Proactive Dispatching of Railway Operation

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Abstract
Railway networks are often operated close to their full capacity due to limited infrastructure expansion and increasing traffic demand. Hence, basic timetables are fairly vulnerable to random operational disturbances. In consequence of this, the service level for passengers decreases through a combination of delay propagation and delay accumulation. To solve this problem, a possibility widely used in research is to add extensive recovery and buffer times. Nevertheless, the resulting robust basic timetables would lead to a deterioration of the operating capacity, especially in congested areas. Another approach to reduce the impact of operational disturbances on railway operation is to use conventional dispatching algorithms. Unfortunately, most of them ignore further potential disturbances during the dispatching process, which is why the generated dispatching solution might even worsen train's punctuality.

In this context, at the Institute of Railway and Transportation Engineering (IEV) at the University of Stuttgart a proactive dispatching algorithm has been developed, that generates dispatching solutions under consideration of random disturbances in dynamic circumstances. The algorithm is divided into two main processes. First, the block sections are classified depending on their specific operational risk index by simulating numerous timetables with random disturbances generated in a Monte Carlo scheme and the related negative impacts in the studied railway network are calculated. Second, near-optimal dispatching solutions are automatically generated based on Tabu Search algorithm. This is achieved within a rolling time horizon framework, taking risk-oriented random disturbances in each block section into account.

Keywords
Disturbance management, proactive dispatching, punctuality, capacity research, vulnerability of block sections

1 Introduction and State of the Art

Railway networks are often operated close to their full capacity due to limited infrastructure expansion and increasing traffic demand. Hence, basic timetables are fairly vulnerable to random operational disturbances. In consequence of those endogenous and exogenous disturbances, the service level for passengers decreases through a combination of delay propagation and delay accumulation. To solve this problem, a possibility widely used in research is to add extensive recovery and buffer times (Anderson et al. (2013), Huisman et al. (2007), Kroon et al. (2008), Lindfeldt (2015)). Nevertheless, there are two aspects that restrict the application of this strategy. On the one hand, the resulting robust basic timetables would lead to a deterioration of the operating capacity and to larger travel times, too. On the other hand, there is especially in congested areas no or only severely limited leeway for additional time reserves. Another approach to reduce the impact of operational disturbances on railway operation is to use conventional dispatching algorithms (Bidot et al. (2006), Cheng (1998), D'Ariano (2008), Espinosa-Aranda and García-Ródenas (2012), Quaglietta et al. (2013)). Unfortunately, most of them ignore further potential disturbances during the dispatching process, which is why the generated rescheduled timetable might even worsen train's punctuality as a result of non-implementable dispatching solutions (Zhao et al. (2017)).

Extensive research activities have been conducted by focusing on the strategies stated above. Regarding this, reference is made to Zhao (2017) for a more detailed literature evaluation. In this context, at the Institute of Railway and Transportation Engineering at the University of Stuttgart an innovative dispatching algorithm has been developed based on several research activities. For instance, Cui et al. (2017a) and Liang et al. (2017) both investigated systematically the influence of dispatching on the relationship between capacity and operation quality. In Cui et al. (2017b), a method not only to prevent, but also to avoid deadlocks in synchronous simulation for railway planning and operations has been developed. Furthermore, Martin et al. (2015) studied, which influence selected disposition parameters have on the result of operational capacity researches.

The proposed dispatching algorithm bases on an operational risk analysis for each block section of the studied railway network, which make it, inter alia, stand out clearly from approaches that uses rolling time horizon frameworks (e.g. Zhan et al. (2016)). Hereby, especially railway infrastructure managers will be capable of generating robust dispatching solutions during operation stage as well as optimising the basic timetable during planning stage. For the former, the algorithm forecasts on the basis of the risk analysis the negative impacts caused by stochastic disturbances occurring in each block section and takes the severe ones more seriously during the generation of dispatching solutions in advance (Tideman et al. (2018)). For the latter, the proposed proactive dispatching approach points out potential for improvement not only of the operating program but also of the existing infrastructure. Based on a classification of the block sections according to their operational risk index, users are even able to prioritise construction measures.

