Pre-planned Disruption Management in Commuter Railway Transportation: Algorithms for (partial) Automation of passenger-oriented Design and Evaluation

Anna-Katharina Brauner [a, 1], Andreas Oetting [a]
[a] Chair of Railway Engineering, Technische Universität Darmstadt
Otto-Berndt Straße 2, 64287 Darmstadt, Germany
[1] E-mail: brauner@verkehr.tu-darmstadt.de, Phone: +49 (0) 6151 16 65916

Abstract
A pre-planned disruption management helps to amend disruption operations. Pre-planned train dispatching instructions, unified in a so-called disruption program for a typical disruption situation facilitate the work of the dispatchers. Those instructions are mostly manually designed and often focus solely on the train runs. The proposed approach aims to improve the quality of disruption programs concerning operations and especially concerning the reduced passenger mobility. For this purpose, the algorithms to be presented evaluate the operating concept on its functionality and transition capability in a solely train operations focused way. A stable and fast transitioning disruption program is already enhancing the passenger mobility in a disruption, but this is not enough to call it passenger-friendly. The goals of a fast transitioning, realized by a low number of train runs and the quality of the passenger's mobility are strongly conflicting. For this purpose, the algorithms design a transportation concept including passenger guidance measures and comprise a final evaluation of the disruption program in a passenger-oriented way.

Keywords
disruption management, disruption programs, passenger-oriented, operating concept, transportation concept

1 Motivation

Major disruptions in commuter railway transportation alter railway operations significantly and affect passenger mobility tremendously. Pre-planned disruption programs (DRP) contain a substantial amount of train dispatching decisions for the event of a disruption. They facilitate the work of the train operating company's dispatchers since the operating concept for the disruption is known. Therefore, measures can be taken and communicated quickly.

Currently, highly experienced employees are responsible for drawing up the DRP. They design the operating concepts manually and use their dispatching experience to foresee effects and interactions of the potential disruptions and especially the operational measures. Reaching a stable - smooth, punctual and reliable - operation is the first main aim in disruption operations. The second aim is to reach this state of operations as fast as possible. So far, this can only be estimated by an employee on the basis of his own experience. Therefore, it is not thoroughly ensured that the DRP consists of an actually viable set of operational measures for the typical disruption.

The manual design of an operating concept and the experience-based consideration of interdependencies is highly time-consuming; therefore, they mostly leave passenger guidance measures aside. A fast transitioning, realized by a low number of train runs, and the quality of the passenger's mobility are strongly conflicting goals. This conflict is not yet solved in the creation process, as the focus and the expertise are mainly on the dispatching side.

Next to the high effort of designing DRPs, there is another reason why they are lacking a thoroughly prepared passenger guidance. The experience based on rough estimation whether the concept could be working, should not be the basis for a transportation concept. To enhance DRPs covering also passenger guidance measures, the operational functionality itself needs to be ensured first, because constant ad-hoc dispatching interventions might generate deviations conflicting with planned guidance measures. This would then result in an unstable disruption situation for the passengers with unreliable information.

2 Related Work

Real-time traffic management and support tools targeting dispatching assistance are discussed in Corman and D'Ariano (2011), Ochiai et al. (2016) and Törnquist (2012) for example. Toletti (2018) discusses algorithms for dispatching support concerning dynamic capacity increase. However, dispatching support tools for train operating companies (TOC) mostly focus merely on parts of their dispatching processes, like connection dispatching in Stelzer (2016) and Schütz and Stelzer (2015), as most operational dispatching decisions of a TOC have to be accepted by the rail infrastructure company first. Next to that, TOCs only have restricted access to the infrastructure data. For those two reasons, it is difficult for TOCs to constitute an overall real-time dispatching tool including occupation conflicts, whereas a pre-planned operating concept can be pre-coordinated with the rail infrastructure company. Therefore, DRPs imply an approach with high practical relevance and actual application especially for the Swiss and German commuter railway networks.

The manual drawing up of a disruption program by applying a well-defined procedure including related operational measures, relevant dependencies to consider and which stakeholder to include was presented by Chu et al. (2012), enabling decision-makers to work in a structured way using the proposed flowcharts. They also introduce different phases of a disruption, as illustrated in Figure 1, including key characteristics according to DRP usage. Subsequently, the causes of delays and the importance of the transition phase are determined in Chu et al. (2013). A steady disruption operation has three key characteristics: all train runs are on the DRP planned tracks, the number of trains is reduced according to the DRP and all train runs operate at the typical level of punctuality as without disruption. Therefore, capacity must not be exceeded. (Chu 2014)

Oetting and Chu (2013) analyzed the transition phase and performed a case study on operational data of two big German urban railway networks, where they identified the main influences on the duration of the transition phase. One main reason for delays is the queuing of trains at and in front of stations, especially at the turning stations in front of the disruption. The generated congestion influences the duration of the transition phase primarily. The

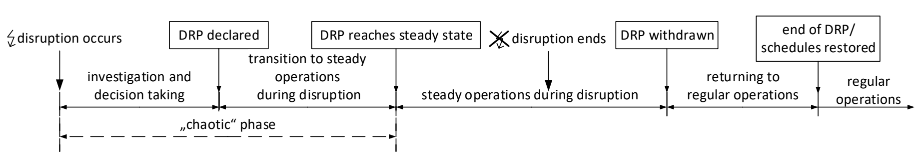

Figure 1: phases of a disruption using DRPs (Chu and Oetting 2013)

initial approaches to perform an operational evaluation of capacity in stations during the transition phase are presented in Chu and Oetting (2013) and Chu (2014), but the transition phase is not yet modelled in a predictable way.

As disruptions lead to limited mobility options, the negative impacts on the passenger's travel routine are important when assessing the dispatching of a disruption. Josyula and Törnquist Krasemann (2017) studied alternative strategies to utilize passenger flow data in re-scheduling. They observed, that re-scheduling models which include passenger flow data, mostly did not choose the metrics according to the changed passenger needs in a disruption. Passenger guidance measures combined into an applicable concept as part of a DRP do not play a significant role the DRP related publications yet.

