Applying multiscaling analysis to detect capacity resources in railway networks

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Abstract

A substantial part of railway engineering is modeling of the real track infrastructure and train operation processes in computer applications. The electronic data created can be analysed and evaluated for research purposes. Depending on the aim of the research, three different models can be used which differ in their level of itemisation. Macroscopic models have a relative low level of accuracy, mesoscopic a medium and microscopic models have the highest.

The Institute of Transport, Railway Construction and Operation (IVE, Hannover) researches computing solutions to deliver the data in the requested level of detail. This is then used for generating and providing infrastructure and train operation data such as timetable data, running times of trains or block occupancy times. The Multiscaling Analysis offers the opportunity to use the appropriate model depth (level of detail) for each request and enables work to progress efficiently.

For tasks like long term capacity planning in railway networks no high detail level data is required normally, so macroscopic models can be initiated. To verify if train paths of a timetable, developed on a macroscopic or mesoscopic railway infrastructure, can actually be arranged without conflicts within the block occupancy times or the headway, a more detailed microscopic model is required. Therefore trains with only a low detail level of information like their route, stopping locations and stopping times can be mapped onto a microscopic infrastructure model to prove the feasibility and to determine capacity resources.

Keywords: infrastructure, capacity resources, networks, microscopic model, mesoscopic model, macroscopic model, RailSys, NEMO.

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1 Itemisation of railway infrastructure models

The detail level of a railway infrastructure or a railway operation model depends on the quality and accuracy requirements for generating appropriate results, and on the availability of the basic data. For some purposes high accuracy data is non-existing or cannot be provided on time. Also formal and legal reasons might prohibit free access to high detailed infrastructure data [1].

1.1 Microscopic model

Whenever high detailed data is available, microscopic models should be used to produce results with high quality, especially for timetable planning with an exact running time calculation.

In railway business, microscopic models are used for the exact reproduction of the infrastructure network and train operation. A microscopic infrastructure model consists of a node-link system with an accuracy of, for example one meter. It contains all necessary characteristics and parameters of the real infrastructure. The links represent the tracks and cover information about the length, gradient and maximum speed of a track section. The nodes represent the railway equipment and contain information about signalling systems, accessibility within block sections and can carry the function of a signal, switch, speed indicator or a release contact for instance. Whenever one parameter of two links is different, a node has to be set too. Microscopic models are indispensable for running time calculation, timetable calculation and simulation of railway operation processes because of the high level of itemisation that is necessary for these tasks (Figure 1).

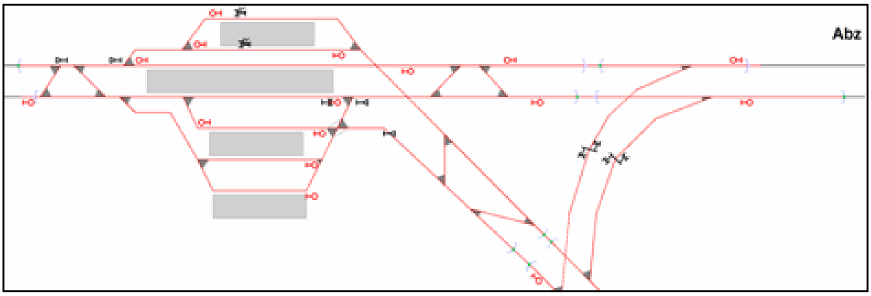

Figure 1: Microscopic model of railway infrastructure [2].

1.2 Mesoscopic model

The mesoscopic model is an intermediate stage between the micro- and macroscopic model. It reduces the data complexity and storage capacity compared to a microscopic model. Mesoscopic models are used when microscopic data is not available. If detailed results are required, but only macroscopic data is available, it is necessary to transform the approximate information into data with a higher level of accuracy. An established knowledge of the rationalities and habits in railway construction and operation is the precondition for putting these processes into computer algorithms to generate the required data automatically. The differences and the advantages to the macroscopic simple node link model include obtaining more detailed information for the station characteristics like accessibility and exclusion routes. This information is a basic requirement for an estimate railway capacity analysis (Figure 2).

