetables on corridors integrating macroscopic and microscopic approaches

Ángel Marín†a, Esteve Codinab,*

aInstitute of Research in Technology, Pontificia Universidad de Comillas, Madrid
bUniversitat Politècnica de Catalunya, Statistics and Operational Research Department c/Jordi Girona 1-3, Campus Nord, C5 Building, 08034 Barcelona, Spain

Abstract

This paper proposes an integrated framework for timetable design that meets the needs of service planners, who usually adopt a purely macroscopic point of view toward the demand requirements and conflicts that these timetables may cause at stations due to their particular configurations and structures. Service planners may not take these aspects into account, which require a microscopic analysis of the structure of the stations, considering possible conflicts at platforms and/or internal junctions. To this end, the proposed integrated model guarantees feasible timetables while balancing performance indexes for the interests of passengers and operators. Specified bounds are maintained for the differences between service planners optimal timetables and those that are operational at stations. The resulting problem is modeled as a multi-objective Mixed Integer Linear Programming problem. The model can be solved with sufficient accuracy and in a reasonable amount of computing time, as shown by tests on the Madrid-Zaragoza-Barcelona high speed railway network. In this case, we perform a Pareto frontier analysis and find that the problem is well-posed. In addition, the previous model forms the basis of a heuristic procedure for obtaining timetables that avoid, as much as possible, conflicts and concentrations of arrivals/departures at/from stations, thus allowing for improved timetable recoverability and robustness in case of unexpected disruptions.

Keywords: Train timetables; feasibility; robustness; macroscopic; microscopic; multi-objective.

1. Introduction

With the growth in railway travel demand, rail transport managers must produce better and faster tools to provide viable train schedules, and this requires more accurate models for evaluating available capacity and reducing calcu-

* Corresponding author.
E-mail address: esteve.codina@edu.edu

† To the memory of Ángel Marín, friend and colleague, who could not see the final version of this paper finished, as he sadly passed away on July 4th 2019.
lation times. Optimization problems for routing and programming passenger train schedules are a component of the tactical and operational stages of decision-making processes, as the outputs of tactical models constitute the inputs of operational models. The Train Timetabling Problem (TTP) is treated at the tactical level, and the ideal train schedule is the basis for solving the TTP at the operational level. At the tactical level, the stations are treated as a single node for schematically describing passenger journeys, and the infrastructure is represented in a simplified form by considering only segments that join consecutive stations. However, at the operational level, a detailed description of the railway infrastructure is needed in order to manage the operational conflicts of trains arriving at stations and intersections. The first TTP objective is to build a feasible timetable. A table of schedules is feasible if all the scheduled train circulations are free of conflicts and observe the limitations of railway station capacity and safety. These aspects of the problem are considered in the approach mentioned as MICRO. On the other hand, the MACRO approach takes into account the needs and interests of the demand (passengers) and the railway operators. Thus, from this point of view, there are two main conflicting objectives to be pursued when planning the TTP, namely: (i) optimizing passenger service (passenger satisfaction); and (ii) minimizing the operational costs of the railway system (operator interests). In order to meet the needs of (i) and (ii), this paper presents a combined micro-macro model for setting timetables on a railway network by means of a multiobjective macro-micro approach.

**Brief state-of-the-art.** An extensive review of TT problems is given in Cacchiani and Toth (2012) and Kroon et al. (2009), specifically in terms of implementing timetable optimization models for Netherlands Railways. These works follow a macroscopic approach and use safe separation time constraints for crossing and meeting trains. These constraints cannot guarantee conflict-free train routes, and they are imposed at the expense of relatively large buffer times. Interactions with the line planning step are reviewed in Schöbel (2012).