The literature shows that DRPs are very useful, however the manual creation is time-consuming, and the functional testing is rough and based on experience. Passenger guidance plays mostly a marginal note. A (partial) automation of design and evaluation would be necessary to enhance the benefits of DRPs. The logical and initial mathematical relations for delays, capacity and implemented measures are not yet sufficient as models for (partial) automation. The aim of the research described in this paper is to develop algorithms that ensure the development of operationally functional concepts, which have a reliable passenger guidance and information established on top, to handle the conflict of goals mentioned in chapter 1. The approach to be presented aims to support the design of customer-oriented disruption programs with general validity for commuter rail transport.

3 Research Contribution and Methodology

A disruption program with its applied measures and the following information is the more reliable the faster it works as a whole. To this end, the time required identifying the cause of the disruption, to decide on a bundle of measures and to implement it initially, must be minimized. (Chu and Oetting 2013)

This can become challenging if a disruption program is applied, because the actual advantage of a disruption program can also be a disadvantage: its concreteness. It must fit as exact as possible to the present disruption, because the concreteness enables to process train dispatching quickly, but makes this even more difficult if the DRP does not fit exactly and adjustments have to be made by the dispatcher. These adjustments always have to be made during the transition phase as the actual operating situation cannot be planned as it appears different every minute. Crespo (2018) is dealing with the automation of the non-pre-plannable decisions in the transition phase. This does not counteract with the application of a DRP and is part of the idea including a transition phase. However, the planned stable phase should be applicable as planned.

Therefore, it might make sense to have a large number of disruption programs for many different variants of a disruption. As already mentioned, the effort required to create a disruption program is very time-consuming for now. Therefore, usually DRPs are either very generic or concentrate purely on the most critical points within the network. In addition, the DRPs are limited to the dispatching of trains and focus on the operational events, thus the effects and measures for the passenger remain rather unnoticed. The aim of the concept presented is to achieve a reduction in effort and a quality increase in the creation and evaluation of disruption programs through (partial) automation.

(Partial) automation aims for the evaluation of the operating concept and the creation and evaluation of a transportation concept. Many operating circumstances cannot yet be reliably described with data, like common daily problems or are not available to the TOC as data sets, e.g. freight trains. Freight trains can be very relevant for the disruption dispatching in German commuter railway networks, as there are many mixed traffic railroads in commuter rail networks existing. Especially when deviating is applied as a measure for the commuter trains, they might use mixed traffic railroads like the Güterumgehungsbahn in Hannover. However, an experienced employee has this background information due to his many years of experience and can incorporate it into a DRP. Therefore, the design of the operating concept remains a task, which has to be carried out by an experienced employee of the TOC, who is familiar with the network. The creation process is ought to be considerably simplified and the quality of the results shall be increased by the underlying automated test algorithms. The DRP designer‘s work is supposed to be supported by a software implementing the presented concept with evaluating his operational planning and creating a transportation concept based on it automatically. Besides the DRP designers, there is also the perspective of the DRP users.

As a user of a DRP, the dispatcher expects the results to ensure operational functionality. Therefore, DRPs need to be operational feasible. Since not all operational data is available for TOCs, relevant assumptions must be included in the developed algorithms. The result must then be edited in an easy understandable way for use of dispatchers, train drivers, the railway infrastructure undertaking (RIU) and others, so that a simple and uncomplicated operational implementation is guaranteed. Misunderstandings and frequent inquiries should be avoided in terms of the workflow during the disruption.

Next to the operational flow in the disruption, should the disruption program be in the passenger’s interest. The passengers also want to fulfill their mobility needs in the event of a disruption. Therefore, a mobility preservation is aimed at. The design and evaluation of DRPs should be carried out from a passenger’s point of view.

The passengers must be informed about the occurrence of the disruption and the subsequent applied operational measures. They eventually have to change their planned travel behavior but despite the disruption, passengers should have to make as few changes as possible to their usual mobility behavior. Therefore, a DRP should not intervene in the connections that are still functioning in the event of a disruption.

A DRP affects many train journeys and many more passengers. In order to implement (partial) automation, the complexity of the interrelationships between operational and transportational events must be simplified to a manageable extent. The algorithms should therefore be clear and efficiently convertible into software. This also includes the supply of data available that is at a TOCs disposal.

As a first step, the evaluation algorithms intend to enable the creation of validated, operationally functional DRPs (solely focusing on the train operations). These so called operating concepts are manually designed and can then be evaluated automatically by the algorithms. In a second step, a functional operating concept can be complemented with

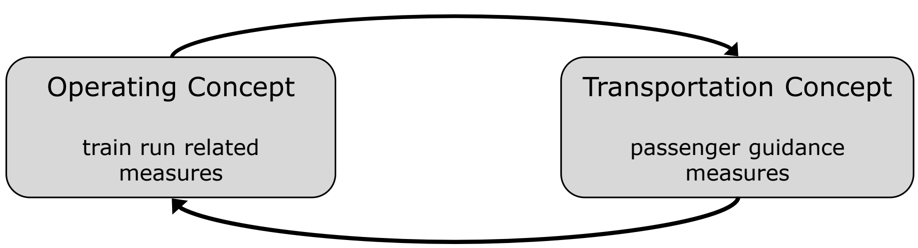

Figure 2: DRPs as a combination of operating and transportation concept

passenger guidance and related communication measures. This so called transportation concept is created and evaluated automatically. Both concepts, as to be seen in Figure 2, are mutually dependent as explained in the following.

Disruptions result in reduced availability of infrastructure and therefore operational measures have to address the availability of infrastructure by omitting the disrupted area. Turning, diverting and parking selected trains reduces a potential capacity over-use. A passenger-friendly disruption management needs as little deviations from regular operations as possible, but if the original timetable is fully preserved, the DRP cannot function in a stable way. A functioning operating concept is the basis for the transportation concept. The evaluation of the transportation concept is used to detect, whether the operating concept is passenger-friendly or whether it needs to be designed differently. A DRP in the future is supposed to be the combination of an operating and a transportation concept to enable a both reliable and passenger-friendly disruption management.