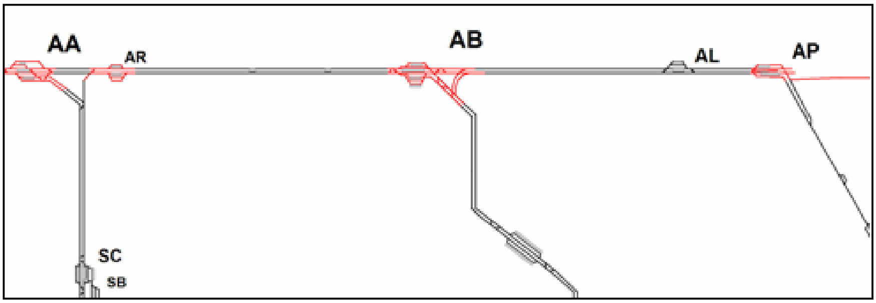

Figure 2: Mesoscopic model of railway infrastructure [2].

1.3 Macroscopic model

Within a macroscopic model each link only contains information about the number of tracks, the average speed, the average block length and the length of the track sections on the whole. Each node only represents, for example, the location of a station or the location of a branch. For some purposes like vehicle circulation planning, long term traffic planning and strategic infrastructure planning it is adequate to use macroscopic models or if necessary to transform microscopic data into macroscopic models. For purposes such as these, high accuracy data is not required.

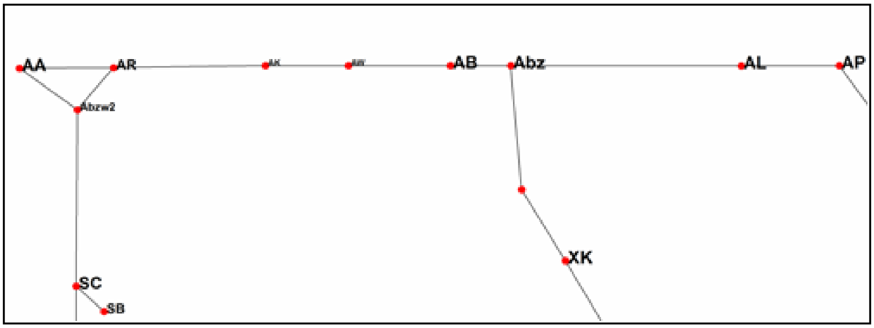

Figure 3: Macroscopic model of railway infrastructure [2].

2 Limits of adopting macroscopic infrastructure models

In most cases macroscopic models are used for long-term traffic planning or calculating average values for train running times. An exact modelling of train runs for running time calculation or the determination of line or station capacities is only possible through working with a detailed microscopic database including the exact positions of infrastructure elements and line parameters. Especially the gradient, which has a wide influence on the train running times. Using a macroscopic model only average gradient values can be applied. To detect every single gradient change a detailed microscopic model is necessary. The determination of running times using macroscopic infrastructure models does not fulfil the requirements of an accurate running time calculation and can be declared as a running time approximation.

Particularly in station areas, the imperfection of macroscopic models is a problem. The internal dependencies of a station require an accurate model. In addition, it is not possible to consider train route exclusions, accessibilities, connections or the consequences of the release contacts, speed boards or stopping boards position for the headway in an adequate way. In some cases the stopping board might be positioned in the influence area of the signalling system, so that a train can only travel with reduced velocity after stopping at this position until it reaches the next block section. Due to this the running time of a train can lengthen significantly. Hence microscopic or mesoscopic models must be used for more detailed planning.

The following example should clarify the exigency of detailed infrastructure modelling.

2.1 Example (route exclusion)

In this example two trains coming from the same direction, but from different tracks arrive in a station. In real train operation no simultaneous route setting would be possible because of a route exclusion for train 1 and train 2 through this arrangement. Such a dependency cannot be considered in a sufficient way using a macroscopic model (Figure 4).

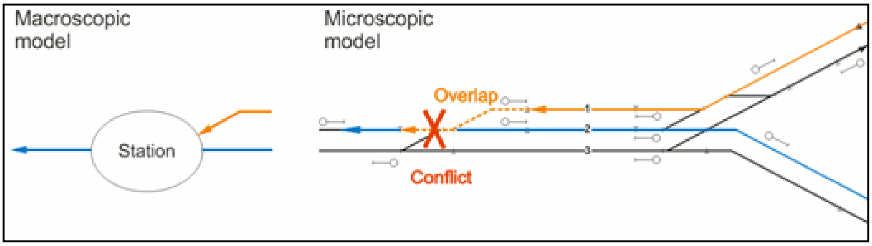

Figure 4: Necessity of detailed infrastructure modelling.