2 Functionality

The above-mentioned advantages of the proposed proactive dispatching algorithm are achieved by a combination of two main processes. The first is to determine the previously alluded operational risk index of each block section of the investigated railway network in offline mode. The second process has the function to automatically generate appropriate dispatching solutions in dynamic circumstances under consideration of the operational risk classification as well as further random disturbances in online mode during railway operation.

2.1 Operational Risk Analysis

To analyse the operational risk of the network's block sections as shown in Figure 1, numerous timetable variants are simulated with the aid of RailSys® software. Due to the use of RailSys® software, a high user comfort can be ensured. As a basic requirement, the infrastructure has to be divided into appropriate sections, such as, for example, block sections.

Starting the procedure of the first algorithm process, a block section is chosen as the so-called target block section, for which a set of disturbed timetables are generated. Those timetable variants are obtained by artificially imposing random disturbances generated in a Monte Carlo scheme and only occurring on the target block section based on an appropriate disturbance distribution. For instance, the negative exponential or the Erlang distribution could be adapted depending on the specific case of application (Zhao et al. (2017)). After running the simulation for each so-called disturbance scenario within RailSys® software,

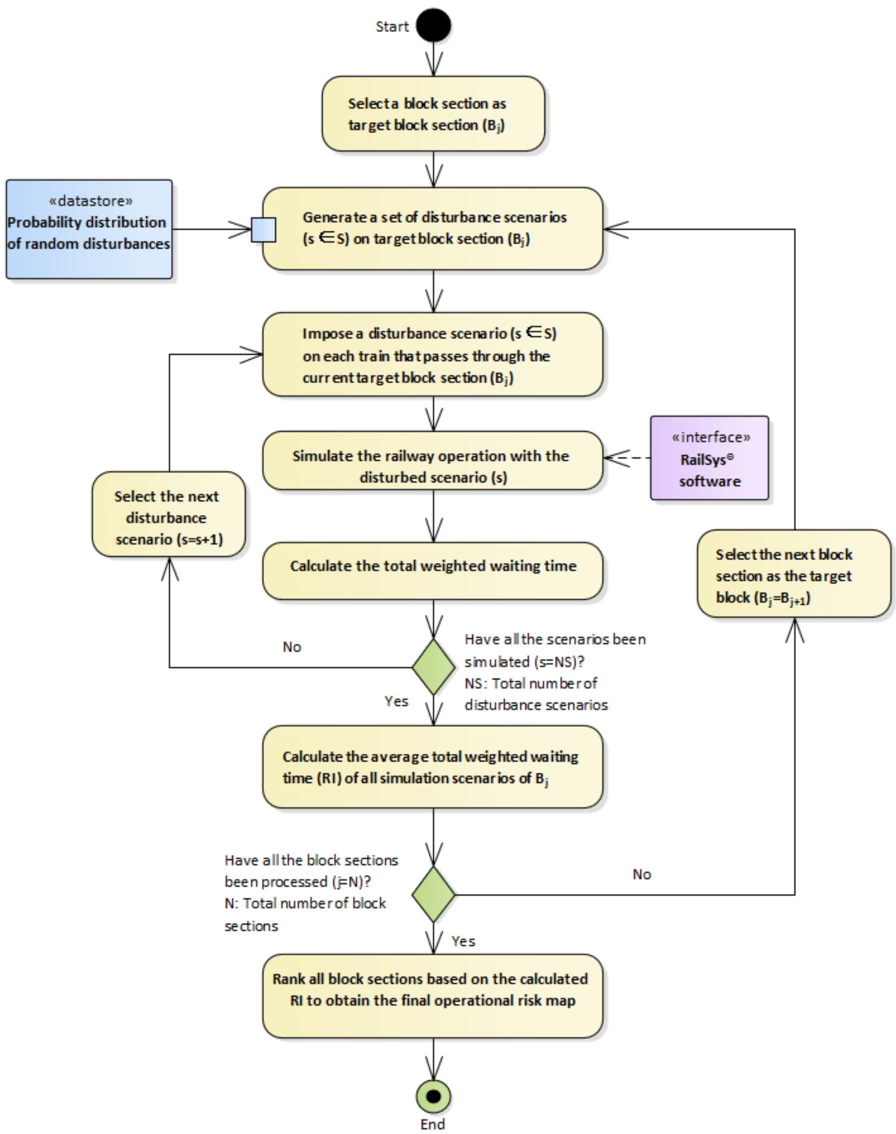

Figure 1: Workflow of the operational risk analysis

