Review of railway disruption management practice and literature

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Abstract

This paper investigates the challenges of railway traffic controllers in dealing with big disruptions and the kind of support tools that could help to improve their task in terms of performance and lead time. The disruption handling process can be partitioned into three phases according to the bathtub model and to each phase the essential decision making processes have been identified. Currently, the support to rail traffic controllers in case of severe disruption is limited to predefined contingency plans that are not always feasible or applicable. In the literature models and algorithms have been identified that could be used in the different parts of the three phases of the disruption handling process. The contribution of this study is threefold. The processes of disruption management in practice and the challenges that traffic controllers are facing during a disruption are brought forward. Next a literature review of models applicable to disruption management are reviewed and classified based on the three phases of the traffic state during disruptions. Finally, an example illustrates how microscopic models could support a traffic controller in filling in the gaps of the current contingency plans.

Keywords

Railway disruptions, rescheduling, disturbances, microscopic models, bathtub model

1 Introduction

In case of large disruptions (e.g. blocked tracks or catenary breakdown) traffic controllers should apply fast and proper measures, to resolve the traffic and prevent delay propagation to the rest of the network. In the Dutch railway network predefined solutions called contingency plans are used to assist the traffic controllers in dealing with such disrupted traffic. Each contingency plan corresponds to a specific disruption scenario at a specific location designed manually by experienced traffic controllers. These location specific plans define which trains should continue, and which should be cancelled, short-turned or re-routed. For the trains that should be short-turned it is identified which station the short-turning should take place, as well as the departure time and platform. The aim of short-turning trains is to replace the train that is supposed to operate in the opposite direction, but is not able to pass the disturbed area. In this way short-turning will avoid delay propagation to a great extent.
These plans are however not worked out in detail on infrastructure allocation level and they do not cover all the possible disruption cases throughout the network. In practice, it thus might happen that no suitable contingency plan is available for a disruption situation. In such cases the traffic controllers are faced with a high workload and a lot of communication to reach an agreement about a suitable recovery plan. These plans are thus static and inflexible, and even if a suitable plan is available the traffic controllers still need to make adjustments and fill in the details to implement them. It would be of great help if for instance decision support would be available that could suggest conflict-free routes and details of the short-turned trains on both sides of the disruption area.

The bathtub model is used to study the disruptions. The bathtub scheme is shown in Figure 1. This model is divided into three phases. When a disruption occurs, the traffic decreases (first phase). The traffic remains at a lower level during the time the problem is being handled (second phase). After the problem has been solved the traffic increases to the original timetable (third phase). In practice the traffic might even be stopped entirely near the disruption area to remove trapped trains and restart a rescheduled solution from empty tracks. The first and third phases are called transition phases, since they represent a transition of the operation from the original timetable to the disruption timetable and vice versa, respectively. The disruption timetable is usually based on a pre-defined macroscopic timetable from a contingency plan.

In this paper the problems that traffic controllers face when dealing with disruptions are put forward. Then these problems are classified based on the three phases of the bathtub model. Next a critical review of the models and approaches known from the literature is carried out. In the following step the applicability of the models for the defined problems is investigated. Moreover, an illustrative case shows the applicability of such models.

The structure of the paper is as follows. Section 2 describes the current disruption management practice from the Netherlands and identifies the problems that need improvements. Section 3 reviews relevant disruption management models from the literature. Section 4 then gives an illustrative example on how models could support the disruption management and thereby improve problems experienced in practice. Conclusions are given in section 5.
2 Disruption management in practice

This section describes the practice of disruption management focusing on the Netherlands, and identifies the problems encountered based on interviews with traffic controllers, contingency plan developers, and railway control staff.

2.1 Design of the contingency plans

The contingency plans are designed by experts who used to be train signallers or traffic controllers. The design of these pre-defined solutions is based on the basic hour patterns of the Dutch timetable and station track occupations. Based on these patterns and a specific disruption scenario, the planner estimates the remaining capacity and decides which trains should be cancelled or short-turned. The cancellation of services should be divided between the different railway undertakings that are operating in the area. Then the stations at which the trains should be short-turned are defined. In defining the short-turning, it is anticipated that the short-turned trains replace the trains in the opposite direction.

