Design of passenger oriented timetable rescheduling in railway disruptions

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Abstract

Disruption management is a cutting-edge field in current transport operation research. More precisely, it is mostly studied from operations-centric views, while only few literatures exist from passenger-centric views. This research aims at developing timetable rescheduling strategies from passengers' viewpoint in case of severe disruptions of rail services. It will improve service quality for passengers and also attach importance to rescheduling efficiency as well as operational feasibility.

To achieve it, passengers, train operators and infrastructure managers are inevitable to be considered holistically in case of railway disruptions. It is of great importance to expound the interactions among these three stakeholders. Taking passengers' quantities and priorities into consideration, train operators design adapted services and infrastructure managers test operational feasibility from the perspective of the network. The information feedback among three stakeholders links them into an iterative process.

By establishing evaluation criteria for passengers' satisfaction, rescheduling efficiency and operational feasibility, respective and overall objectives of three stakeholders will be identified in case of railway disruptions. An integrated and flexible model is to describe the whole optimisation problem in different disruption patterns. Passenger simulation, adapted services design and operational feasibility will be optimised individually. Then, dynamic information interactions among three stakeholders will be solved by designing iterative algorithm. Case studies will illustrate passenger-oriented dispatching strategies in different disruption patterns.

Keywords

Timetable rescheduling – passenger simulation – railway disruptions

1. Introduction

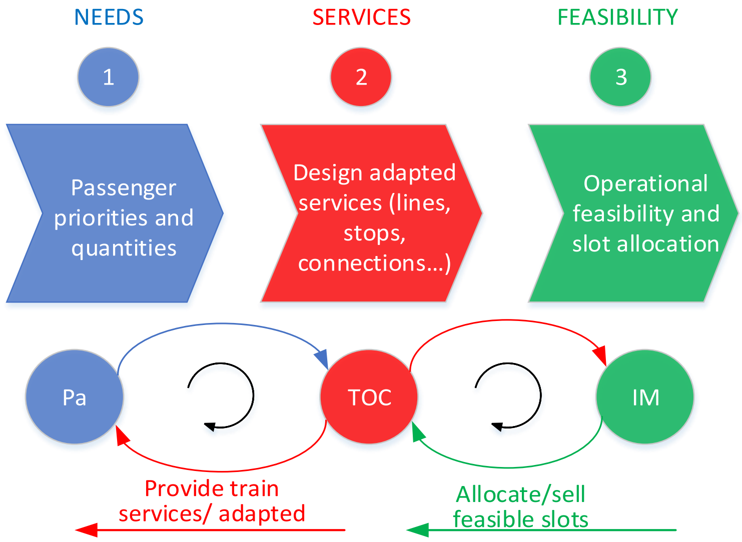
Timetable is usually expected to be stable, however, railway operation is inevitably disrupted by accidents, natural disasters, malfunctions of facilities, etc. (Dorbritz, 2012). The main problems of railway operation disruptions are insufficient resources, such as tracks, rolling stock, staff, power supply, information and train protection systems (Schranil, 2013). In general, disruptions last for a long period from several minutes to a few hours, which increases the difficulties of timetable rescheduling.

Passengers are the main service clients of railways, who have their own travel demand in terms of punctuality, routes, stops, transfers, comfort, etc. Severe disruptions would result in passengers' inconvenience (e.g. increased travel time and compelled transfer). Due to personal attributes or preferences, their demand may vary with the changes of operation environment. It is of great significance to increase passengers' satisfaction in railway disruptions and improve qualities of railway services, which is the core motivation of this research.

In the real-time and large-scale timetable rescheduling process, dispatching efficiency cannot be ignored. From the perspective of functional requirements, a distinction can be made between train operators and infrastructure managers. Generally speaking, train operators focus on designing adapted services for passengers, while infrastructure managers pay more attention to operational feasibility. Therefore, the trade-off of interests and information interactions among passengers, train operators and infrastructure managers should be valued in railway disruptions (see Figure 1).

Passengers have different priorities and behaviours (e.g. cancelling schedules directly, waiting for recovery or transferring to other trains) reacting to different disruption scenarios. The passenger information is an important input for train operators to design adapted services (e.g. which trains should be cancelled or which train connection should be kept). Then, train operators' dispatching advices will be sent to infrastructure managers who are in charge of eliminating timetable conflicts. The possible contradiction between passenger services and operational feasibility can be resolved via negotiation between train operators and infrastructure managers. The updated timetable may cause passengers' new reactions and such dynamic passenger information links three stakeholders into a close loop which should be optimised iteratively.