the related mean value of the target function, e. g. total weighted waiting time in the whole studied network, can be calculated. Repeating this for every block section, they can be classified according to the obtained mean values, which represent the operational risk indexes. Finally, to facilitate the further activities regarding the second algorithm process, an operational risk map can be drawn. As long as no significant changes both on infrastructure and operating program take place, the classification of the block section can be maintained.

2.2 Generation and Implementation of Dispatching Solutions

Once the first process of the algorithm has been performed, the second process can be executed as shown in Figure 2.

Initially in Task 1, the investigation period is divided into multiple time periods named "dispatching horizon", which are partially overlapping and spaced at fixed time intervals named "dispatching interval". This stage division is depicted in Figure 3 and represents the foundation of a rolling time horizon framework. With the beginning of every new dispatching interval the risk-oriented conflict detection is performed within the prediction horizon of the corresponding stage and with the aid of RailSys® software (Task 2). Hereby, the blocking times of the operating trains are artificially disturbed according to the respective risk index of each passed block section, by what the generated rescheduled timetable should be more robust against potential disturbances. If the algorithm doesn't detect overlaps between the blocking times, no further action will be arranged and the basic timetable will be maintained until the beginning of the next dispatching interval as a time-driven procedure (Task 4). In case of detecting one or more blocking time conflicts, a near-