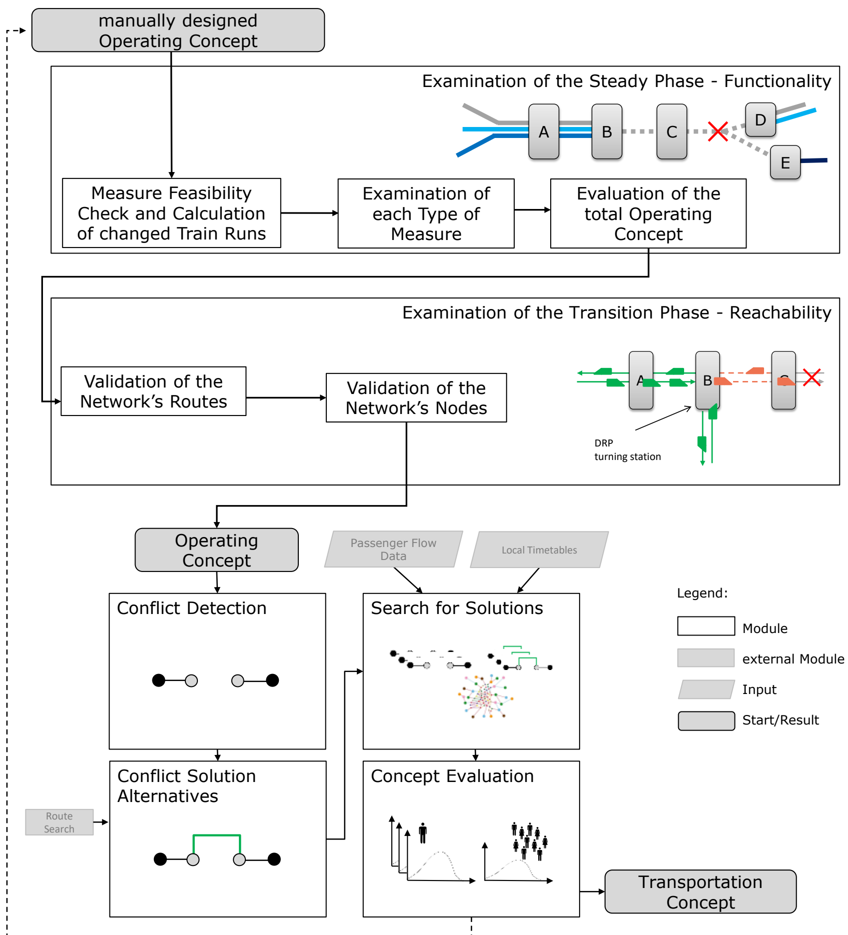

Figure 3: modular structure of the DRP creation and evaluation

To sum up, the evaluation of disruption programs consists of the two superordinate modules: the operating concept and the transportation concept. These two modules can interact with each other cyclically. The transportation concept is built based on the operating concept. In case the transportation concept is evaluated being not sufficient for the passengers, adaptions in the operating concept have to be made and a new transportation concept is built on that. The modular concept and all of its submodules are already shown in Figure 3. In the following, the subordinated modules for these two concepts are derived and the algorithms, which work in these modules and their output are described.

4 Operating Concept

A disruption program pursues the goal of ensuring operational stability. The operating concept ensures that initial effects of the disruption are spatially limited and that delays do not propagate by a rapid application of measures. The operating concept must be able to achieve a stable, delay-free condition: this is called the transition capability. Subsequently, the operating concept should enable to keep up a stable, delay-free, although still disturbed operation: this is called the concept functionality. To this end, the operational measures planned must be capable of being implemented individually and in combination. Thus, the operating concept can be divided into the transition phase and the steady phase. Functionality in the steady phase is a prerequisite for a successful transition. If the planned measures do not enable stable operations, the previous transition phase is also not feasible. It makes sense to first check, whether a steady phase can exist and to model the transition phase afterwards. Therefore, the algorithm does not work along the chronology of the disruption when using a DRP.

4.1 Operational Measures in a Disruption Program

In order to check the functionality in the steady phase, the following measures have to be evaluated during their application:

- Partial cancellation: The line carries out a turnaround at a deviating turning station. This turning station is called a "DRP turning station". The rest of the route is no longer served. This means that only one section of the line and one original terminal station are served.
- Partial cancellation with replacement: The line carries out two turnarounds at two new DRP turning stations - one on each side of the disruption. Two route sections of the line are served. The disrupted course connecting the two sections is not used. Both original terminal stations are served and two additional DRP turning stations are declared. Replacement therefore means that another train serves part of the line on the other side of the disruption. Therefore, the partial cancellation of that line is located in between those two operating trains.
- Total cancellation: The selected train run of the line or the whole line is cancelled completely and the vehicle is either parked or stops at a platform.
- Diversion: The route of the selected train run of the line or the whole line is directed through a section of the scheduled route and/or on a completely different route. The two original terminal stations remain intact. This can be done under simplified conditions if the rules according to Ril 408.1431 (DB Netz AG 2011) are complied.
- Diversion with replacement: The route of the selected train run of the line or the whole line is run on a section of the scheduled route and/or on a completely different

route. In addition, one turnaround at a terminal station is carried out at a different station. The remaining section of the route is not operated. This means that only one original terminal station is served and the other one is replaced with a different terminal station.

These measures have various effects: on the one hand, they can reduce the number of trains in the network or influence the characteristics of a train journey (running length, route, turning station, journey time, etc.). Both can lead to a relief of the infrastructure usage and thus make it possible to reduce and avoid the occurrence and transmission of delays.

First of all, a measure needs to be feasible independently to its application being checked in module 1. However, that is not sufficient. The functionality of all measures together within the surrounding operational situation in the network is important. Thus, each measure has to be examined when scheduled, whether there are restrictions that make it unusable for the typical planned application. However, after the scheduling of all measures, the whole network is examined because the feasibility of each measure individually cannot be equated with the functionality of the operating concept. This is mainly a search for arising delays due to overload or other reasons that lead to deviations from the timetable. Effects of the changes in operations can be detected on the routes or at nodes. Furthermore, depending on the usage of a route or node, occupancy conflicts possibly arising on routes or in nodes are not always part of the consideration that can be made as a TOC.