Microscopic approaches are followed by Rodríguez (2007), who proposes two constraint-programming algorithms that consider both fixed-speed and variable-speed models. The latter case does not consider proper speed variation dynamics but instead focuses on traveling time constraints while keeping them coherent with train braking and acceleration in case of conflict. Transformations between micro and macro models are also studied in Schlechte et al (2011). Pellegrini et al. (2015) propose a MILP formulation for the real-time Railway Traffic Management Problem (rtRTMP) and, in Pellegrini et al. (2017), the MILP formulation is oriented toward saturation problems. They find the optimal solution to the rtRTMP by allowing train routing along all possible routes in the control areas. They solve instances by representing the infrastructure in terms of track-circuits, which represent the infrastructure on a time-expanded network with fine granularity. Through this formulation, they can incorporate constraints which allow it to be used in a rolling-horizon framework. Dollevoet et al. (2015) address the delay management problem by developing a model that includes station capacity. This model allows a rescheduling of the platform track assignment. Furthermore, they propose an iterative heuristic in which the delay management model is initially solved with a fixed platform track assignment, and then this platform track assignment is improved at each step. Besinovic et al. (2015 and 2016) propose a hierarchical framework for TT design, where separate microscopic and macroscopic models of the network work interactively. The framework performs an iterative adjustment of train running times and minimum headways until a feasible and stable TT is generated at the microscopic level. The macroscopic model optimizes a trade-off between minimal passenger travel times and maximal robustness by using a MILP formulation that includes a measure for delay recovery, which is computed by means of an integrated delay propagation model.

The above references tackle the problem of establishing robust train schedules that consider the interaction between macro and micro models. This article, on the other hand, combines a micro-macro model that simultaneously minimizes passenger disutility and other operational costs at the macroscopic level while examining the possible conflicts that may arise from the configuration of train services at stations. We take a multi-objective programming approach to studying the interaction between both models while also analyzing various realistic scenarios together with the model responses to the station operators.

### 2. Macroscopic representation

Let us consider a railway network containing a set of stations $S$, and let $W$ the set of origin-destination pairs with passenger’s demand to be satisfied. An origin destination pair (o-d pair in the following) will be denoted by either a double index $(p,q)$, $p,q \in S$ or a single index $\omega = (p,q) \in W$. Let $T$ be the set of services on the railway network
in a time period \([\tau_a, \tau_e]\) used by the passengers, let \(T(s)\) be the set of services incorporating station \(s\) into its route, and let \(T_\omega\), with \(\omega = (p, q)\), be the set of services joining origin \(p\) to destination \(q\). It will be assumed that the time period is subdivided into a set of time subperiods \(J\). Also, let \(J_\omega\) be the set of time intervals for o-d pair \(\omega \in W\). The demand model will be assumed inelastic and therefore is not affected by the network congestion. Let \(\chi_{\omega,j}\) be the number of passengers for o-d pair \(\omega = (p, q)\) in \(W\), who are willing to reach destination \(q\) at time subinterval \(j \in J\) and let \(\chi = \sum_{\omega \in W} \sum_{j \in J_\omega} \chi_{\omega,j}\) be the total demand.

Services \(t \in T(s)\) will be assumed to be planned from a macroscopic point of view with an arrival time instant \(\alpha_{t,s}\) and a departure at time interval \(\delta_{t,s}\) at station \(s \in S\). If \(x_{s,j}\) is the dwell time and \(k_{t,s}\) is the minimum dwell time at station \(s\) for service \(t \in T(s)\), then the following constraints should hold:

\[
\begin{align*}
\tau_a \leq \alpha_{t,s} & \leq \delta_{t,s} \leq \tau_e & \forall t \in T(s), \forall s \in S \quad (1) \\
x_{t,s} = \delta_{t,s} - \alpha_{t,s} & \geq k_{t,s} & \forall t \in T(s), \forall s \in S \quad (2)
\end{align*}
\]