3 Transformation of different infrastructure models

With the information provided through a considered model, the Multiscaling Analysis is able to generate the missing information for either a higher detail level or a lower detail level. For example when only rough results are required, but microscopic data is existing, the data can be transformed into a macroscopic model. Therefore average values are calculated for the track sections and no relevant nodes are neglected (Figure 5).

When detailed results are required, but only macroscopic data is existing, it is necessary to generate data with high-level accuracy out of low-level accuracy infrastructure information. The requirement to transform data in this direction is an established knowledge of the rationalities and habits in railway construction and operation. With this knowledge, logical connections can be put into the algorithms of computer models using the Multiscaling Analysis to generate the required data automatically.

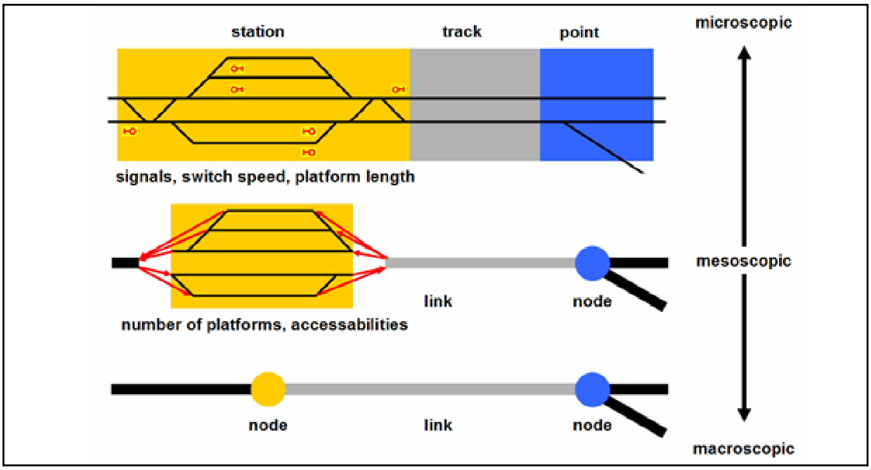

Figure 5: Transforming detail level of railway infrastructure models [3].

For purposes where mesoscopic modelling is sufficient to gather adequate results or no microscopic infrastructure data is available the macroscopic infrastructure manager of the program RailSys® [8] can be used to generate a mesoscopic infrastructure from a macroscopic infrastructure. The following chapter deals with an explanation of the main components of the macroscopic infrastructure manager of RailSys®.

3.1 Construction of a mesoscopic network

The first step for constructing mesoscopic from macroscopic networks is to edit nodes and links to model the railway infrastructure. The nodes represent the stations or branches (operating points) of the railway network as usual in macroscopic models (Figure 3).

The macroscopic model becomes a mesoscopic model through conducting the following steps:

1) Approaches

To model the different train routes in a station, approaches from station to the free track (or the reverse) need to be in place. This means the infrastructure must carry the information as to which platforms can be reached from which track. Through this the switch areas are mapped. (Figure 6)

2) Route exclusions

To complete the modelling, route exclusions have to be defined to make sure that no train runs can take place simultaneously on the same switch or track.

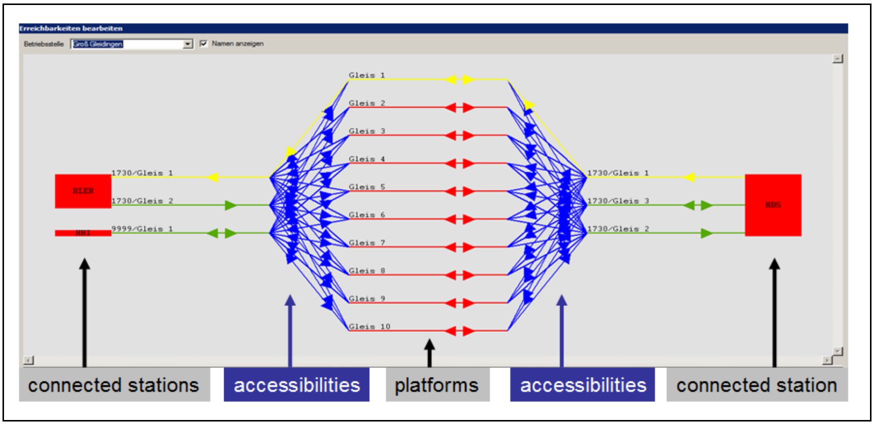

Figure 6: Accessibilities in a mesoscopic network [2].