On the routes, the measures generate changes in the minimum headways, the occupancy times, the waiting times and therefore have an influence on its occupancy level. This means, that those routes have to be checked towards the changes in the occupancy that are caused by the operating concept. Nodal changes occur in stations that show additional usage. Additional time requirements for turnarounds and changed arrival and departure times influence the occupancy rate of these stations. Thus, module 2 examines the routes and module 3 examines the stations, for each that has a different use due to the operating concept. Lines and stations, which are exclusively relieved by the measures do not have to be checked.

If an operating concept has successfully completed modules 1 - 3, it is functional in the steady phase, and can now be examined for its ability to achieve this stable state. The ability to transition is given, if the network is able to have all train runs on the lines planned for in the disruption program, in the planned number and with the punctuality of regular operations. This condition indicates a steady state. It is now to be determined, whether any exclusion criteria exist, that would prevent a successful transition. However, some exclusions for a transition cannot be determined individually, but result from interdependencies and thus generate a constant development of delays, which would inhibit a transition or extend its duration extremely. Therefore, the transition phase and its duration must be modelled in a further module. Thus, module 4 checks for exclusion criteria such as the non-achievement of the planned number of trains (in an appropriate duration) and constant congestion and module 5 determines the transition quality on the basis of duration. After applying modules 4 and 5, the operating concept created and tested is considered functional for the corresponding disruption.

4.2 Evaluation of the Steady Phase

A stable disruption operation is characterized by the fact that all trains are on the routes according to the disruption program, in the planned number and with the punctuality of regular operations. Neither the recommended limit values for capacity utilization nor the regular capacity utilization (of the regular routes and stations) is exceeded.

In a steady disruption state, dispatching actions are predictable and information (internal and external) is reliable. In the interest of the passengers, as much traffic as possible should still be maintained unchanged and as few deviations from regular operation as possible are to be planned. However, if too much regular operation is preserved, a DRP cannot function stable. It is therefore necessary to typically check, whether a DRP can be functional for all measures of the pre-planned disruption.

4.3 Feasibility Check and Calculation of the Modified Train Runs

The feasibility of each planned measure must be examined along the following three dimensions: technology, operations and transportation. A distinction is made between absolute and soft exclusion criteria for the selected train or line. Absolute exclusion criteria do not allow the measure for the typical application. Soft exclusion criteria allow an application after adjustments by the creator.

The *technical* feasibility means that the infrastructure intended for the train in question is available. Absolute exclusion criteria can be, for example, the track gauge or the need for an overhead line. Soft exclusion criteria may englobe the non-existence of switches, signals, tracks or appropriate train protection system. With soft exclusion criteria, the measure cannot be applied as planned, but can possibly be implemented using operational rules like written commands. It is suggested that no operational measures such as operating with written commands are to be used in a disruption program, as this would restrict the workflow largely. The data basis available to a TOC for setting up the infrastructure is usually not sufficient to carry out an automated check at this level of detail. Since a release test of DRPs by the RIU is mandatory, the technical test is not carried out within the framework of (partial) automation at the TOC. The creator should apply his local knowledge and use routes that are expected to be feasible.

The *operational* feasibility means that train runs are feasible on the existing infrastructure. Absolute exclusion criteria can be, for example, operational parameters such as the clearance gauge or the line category or operational regulations such as route knowledge or local guidelines. The regulations allow (approved) deviations to a limited extent in some cases. However, if these limits are exceeded, the train run is not permitted. Therefore, there are no soft exclusion criteria. For the examination of the operational measures, it is not possible to use data records, as these rules and regulations cannot yet be read automatically. In addition, there are still required skills of the driving personnel whose allocation and abilities (e.g. route knowledge) are not consistent.

The *transportation* feasibility is the accomplishment of the planned (adapted) transportation service by the TOC. In this examination, only soft exclusion criteria are initially considered, as they do not imply safety issues. The creator can define them as absolute exclusion criteria if required, e.g. depending on the requirements of the transportation association. This includes, on the one hand, the handling of a train's traffic performance: service frequency, punctuality, required train length, stops and on the other hand, the passengers' access to the platform and access to the train there (distance between platform edge and vehicle entrance).

The feasibility check can only partially be automated and the creator is required to plan reasonable measures that can be carried out according to his level of knowledge.

In this module, the (partial) automation mainly serves the recalculation of the time requirements of the trains, which change due to the application of a measure.

This includes:

- determination of delays at initial departure due to creation of a timetable message
- calculation of the duration for threading and unthreading into a diversion
- determination of the stopping time for new stops on deviations
- calculation of the minimum turning time at the selected DRP turning station
- determination of the turning buffer as a function of the selected frequency to which the turn is applied
- calculation of the actual turning time
- driving and occupancy time calculation
- determination of possible effects of a driving time extension on the return train
- preparation times for parking

After applying module 1, it is known whether the selected measure is feasible and the temporal changes in the train run become clear.

4.4 Validation of the Network's Routes

From module 2 onwards, the planned measures are no longer considered independently, but always in their entirety and in relation to the resulting effects in the network. As deduced in chapter 4.1, an evaluation of the network's routes becomes necessary if a change in use occurs while not being exclusively a reduction in capacity utilization.

The occupancy changes because of operational measures, but it must not get a height, which generates delays. The diversion measure leads to an increased occupancy of the routes that are additionally used. For each of these routes, it is therefore necessary to check whether the capacity is sufficient. Known characteristics of the route are the timetables of the existing TOC own trains and their number. The TOC is not aware of the timetables of the other services and the timetables for its own trains, which run on this route DRP exclusively, as these timetables have to be created by the RIU. For both, only assumptions can be made, which means that all timetable-dependent and exact methods are omitted. The massive change on the route results from the additional assignment of trains and their running times, which now have to be handled on it. These can be incorporated by rough information and empirical values concerning the missing characteristics, whereby the occupancy rate is suitable as a rating.

It is a rough rating method, which does not supply exact quality limit values and does not recognize occupancy conflicts. However, neither is within the scope of the possibilities of a TOC. It is important to use an evaluation method that offers a possibility to check the planned measures for the disruption, avoiding unrealistic planning and thereby limiting the revision effort for TOCs and the reconciliation effort with the RIU.