The following sets of constraints, (3) and (4), consider the sequencing of trains. For simplicity a minimum time \(h\) between consecutive services has been considered, although they could be specific for each track circuit. Let \(T(s)\) be defined as the set of pairs of services assigned to the same unit which end and start at station \(s\), i.e.: \(T(s) = \{(t, t') : s = s^+(t) = s^-(t'), t, t' \text{ same track}\}\). Arrival and departure times of services \(t, t'\) assigned to the same unit must verify:

\[
\begin{align*}
\alpha_{t,s} + x_{t,s} + h & \leq \delta_{t,s} + M(1 - e_{t,t'}), \quad e_{t,t'} \in \{0, 1\} & \forall (t, t') \in T(s), \forall s \in S \\
\alpha_{t,s} + x_{t,s} + h & \leq \delta_{t,s} + Me_{t,t'} & \forall (t, t') \in T(s), \forall s \in S \quad (3) \\
\alpha_{t,s} + x_{t,s} + h & \leq \delta_{t,s} + M & \forall (t, t') \in T(s), \forall s \in S \quad (4)
\end{align*}
\]

In the model, passengers are assumed to choose the right service for reaching their destination by seeking to minimize their disutility or generalized cost. This disutility of traveling can be considered a function of various features of the trip: the travel time spent on board the train unit, the time in advance that they must be at the station waiting and the delay of arrival at their destination. The generalized cost of passengers for o-d pair \((\omega, j)\) and the delay of arrival at their destination. The passenger’s generalized cost for each \((\omega, j)\) and each service \(t \in T\) (or passenger disutility) is assumed to have the following expression:

\[
c_{\omega,j} = \xi_{\text{pass}}(z_{\omega,j} + \beta_E \eta_{\omega,j} + \beta_L \gamma_{\omega,j}) & \forall \omega \in W, j \in J_\omega, t \in T \quad (5)
\]

where \(\xi_{\text{pass}}\) is the perceived value of the in-vehicle time and the parameters \(\beta_L, \beta_E \geq 0\) are, respectively, the weights for the effect of lateness and earliness on the generalized time.

Then, because of specific questions relative to the configurations of station and the traffic in their facilities, the actual arrival and departure time instants will be denoted by \(a_{t,s}\) and \(d_{t,s}\) respectively. The differences between planned and actual arrival and departure times can be expressed by means of the following non-negative variables, \(a_{t,s}, d_{t,s}, \delta_{t,s}, \delta_{t,s}\), which will be referred to as shifts.

\[
a_{t,s} = \alpha_{t,s} + \alpha_{t,s}^+ - \alpha_{t,s}^- , \quad d_{t,s} = \delta_{t,s} + \delta_{t,s}^+ - \delta_{t,s}^- & \quad \text{for} \quad t \in T(s), s \in S 
\]

We denote by \(\zeta_{\omega,j}\) the time instant at which these passengers wish to reach their destination. In order to set the passenger assignment to the services that may deliver them to their destinations, the binary variables \(\pi_{\omega,j}^t \in \{0, 1\}\) will be considered. If \(\pi_{\omega,j}^t = 1\), then passengers willing to get to their destination at time subinterval \(j \in J_\omega\) will choose service \(t\) and if \(\pi_{\omega,j}^t = 0\), then they will not choose service \(t\). It will be assumed that the actual arrival time at their destination and the desired arrival time at their destination will be related in the following way:

\[
M(1 - \pi_{\omega,j}^t) + \eta_{\omega,j} + \alpha_{t,d(\omega)} \geq \zeta_{\omega,j} \geq \alpha_{t,d(\omega)} - \gamma_{\omega,j} - M(1 - \pi_{\omega,j}^t) & \forall \omega \in W, j \in J_\omega, t \in T_\omega \quad (7)
\]

Next, the first constraints (8) select the service \(t\) with the smallest generalized time for each passenger \((\omega, j)\). The second constraints (9) consider that if a passenger group is not attended to in the planning period (by fleet capacity), then the following service will be assigned after the planning period. The third constraints (10) establish that the passengers \((\omega, j)\) use a single service. The fourth constraints (11) establish that passengers do not exceed the service capacity. The fifth constraints establish the minimum occupation level for each service.
In the above constraints (8) to (11), \( M \) is a large constant, \( \hat{k}_s, \hat{k}_t \) are the passenger capacity and minimum occupation of a single train unit of service \( t \), and \( p_{o,t} \) is the cost of making the trip for \( o-d \) pair \( \omega \) at time \( j \), without using the railway.