Now the program is able to generate the missing information for timetabling and feasibility confirmations automatically, and produce an artificial microscopic railway infrastructure model through setting entry and exit signals, timing points, release contacts, speed boards and block sections for station and line areas.

4 Timetable feasibility confirmation and capacity analysis

The Multiscaling Analysis has already been applied in the project ”Railway Slot Allocation” [4]. In this project a macroscopic infrastructure is used for calculating an optimised timetable referring to running time approximations. To prove if the approximated running times can be confirmed, and the train paths are feasible without conflicts, the macroscopic timetable must be mapped onto a high accuracy infrastructure model. In this case a mesoscopic infrastructure model with detailed station areas was built from the macroscopic model because no microscopic data was available. Before the feasibility confirmation of the macroscopic timetable, it must be mapped onto the mesoscopic infrastructure. Therefore the macroscopic timetable must be converted into an accurate timetable format. This can be arranged with the program ”Slot Allocation-Converter” of RailSys® (Figure 7).

The feasibility of the originally macroscopic timetable can be certified under consideration of buffer times, or minimum headways, within the mesoscopic model. As an example, when conflicts from super-imposed block occupation times of two trains are remaining, a conflict protocol is produced from the Slot Allocation-Converter. Thus the macroscopic model can be adjusted, for example, through changing the allowed headway times.

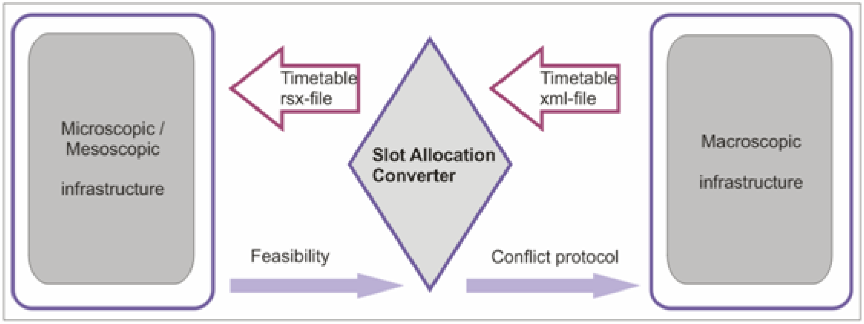

Figure 7: Timetable file conversion using the “Slot Allocation-Converter” [4].

4.1 NEMO-RailSys - Data exchange between macroscopic and microscopic railway infrastructure models

Another approach is the transformation from microscopic to macroscopic infrastructure without using the mesoscopic level of itemisation. This approach is initiated for long term traffic and capacity planning purposes with the program NEMO [7] in association with RailSys®. NEMO is a strategic planning tool for the evaluating infrastructure and train operation in guided transport systems. It can disclose saving possibilities and capacitive and operational bottlenecks. Because complex microscopic infrastructure data is existing no mesoscopic model is required. The possibility for adopting a mesoscopic infrastructure model within NEMO-RailSys® is not yet verified but possible [9].

Figure 8 shows the interaction between NEMO and RailSys®. For identifying bottlenecks and evaluating transport supply and demand NEMO uses a macroscopic network database. This macroscopic database is generated from a microscopic network in RailSys®. Also running times and minimum headways are calculated on the microscopic infrastructure before adopting the macroscopic NEMO evaluation. After scenario selection and determination of the required train paths to fulfil the demand is done with NEMO the remaining line capacity can be calculated on the microscopic RailSys® network. The capacity determination in RailSys® is made by means of UIC data sheet 406 (“Capacity”) [10].