The occupancy of routes is also diverting if a single track using both directions is created out of a regular double track. For this purpose, the mean minimum headway including the number of trains must be recalculated.

The UIC recommended limit values must not be exceeded. A stable condition would not be ensured if the limit values were exceeded, and congestions could cause disruptions and delays.

However, this does not mean that a train must not arrive delayed at the terminal station. In addition to unscheduled waiting times caused by an excessively high occupancy rate, scheduled waiting times and extended driving times can also lead to a delayed arrival in disruption operations compared to the regular operations schedule.

If a route causes a delay, e.g. due to additional travel time on a deviation route, it is acceptable, if the return service can start on time. This prevents delays from continuously

1. calculation of the scheduled waiting times for threading and unthreading		
$t_{Wm} = \frac{1}{2} \cdot t_{Bnm} \cdot \frac{\rho}{(1-\rho)} \cdot (1 + V_b^2)$ (Fischer and Hertel 1990)	with	
	t_{Wm}	waiting time for threading/unthreading
	t_{Bnm}	mean operating duration
	ρ	occupancy rate
	V_b	coefficient of variation

2. estimation of the driving time expected in the event of a disruption		
$t_{journey,DRP} = t_{journey,dev} + a_{stops} \cdot t_{stop} + t_{Wm,threading} + t_{Wm,unthreading}$	with	
	$t_{journey,DRP}$	driving time when applying a DRP
	$t_{journey,dev}$	driving time on the deviation
	a_{stops}	number of stops
	t_{stop}	duration of one stop

3. departure time at the last node before leaving the standard route		
$CET_{departure,start}$	with	
	$CET_{departure,start}$	time of departure at last standard node

4. determination of the new arrival time at the destination		
$CET_{arrival,end} = CET_{departure,start} + t_{journey,DRP}$	with	
	$CET_{arrival,end}$	time of arrival at terminal station

5. determination of the feasible departure time for the return		
$CET_{mindeparture,return} = CET_{arrival,end} + t_{turn,DRP}$	with	
	$CET_{mindeparture,return}$	feasible time of departure for return
	$t_{turn,DRP}$	turning time at DRP turning station

Comparison with the actually planned departure time for the return	
$CET_{mindeparture,return} \leq CET_{plandepartue,return}$	

Figure 4: flowchart for evaluating a planned deviation

establishing and spreading uncontrollably. If the train arrives only slightly delayed, it might be compensated by the turning buffer. Therefore, the departure time of the return service must be checked for adherence using the algorithm shown in Figure 4.

To sum up, a critical influence on the route utilization is caused by diversion, diversion with replacement and a single instead of double track operation. Routes that show these measures, have to be evaluated using this module. Unchanged routes with lower or regular occupancy and routes that are cleared by module 2 are functional in a disruption.

4.5 Validation of the Network's Nodes

The transfer of the delay at the terminal station as discussed in module 2 can originate not only on the line, but also in the nodes. Since occupancy conflicts cannot be determined, not all stations and operating points with changes are considered. The additional rides and stops in between are not examined. In this module, the nodes at which the DRP measures are applied and thereby generate far-reaching effects for the station, are validated. Deviations due to measures occur at:

- DRP turning stations
- stations, where trains with total cancellation are parked on the platform
- original turning stations (not relevant as there is no additional use, reduction leads to free capacities)

Therefore, the question arises, as to how high the utilization at the application points in the DRP will be. All application points are checked also using the occupancy rate calculation.

The following validation must be carried out for all operating points that have been declared as DRP turning stations:

The first step is to determine which driving relationships are possible. Based on this, driving types can be determined based on an adaption of the method of Chu (2014). For the modelling of the infrastructure use of the station, the number of tracks i to be considered has to be determined. The possible driving relationships are determined as follows:

Find all combinations of entry from *previous station* to *station track* <u>and</u> exit from *station track* to *next station*
if *previous station* = *next station*, then categorize as turnaround
if *previous station* ≠ *next station*, then categorize as continuation

All trains existing in the timetable for the period under review are determined and journeys for long-distance and freight transportation are supplemented. Subsequently, the train movements f are assigned to possible driving types j within the station. A type is, for example, j_1 from A to 1 with turnaround or j_2 from A to 1 being a continuation. This means that the example pictured in Figure 5 has eight types j. For each track i, the total occupation time $t_{B,f}$ must be calculated. For this purpose, the occupation time shall be calculated for each train f for all journey types j using the track i concerned.

Occupancy time $t_{B,f}$ by train f with $j_{continuation}$ $$t_{B,f,continuation} = t_{Sp} + t_H$$

Occupancy time $t_{B,f}$ by train f with $j_{turnaround}$ $$t_{B,f,turn} = t_{Sp} - t_H + t_{turn,DRP}$$

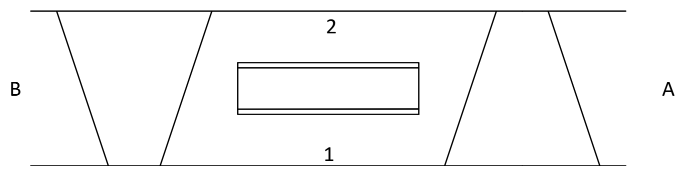

Figure 5: example station for deducing driving types j

with

t_{Sp}	blocking time
t_H	stopping time
$t_{turn,DRP}$	turnaround time at chosen DRP turning station

The total occupation time of a track $t_{B,i}$ is therefore the sum of all runs f on the track i under consideration.

$$t_{B,i} = \sum_{f=1}^{n} t_{B,f}$$

After determining the total occupancy times of the individual tracks $t_{B,i}$, the occupancy rate ρ_i is now calculated for each track i and compared with the recommended occupancy rate according to UIC (2013): check all ρ_i for the following condition: $\rho_i < \rho_{max}$.

The same calculation procedure can be applied in stations where one track is occupied by a parking train. For this, the allocation of the trains that would have used the occupied track must be transferred to other tracks. The calculation procedure can also easily depict the combination of measures at one station.

After applying module 3, it is known whether the measures and their effects are feasible at the individual application points.