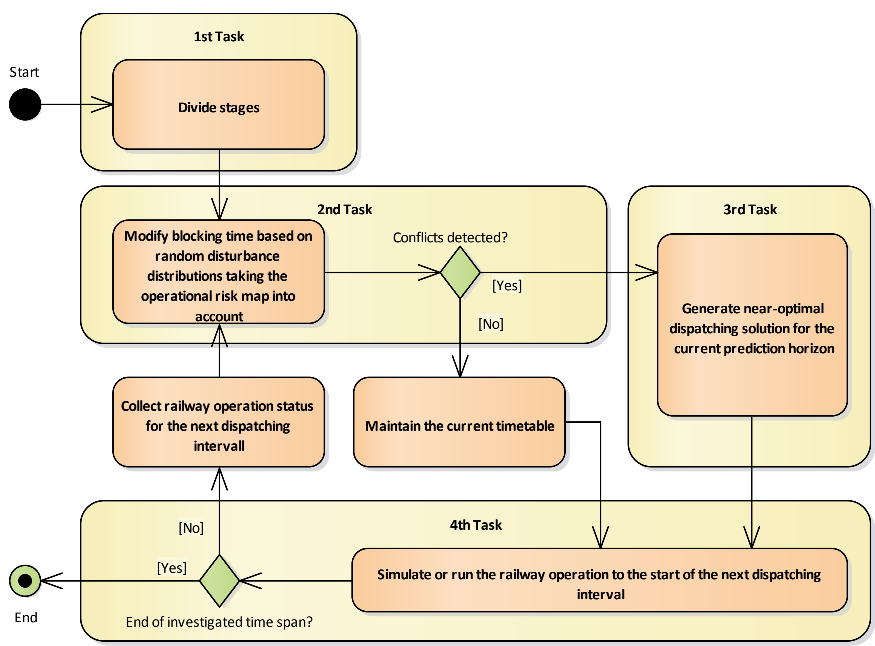

Figure 2: Simplified procedure of the dispatching solutions generation

optimal dispatching solution for the current prediction horizon will be automatically generated (Task 3). Regarding this, two cases must be distinguished. If the value of the target function, e.g. total weighted waiting time, falls below a user-defined limit value, the algorithm will solve the detected blocking time conflicts by retiming the train runs. By contrast, the conflicts will be solved by reordering of the train runs based on Tabu Search algorithm, whenever the value of the target function exceeds the limit value. Subsequently, the resulting rescheduled timetable contains retimed or reordered train movements and will be used for the railway operation unto the beginning of the next dispatching interval (Task 4).

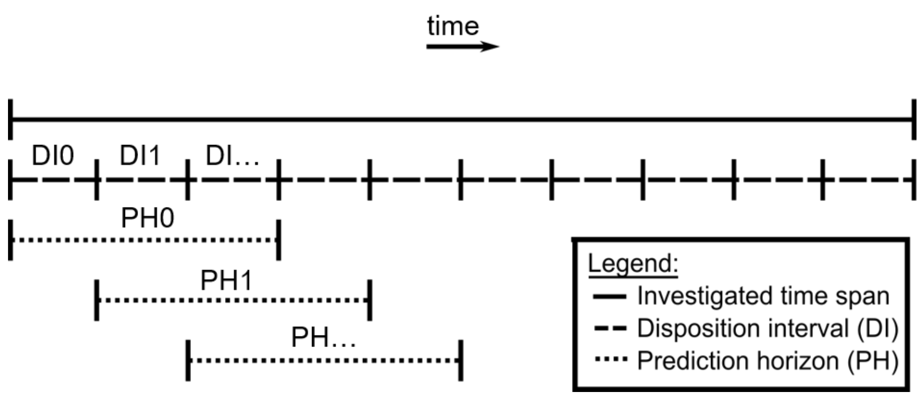

Figure 3: Schematic representation of the rolling time horizon framework

3 Reference Scenario

The development of the proposed proactive dispatching algorithm has taken place based on a realistically reference example, what is standardly used for algorithm development at the Institute of Railway and Transportation Engineering at the University of Stuttgart. The reference model is emulated in RailSys® software, which assists to generate effective and realistic dispatching solutions. This railway network is shown in Figure 4, contains over 43 kilometre track length and includes in total up to 72 long-distance passenger transport, regional passenger transport and freight transport train runs within a time span of six hours.

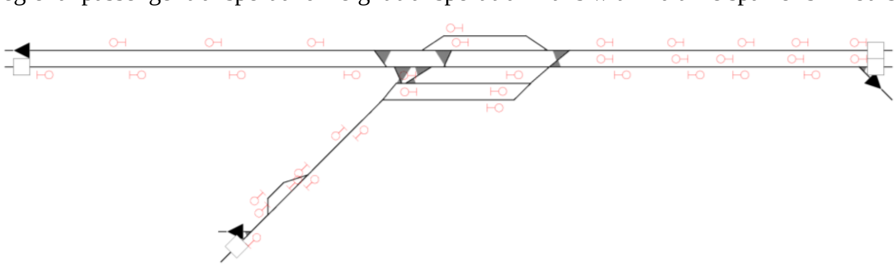

Figure 4: Track layout

Furthermore, the reference model ensures that the proposed dispatching algorithm is capable of handling various types of conflicts such as crossing, following, merging and opposing conflicts.

