Methods to estimate railway capacity and passenger delays

CHAPTER 1 explains the importance of having knowledge about railway capacity and how, over time, it has become possible to operate more trains by improving the infrastructure and rolling stock. Additionally, the aim and structure of the thesis are outlined. CHAPTER 2 describes the difficulties of defining railway capacity, which depends on the infrastructure, the rolling stock and the actual timetable. In 2004, the International Union of Railways (UIC) published a leaflet giving a method to measure the capacity consumption of line sections based on the actual infrastructure and timetable (and thereby also the rolling stock used)—the UIC 406 capacity method. The UIC 406 capacity method can be used in an analytical way determining the capacity consumption as the sum of the occupation time, buffer time, and time supplements. This sum is then divided by the time window observed. In addition to the analytical way of determining the capacity consumption, capacity consumption can be measured by compressing the timetable graphs as much as possible for the line section and then using the compression ratio as a measurement of the capacity consumption. CHAPTER 3 shows how the UIC 406 method can be expounded in different ways. It is, therefore, important to divide the railway line into line sections of the “right” length. The thesis illustrates that it may be reasonable not to divide the railway lines into line sections at all locations as suggested in the UIC 406 capacity method. Not dividing the railway lines into line sections at overtakeings may result in additional challenges when working out the capacity consumption. To handle overtakeings in line sections, the thesis recommends maintaining the order of the trains (both before and after the overtaking) and allowing for changing the dwell time to the minimum dwelling time for exchange of passengers and/or the needed time for start moving (a freight train) after a complete halt. At crossing stations, line end stations, larger stations with shunting, and junctions, the thesis recommends that attention be paid to conflicting train paths. The crossing station’s lack of ability to handle parallel movement can reduce the capacity of the line section as the dwell time is extended. The line end stations can be limiting for the capacity because the time between the trains may be scheduled and thereby a minimum capacity is reached. The thesis recommends dealing with this by reducing the layover time to a minimum and by using all possible avoiding tracks. Larger stations with shunting can be difficult to examine due to lack of knowledge of the exact shunting operation. Therefore, the thesis recommends that larger stations should be evaluated according to the published timetable and only the known shunting operations but with a higher quality factor or other time supplements to include the remaining shunting implicitly. At junctions and crossing stations, conflicting train routes can result in reduced capacity for some train paths. Accordingly, the thesis recommends extending the analysis area for crossing stations and junctions to include the entire crossing station and/or junction. For line sections with more than two tracks, the thesis illustrates that attention must be paid to the order of the trains at both the beginning and the end of the line section as otherwise there is a risk of additional overtakeings occurring. Furthermore, more tracks can result in uneven capacity consumption. Accordingly, the thesis recommends allowing trains to change from one track to another if there is a large difference in the capacity consumption of the tracks. If tracks are located apart from each other it might be difficult to determine how many tracks a railway line comprises. Therefore, the thesis proposes that the railway line is considered as one line section if there is mainly one-way operation on the tracks and if both corridors are served in both directions and different stations are serviced it should be considered as two lines. The thesis puts forward a method to use the UIC 406 capacity leaflet to evaluate the future capacity consumption without knowing the exact infrastructure and/or timetable. This is done by using successive calculation, where the capacity consumption is calculated for the best-case situation (where the lowest capacity consumption is achieved by bundling the trains) and the worst-case situation (where the highest capacity consumption is achieved) together with the capacity consumption of a proposed future timetable. These capacity consumptions are then weighted together to describe the expected capacity consumption. IV DTU Transport, Technical University of Denmark. The thesis shows that not all idle capacity can be used to operate more trains—this can be due to capacity constrains outside the analysis area, network effects or the fact that more trains will reduce the punctuality of the railway line. Although the UIC 406 capacity method is a straightforward and (with the right tools) fast method to evaluate railway capacity, the method has paradoxes. The thesis demonstrates that if the UIC 406 capacity method is used stringently, an extra overtaking due to lack of capacity can result in much more capacity as the railway line is divided into shorter line sections. The thesis also shows that an extra train line resulting in shorter line sections can result in more capacity as the railway line should be divided at all line end stations. For single track railway lines, the thesis shows that there is a paradox of an extra train line resulting in more capacity as a consequence of more stations where the trains pass each other. This uncertainty can be reduced by adding “dummy” trains in the timetable and dividing the railway line into line sections where crossings occur and then compressing the timetable (without the “dummy” trains). To obtain a detailed overview of railway capacity, it is not sufficient to describe merely the capacity consumption. With this in mind, the thesis recommends also describing how the capacity is utilized. The UIC 406 capacity method describes how the capacity is utilized based on four topics (Number of trains, Average speed, Heterogeneity, and Stability)—the so-called “balance of capacity”. The four topics are normally correlated, but analytical measurements dealing with each topic individually are developed in CHAPTER 4. The thesis illustrates that the four