Based on the station track occupation pattern, it is checked whether the trains could short-turn at the proposed time and platform. Since these solutions are static plans, they are designed based on the mentioned patterns and for this reason their realization might not be possible if the actual traffic deviates from these basic patterns.

Recently, for each corridor so-called decoupling stations are defined in advance where trains will short-turn if tracks are blocked. Different train types (Intercities or local trains) may have different decoupling stations for short-turning.

2.2 Workflow of the disruption management

Since 2010, the Netherlands have a centralized Operation Control Centre Rail (OCCR). The aim of having a centralized control centre is to bring the different railway stakeholders such as the traffic controllers from the infrastructure manager, operations controllers from the railway undertakings and delegates from several contractors together to achieve a higher performance by better communication. This becomes especially important with big disruptions on the network when the stakeholders have to cooperate closely. Figure 2 shows the workflow during a disruption. If the train traffic is hampered due to a serious failure of infrastructure or rolling stock, the back office of the OCCR gets informed and sends an inspector (a.k.a. general controller) to the location of the failure to get updates about the status of the problem.

In the meantime the back office creates an announcement notification in the online traffic control information system, so the train signallers, traffic controllers and other involved actors could access the announcement and get informed. In this notification, the problem, the people who should be involved, and the specific location that should be identified by the signaller are mentioned.

If necessary the contractors are sent to the location to repair the problem. Meanwhile the signaller should deal with the disturbed trains that cannot proceed with their schedule. Based on the information from the field such as the location and severity of the disruption the signaller finds the relevant contingency plan and communicate it with the traffic controllers located in the OCCR.
Before implementing any plan, it first should be agreed between the traffic controllers of the infrastructure manager and the railway undertakings that the selected plan offers the suitable solution for the disrupted situation. Finally the traffic controllers in the OCCR should authorize the implementation of the contingency plan. In case of required changes to the contingency plan, this should be performed in consultation with the train signallers. Once authorized the contingency plan will be formalized and implemented by the signaller. After the repair crew solved the cause of the disruption and this has been approved by the general controller, the termination of the repair in the field will be announced in the online information system.

2.3 Identified problems in the OCCR

In this section the difficulties regarding the processes mentioned earlier are presented and projected on the three phases of the bathtub model.

The first phase starts as soon as the traffic becomes disturbed due to an unplanned event or an incident is communicated to the back office. The situation is communicated to the back office of OCCR where a decision should be taken. The decision about implementing a contingency plan in the first place depends on the disruption duration estimation. If the estimated duration is less than 45 minutes then it is preferred not to implement any contingency plan. Thus, it is important to have a fast and accurate duration estimation which is currently missing. If it is expected that the disruption lasts longer than 45 minutes, the search for a suitable contingency plan starts. This search is based on the information received from the field such as the exact location of the disruption and its severity. In case of an existing suitable contingency plan, there is another problem regarding the implementation of these plans in the short-turning stations. The contingency plans correspond to the second phase of the bathtub model with the reduced traffic. However since the detailed information regarding the implementation of this reduction depends on the real state of traffic, it cannot be specified in the predefined solution. For example a contingency plan suggests that a specific train should short-turn at a specific station platform.

Figure 2: Workflow of disruption management
It might happen that at the moment when the suitable contingency plan is selected, the train already left the station where it had to short-turn and the traffic controller needs to take care of the operation of this train in the following station. Thus, the traffic reduction might not be implemented as straightforward as is suggested in the contingency plan. Therefore these plans do not provide sufficient detailed information about the processes that were unplanned in the original timetable.

Since these contingency plans are predefined, they may need to get adjusted to reflect the real traffic status. For example, if the trains do not operate according to the plan and their platform track occupation does not correspond to the planned pattern, then the specific station platform might still be occupied by other train and accordingly a suggested short-turning might not take place at the defined time or platform. Hence, the most relevant contingency plan is chosen by the train signaller and then modified in collaboration with the traffic controllers in the OCCR. A problem might occur when the traffic controller and signaller do not agree on a decision and have different opinions about which decision should be taken. Then reaching an agreement might take long and moreover the final decision might not be the optimum, since it depends on the experience of the traffic controller and signaller.

If no suitable contingency plan is available then the traffic controllers are in charge of providing a feasible plan based on the actual traffic state. The common practice is to isolate the disrupted area and prevent the delay propagation to other lines. This task is rather difficult especially in the main stations with many trains. In current practice, handling the disruption directly depends on the experience and skill of the person in charge. This is the main reason of disagreement between the controllers and signallers.