The macroscopic model represents the operator’s goal to minimize his operational loss and the passengers goal to receive the best possible service for traveling from their origin to their destination at the desired time. By taking a multi-objective approach, both objectives are taken into account. The rail objective function is composed by the revenue calculated using the ticket price multiplied by the number of passengers, minus the operational costs and the cost of trains kept waiting at stations in order to avoid conflicts with other services. The normalized index of operational rail costs, \( Z_{\text{rail}} \), is defined by:

\[
Z_{\text{rail}} = |T|^{-1}|S|^{-1} \left\{ \sum_{t \in T} \sum_{\omega \in W} \sum_{j \in J_{\omega}} c_t^x \pi_{t\omega,j}^x + \sum_{s \in S} \sum_{t \in T(s)} \xi_{\text{op}}(x_{t,s} + y_{t,s}) \right\}
\]

where \(|S|\) is the number of existing services, \( c_t^x \) is the operational cost of service \( t \), \( \xi_{\text{op}} \) is the railway waiting time to avoid a conflict, \( x_{t,s} \) is the waiting time of service \( t \) at station \( s \), and \( y_{t,s} \) is the additional time needed at the station, necessary to enter/leave the assigned platform.

The passenger objective function is composed of the sum of the minimization of the passenger disutility \( Z_{\text{pass}} \), which minimizes the average total passenger travel time.

\[
Z_{\text{pass}} = \sum_{\omega \in W} \sum_{j \in J_{\omega}} c_{\omega,j} x_{\omega,j} / X
\]

### 3. Microscopic model

The microscopic model is based on the formulation proposed by Rodríguez (2007) and Pellegrini et al. (2015). It describes the constraints relative to the infrastructure of stations and junctions in terms of track-circuits within a control area (CA). Sequences of track-circuits are grouped into block sections, which are opened by a signal indicating their availability. The timetabling problem needs to be solved in the planning phase, which takes place several months before the day of operations. In this phase, for a timetable to be feasible, it needs to be conflict-free: trains must be able to travel at their planned speed without ever having to stop or slow down due to restrictive signals. In order to ensure the feasibility of the timetable, it is necessary to define a MICRO model that takes into account the specific configurations of the elements in each CA. To this end, the RECIFE-MILP model in Pellegrini et al. (2015) has been conveniently adapted to allow longer stays only at locations where the trains have planned stops. Let \( B(r) \) be the set of track circuits contained in route \( r \), and let \( R(s) \) be the set of routes contained in the CA (or station) \( s \in S \). Also, given a track circuit \( b \), its backward and forward track circuits on route \( r \) will be denoted by \( p(b, r) \) and \( f(b, r) \), respectively.

There follows a description of the main constraints associated to a CA in the micro model. For simplicity of exposition, it will be assumed that each CA corresponds to a station \( s \):

Service \( t \) arrives at the platform of CA \( s \) at the actual arrival time \( a_{t,s} \), as defined in (6). Also, the starting time of service \( t \) using track-circuit \( b \) along a route \( r \), \( \lambda_{t,r,b} \), is zero if the route itself is not used:
σ 11 more constraints whose precise definition can be found in the references by Rodríguez (2007) and Pellegrini et al. (2015).

\[ Z \text{ at the macro level will grow closer to those defined at the micro level. Thus, the following index}\]

\[ \minimizes \text{ of a weighted function,} \]