Figure 1 Interactions among Passengers, Train operators and Infrastructure Managers in Railway Disruptions



The research question is: How to improve passengers' satisfaction to the maximum in case of severe disruptions of rail services, considering the interactions among three stakeholders (passengers, train operators and infrastructure managers)?

2. State of research

Cacchiani et al. (2014) presented a schematic overview and showed that most literature deals with *disturbances* affecting the railway system rather than *disruptions*. In general, a disturbance refers to trains departing or arriving later than planned, while a disruption is usually related to large delays or cancelations of a number of trains. The most disruption scenario that has been investigated in literature is partial track blockages (e.g. Hirai et al., 2009; Corman et al., 2011; Louwerse & Huisman, 2014; Binder et al., 2015). Others include complete blockage of the railway infrastructure (e.g. Zhan et al., 2015; Veelenturf et al., 2016), track maintenance (e.g. Albrecht et al., 2013), and so on.

Parbo et al. (2015) summarised the difference between passenger delay and train delay. Current research with regard to timetable rescheduling in case of *disruptions* is mainly from *operations-centric* views. The objective is train oriented, such as minimising train delays (e.g. Albrecht et al., 2013; Narayanaswami & Rangaraj, 2013), the number of cancelled trains (e.g. Zhan et al., 2015; Veelenturf et al., 2016), the deviations from original timetable (e.g. Hirai et al., 2009) or operating approximately same train numbers in each direction (e.g. Louwerse & Huisman, 2014). However, until now, only a small amount of literature in the field of disruption management is from *passenger-centric* views. Kroon et al. (2015) minimised the sum of the individual inconveniences, while Cadarso et al. (2013) and Binder et al. (2015) minimised the overall passenger disutility as well as operational costs. On the other hand, plenty of literatures concern passenger oriented timetable researching in case of relatively small disturbances. In brief, the objective is usually minimising the total passenger delay (Schachtebeck & Schöbel, 2010; Dollevoet et al., 2012) or minimising passenger dissatisfaction (Tomii et al., 2005; Kumazawa et al., 2008; Kanai et al., 2011; Sato et al., 2013).

Sun et al. (2014) presented that the impacts of timetable changes on passengers' travel behaviour should be considered explicitly to accurately quantify the derived impacts. However, literatures regarding *passenger behaviours* due to railway malfunction are still relatively scarce. Most of them just consider passenger flows as static or given input (e.g. Binder et al., 2015; Schachtebeck & Schöbel, 2010; Kumazawa et al., 2008). In contrast, Hurk et al. (2012) proposed a new algorithm that transforms the smart card data for forecasting real-time passenger demand based on the characteristics of the disruption. Kroon et al. (2015) took the dynamic passenger flows into consideration. Kanai et al. (2011) proposed a delay management algorithm considering dynamic interaction between trains and passengers. Kunimatsu et al. (2012) demonstrated a dynamic evaluation method by simulating train operation and passenger flow.

Several papers proposed advanced methods to optimise dispatching strategies in case of disruptions, such as alternative graph (e.g. Corman et al., 2011), Problem Space Search (PSS) meta-heuristic (e.g. Albrecht et al., 2013), petri-net-based modelling approach (e.g. Hirai et al., 2009), two-stage approach (e.g. Zhan et al., 2015), and so on. Moreover, approaches applied in timetable rescheduling of railway disturbances also can be referred, such as MIP-based approach (e.g. Sato et al., 2013), simulation model (e.g. Kanai et al., 2011), heuristic approaches (e.g. Tomii et al., 2005).

Until now, research on railway operation has connection with many fields, such as capacity, train automation, energy supply, environmental and safety issues. However, the links to passengers, especially in case of severe disruptions of services, are still in the initial stage. In the limited research of passenger oriented disruption management, mostly only considered passenger flows as static input and regarded the problem as one-direction optimisation. A few literature took the interactions between passenger flow and railway operation into consideration (e.g. Kroon et al., 2015), but they neglected the trade-off of interests among the stakeholders. Hence, in the field of passenger oriented timetable rescheduling in railway disruptions, both the trade-off of interests and the information interactions of three stakeholders (i.e. passengers, train operators and infrastructure managers) need to be extended.