Technically, the operational risk analysis (first process) as well as the dispatching algorithm (second process) is developed in Microsoft Visual Studio 2015 environment with C#. This code runs the simulations in RailSys® software automatically. Due to the large amount of disturbance scenarios that has to be imposed on every block section separately, the operational risk analysis has to be executed in an offline environment. For the reference scenario this process takes at least four hours (Fujitsu computer, Intel Core i5-4670 CPU @ 3.40 GHz, 8 GB RAM). After achieving the operational risk classification once, the classification will remain its validity in the future as long as there won't occur changes in infrastructure layout or operating program. The code for the dispatching algorithm, which is also written with C#, has to be started manually by the user. With the objective of using this second process in online mode, the calculation of both conflict detection and conflict resolution takes about 20 seconds for each stage.

3.1 Operational Risk Analysis

Regarding the first algorithm process, the railway infrastructure is divided into 35 block sections. Then, a significant amount of disturbed timetables is generated, which consider only within the target block section entry delay, departure time extension, running time extension and/or dwell time extension depending on the characteristics of the target block section, e.g. existing stations. On the supposition that 1 denotes the lowest and 5 the highest risk level and by following the above stated algorithm procedure, it can be obtained that seven block sections belong to each risk level, as it is shown in Figure 5. Based on this, the blocking time of each train passing the respective block section are prolonged for the conflict detection in Task 2 of the second algorithm process.

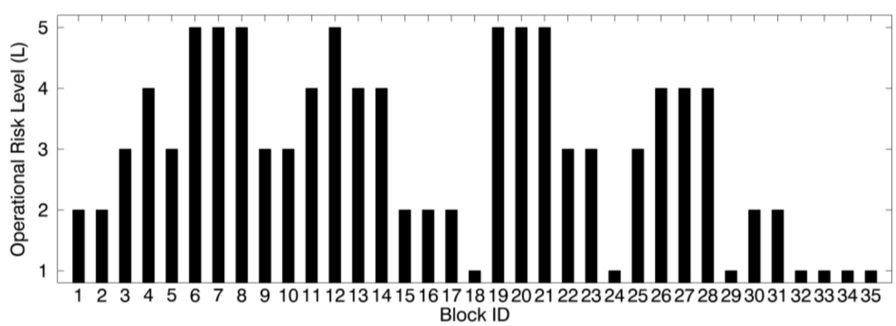

Figure 5: Operational risk levels of all 35 block sections of the reference scenario

3.2 Generation and Implementation of Dispatching Solutions

According to Figure 3, in Task 1 of the second algorithm process the six hours investigation period of the reference example is divided into twelve dispatching horizons with a length of two hours and twelve dispatching intervals (DI-0, DI-1, …, DI-11) with a length of 30 minutes. Based on the results of the operational risk analysis, in Task 2 the scheduled blocking times of the trains are modified at the beginning of a dispatching interval in accordance to the specific risk level of the block sections the trains are operating in. This is done by adding extra time to the scheduled blocking times with the aid of imposed disturbances. As an example for high-speed trains, in Table 1 the risk-oriented disturbances are listed broken down for the five different operational risk levels.

Table 1: Risk-oriented disturbances imposed on high-speed trains for conflict detection

Operational risk level:	**1**	**2**	**3**	**4**	**5**
Dwell time extension [s]:	3	12.6	23.4	37.2	55.2
Departure time extension [s]:	3	12.6	23.4	37.2	55.2
Entry delay [s]:	15.6	62.4	118.2	186	274.8
Running time extension [s]:	3	12.6	23.4	37.2	55.2

Also in Task 2, the conflict detection for each time stage is performed after the modification of the blocking times has taken place. In doing so for the reference case, it turns out that during seven dispatching intervals no further dispatching actions are necessary and the current timetables can be maintained. For the remaining dispatching intervals the 3rd task has to be executed. Here, the near-optimal dispatching solution for the current prediction horizon is generated. In DI-3 and DI-9 it is sufficient to retime the train runs, whereas for the three remaining dispatching intervals DI-0, DI-4 and DI-8 a new order of the train runs has to be generated by Tabu search algorithm (see Table 2). Irrespective of whether the initial timetable or a generated dispatching timetable are used hereinafter, the 4th task deals as a proxy of the real world railway operation.