The macro-micro model combines the previous families of constraints - namely, (1) to (11) and (14) to (18) - and it minimizes of a weighted function, \( Z \), of the previous three indexes, \( Z_{\text{pass}}, Z_{\text{rail}} \), \( Z_{\mu} \), i.e.:

\[
Z = \theta_{\text{pass}} Z_{\text{pass}} + \theta_{\text{rail}} Z_{\text{rail}} + \theta_{\mu} Z_{\mu}
\]

where the positive weights \( \theta \)'s are assumed to sum up to 1. This paper shows that the model presents good computational performance for a large range of values of the weights \( \theta_{\text{rail}}, \theta_{\text{pass}} \) and that the deviation function \( Z_{\mu} \) is zero most of the time, unless very small values of the corresponding weight \( \theta_{\mu} \) are used.

By means of the shifts \( \alpha_{t,s}^{+}, \alpha_{t,s}^{-}, \delta_{t,s}^{+}, \delta_{t,s}^{-} \) it is possible to accommodate the arrival/departures time instances \( \alpha_{t,s}, \delta_{t,s} \), which are determined from a macro perspective, and match them to the required arrival/departure times of the CA's, since the particular configurations and level of internal traffic in these CAs are explicitly modeled in our approach. The shifts \( \alpha_{t,s}^{+}, \alpha_{t,s}^{-}, \delta_{t,s}^{+} \) can also be considered as disruptive values and will thus also be referred to as disruptions. The adjustment of the macro arrival/departure time instances to the micro arrival/departure time instances may be sharp (i.e., aiming at \( \sigma_{t,s} \to 0 \)) or some thresholds may be allowed at a global or local level for the disruptions. The disruptions
associate with service conflicts in the CAs show the level of infeasibility in each CA, so a timetable solution is macro-
micro feasible if $Z_\mu$ is zero, which is the total shift $\sigma_{t,s}$ in the departure and arrival times in the CA for all services. This
opens the possibility for defining alternatives to the index $Z_\mu$ in (19), which can be defined as \"average disruptions\”. Thus, if a threshold of acceptance for disruptions $\hat{\sigma}_{t,s}$ is defined at station $s$ for service $t$, an alternative index $Z'_\mu$ can be defined on the basis of \"average excess disruptions\” as follows:

$$Z'_\mu = |S|^{-1}|T|^{-1} \sum_{s \in S} \sum_{t \in T(s)} \sigma^+_t, \text{ where } \sigma^+_t \geq \sigma_{t,s} - \hat{\sigma}_{t,s}, \sigma^-_t \geq 0, \quad t \in T(s), s \in S$$ (21)

or, in a more detailed approach, specific thresholds can be defined as $\hat{a}^*_t, a^*_t, d^*_t, d^-_t$ for the disruptions, together
with specific weighting coefficients $w^a_{t,s}, w^d_{t,s}, w^d_{t,s}, w^d_{t,s}$, for each of them. It will be assumed that these coefficients
have been normalized so that $w^a_{t,s} + w^d_{t,s} + w^d_{t,s} + w^d_{t,s} = 1$. In this case, the disruptions are disaggregated by arrivals
and departures, and they are weighted individually. An index $Z'_\mu$ can be defined on the basis of non-negative excess
variables $a^*_t, a^*_t, d^*_t, d^-_t$, thus verifying the following constraints, which should also be part of the macro-micro
model:

$$a^*_t \geq \sigma^+_t, \quad a^*_t \geq \sigma^+_t - \hat{a}^*_t, \quad a^*_t, a^-_t \geq 0$$

$$d^*_t \geq \sigma^+_t - \hat{d}^*_t, \quad d^-_t \geq \sigma^+_t - \hat{d}^-_t, \quad d^*_t, d^-_t \geq 0$$

and then $Z'_\mu$ can be interpreted as \"average weighted excess disruptions\”:

$$Z'_\mu = |S|^{-1}|T|^{-1} \left\{ \sum_{s \in S} \sum_{t \in T(s)} \left( w^a_{t,s}a^*_t + w^d_{t,s}a^-_t + w^d_{t,s}d^*_t + w^d_{t,s}d^-_t \right) \right\}$$ (23)