4.6 Evaluation of the Transition Phase and Examination of the Transition Capability

The section "reachability" verifies the transition capability. A stable disruption condition is characterized by the fact that all trains runs are on their planned DRP lines, in DRP planned quantity and with the punctuality of regular operations. This needs to be reached within the transition phase.

When evaluating the transition phase, the first step is not to state whether the transition is feasible, but whether there are exclusion criteria that can prevent a successful transition. These are the non-achievement of the planned number of trains (in an appropriate duration) and a constant congestion of the infrastructure in the area under consideration.

Reaching the planned number of trains is achieved by the measure total cancellation being applied only in the transition phase. It leads (temporarily) to an increased occupancy of the stations at which the parking is to be carried out. For each of these stations it must be checked whether the capacity is sufficient. The validation of the measure by considering the capacity of the station tracks, is analogous to the calculation of the capacity of the DRP turning stations in chapter 4.5. However, the following adjustments must be made:

For trains to be parked, the preparation time t_{Vb} instead of the stopping time is to be used to calculate the occupancy time. When driving into the parking area after turning the blocking time is increased as the block is used twice: the signal viewing time and the travel time in the block are set twice. It is assumed that the first route release time and the setting of the second route take place during the preparation time. In this case, there is no driving time for the approach signal distance and clearing time for the entrance.

Occupancy time $t_{B,cancel,noturn}$ due to one train parking without turnaround	$t_{B,cancel,noturn} = t_{Sp} + t_{Vb,noturn}$
Occupancy time $t_{B,cancle,turn}$ due to one train parking without turnaround	$t_{B,cancle,turn} = t_{Sp,turn} + t_{Vb,turn}$

The reduced number of trains in the system is reached before punctuality of the system can be reached. Therefore, the average duration of the cancellations should only take up a part of the desired transition time.

The following model determines the average duration of the cancellations. If the disruption interrupts a line, there may be trains to be parked on both sides of the lines being interrupted by the disruption. Both sides of must be examined.

The observation period $T_{U,AD}$ corresponds to the frequency of the line to be observed. The reference point for determining the average duration of the cancellation is the parking station. This model has to anticipate the different situations (location of the train in relation to the location of the parking station) that can be present in the disruption.

a) train drives in the direction of the railway station where the train is parked
b) train drives in the opposite direction to the holding station

If only one holding station has been declared for each side of the disruption, cases a) and b) must be taken into account. If a holding station is declared on each side, at each end of the remaining route, only case a) must be considered. If there are two stations but they are not at the end of the route, a) and b) must be taken into account.

For each trip f of the line L in question, it must be determined for every minute where it is located for the respective timetable minute m. Subsequently, it must be determined how much of the travel time on a) or b) has already been driven for the respective timetable minute m and how much of the travel time remains.

For each timetable minute m, the maximum value of all trips is selected and defined as the relevant value M_m for this timetable minute. This results in the following for the determination of the average duration of the parking of all trains.

$$t_{B,i} = \sum_{f=1}^{n} t_{B,f}$$

To test for a constant queue, the occupancy rate

$$\rho = \frac{\lambda}{\mu}$$

with

λ	arrival rate
μ	operating rate

is checked for being greater than 1 during the entire transition phase in the direct disruption influence area, as seen in Figure 6. If it is greater than 1, the DRP cannot transition because of a constant queuing and the resulting waiting times.

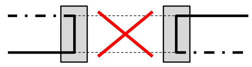

Figure 6: area under consideration in the transition phase

ρ can be reduced during the transition phase by parking trains. If the measure total cancellations affects the area under consideration, the occupancy rate can be calculated before and after completion of the parking.

After applying module 4, it is known whether there are serious exclusion criteria, which prevent the transition to be completed. However, it is not yet certain if the transition is conceivable or possible in the desired time.

4.7 Determination of the Transition Duration

A disruption program is stable if the delays in the system correspond to the delays in regular operations. Timetable conformity is assumed for both, therefore punctual means scheduled and the considered delayed trains must undergo a delay reduction down to 0 minutes.

As shown in Figure 6 the congestion and the resulting delays are mainly on the two sections of the route with occurrence exclusively in the direction of the disruption. There are no delays in the opposite direction, as there are no operational restrictions during the investigation and decision phase.

The duration is modelled in three phases: detection of disruption induced delays before applying the DRP, detection of delays arising from congestions in front of DRP turning stations and the calculation of the probable time, which is most likely needed to fully reduce the delay.

Phase 1: Detection of Disruption induced Delays before applying the DRP

The vehicles comes to a stop when the disruption occurs or at the latest when they reach the last turning point and can then only continue with the start of the DRP and the decision on how to proceed. The vehicle closest to the last possible turn before the disruption is considered at first.

If this vehicle is in the turnaround station at the time of the disruption, the resulting delay $t_{w,first}$ complies with the duration of the investigation and decision phase. Every minute that the vehicle can still drive to that station reduces the delay by one minute.

Since the time of the disruption is purely random, each line can be the foremost vehicle in the queue.

Phase 2: Detection of Delays arising from Congestions in front of DRP Turning Stations

After the DRP has started, all other following vehicles must first wait to be operated in the turning station and can only move up one after the other. For the following vehicles, the evaluation takes place on the basis of the waiting times, which are determined based on the queue. The examination of the vehicles waiting in the queue begins with the expiry of the planned arrival distance $t_{An,plan}$ after the foremost vehicle.

The queue length L_W is determined for every minute. The following vehicles are included in the calculation:

- vehicles operating in the stable DRP on this route and
- vehicles operating on this route during transition before they are parked or deviated

This queue results in a waiting time $t_{W,rear}$ for each observation minute r, which occurs before entering the turning station. It should be noted that the input values can change, as there can be lines running on the route which are cancelled or deviated during transition. The mean arrival distance t_{Anm} and the mean operating time t_{Bnm} will change then.

The development of the initial delay in the queue is now being investigated. For this purpose, each delay caused by the waiting queue is to be calculated for each observation minute r and each line L. At the DRP turnaround stations, any delays can be reduced or nulled. For further consideration, the delay with which the vehicle leaves the turning station must be determined.