In the second phase any new information about the actual state of the disruption might require some adjustments to the current operation. In this phase, it is also important to plan ahead for restoring the original timetable. Therefore the information about the disruption duration plays an important role in this phase. If accurate information about the disruption length is available, the third phase could be planned to achieve a smooth transition from the disruption timetable back to the original timetable. In this third phase, it is important to reinsert the cancelled services and restore the original plan in such a way that it does not hamper the traffic of the adjacent areas.

Table 1: Identified challenges in each phase

<table>
<thead>
<tr>
<th>Phase</th>
<th>Challenges identified</th>
</tr>
</thead>
<tbody>
<tr>
<td>First phase</td>
<td>● Estimating disruption duration</td>
</tr>
<tr>
<td></td>
<td>● Implementing short-turned trains</td>
</tr>
<tr>
<td></td>
<td>● Adjusting contingency plan</td>
</tr>
<tr>
<td></td>
<td>● Discussing the decision</td>
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<tr>
<td></td>
<td>● Isolating disrupted area (in case of no contingency plan)</td>
</tr>
<tr>
<td>Second phase</td>
<td>● Adjusting and implementing the plan</td>
</tr>
<tr>
<td></td>
<td>● Estimating remaining disruption duration</td>
</tr>
<tr>
<td></td>
<td>● Preparing transition to the next phase</td>
</tr>
<tr>
<td>Third phase</td>
<td>● Adjusting and implementing the transition plan</td>
</tr>
<tr>
<td></td>
<td>● Reinserting cancelled services</td>
</tr>
<tr>
<td></td>
<td>● Restoring the original plan</td>
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</tbody>
</table>

Table 1 summarizes the identified challenges in each phase. Looking at the identified
problems, it can be concluded that the traffic control faces most problems during the first phase where the uncertainty regarding the exact disruption and a suitable solution are the highest.

3 Review of scientific literature

There is a rich literature and overview of models and methods used for dealing with operational uncertainties. However, there are limited references addressing the large disruptions where many trains should be cancelled or short-turned.

Cacchiani et al. (2013) provide an overview of models and algorithms for real-time rescheduling. In this overview, the literature is classified into two categories. The models and methods that are handling relatively small deviations from the scheduled timetable referred to as disturbances, and those which deal with large deviations that usually involve long delays and cancellation of trains which are referred to as disruptions. The models for disturbances and disruptions are developed based on either microscopic or macroscopic detail of the infrastructure and operations. The review concludes that the research on disruption management and especially with microscopic level of detail is surprisingly limited.

To provide a feasible solution we believe that it is of great importance to formulate the operations and infrastructure with fine granularity. Hence, in our review it is also indicated whether the developed model is microscopic or macroscopic.

In this section a review of the applicable literature with a special attention to three phases of bathtub model is provided. Finally the models relevant for the challenges mentioned in Section 2.3 are identified in Section 3.2.

3.1 Classifying the literature based on the bathtub model

Hirai et al. (2009) developed a train stop deployment algorithm, which determines the stop locations for the trains that are hindered and cannot operate based on the plan. Petri nets and integer programming (IP) is used to formalize and solve the train stop deployment problem. The main focus is on isolating the disturbed area from other lines, to avoid delay propagation. This is done through assigning stops to hindered trains in different locations to clear the route for trains commuting on other lines.

The model is considered to be microscopic since the infrastructure is modelled at the level of block sections. This method partly addresses the first phase of bathtub model where the traffic is decreased due to a disruption but it does not provide any plan for the hindered trains or whether they should possibly be shunted or short-turned, in case of a complete blockage.

Corman et al. (2011) study centralized and distributed rescheduling for handling disruptions in large and busy railway networks. For the distributed approach, the rescheduling is done based on alternative graphs and blocking time theory. Then a set of constraints are defined for coordination between different areas. Case studies show that both approaches face difficulties in finding feasible schedules for increasing prediction time horizons in real-time application. For shorter prediction time horizons, the distributed approach achieves smaller delays than the centralized one. This microscopic formulation provides rescheduling and hence can support traffic controllers in the first and second phases.