5. Computational results and discussion

The computational tests were carried out on the high-speed railway (HSR) corridor Madrid-Zaragoza-Barcelona, the most important line in the HSR network in Spain. Two test cases were studied. The first was a \"reduced one\”, comprising just 9 services: 6 from Madrid to Barcelona, performed by 3 trains, and the other 3 from Barcelona to Madrid, performed by 1 train. The second is a \"complete case\”, with 42 services. Of these, 18 cover all the stations, in the Madrid-Zaragoza-Barcelona network, 9 in each direction. Another 12 services operate between Madrid-Zaragoza, 6 in each direction; and, finally, the remaining 12 services operate between Zaragoza-Barcelona, also 6 in each direction.

These two cases were initially solved by using the previously mentioned index function $Z$ in (20), and the Pareto
frontier was obtained for the functions $Z_{pass}$ and $Z_{rail}$. The results show that the deviations between macro and micro
timetables remain below the specified bounds ( i.e., $Z_\mu$ function is zero ) for a wide range of the weights of the multi-
objective function ( $Z_\mu$ is different from zero when $\theta_\mu$ is less than 0.3 ) and that the computational times are on the
order of a few minutes in a wide range of the Pareto frontier. The same proofs were made using function $Z'_\mu$ in (21)
as the third component of the multiobjective function $Z'$, with similar results. However, a common drawback of these
two cases was that several shift variables $\hat{a}^*_t$ appeared non-null in the solutions. This problem did not occur when the
function $Z' = \theta_{pass}Z_{pass} + \theta_{rail}Z_{rail} + \theta_\mu Z'_\mu$ was tested for the model, i.e., by setting $Z'_\mu$ in (20) instead of $Z_\mu$, for the
\"reduced\” case and by considering the following thresholds and weights:

$$\hat{a}^*_t, \hat{a}^-_t = 5/60 \text{ hours}, \quad \hat{d}^-_t = 0, \quad w^a_{t,s} = w^d_{t,s} = w^{d+}_{t,s} = 0.5, \quad w^{d-}_{t,s} = 2.5$$ (24)

Table 1 above shows the values of the objective function and its components with $\theta_\mu$ for the \"reduced\” case. The shift in departure $\hat{a}^*_t$ appears only in Service t7 in Madrid, which can be eliminated either by increasing $w^{d-}_{t,s}$
or by setting $\theta_\mu$ greater than 0.3. For the case with 42 services, also by setting $\theta_\mu \geq 0.3$, feasible solutions are obtained, although the values of $Z''_\mu$ are very reduced for values $\theta_\mu < 0.3$. Table 2 below shows the components of the multiobjective function $Z''$ and Figure 2 displays the Pareto frontier for the index functions $Z_{pass}, Z_{rail}$. Notice that, because $Z''_\mu$ is very low or zero, the Pareto frontiers ($Z_{pass}, Z_{rail}$) are practically equal for any value of $\theta_\mu$. It must be noted that the CPU time is in general higher and increases for large values of $\theta_{pass}$. Therefore, in order to keep low CPU time requirements, $\theta_\mu$ and $\theta_{rail}$ should not have very small values. This shows that the problem of optimizing $Z_{pass}$ in the macro-micro combined model is a much harder than optimizing a balanced function comprising both, $Z_{pass}, Z_{rail}$. This aspect is very relevant when exploring the application of this model for mitigating timetable disruptions, where quick computational responses are needed.

### Table 1. Values of the components of the objective function $Z''$ for different values of $\theta_\mu$ in the “reduced” case.