For this the following two rules apply, with which the delay after the turn can be determined.

$$\text{for } t_{\text{turn,DRP,tstation}} - t_{\text{W,E,tstation}} < t_{\text{minturnRil,tstation}}$$

$$\text{applies } t_{\text{turn,DRP,is,tstation}} = t_{\text{minturnRil,tstation}}$$

$$\text{then } t_{\text{W,A,tstation}} = t_{\text{W,E,tstation}} - t_{\text{turn,DRP,tstation}} + t_{\text{minturn,Ril,tstation}}$$

$$\text{for } t_{\text{turn,DRP,tstation}} - t_{\text{W,E,tstation}} \geq t_{\text{minturnRil,tstation}}$$

$$\text{applies } t_{\text{turn,DRP,is,tstation}} = t_{\text{turn,DRP,tstation}} - t_{\text{W,E,tstation}}$$

$$\text{then } t_{\text{W,A,tstation}} = 0$$

with

$t_{\text{turn,DRP,tstation}}$	planned turning time at the DRP turning station
$t_{\text{W,E,tstation}}$	delay when entering the DRP turning station
$t_{\text{minturnRil,tstation}}$	minimum turning-time needed at the DRP turning station
$t_{\text{turn,DRP,is,tstation}}$	realized turning time at the DRP turning station
$t_{\text{W,A,tstation}}$	delay when leaving the DRP turning station

After the turnaround at the DRP turning station, the line goes back to the other terminal station. At the turnaround there, delays may also be reduced or nulled. After the turnaround the train drives back in the direction of the DRP turnaround station under consideration. It has to be determined at which observation minute the train will be at the DRP turning station again.

The system then checks whether there is still a queue at that time. If this is the case, the waiting time caused by the new queue is added to the previous delay. This results in a new delay with entry into the DRP turning station. The previous steps are then repeated until no further delay is caused by a new queue.

Phase 3: Calculation of the probable Time, which is most likely needed to fully reduce the Delay

If there is no additional delay created by a queue, phase 3 follows with the reduction of the delays by turning buffers at the turnarounds until there are none left. The transition time results from the duration of the delay reduction plus the duration of the DRP in which a delay development occurred.

The average duration of the transition $\overline{t_{ED,y}}$ for a vehicle y depends on which line L represents the foremost vehicle in the queue. Thus, all cases of the foremost vehicle are to be mapped and calculated.

$$\overline{t_{ED,y}} = \frac{t_{ED,1} + t_{ED,2} + t_{ED,3} + \cdots + t_{ED,r}}{n_r}$$

with

$\overline{t_{ED,y}}$	mean transition duration for vehicle y
$t_{ED,r}$	transition duration at the minute r under consideration
n_r	number of minutes r under consideration

The number of cases corresponds to the number of lines L that are part of the transition phase. For each case (different vehicles being the foremost in the queue), the maximum transition duration $t_{ED,V}$ of each vehicle and line must now be determined. They are averaged over their probability of occurrence P according to the corresponding line frequency. This results in the average duration of transition on the considered side of the disruption.

All t_{ED} are to be compared with each other and the largest mean transition duration $t_{ED,max}$ must be used.

If a reduction of the delays to zero minutes can be achieved, a DRP is capable of transitioning. Whether it is suitable for practical use, however, depends decisively on its duration. It is recommended to classify DRPs, which do not settle within the observation period T_U = 4 hours as not transitional, since a usage longer than this period is unlikely. However, this is not to be equated with a desired duration of transition, which should be significantly lower in order to give a large share of the DRP to the steady phase.

After applying module 5, it is not only certain whether the operating concept can transition from chaotic to stable, but it is possible to appraise its quality.

The approach enables the assessment of the operating concept based on its operational functionality and the quality of its transition phase. If the assessment is validated positively, the algorithm starts with the design and evaluation of a fitting transportation concept.

5 Transportation Concept

Based on the functional operating concept, four modules develop and evaluate passenger guidance and information measures for a corresponding *transportation concept*, also seen in Figure 3. The concept allows a customer-oriented creation and assessment of a transportation concept and therefore an indirect evaluation of the underlying operating concept.

Module 1 *Conflict Detection* searches for conflicts that imply perceptible restrictions for passengers like the non-availability of a regularly scheduled connection. Train runs that are influenced by the operating concept are determined and the resulting train relation conflicts are transferred from the operational basis into travel connection conflicts, which are perceived in the passenger’s travel routine.

Module 2 searches for possible *Conflict Solution Alternatives*. Every individual conflict is provided with alternative travel connections being a feasible and acceptable solution for an individual passenger. The algorithm works with a hierarchical search behavior as seen in Figure 7. It favors the diversion of passengers in the regarded system (S-Bahn) as level 1 over the diversion of passengers in the entire public local transportation network (level 2). Releasing other trains for use like long-distance trains is the third level. Additional transportation capacities like bus distress traffic is not an option in this module but in module 3 “Search for Solutions”, if necessary. To decide whether a level offers an acceptable solution, the connection alternatives are checked on their impact concerning feasibility of the alternative for the passenger, acceptable height of delays and transfers.

Module 3 *searches for Solutions* relating to the whole network and not only to individual conflicts. The transportation concept shall be universally valid for the typical disruption so that communication measures can be applied based on it. By allocating passenger flows, general travel connection corridors for the disruption are to be found. They are created for important connections e. g. linking both sides of the disruption. The best corridor for an important connection shows the lowest resistance increase for the related passenger flow. These optimal solutions need to be evaluated with a bottleneck analysis to check whether capacity problems at stations or in trains occur because to many corridors plan to use the same infrastructure. The overall aim is to get as many passengers to their destination as possible. A bottleneck is solved by aspiring the lowest resistance increase throughout the whole network.

Module 4 *evaluates the Passenger Guidance Concept* resulting from the conflict solution in module 3, considering the overall destination attainment of the affected passengers. The quality of the offered transportation services is reviewed from the subjective passenger's point of view. Using the method of resistance alteration modelling, the changes in passenger travel comfort, especially concerning delays and transfers are evaluated. Therefore, these characteristic values of this evaluation process are already part of the modules two and three. Every disruption that creates a conflict for the passenger leads to a resistance increase because of the necessary adaption to the situation and the deviation from the usual travel routine. The algorithm of this module identifies the changes in passenger travel comfort concerning delays and transfers by calculating the resistance alteration and evaluates the concept in context with the overall destination attainment of the affected passengers. If the transportation concept is validated positively, the DRP is completed, otherwise the operating concept needs some revisions or quality losses would have to be accepted for the transportation concept.

