



ASSESSMENT OF RESIDUAL CAPACITY OF SINGLE-TRACK LINES FROM SIMULATION USING UIC 406 COMPRESSION

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Abstract – How many additional trains a line can accommodate is a recurring question in timetable planning and infrastructure management. This paper presents a computational procedure that derives line-capacity indicators directly from the output of the microscopic simulator OpenTrack. The existing timetable is first adapted for import into OpenTrack; the simulator then generates, for each train, a blocking time stairway, which is converted into section occupancy intervals and compressed according to the UIC 406 method (greedy left-shifting with backward propagation and an optional overlap policy for single-track operation). From the compressed diagram, the bottleneck, infrastructure occupancy and a free-capacity indicator are determined. A residual-capacity estimate “in the tail of the day” is proposed: instead of counting gaps between existing trains, additional homogeneous paths are packed into the interval after the last compressed train, using speed profiles by official train categories. The compressed timetable is exported in an OpenTrack-compatible format for re-simulation. The procedure is demonstrated on a single-track section of main line M202 Zagreb – Rijeka in Croatia for a representative working day, quantifying the bottleneck, its utilisation and the number of additional paths by category and direction.

Keywords – Line capacity; UIC 406; infrastructure occupancy; blocking-time compression; microscopic simulation.

1. INTRODUCTION

The capacity of a railway line is not a single value but the result of the interaction between infrastructure, timetable and operating rules [1], [2]. As demand grows on regional and single-track lines, planners increasingly need a fast and defensible answer to the question: how much room remains alongside the existing timetable, and for which type of traffic? An accepted framework is provided by leaflet UIC 406 [3]: the timetable is compressed without adding time until trains are as close as signalling and running times permit, and the resulting infrastructure occupancy is compared with the available time. The theoretical basis is the analysis of blocking times (the blocking-time stairway), described in [1] and [2].

For realistic running and occupancy times, microscopic simulation is routinely used; in this work OpenTrack [4] serves as a complement, generating blocking time stairways. The analytical part — construction of blocking intervals, UIC 406 compression, bottleneck identification, utilisation and residual-capacity estimation — is carried out in the Etiris RailPrep environment (see Sec. 2). Method reviews [5], [6] distinguish analytical, optimisation and simulation

approaches; here simulation (OpenTrack) and an analytical procedure (RailPrep) are combined.

The contribution is twofold: (i) a reproducible procedure that builds occupancy intervals from blocking time stairways and compresses them according to UIC 406, and (ii) a residual-capacity estimate that quantifies the number of additional trains in the interval after the last compressed train, resolved by train category. Both steps are implemented in the Etiris RailPrep module; the paper focuses on method and results rather than implementation.

2. ETIRIS RAILPREP AND DATA

For this research, Etiris RailPrep was used — an auxiliary software module for the preparation, validation and harmonisation of input data and for line-capacity analysis. The module supports editing of timetable and infrastructure data, their export in OpenTrack-compatible formats and — after simulation — import of blocking time stairways, construction of blocking intervals, UIC 406 compression, bottleneck identification, utilisation and residual-capacity estimation. OpenTrack is used solely as a complement for microscopic simulation and for checking proposed

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timetable changes.

2.1. Courses and their editing

In OpenTrack, each individual train run is described by the notion of a course. A course links three data sets: rolling stock (traction/resistance characteristics and running dynamics), an itinerary (the path through the infrastructure model) and times (arrivals, departures and dwells at stations). For an existing timetable to be simulated faithfully, its courses are prepared and aligned with this structure.

In the RailPrep module, courses are imported, edited and exported in a format compatible with OpenTrack's Courses data. In this way courses can be modified and adjusted before simulation — for example correcting station labels (stationSign), arrival and departure times (arrTime, depTime), dwell times (dwell) or assigning a suitable itinerary — and then exported to OpenTrack. This ensures consistency between the original timetable and the simulation input, while allowing timetable variants to be created easily.

2.2. Timetable

The complete timetable is prepared in the RailPrep module in OpenTrack's text format OT_tt_ie (.txt). Files are stored with a date and name, and on export they retain the original header and footer, preserving version traceability and re-import compatibility with OpenTrack. It is a tab-separated file with one row per course and operating point, with the following columns:

Tab. 1. Columns of Timetable

Column	Description
courseID	Train (course) identifier
intervalCourseID	Interval identifier of the course (if any)
timeToIntervalReference	Reference to the course interval
stationIndex	Sequential number of the operating point along the course route (0, 1, 2, ...)
stationSign	Operating-point label
trackName	Track label (if specified)
arrTimeDayOffset	Day offset for the arrival time (0 = simulation day)
arrTime	Arrival time (HH:MM:SS)
depTimeDayOffset	Day offset for the departure time
depTime	Departure time (HH:MM:SS)
useDepTime	Whether the prescribed departure time applies (1/0)
dwell	Minimum dwell time [s]
stopAtStation	Scheduled stop at the station (1/0)
meanDelay	Mean delay [s]
Distribution	Delay distribution
deltaMass	Train mass correction

Courses prepared in this way, together with the infrastructure model and rolling stock, form the complete input for microscopic simulation.