Shen and Wilson (2000) developed a real-time disruption control model based on mixed-integer linear programming (MILP). The macroscopic model considers a single...
line and formulates the route between stations as a sequence of block sections. Different control strategies such as short-turning, holding and stop skipping are tested. The authors conclude that the combination of holding and short-turning strategies reduces the mean passenger waiting time remarkably well. The research gives insight about the third phase where the main attempt is to restore the original timetable. Since the plan for the third phase is developed in the second phase, the model can be used in both phase.

Nakamura et al. (2011) developed a macroscopic model for dealing with a complete blockage of a double-track network. The model uses three predetermined factors: train group, train cancellation sections and short-turning patterns, which result in the train-rescheduling pattern. The model cancels the trains running in the disrupted area and connects the short-turning trains to the trains running in the opposite direction. Then it identifies those train lines that have either no assigned rolling stock or no planned route. At the final step of the algorithm, the process of matching the plans and rolling stock takes place. The main focus of the paper is to support the traffic controllers by proposing train cancellations and short-turnings. The support covers the three phases of the bathtub model.

Narayanaswami and Rangaraj (2013) developed an MILP for a single-track line. The only dispatching measure considered is delaying trains. Thus, no rerouting, cancelling and new services are included in this work. The model assumes disruption length to be given, as well as the starting and ending time of the disruption. The decision variables of the model represent the arrival and departure of the trains in the station. The model is macroscopic and thus does not consider blocking times. Minimum process times and scheduled arrival and departure times are the inputs of the model. The objective is to minimize the weighted difference between the scheduled and actual arrival time at the final destination for all trains. The model computes the decision variables by delaying trains until the disruption is over and then defines the order and schedules of departing trains based on the weights. The disadvantage of this model is that the delay could propagate easily if the trains are not short-turned to compensate for the cancelled ones. The model is useful for the second and third phase of the bathtub model when the disruption cause is repaired and the operations can get back to the original timetable.

The objective for dealing with large disruptions may be to maximize the service level. Louwerse and Huisman (2014) formulated the problem as a macroscopic MILP, considering both partial and complete blockages of a railway line. Their main focus is on the rescheduled timetable after the first transition phase, which thus supports the traffic controllers in the first phase. The original timetable and an estimation of the disruption duration are used as input of the model and the output of the model is the rescheduled timetable indicating which trains should run with their schedules.

Veelenturf et al. (2014) extend the previous macroscopic model of Louwerse and Huisman. In the extended model, a real case of a railway network is used with more than two tracks between and in stations, and the trains services are able to use other tracks than they were originally assigned to. The objective of the model is to minimize the delay and the number of cancelled trains. The transition phases are implicitly addressed. The focus of the paper is on the phase 1 timetable rescheduling including some rolling stock constraints on a macroscopic level.

Zilko et al. (2014) developed a model for estimating the disruption duration. A Non-Parametric Bayesian Network (NPBN) is used to model the joint distribution between variables that characterizes the nature of the disruption. By conditioning based on new information the estimation of the disruption duration can be improved whenever information updates become available. Accurate estimates of the disruption duration are
very useful to achieve smooth transition phases. Thus, the model provides support for the first and second phase of the bathtub model.

Despite the importance of short-turning strategies in case of disruptions, there are only limited references that investigated this topic. Coor (1988) macroscopically modelled a high frequency single transit line to simulate short-turning trains with the objective to decrease the passenger waiting times. He concluded that a short-turning strategy is more beneficial in case of severe delays than small delays. The model represents the second phase of the bathtub model.

Chu and Oetting (2013) considered the additional processes that are not planned and are caused by disruptions. The extra processes refer to communication, gathering information about the disruption, taking decisions about the suitable contingency plan and implementing the selected solution. To gain an insight to the first transition phase, they analysed the operational data of two big German urban railway networks where contingency plans were implemented.

They concluded that one of the main reasons for delay during this phase was due to the queuing of trains at the short-turning stations. Looking into the extra processes, they make a distinction between non-recurring and recurring processes. The first one refers to those specific processes that belongs to specific trains (e.g. giving written orders train by train) which do not repeat and the second one refers to the ones that reoccurs such as short-turnings. They highlighted the importance of these extra processes in deriving feasible contingency plans in stations using microscopic modelling of the blocking times. This research gives insight about the first phase of bathtub model.