<table>
<thead>
<tr>
<th>$\theta_\mu$</th>
<th>$Z''$</th>
<th>$Z_{pass}$</th>
<th>$Z_{rail}$</th>
<th>$Z''_\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>0.399</td>
<td>211.989</td>
<td>579.667</td>
<td>0</td>
</tr>
<tr>
<td>0.3</td>
<td>0.466</td>
<td>212.326</td>
<td>579.667</td>
<td>0.009</td>
</tr>
<tr>
<td>0.0001</td>
<td>0.667</td>
<td>209.832</td>
<td>613.000</td>
<td>0.541</td>
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### Table 2. The objective function for different values of the weights in the “complete” case.

<table>
<thead>
<tr>
<th>$\theta_\mu=0.5$</th>
<th>$\theta_{pass}$</th>
<th>$\theta_{rail}$</th>
<th>$Z_{pass}$</th>
<th>$Z_{rail}$</th>
<th>$Z''_\mu$</th>
<th>CPU(sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>0.35</td>
<td>304.73</td>
<td>110.52</td>
<td>0</td>
<td>103.61</td>
<td></td>
</tr>
<tr>
<td>0.20</td>
<td>0.3</td>
<td>306.87</td>
<td>110.52</td>
<td>0</td>
<td>105.83</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>0.25</td>
<td>304.52</td>
<td>110.52</td>
<td>0</td>
<td>131.19</td>
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</tr>
<tr>
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<td>139.10</td>
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<td>107.59</td>
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</tr>
<tr>
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<tr>
<td>0.40</td>
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<td>191.98</td>
<td>0</td>
<td>118.02</td>
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</tr>
<tr>
<td>0.45</td>
<td>0.05</td>
<td>238.51</td>
<td>201</td>
<td>0</td>
<td>100.94</td>
<td></td>
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<table>
<thead>
<tr>
<th>$\theta_\mu=0.3$</th>
<th>$\theta_{pass}$</th>
<th>$\theta_{rail}$</th>
<th>$Z_{pass}$</th>
<th>$Z_{rail}$</th>
<th>$Z''_\mu$</th>
<th>CPU(sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.35</td>
<td>0.35</td>
<td>305.82</td>
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<tr>
<td>0.45</td>
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<tr>
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<tr>
<td>0.55</td>
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<td>241.26</td>
<td>189.10</td>
<td>0</td>
<td>681.25</td>
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</table>

<table>
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<tr>
<th>$\theta_\mu=0.1$</th>
<th>$\theta_{pass}$</th>
<th>$\theta_{rail}$</th>
<th>$Z_{pass}$</th>
<th>$Z_{rail}$</th>
<th>$Z''_\mu$</th>
<th>CPU(sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>0.5</td>
<td>304.84</td>
<td>110.52</td>
<td>0.1</td>
<td>60.61</td>
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</tr>
<tr>
<td>0.5</td>
<td>0.4</td>
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6. Conclusions

In this paper, we have presented a combined micro-macro model for setting timetables on a railway network under a multiobjective approach. Three index functions are combined in order to obtain balanced timetables according to: a) passenger disutility; b) operators interests; and c) the fitting of the timetable to the topology and operational timings at stations in the network. The distinctive approach of this model for setting timetables is the representation of train flows in a time-space network that is fully adapted to station topology, thus conflicts at critical points and platform occupancy are taken into account in order to model congestion in the network. Also, the model is formulated entirely as a linear integer mathematical programming problem. The model has been tested on a high speed corridor that links three major cities in Spain - Madrid, Zaragoza and Barcelona - and the results are reported for two scenarios: a reduced one with only 9 services and a complete one with 42 services. The model has shown its computational viability for a very wide range of the index function weights that make up the multiobjective model. Furthermore, different ways to characterize the feasibility of the timetable were studied and applied to the test cases. As future extensions of the model, aspects regarding timetabling robustness should be included via different concepts and approaches. We are currently studying a heuristic procedure based on the above model in order to provide robust solutions for refining timetables while avoiding, as much as possible, concentrations of arrivals/departures at/from stations. This will allow better recoverability of the timetable in case of unexpected disruptions.

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References