measurements (developed in chapter 4) describing the balance of capacity can be used at different levels of detail. The different levels of detail make it possible to describe how the capacity is expected to be utilized in all stages of planning. In the first stages of planning—with only limited knowledge about infrastructure and timetable—the measurements describing how the capacity will be utilized are uncertain but as more detailed information becomes available, a more precise description of the capacity utilization can be given. When conducting capacity analyses, it is important to be able to communicate the results in an understandable way. CHAPTER 5 suggests this to be done by visualizing the results in different intervals on maps, e.g., free capacity, balance, shortage and problem. The thesis demonstrates that when visualizing and describing the results, the results depend on the quality factor used and the accepted level of punctuality. Consequentially, it is important that the same intervals and quality factors are used for the different analyses in order to be able to compare the results. The thesis shows that while it is possible to illustrate individually the capacity consumption, number of trains, average speed, heterogeneity, complexity, and stability, it is difficult to illustrate the factors simultaneously and in a straightforward manner. Therefore, the thesis suggests using a
GIS-based system to show maps of the capacity with the possibility of clicking on a line section to get other details of the capacity consumption. If changes are made in the way of stating railway capacity, the line sections or the methodology behind the calculations, it is difficult/impossible to compare the results. For this reason, the thesis recommends documenting the changes and make overlapping statements to be able to compare the results over time. CHAPTER 6 shows how capacity is affected in the event of contingency operation such as reduced number of tracks and/or speed restrictions on a railway line. Further, the chapter shows how the best location of crossovers can be found to ensure a reasonable service in times of contingency operation. However, to ensure sufficient capacity in the case of (un)scheduled single track operation, the chapter describes how capacity can be gained by bundling the trains. Contingency operation can result in delays, but delays can also occur due to smaller incidents such as errors on trains and/or signal failures.

CHAPTER 7 divides the delays on railways into initial delays and consecutive delays. The thesis demonstrates that the amount of consecutive delays can be estimated DTU Transport, Technical University of Denmark, analytically based on the initial delay, the headway time, and the minimum headway time. The thesis also shows that the amount of consecutive delays depends on the consumption of the railway line. Consecutive delays can be estimated analytically only for idealized situations, as, for example, delays can propagate from railway line to railway line. The thesis shows that two initial delays occurring just after each other can result in fewer consecutive delays than if the initial delays occurred at longer time intervals, and that this situation may be difficult to detect analytically. To have a more accurate estimation of delays, the thesis proposes using simulation models. The simulation models can calculate the delays for an entire network and take the time interval between the initial delays into account too. Although simulation models are the most accurate method to estimate delays, the thesis states that models could be improved if more realistic dispatch strategies were developed. When a train is delayed the passengers, too, are delayed. CHAPTER 8 presents different methods and models that can be used to calculate these passenger delays. The thesis categorizes the passenger delay models into generations and evaluates their advantages and disadvantages. "0th generation" models that do not incorporate route choices of the passengers are highly inaccurate, whilst 1st generation models that assume full knowledge of the delayed timetable systematically underestimate the passenger delays. 2nd generation methods that simulate several timetables partly overcome this problem. The 3rd generation models incorporate en route changes of decisions, whereby the passengers are first assumed to act on delays when they occur in time and space. The thesis also describes how the en route changes increase the accuracy of the passenger delay model. The thesis shows that it is possible to implement and run a 3rd generation passenger delay model for a network the size of the Copenhagen suburban railway network. Dependent on the amount of delays, the run time of the model is 5–10 minutes for one day. Since the routes are recalculated when delays occur, the calculation time increases with the irregularity of the operation. The thesis shows that the resulting passenger delays differ largely from the train delays in the Copenhagen suburban railway network. The difference between the train punctuality and passenger delays is due to the different number of passengers in the trains during the day, transfers between lines, and the fact that passengers (to some extent) will change routes due to delays. Furthermore, there is a higher risk of delays in rush hours due to more trains and more passengers on the trains. Chapter 8 develops a method to combine 3rd generation passenger delay models with simulation software for railway operation on the microscopic level. This makes it possible to generate a number of timetables that can be used as input when calculating the expected passenger delays in a future situation. The thesis shows that an evaluation of passenger delays obtained with simulation software (in this case RailSys) and the passenger delay model is comparable with the daily operation of the Copenhagen suburban railway network. Using a microscopic simulation model, the thesis demonstrates that it is possible to compare travel times and delays (for both trains and passengers) for different future scenarios and for changes in the infrastructure as well as in timetables. CHAPTER 9 illustrates that railway operation can have scheduled delays denoted as scheduled waiting time. This is when a fast train in the timetable must reduce speed because it cannot overtake a slower train. The additional running time affects both the trains and the passengers on the trains. However, the