Jespersen Groth et al. (2006) focus on the recovery transition from a disruption timetable to the original timetable. When a disruption occurs, the trains are shunted away to the closest depots in the same direction. After the cause of disruption has been resolved, first a train should take the train drivers from the central station to the depots so that the cancelled trains can resume their operations. This recovery is modelled macroscopically by mixed integer programming (MIP) to calculate the best reinsertion of cancelled trains in the network to fit to the periodic timetable.

Meng and Zhou (2011) used stochastic programing to incorporate the uncertainty of the disruption duration in probabilistic scenarios. The rescheduling is then performed based on a rolling horizon. The selected solution is the one with the minimum expected delay at the final station of all services. In this paper, the services resume as soon as the infrastructure is available, thus no other strategy such as short-turning and cancellations are considered and the focus is on the third phase. Table 2 summarizes of the reviewed models. For each model, it is identified the phases for which the model is applicable. Most models are macroscopic and together they cover all phases.

### 3.2 Applicability of models to the identified problems

This section investigates the applicability of the reviewed models to the identified problems for each phase. Table 3 shows the summary of the models within three phases.

#### 3.2.1 First phase

The traffic controllers are facing most challenges during the first phase. The first difficulty is to have an accurate estimation about the disruption length. Zilko et al. (2014) developed a model specifically to estimate the disruption length, which includes the latency time and repair time.

The following problem is about implementing the contingency plans with the main
difficulty concerning the short-turned trains. Nakamura et al. (2011) is one of the few references that model short-turning trains in stations, although the model does not provide microscopic insight into the station capacity consumption.

Table 2: Summary of the review models

<table>
<thead>
<tr>
<th>Paper</th>
<th>Microscopic</th>
<th>1st Phase</th>
<th>2nd Phase</th>
<th>3rd Phase</th>
</tr>
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<tbody>
<tr>
<td>Hirai et al. (2009)</td>
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<tr>
<td>Corman et al. (2011)</td>
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<td>√</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Shen &amp; Wilson (2001)</td>
<td>-</td>
<td>-</td>
<td>√</td>
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<tr>
<td>Nakamura et al. (2011)</td>
<td>-</td>
<td>√</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Narayanaswami &amp; Rangaraj (2013)</td>
<td>-</td>
<td>-</td>
<td>√</td>
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<tr>
<td>Louwerse &amp; Huisman (2014)</td>
<td>-</td>
<td>-</td>
<td>√</td>
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<tr>
<td>Veeleenturf et al. (2014)</td>
<td>-</td>
<td>√</td>
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<td>-</td>
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<tr>
<td>Zilko et al. (2014)</td>
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<td>√</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Coor (1988)</td>
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<td>Chu &amp; Oetting (2013)</td>
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<tr>
<td>Jespersen Groth et al. (2006)</td>
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<td>√</td>
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<tr>
<td>Meng &amp; Zhou (2011)</td>
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</table>

Chu and Oetting (2013) studied the effects of unplanned events that result in extended processes time. The research provides a clear understanding on the capacity consumption in stations with short-turning, although it does not provide a rescheduling model to compute solutions including short-turnings. The implementation of short-turning trains still needs to be investigated more at a microscopic level of details. Another problem in the first phase is how to adjust a contingency plan and reaching agreement on a decision, for which can be referred to the papers on rescheduling including cancelling and short-turning trains that can be viewed as dynamic contingency plans. The following references provide solutions for rerouting and rescheduling: (Corman, D’Ariano, Hansen, Pacciarelli, & Pranzo, 2011), (Nakamura, Hirai, & Nishioka, February 2011), (Louwerse & Huisman, 2014) and (Veeleenturf, Kidd, Cacchiani, Kroon, & Toth, July, 2014). The research done by Nakamura et al. (Nakamura, Hirai, & Nishioka, February 2011) focus on avoiding delay propagation while the other references focus on minimizing delay and number of cancelled trains. The final problem concerns the cases where no contingency plan is available and traffic controllers should isolate the disrupted area to avoid delay propagation. Hirai et al. (2009) provide a model that can be used to calculate the stop positions for the trains that are affected directly so that the other trains could continue their trips conflict free.