Furthermore, there are still some interesting and relevant problems to be addressed in detail. First, how railway disruptions influence passengers' behaviours need to be more precisely explored. If passengers can be informed about detailed information of disruptions and updated timetable, what are their behaviours and corresponding effects to the whole problem needs to be discussed. Second, very few literatures are available addressing the issue of passenger congestion (e.g. Kumazawa et al., 2008). More attention should be paid on quantification of train occupancy. Last but not least, how to transform passengers' information to train alternative sets still needs to be studied.

3. Detailed research plan

3.1 Hypotheses

H1 It is possible to establish suitable functions to estimate passengers' satisfaction, including travel time, transfers and train occupancy.

H2 Objectives can illustrate the trade-off of interests between passenger satisfaction and railway operation quality, depending on different disruption patterns and passenger behaviours.

H3 It is feasible to establish a unified and integrated model to demonstrate the interaction among passengers, train operators and infrastructure managers.

H4 The integrated model (H3) is flexible in case of different disruption patterns and network types.

H5 The integrated model (H3) consists of three subtasks which are divided according to functional requirements of passengers, train operators and infrastructure managers.

H6 In case of severe railway disruptions, passengers' quantities and behaviours can be simulated and translatable into parameters on the basis of literatures or intelligent assumptions.

H7 Adapted services such as train lines, stops and connections can be designed by train operators for passengers, taking passengers' quantities and priorities into consideration.

H8 Train operators can also help infrastructure man-agers by providing dynamic information of passengers' behaviours.

H9 Infrastructure managers can resolve conflicts and allocate feasible slots to train operators from the perspective of networks.

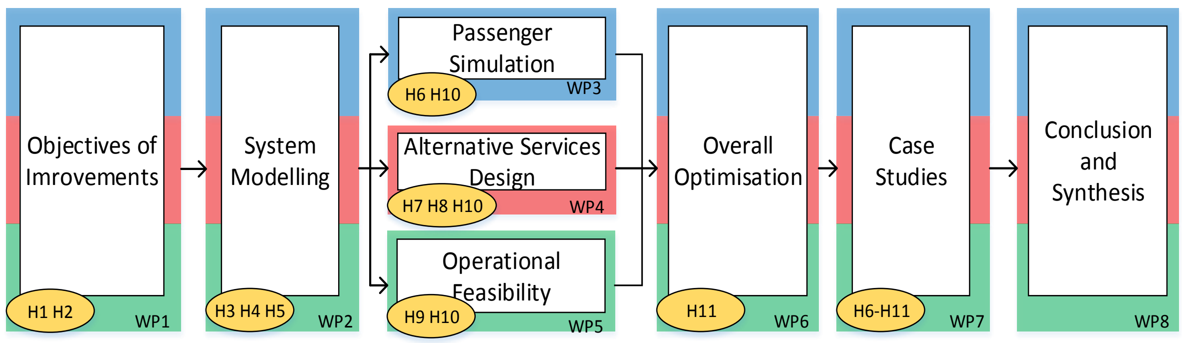
H10 To optimise each subtask of H5, advanced algorithmic methods can be applied to find solutions within given time.

H11 Considering the overall optimisation which links needed in-formation of each subtask into a close loop from the functional level, there is an algorithm to solve it or it proves that no such a solution exists.

3.2 Work packages

The proposed research is divided into eight Work Packages (WP1-8) which are described below. Figure 2 shows the workflow of WPs and interconnections with hypotheses (H1-11).

Figure 2 Work Packages



WP1: Objectives of improvements

The first step which answers H1 and H2 is to identify respective and overall objectives of three stakeholders in case of railway disruptions. This chapter will enumerate evaluation criteria of passengers' satisfaction, rescheduling efficiency and operational feasibility, respectively. Then, the potential overall objectives considering the trade-off of interests of three stakeholders are to be proposed.

WP2: System modelling

The second step which answers H3-5 is to establish an integrated and flexible model to describe the whole optimisation problem in different disruption patterns. This model should be able to reflect the information interactions among the three stakeholders on the basis of analysing each one's functional requirements. And it should be dividable into three subtasks which can be optimised separately.

WP3: Passenger simulation

The third step which answers H6 and H10 is passenger simulation in case of severe disruptions of rail services. One applicable method is agent-based simulation. This chapter will simulate passengers' behaviours (e.g. route choice behaviour) and estimate their satisfaction depending on different disruption patterns. Results of this step are both input and evaluation index for train operators and infrastructure managers.