thesis demonstrates that the passengers are also affected by scheduled waiting time in the case of transfers. The thesis explains how scheduled waiting time for trains can be calculated by simulation models, such as the Danish SCAN model and the North American TPC model. Based on the scheduled waiting time for trains and passenger delay models (1st generation and upwards) it is possible to calculate the scheduled waiting time for passengers. The thesis also explains how it is possible to estimate the scheduled waiting time in the case of delays. In this case, the thesis recommends that the 3rd generation passenger delay model is used (when the data are available) since it is the most precise type of passenger delay model and does not require more work effort than previous generations of passenger delay models. VI DTU Transport, Technical University of Denmark Calculating scheduled waiting time for candidate timetables makes it possible to test different timetable strategies and choose the best strategy for the final timetable. This can improve the timetables for both the operator(s) and the passengers. In the longer term, the approach can be used at the centralized control offices in the event of contingency operation. Here, an evaluation of the network effects can be used to select the dispatching strategy that results in the smallest possible amount of additional travel time. The differences between the different kinds of delay (train delays, passenger delays and scheduled waiting time) are illustrated through simple, but representative, case examples in CHAPTER 10. The examples demonstrate that 3rd generation passenger delay models are more realistic than previous generations of passenger delay models, and that train delays can result in a situation where it is beneficial to passengers as the passengers as a whole spend less time in the railway system. The chapter also shows that passenger delay models can be used to evaluate and test various timetable alternatives, passenger delays in the case of contingency operation, and dispatching strategies. The simple cases presented in the thesis can be calculated either manually or by a passenger delay model. However, in more complicated cases (e.g. larger networks or situations where different case examples are combined) the calculations become too complicated to work out manually, and a passenger delay model becomes necessary. CHAPTER 11 illustrates that railway operation is affected by network effects because a change in one part of the network can influence other parts of the network too. The chapter shows that the influence can be far from where the original change was made. This is because the train services are (often) relatively long and because most railway systems have a high degree of interdependency, as trains cannot cross/overtake each
other everywhere in the network. The thesis shows that network effects depend on the given infrastructure and timetable and can result in longer travel times for trains and passengers. Furthermore, the thesis shows that the network effects can result in reduced capacity as some trains or train services can make it impossible to operate other planned/desired trains or train services. Therefore, the thesis recommends including network effects in the analyses. The chapter divides network effects into four categories: network effects in the schedule planning phase, network effects for trains, network effects for passengers, and network effects in the case of contingency operation. The thesis shows that the network effects can affect both trains and passengers, resulting in a “planned delay”. Therefore, the thesis recommends using scheduled waiting time to quantify the network effects in the following way: • Network effects in the timetabling process—scheduled waiting time for both trains and passengers. In the screening phase it is recommended to calculate the scheduled waiting time for trains only, while it can be calculated for both trains and passengers in the later phases • Network effects for trains—scheduled waiting time for trains • Network effects for passengers—scheduled waiting time for passengers • Network effects for contingency operation—scheduled waiting time for trains if the analysis is conducted from a purely operational viewpoint, but scheduled waiting time for both trains and passengers is preferred in general plans for contingency operation. The scheduled waiting time can be calculated based on either the optimal timetable or the planned timetable. The thesis states that the amount of network effects in the railway network increases with the complexity of the operation, which is why there are more network effects in cases with planned transfers. Therefore, the thesis recommends that timetable planners should be more precise when timetabling for larger networks (and networks with transfers) than for a railway line with no track connection to other railway lines. DTU Transport, Technical University of Denmark VII Main contributions of the thesis The thesis is a methodological contribution to extending the applicability of the UIC 406 capacity method and the calculation of delays in railway operation. The thesis uses a systems engineering approach to examine the UIC 406 methodology in a methodical way and to work out a consistent way of expounding the said methodology. The thesis also presents applicable models to calculate delays for both trains and passengers. These different delay models are examined and compared. Throughout the thesis, focus is on applicability of the methods. Therefore, both fictitious and representative examples and illustrative cases from the real world are used to illustrate the approaches. The main contributions of this thesis are: • Thorough examination of the UIC 406 capacity method • Recommendations of how to expound the UIC 406 methodology in a coherent way • Analytical method to describe how railway capacity is utilized • Methodology to state railway capacity according to the UIC 406 method • Methods to describe and present railway capacity • Evaluation of approaches to calculate passenger delays • Estimation of future passenger delays • Comparison of train delays and passenger delays • Methodology to estimate scheduled waiting time for trains and passengers • Quantification of network effects using scheduled waiting time • Applicability of the UIC 406 capacity methodology and the delay models

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