Table 2: Dispatching solutions for each dispatching interval (DI)

	Start time	**End time**	**Dispatching solution**
DI-0	0:00	0:30	Reordering
DI-1	0:30	1:00	-
DI-2	1:00	1:30	-
DI-3	1:30	2:00	Retiming
DI-4	2:00	2:30	Reordering
DI-5	2:30	3:00	-
DI-6	3:00	3:30	-
DI-7	3:30	4:00	-
DI-8	4:00	4:30	Reordering
DI-9	4:30	5:00	Retiming
DI-10	5:00	5:30	-
DI-11	5:30	6:00	-

3.3 Comparison with FCFS-Principle

To underline the advantage of the proposed proactive dispatching algorithm and to ensure its effectiveness, the calculated total weighted waiting time of each stage is compared with the total weighted waiting time that results by using first come – first serve (FCFS) rule for the dispatching process. As depicted in Figure 5, it can be seen easily that for both dispatching strategies in sum the curves decrease and that for every stage the proposed

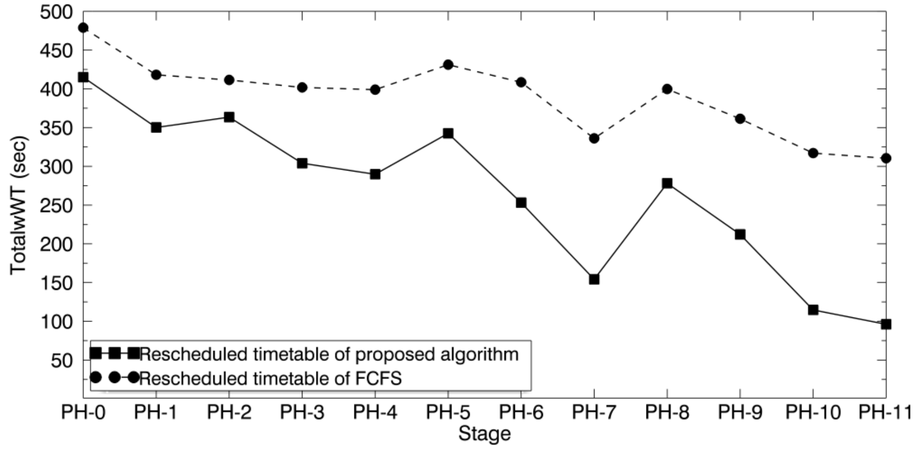

Figure 6: Comparison of the results of the proposed algorithm and FCFS principle

algorithm enables a significantly better operating quality expressed by a higher overall punctuality of the railway network. Regarding this, the two final values differ by ca. 215 seconds.

4 Conclusion

Heavily summarized, the main innovation or rather benefits of the developed algorithm are the automatic calculation of the operational risk of every block section of any investigated railway network in offline mode, the consideration of the operational risk during the automatic generation of dispatching solutions in online mode and the algorithm's sustainable impact on the operation quality due to the implementation of a rolling time horizon framework.

Furthermore, as explained in section 3, the proposed proactive dispatching algorithm is able to solve crossing, following, merging and opposing conflicts. This happens in a very effective manner, mainly because the dispatching algorithm takes the operational risk index for each appropriate infrastructure segment into account. Moreover, the proposed method bases on a rolling time horizon framework, by what the performance of the generated dispatching solutions is evaluated after a certain time span.

Additionally, the reference model enhances the extensibility of the algorithm to large railway networks. Not least because of this, one of the current research activities of the IEV (Martin et al. (2018)) deals, inter alia, with the application of the discussed proactive dispatching approach within a real railway network in Germany for manifesting its practical use.

Also, the presented dispatching approach isn't restricted to the field of railway operation, which is why the IEV also investigates the algorithm's usability in the context of other transportation systems, such as aviation (Tideman and Martin (2018)).

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