2.3. Infrastructure data (XML)

The infrastructure model is edited in the RailPrep module in an XML format compatible with OpenTrack's infrastructure data. Several files may be open simultaneously, and on export the original file structure is retained. From these data the operating points and their order are derived, defining a sequence of sections (resources) onto which blocking intervals are later mapped.

2.4. Simulation in OpenTrack and .step2 import into RailPrep

The prepared data (courses, timetable, infrastructure) are loaded into OpenTrack, which performs the microscopic simulation. For each train the simulator exports a blocking time stairways (begin and end). In OpenTrack terminology, the .step1 export gives the distance of the reserved section as a function of time, and the .step2 export the distance of the released section as a function of time. This work uses the .step2 export (release): a piecewise-constant time–distance curve that, at each instant, shows how far along its itinerary a train has released the infrastructure behind it — the trailing edge of the blocking-time stairway. The RailPrep module imports the .step2 files and converts them into blocking intervals (see below).

The line is described by operating points and their order, defining a set of consecutive sections (resources). For each train, the local path from the .step2 curve is mapped onto the line order, and the running direction is recognised from the itinerary header. For a section r , the occupancy interval is obtained as the union of the blocking intervals $[a_i, b_i]$ of all trains using it, which avoids double-counting of overlaps:

$$t_{0ii}(r) = |U_i[a_i, b_i]| \quad (1)$$

The result is a set of blocking intervals (train, section, start a_i , end b_i , direction). Station dwells and shunting are naturally contained in the curves; an optional limit on the stationary “tail” at the terminal station prevents shunting from artificially inflating section occupancy. Using release times (rather than nominal departure/arrival times) keeps occupancy consistent with the simulator's signalling behaviour [2].

3. COMPRESSION ACCORDING TO UIC 406

In the RailPrep module the blocking intervals are compressed according to UIC 406. Compression places the intervals as early as possible, respecting two constraints: the order of sections within each train and conflicts on shared sections [1], [3]. Two overlap

policies are supported. The strict policy allows no overlap on a section (classic UIC 406). The conservative policy (UIC 406+) allows overlap on a section only if the same pair of trains was already overlapping in the original timetable, and never more than the original amount; this accommodates single-track lines where simultaneous occupancy is a consequence of data granularity rather than an actual conflict. A backward-propagation pass then delays the earlier sections of each train so that it arrives “just in time”, removing artificial intermediate dwells.

The span of the compressed timetable T_{comp} is defined by the extreme instants of all intervals:

$$t_{comp} = \max_i b_i - \min_i a_i \quad (2)$$

According to UIC 406, the infrastructure occupancy (consumed capacity) k is the ratio of total occupancy on the governing (critical) section r^* to the chosen time window T_{period} [3], [7]:

$$k = T_{occ}(r^*) / T_{period} \quad (3)$$

The value of k is compared with the recommended UIC limit values: if it is higher, the section is considered congested; if lower, free capacity remains. In addition, the share of the window covered by the compressed timetable is tracked through the ratio T_{comp} / T_{period} , as a measure of the temporal distribution of traffic over the day.

The compressed timetable and the added paths (Sec. 5) are exported by RailPrep in an OpenTrack-compatible format; the proposed increase can be re-loaded into the simulator to check feasibility and delays. Quantitative validation — comparing the analytical estimate with re-simulated delays — is the subject of ongoing work and is not covered here.

4. BOTTLENECK IDENTIFICATION

For each section, the utilisation U_r is computed as the ratio of its occupancy $t_{occ}(r)$ to its compressed span $T_{comp}(r)$:

$$U_r = t_{occ}(r) / T_{period}(r) \quad (4)$$

Besides utilisation, the average spacing between consecutive trains is tracked for each section — the mean buffer time between adjacent blocking intervals. Each section is scored by a weighted combination of utilisation, total occupancy, average spacing and the share of the compressed span it covers. The highest-scoring section is reported as the bottleneck, together with the number of trains, occupancy, compressed span, utilisation and average spacing. The bottleneck defines the governing limit for any capacity addition [1], [6].

In the analysed data the governing section is also the longest and slowest inter-station section and has the highest occupancy and utilisation; the choice is therefore

robust — the same section is identified as the bottleneck over a sensible range of weights. On single-track lines, UIC 406 requires the compression (measurement) points to be placed at crossing stations [7], [8], because the section between two crossings belongs at any instant to a single train of one direction.

5. RESIDUAL-CAPACITY ESTIMATION (“TAIL OF THE DAY”)

Counting the empty gaps that remain between trains after compression overestimates the usable capacity, because these gaps are fragmented and often shorter than a feasible path. Residual capacity is therefore estimated only in the “tail of the day” — the interval on the governing section that follows the last compressed train, up to the end of the analysis horizon.