WP4: Alternative services design

The fourth step which answers H7, H8 and H10 is that train operators design adapted services for passengers in case of different disruption patterns. This chapter will apply mathematical methods to transform passengers' behaviours into alternative sets of train services (e.g. train line, stops and connections).

WP5: Operational feasibility

The fifth step which answers H9 and H10 is that infrastructure managers ensure the operational feasibility of rescheduled timetable and allocate slots to train operators. Taking service requirements from train operators into account, this chapter will apply advanced algorithms to generate feasible timetable and optimise it from the perspective of railway network.

WP6: Overall optimisation

The sixth step which answers H11 is to design iterative algorithm to solve dynamic information interactions among three stakeholders in different disruption patterns. This chapter will link WP3-5 into a close loop to find overall optimal solutions. The method is supposed to a combination of advanced algorithms.

WP7: Case studies

The seventh step concludes a category of disruption scenarios and tests the methods mentioned in WP3-6. Actual passenger and operations data will be used to calibrate parameters, if necessary virtual experiments are to be designed. The results based on different objectives and methods will be compared.

WP8: Conclusion and synthesis

The last step is to conclude research results and conduct the synthesis. Which dispatching strategies are more efficient and passenger-oriented in different disruption patterns will be proposed.

3.3 Research approach

The respective and overall objectives of passengers, train operators and infrastructure managers (WP1) will be illustrated through literature review. The disruption patterns (WP1) will be summarised based on system analysis. System modelling is the approach to establish an integrated and flexible model for the whole optimisation problem (WP2). Passenger simulation (WP3) relates to the methods of passenger assignment or agent-based simulation. The simulation environment can be built via commercial tool (e.g. MATSim). The known solution methods for timetable rescheduling (WP4-5) include Branch and Bound, Tabu Search, Lagrangian Relaxation and Column Generation, etc. This research will refer to these advanced algorithms depending on disruption patterns. There are two directions to solve the overall optimisation (WP6). One is to design and coordinate two simulators (i.e. passenger flow and timetable), the other is to regard passenger flow as constrains in the timetable rescheduling model. Case study as well as result comparison is applied in WP7, and scientific reporting is finished inWP8.

4. Conclusions

The main scientific contribution of this proposed research is to link passengers, train operators and infrastructure managers in the dispatching process of railway disruptions. The objectives will identify the trade-off of interests among these three stakeholders in different disruption patterns. The optimisation process will combine passenger simulation and railway operation, explaining their information interactions and mathematical relations. Moreover, other contribution will be made to scientific community in the following fields. First, studies on passenger simulation in case of disruptions will supplement methods for dynamic passenger flows. Second, defining and quantifying passengers' levels-of-service in detail will enrich the evaluation criteria of real-time railway rescheduling. Third, the approaches about transforming passenger information to railway operation will be supplemented, and the application of different dispatching methods will be contrasted based on different disruption patterns and network styles.

All three stakeholders will benefit from this proposed research. For passengers, although in case of severe railway disruptions, their demand (e.g. travel time, transfer and train occupancy) can be met to maximum extent. That means passengers' economic loss can be relatively reduced to certain extent. For train operating company, more reliable and efficient services in railway disruptions can reduce its financial compensation. In the future market's competition, the train operating company who can provide more convenient services to passengers will yield higher passenger confidence and take more share of passenger transport market. For infrastructure managers, this research gives suggestions on practical dispatching strategies with respect to customer services in case of railway disruptions. More targeted train rescheduling will save the decision cost without wasting transport resources.

5. References

Albrecht, A.R., Panton, D.M. and Lee, D.H. (2013) Rescheduling rail networks with maintenance disruptions using problem space search, *Computers & Operations Research*, **40** 703-712.

Binder, S., Maknoon, Y., and Bierlaire, M. (2015) Passenger-oriented railway disposition timetables in case of severe disruptions, paper presented at the *15th Swiss Transportation Research Conference*, Ascona, Switzerland.

Cacchiani, V., Huisman, D., Kidd, M., Kroon, L.G., Toth, P., Veelenturf, L. and Wagenaar J. (2014) An overview of recovery models and algorithms for real-time railway rescheduling, *Transportation Research Part B: Methodological*, **63** 15-37.

Cadarso, L., Maroti, G., Marin, A. (2013) Recovery of disruptions in rapid transit networks, *Transportation Research Part E: Logistics and Transportation Review*, **53** (1) 15-33.