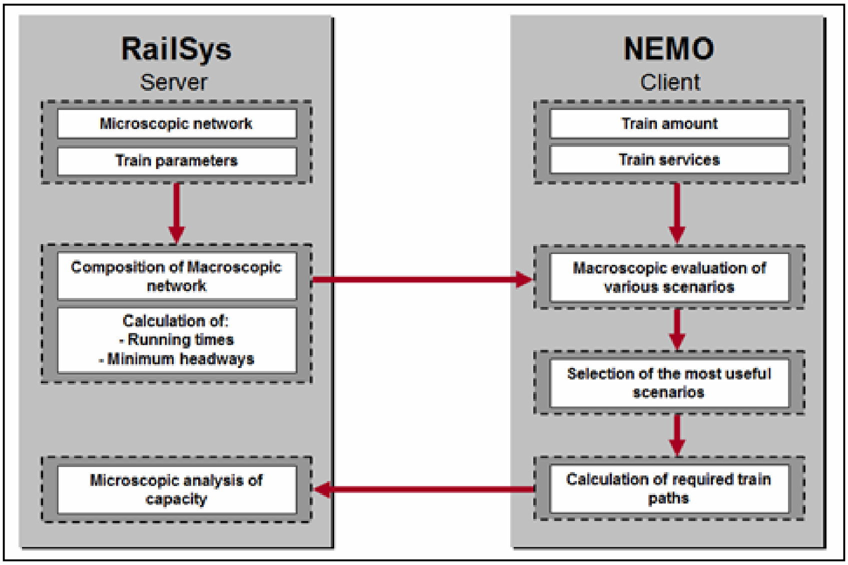

Figure 8: Workflow NEMO - RailSys® [7].

5 Results, impact on railway business and conclusions

Due to working with the Multiscaling Analysis, railway engineers are able to generate missing information with a higher detail level from a lower level source on the one hand, and reduce the data complexity from a microscopic to a macroscopic level on the other hand. For many tasks in railway business including vehicle scheduling, traffic generation and assignment and long term capacity planning, no high level data is required. It is possible to work with macroscopic computer models with a low detail level. For tasks such as running time calculation, simulation of train operation and short-term capacity planning of infrastructure projects microscopic or at least mesoscopic models are required. It is inherent that the more detail with which the data is mapped, the more and better results are possible (Figure 9). But, with a higher accuracy, the data complexity rises and it gets more difficult to obtain the data. For example, in many cases detailed track information cannot be obtained from a countries railway infrastructure operating company easily due to formal or legal reasons and must be gathered in another way.

The Multiscaling Analysis can already work with requests concerning train operation feasibilities. For instance, it can be used to verify if macroscopic planned train paths can indeed be arranged within the structure of current train paths. Therefore the trains’ timetable can be mapped onto a mesoscopic infrastructure when no high detailed microscopic data is available. With the mesoscopic or high detailed microscopic infrastructure model running time and block occupancy time calculations can be done. Through this conflicts between

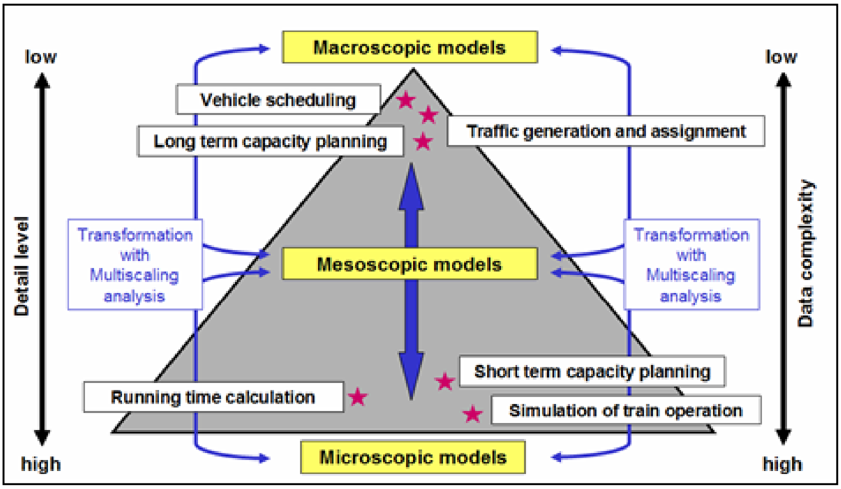

Figure 9: Opportunities for using Multiscaling Analysis [3].

train paths can be found or train paths can be seen as realisable. The Multiscaling Analysis is a useful method to transform data between micros-, mesos- and macroscopic level, considering the dependencies in railway traffic.

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