3.2.2 Second phase

In the 2nd phase the contingency plan might get adjusted with the updated information about the status of the disruption. For example it might be the case that more (or fewer) routes should be cleared due to disruption, for instance to access the tracks where the repair needs to be done. This results to the same problems of adjusting the plan and agreeing on a decision as in the first phase.

Most literature available concerns the development of a disruption timetable for this
phase (Corman, D'Ariano, Hansen, Pacciarelli, & Pranzo, 2011), (Nakamura, Hirai, & Nishioka, February 2011), (Shen & Wilson, 2000), (Narayanaswami & Rangaraj, 2013) (Veelenturf, Kidd, Cacchiani, Kroon, & Toth, July, 2014) (Louwerse & Huisman, 2014). Coor (1988) looked at short-turning trains as a strategy to compensate for the time loss in the second phase and the main conclusion confirms the benefits of short-turning trains in case of large disruptions. Also in the second phase, reliable estimation about the disruption duration is required. As it is mentioned in the first phase, the model developed by Zilko et al. (2014) can be used. In the second phase, it is important to know when the disruption cause is expected to be resolved. This information is essential to plan for the third phase, where the train operations should switch from disruption timetable to the original one. To give an example, if a reliable disruption length is available it can be decided earlier to stop the short-turning and operate trains based on the original plan again which shortens the second phase.

The model of Meng and Zhou (2011) incorporates the uncertainty regarding this information and determines the order of trains to proceed after the disruption with the least delay. Jespersen Groth et al. (2006) focused on the rolling stock circulation after the disruption. This model can also be used to develop a plan for reinserting the services for the third phase.

3.2.3 Third phase
In the 3rd phase the plan needs to be adjusted to get back to the original planned services which again can be supported by the same models for real-time rerouting and rescheduling. The main problem identified in this phase is implementing the transition plan prepared in the second phase.

Nakamura et al. (2011) provide a plan for cancelled and short-turned trains, which helps the traffic controllers to know which cancelled and short-turned trains should be reinserted back in the network. However the implementation of the plan in this phase requires a microscopic representation of the infrastructure and processes, especially in stations where trains were short-turned.

The last problem in this phase is the reinsertion of the cancelled trains. As indicated in the previous phase the models by Meng and Zhou (2011) and Jespersen Groth et al. (2006) provide support how this can be done. Table 4 summarizes the models that can be used to support the traffic controllers with the identified problems in Section 3.

The vast literature on rerouting and rescheduling models did not find their way into the practice of disruption management yet. Traffic controllers are handling disruptions without any support. One important objective in disruption management is to prevent the delay propagation to the neighboring areas. This objective is often disregarded in the literature and might be a reason that such models are not yet implemented in practice.

The model developed by Nakamura et al. (2011) focuses on this objective but it is not based on a microscopic level of detail. For this reason the feasibility of the produced plan should be checked at the microscopic level. Another research by Hirai et al. (2009) also focuses on isolating the disrupted services, but the model does not provide the complete rescheduling solution.

4 Case study
In case of disruptions where many trains cannot proceed with their original plan and some might be short-turned, the traffic controllers need decision support to rapidly compute
feasibility and stability of possible routes and schedules associated to (adjusted) contingency plans or dynamically computed new plans. At this stage it is required to take into account a microscopic level of detail to prove feasibility of the solutions (Chu & Oetting, 2013).

This section illustrates how such models can improve the process of disruption management and support the traffic controllers. The approach used in this example is based on blocking time theory which is the commonly accepted method for conflict detection and computing capacity consumption (UIC, 2013).

Table 3: Identified problems and relevant literature

<table>
<thead>
<tr>
<th>Challenges</th>
<th>First Phase</th>
<th>Second Phase</th>
<th>Third Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimating disruption duration</td>
<td>Zilko et al. (2014)</td>
<td>Zilko et al. (2014)</td>
<td>NA</td>
</tr>
<tr>
<td>Isolating disrupted area</td>
<td>Hirai et al. (2009)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Reinserting cancelled services</td>
<td>NA</td>
<td>NA</td>
<td>Jespersen Groth et al. (2006), Meng and Zhou (2011)</td>
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</table>

The blocking time of a track section refers to the total time that the section is assigned to a specific train movement and is blocked for other trains (Figure 3). The blocking time starts from the sight distance before the approach indication to the block section (Hansen and Pachl, 2014).