The algorithms give feedback on the strong weaknesses of the transportation concept like open conflicts or poorly solved conflicts. Those can be displayed as problem areas in the operating concept, so that those can be rechecked by the creator for further improvement in terms of the passengers.

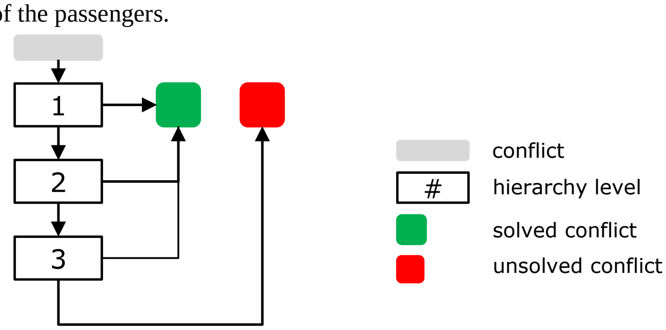

Figure 7: hierarchical search for a conflict solution alternative

6 Discussion

The presented approach can be summed up in Figure 3 and it enhances disruption programs covering both stable operations as well as passenger-friendly solutions including passenger guidance measures, which can now be reasonably designed based on a functionality checked operating concept. The algorithms enable an automated evaluation of the disruption programs in commuter railway transportation in a customer-oriented way by including and evaluating the resulting travel changes for the passengers.

The objective of the evaluation algorithms presented is to support the creation of an operationally functional and at the same time customer-oriented disruption program.

A manually created operating concept is checked for operational functionality and evaluated on the basis of the automatically calculated transition time into stable disruption operation. One the one hand, the algorithms ensure that an attainable disruption operation has been planned.

On the other hand, based on the functional operating concept, the extension of the disruption program by passenger guidance is an aim. The algorithms, which are based on a conflict search and solution approach, determine a customer-oriented transportation concept with the available travel connections and passenger routing options, taking into account passenger flows and possible infrastructural bottlenecks induced by operational measures.

Some parts of the modules principally need data sets that are currently not available for TOCs. This implies the use of sound assumptions by experts. Experienced staff is still needed for the design of DRPs but once implemented their work will be simplified, results might be of higher quality and more DRPs can be created or adapted to network discrepancies due to construction works, for example. The next step is to implement the presented approach into a software and to evaluate the algorithms with experts and test scenarios so that the approach ensures an evaluation of disruption programs based on their transition and their transportation quality for passengers. Future research on how to adapt a pre-planned DRP when in use to a deviating operating and infrastructural situation is the next step to ease disruption dispatching, that has already begun.

References

Chu, F., Fornauf, L., Wolters, A., Böhme, A., 2012. „Methode zur Erarbeitung von Störfallprogrammen“, *Deine Bahn*, 2012(07), pp. 45-48.

Chu, F., Wolters, A., Böhme, A., 2013. „Störfallprogramme betrieblich umsetzen“, *Deine Bahn*, 2013(06), pp. 20-25.

Chu, F., Oetting, A., 2013. “Modeling Capacity Consumption Considering Disruption Program Characteristics and the Transition Phase to Steady Operations During Disruptions”, *Journal of Rail Transport Planning & Management*, 3(3), pp. 54 - 67.

Chu, F., 2014. *Beurteilung von Störfallprogrammen anhand ihres Einschwingverhaltens - am Beispiel des Schienenpersonennahverkehrs*. Darmstadt, TUprints.

Crespo, A., 2018. “Dynamic Disruption Management in Commuter Railway Networks”, In: *Eisenbahntechnisches Kolloquium 2018*, Darmstadt, Germany.

Corman, F., D'Ariano, A., Hansen, I. A., Pacciarelli, D., Pranzo M., 2011. “Dispatching trains during seriously disrupted traffic situations”, In: P*roceedings of 8th IEEE International Conference on Network, Sensors and Control*, Delft.

DB Netz AG, 2011. "Züge fahren. Umleiten unter erleichterten Bedingungen." In: *Ril 408.1431 Abschnitt 2 Absatz 2*, Germany.

Fischer, K., Hertel, G., 1990: *„Bedienungsprozesse im Transportwesen - Grundlagen der Bedienungstheorie"*, Berlin, Germany.

Josyula, S., Törnquist Krasemann, J., 2017. „Passenger-oriented Railway Traffic Rescheduling: A Review of Alternative Strategies utilizing Passenger Flow Data", In: *Proceedings of RailLille - the 7th International Conference on Railway Operations Modelling and Analysis*, Lille, France.

Ochiai, H., Nakamura, T.,, Kitai, M., 2016. ""Traffic Operator Assistance System" aiming at the Next Generation of Integrated Traffic Management System", In: 1*1th World Congress on Railway Research (WCRR 2016)*, Milan, Italy.

Oetting, A., Chu, F., 2013. "Disruption Programs in Passenger Rail Transport — Ensuring Steady Operations During Disruptions", In: *13th World Congress on Transportation Research (WCTR 2013)*, Rio de Janeiro, Brazil.

Schütz, I., Stelzer, A., 2015. "Field Evaluation of a New Railway Dispatching Software", In: *Proceedings of ACHI 2015, The Eighth International Conference on Advances in Computer-Human Interactions*, pp. 63–68.

Stelzer, A., 2016. *„Automatisierte Konfliktbewertung und -lösung für die Anschlussdisposition im (Schienen-)Personenverkehr."* Darmstadt, TU prints.

Toletti, A., 2018. *"Automated railway traffic rescheduling and customer information"*, Zürich, IVT Schriftenreihe, 179.

Törnquist Krasemann, J., 2012. "Design of an effective algorithm for fast response to the re-scheduling of railway traffic during disturbances", *Transportation Research Part C*, 2012, 20, pp. 62-78.