For each train category, a homogeneous running-time profile is derived from the observed section running times, parameterised by a speed factor that linearly interpolates between the shortest and longest observed time of each section. Additional paths of a given category are packed into the “tail” in turn, each departing only once the previous one has cleared the governing section; the number of paths that fit, by category and direction, represents the residual capacity of that category.

For comparison, the theoretical homogeneous maximum at a target utilisation ρ (e.g. 60%, 75%, 100%) on the bottleneck block time t_{block} (the minimum headway, i.e. the mean blocking time per train on the governing section) is [3]:

$$N_{max} = \lceil (\rho \cdot T_{period}) / t_{block} \rceil \quad (5)$$

N_{max} serves as a theoretical reference for the total homogeneous capacity of the governing section over the whole horizon, as opposed to the number of additional “tail-of-day” paths (Tab. 3), which refers only to the remaining interval. Because the categories share the same “tail”, the per-category values are upper bounds for each category alone and are not additive; mixed addition is obtained by greedily packing compatible paths across categories. In the case study the categories follow from OpenTrack’s speed profiles (fast passenger, regional passenger, freight), derived from the observed section running times.

6. CASE STUDY

The procedure is demonstrated on the single-track section Ogulin–Moravice (main line M202 Zagreb–Rijeka, regional in character; about 29.8 km, six stations: Ogulin, Hreljin, Ogulinski, Ljeskovac, Bosiljevski, Gomirje, Vrbovsko, Moravice). The input consists of 65 .step2 exports from microscopic simulation for a

representative working day. The section Moravice–Vrbovsko (MOR–VRB) was identified as the bottleneck, occupied for a total of 07:48:49 (Tab. 2). Over a 24-hour horizon this gives an infrastructure occupancy $k = 32.6\%$, below the recommended UIC 406 daily limit for mixed traffic (about 60%) [3], [7] — the section is not congested. The compressed timetable covers $T_{\text{comp}} = 16:27:27$, i.e. 68.6% of 24 h; within the compressed span the section utilisation is 47.5%.

Tab. 2. Bottleneck indicators (section MOR–VRB)

Item	Value
Bottleneck section	MOR–VRB
Number of trains	65
Occupancy (union of block times)	07:48:49
Infrastructure occupancy k (24 h)	32.6%
Compressed span	16:27:27
Section utilisation	47.5%
Average spacing	12.1 min

Tab. 2. Additional paths in the “tail of the day”, by direction and train category

Direction	InterCity	Commuter	Freight
Ogulin → Moravice	+25	+22	+12
Moravice → Ogulin	+23	+21	+11

Categories follow OpenTrack speed profiles (IC/fast, regional, freight). The values are upper bounds per direction, computed without explicit crossing scheduling (see Sec. 7).

The results show that, although the corridor is busy during the active part of the day, the governing section is occupied for less than half of its compressed span, and a substantial number of additional paths — strongly dependent on train category — can be scheduled after the last train. The additional paths in Tab. 3 were not re-simulated; checking their feasibility by re-simulation is the subject of ongoing work (see Sec. 7).

7. DISCUSSION

The obtained indicators are in line with expectations for single-track regional lines, where train headways are relatively large and the load is concentrated in part of the day [5], [6], [8]. The value of the “tail of the day”, relative to classic gap counting, is that it yields feasible, non-fragmented paths, so the result is directly usable in planning. Equations (1)–(5) are definitional, in accordance with UIC 406; the contribution is the reproducible procedure and the “tail-of-day” logic, not a new theory.

Several limitations should be noted. First, the 24-hour horizon includes night hours that on regional lines are routinely reserved for line closures and maintenance; with a representative service window (e.g. 05–23 h) the occupancy rises to $k \approx 43\%$, still below the UIC limit, but part of the “tail” falls into the night, so the practically usable residual capacity is smaller than in Tab. 3.

Second, on a single-track line the directions are not independent: every added path in one direction consumes crossing capacity for the opposite one, so the values in Tab. 3 are upper bounds without explicit crossing scheduling. Third, the result depends on the quality and calibration of the simulation model [4] and on the simplification by a homogeneous speed profile.

Closing the loop — exporting from the RailPrep module to OpenTrack and re-simulating — enables validation; a quantitative comparison of the analytical estimate with re-simulated delays is the subject of ongoing work.

8. CONCLUSION

A reproducible procedure has been presented that converts the output of microscopic simulation into capacity indicators according to UIC 406 and, additionally, into a residual-capacity estimate based on the logic of packing paths “in the tail of the day”, resolved by train category. The approach gives planners a clear answer to the question “how many more trains, and of which type”, and it identifies the bottleneck section that sets this limit. Future work includes extending to mixed category sequences with explicit crossing constraints and validating the estimates against realised timetables.

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