In the example shown in Figure 3 the blocking time for block section S1-S2 starts at the sight distance to the approach signal S0. It ends when the train has completely left the track section and the signal has been reset to be used for the next train. Figure 4 shows an example of the blocking times for a train stopping in a station. Note that in the station area, track elements, (e.g. switches) are separately released so other trains could run over them to reach other track sections. This sectional release is shown in Figure 4. In this case the dwell time at the platform track is part of the blocking time of the platform track section, and the blocking time after the station starts as soon as the outbound route is set and the signal released.

This section shows a simple case study to illustrate the applicability of a blocking time model to disruption management (Besinovic, et al., 2014). The case represents a disruption near a small station in the Dutch railway network, see Figure 5. The track between station Oss and Den Bosch is completely obstructed which prevents train operations to continue after Oss or reach Oss from Den Bosch. Hence, the trains that are originally planned to run from station Nijmegen to Den Bosch now have to be short-turned in station Oss. This example refers to the second phase of bathtub model, where the
track sections and routes for short-turning trains are identified.

Figure 3: Blocking time of a running train

Figure 4: Blocking times with a station stop
The layout of the Oss station is shown in figure 6. In the original timetable two train lines (3601 intercity and 4401 sprinter) run from station Nijmegen to Den Bosch on the upper track and train lines 3600 and 4400 in the opposite direction on the lower track. Due to the disruption, trains 3601 and 4401 should be short-turned in station Oss and continue their run back towards station Nijmegen. This short-turning implies a changed station track utilization with adjusted routes and platform track allocations that need to be checked on conflicts, acceptable track occupation and fit in the new timetable with preferably all short-turned trains running in the original opposite train paths. Note that the running and blocking times change due to the changed routes, and likewise the platform track occupation time of a short-turning train also takes longer than the minimum dwell time for a continuing train.

The blocking times for the short-turned trains are shown in figure 7. The IC trains 3601, 3603, 3605 are short-turned on track section 114 (TS_114). By short-turning train 3601, it replaces the opposite train 3600 which cannot reach station Oss due to the disruption on the opposite direction. The blocks shown in grey represent the operations of the local trains 4401 and 4403. As it is shown in the figure, these trains are short-turned on track section 22 (TS_22). As it is marked with the red circle in the blocking time diagram in Figure 7, train SPR 4401 leaves the station at the same time that the opposite train is entering the station. Since in the blocking time diagram, both track lines are represented in one dimension, it may perceived as if there is a conflict, while they are operating on different track lines. This becomes apparent by showing the track lines separately. Figure 8 shows the same blocking times for lower and upper tracks separately.
In the undisturbed situation, the trains IC 3600 and SPR 4400 run towards Nijmegen on the lower track. As it is shown in the example, in the disturbed situation trains IC 3601, IC 3603 and IC 3605 should short-turn on the upper track. This change of route results in a change of running time which in this case is about 15 seconds.

This microscopic representation of the trains operation gives insight about the capacity of the station. This way, the traffic controllers are provided with accurate information about the remaining capacity. Such microscopic models are most needed in large stations where there might be many or limited options for short-turning trains which makes the decision more complicated for the traffic controllers. Through these models, the traffic controllers are able to make faster decisions in each phase.
5 Conclusion

In this paper the processes of railway disruption management were investigated and the difficulties that railway traffic controllers are facing during the disruptions were identified. The proposed models and algorithms in the literature are classified based on the three phases of disruption. It is concluded that the main problems are related to the first phase of the bathtub model. Based on a literature review, the applicability of models from the scientific literature to the three phases of the bathtub model was identified. In particular models covering the transition phases are limited and most models lack the microscopic level of detail required to prove feasibility and stability of the rescheduling solution that include significant changes from the original traffic plan, such as short-turning and cancelling of trains. The importance of microscopic models for short-turning trains in stations has been illustrated through an example. The identified direction for follow up research includes the transition phases where the change of timetable in operation is a challenge. It is of great interest to provide a solution that affects the surrounding healthy traffic areas as least as possible.

Acknowledgment

This research has been funded by the partnership programme ExploRail of technology foundation STW and the Dutch railway infrastructure manager ProRail in the project SmartOCCR under grant number 12257. The authors thank the numerous interviewees from ProRail for sharing their knowledge.
Bibliography