Corman, F., D'Ariano, A., Hansen, I.A., Pacciarelli, D. and Pranzo, M. (2011) Dispatching trains during seriously disrupted traffic situations, paper presented at the *IEEE International Conference on Networking, Sensing and Control*, Delft, Netherlands.

Dollevoet, T., Huisman, D., Schmidt, M. and Schöbel, A. (2012) Delay management with rerouting of passengers, *Transportation Science*, **46** 74-89.

Dorbritz, R. (2012) Methodology for assessing the structural and operational robustness of railway networks, Dissertation no. 20250, ETH Zürich, Institut für Verkehrsplanung und Transportsysteme.

Herrigel-Wiedersheim, S. (2015). Algorithmic decision support for the construction of periodic railway timetables, Dissertation no. 22548, ETH Zürich, Institut für Verkehrsplanung und Transportsysteme.

Hirai, C., Kunimatsu, T., Tomii, N., Kondou, S. and Takaba, M. (2009) A train stop deployment planning algorithm using a petri-net-based modelling approach, *Quarterly Report of RTRI (Railway Technical Research Institute) (Japan)*, **50** (1) 8-13.

Hurk, E. van der, Kroon, L.G., Maroti, G. and Vervest, P. (2012) Dynamic forecasting model of time dependent passenger flows for disruption management. , paper presented at *S Voss & J.C. Munoz (Eds.), CASPT*, Santiago, Chili.

Kanai, S., Shiina, K., Harada, S. and Tomii, N. (2011) An optimal delay management algorithm from passengers' viewpoints considering the whole railway network. *Journal of Rail Transport Planning & Management*, **1**(1) 25-37.

Kroon, L., Maróti, G. and Nielsen, L. (2015) Rescheduling of railway rolling stock with dynamic passenger flows. *Transportation Science*, **49** (2) 165-184.

Kumazawa, K., Hara, K. and Koseki, T. (2008) A novel train rescheduling algorithm for correcting disrupted train operations in a dense urban environment, *WIT Transactions on the Built Environment*, **103** 565-574.

Kunimatsu, T., Hirai, C. and Tomii, N. (2012) Train timetable evaluation from the viewpoint of passengers by microsimulation of train operation and passenger flow, *Electrical Engineering in Japan*, **181** (4) 51-62.

Louwerse, I. and Huisman, D. (2014) Adjusting a railway timetable in case of partial or complete blockades, *European Journal of Operational Research*, **235** (3) 583-593.

Narayanaswami, S. and Rangaraj, N. (2013) Modelling disruptions and resolving conflicts optimally in a railway schedule, *Computers & Industrial Engineering*, **64** (1) 469-481.

Parbo, J., Anker Nielsen, O. and Giacomo Prato, C. (2015) Passenger Perspectives in Railway Timetabling: A Literature Review, *Transport Reviews*, 1-27.

Sato, K., Tamura, K. and Tomii, N. (2013) A MIP-based timetable rescheduling formulation and algorithm minimizing further inconvenience to passengers. *Journal of Rail Transport Planning & Management*, **3**(3) 38-53.

Schachtebeck, M. and Schöbel, A. (2010) To wait or not to wait and who goes first? Delay management with priority decisions, *Transportation Science*, **44** 307-321.

Schranil, S. (2013) Forecasting the duration of rail operation disturbances, paper presented at the *Transportation Research Board 92nd Annual Meeting,* Washington DC, America.

Sun, L., Jin, J. G., Lee, D. H., Axhausen, K. W. and Erath, A. (2014) Demand-driven timetable design for metro services, *Transportation Research Part C: Emerging Technologies*, **46** 284-299.

Tomii, N., Tashiro, Y., Tanabe, N., Hirai, C. and Muraki, K. (2005) Train operation rescheduling algorithm based on passenger satisfaction, *Quarterly Report of RTRI (Railway Technical Research Institute) (Japan)*, **46** (3) 167-172.

Veelenturf, L.P., Kidd, M., Cacchiani V., Kroon L.G. and Toth, P. (2016). A railway timetable rescheduling approach for handling large-scale disruptions. *Transportation Science,* Articles in Advance, 1–22.

Zhan, S., Kroon L. G., Veelenturf L. P. and Wagenaar J. C. (2015) Real-time high-speed train rescheduling in case of a complete blockage, *Transportation Research Part B*, **78** 182-201.