Integration of traffic management and train automation for the main line railway

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This article is based on a presentation made at the seminar "*ATO - The Future of Main line Railway*?" organised by the IRSE and the Institution of Mechanical Engineers (IMechE) at London on 16 February 2017, the article "*A new rail optimisation model by integration of traffic management and train automation*" published on Transportation Research Part C in 2016 (Rao et al., 2016) and the PhD dissertation "*Holistic rail network operation by integration of train automation and traffic management*" (Rao, 2015).

Motivation

Nowadays, more and more railway experts and engineers are making their own efforts to optimise railways whether it involves increasing capacity, saving energy and reducing costs. However, the experts from different fields have their own intention, method and evaluation on optimisation. We tried to analyse these differences systematically in order to build a more holistic optimisation method, with special focus on two specific areas: traffic management and train automation.

The current process of manual rail operation is based on a superimposition of two closed control loops (Lüthi et al., 2007), as shown in Figure 1. The outer control loop supervises the status of traffic and infrastructure, detects deviations and conflicts, develops a new schedule (rescheduling) and transmits it to train operation. This rescheduling mainly depends on the expertise of the dispatcher. The inner control loop is responsible for executing the production plan, which depends on the expertise of the driver.

Currently, the focus of railway optimisation is either on improving efficiency for the dispatcher by providing resolutions for traffic conflicts in the outer control loop or on improving driving performance for the driver by providing driver assistance or introducing train automation in the inner control loop.

Traffic management can predict and resolve traffic conflicts by using centralised train data in its controlled railway network, but it can neither avoid the inaccuracy of conflict detection due to incomplete train data and untimely data transmission, nor guarantee that each train will execute the conflict resolution as accurately as expected. Train automation has the most complete and updated train data to minimise the deviation between control targets and the supervised train states, but it depends on two supports. One is an additional onboard support to provide train's over-speed protection and to keep a safe headway between trains, such as the Automatic Train Protection (ATP) system. The other is infrastructure support to provide dynamic traffic regulation to avoid traffic conflicts, such as the Automatic Train Supervision (ATS) system used in metro railways. Since the main line railway has much more complicated infrastructure situations, currently train automation is mainly applied to metro railways.

The optimisation strategies of traffic management and train automation are complementary. Therefore, for the main line railway, we propose to build up an integrated optimisation model to combine the strength of traffic management and train automation. An initial concept of this model is illustrated in Figure 2, which highlights bidirectional communication between traffic management and train automation.

Challenges

Building the integrated optimisation model is not as simple as just implementing traffic management and train automation in parallel, but it faces challenges in several aspects:

Integration

To integrate traffic management and train automation, it is necessary to detail their functions separately and to specify the exchanged information between the two. In addition, a demonstrator is required to prove the feasibility and its benefits.

Optimisation goals

There are multiple optimisation objectives to achieve, such as increasing capacity, reducing energy consumption and improving operational quality. The first challenge is to quantify each optimisation objective appropriately. The second challenge is to calculate the priority of each optimisation objective according to different optimisation demands. The third challenge is to balance these multiple, at times contradictory, objectives.

Interoperability: Automatic Train Operation (ATO) on main line railway

ATO is applied in almost every metro system. ATO is not just eye-catching technology to urban residents, but it is a necessity for efficient metro operation. Metro railways have a frequent stop-and-go operation mode. The introduction of ATO has reduced the burden of train drivers with repeated operation (train start, accelerating, cruising, coasting and braking) and it has helped to avoid manual errors.

Some metro stations are equipped with platform screen doors, which can be seen as one main challenge for train drivers but it is easier for ATO to achieve a precise train stopping. Compared to the main line railway, metro railways have a much simpler timetable design and infrastructure topology. In many cases each metro line is independent of other lines and the trains of metro lines are very homogeneous sets of vehicles. In most cases, there is little influence on the braking capabilities of trains by the weather and the danger of obstacles on the track is considered much lower than on an open line.

ATO has not been applied in the main line railway primarily for several reasons. First, there are two safety concerns. One is to detect obstacles on the track. Another is to detect passenger safety while exiting and entering trains. Most main line railways are open lines and their stations are not equipped with platform screen doors. Therefore, additional solutions are required for these two safety concerns. Second, the main line railway has a much more complicated situation than metro railway, because it

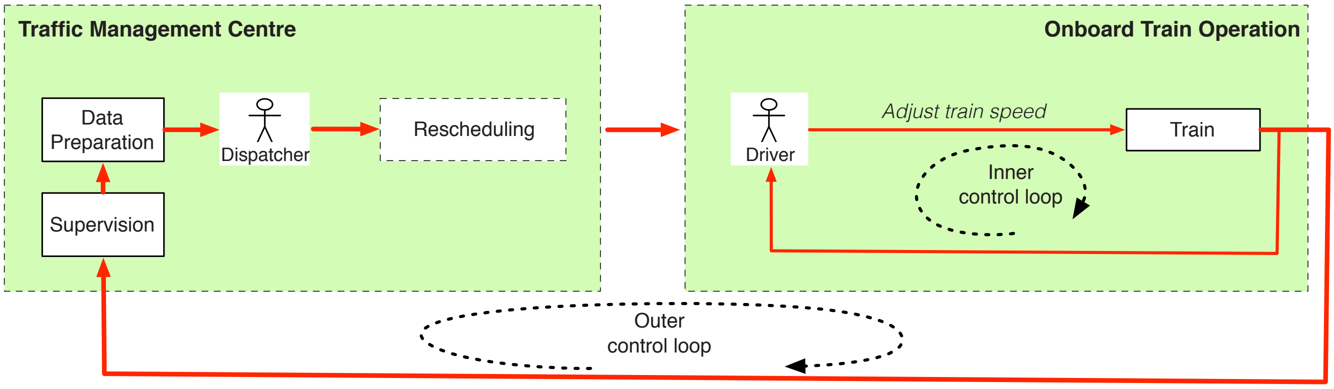

Figure 1 – Non-optimised railway operation depending on the expertise of the dispatcher and the driver.

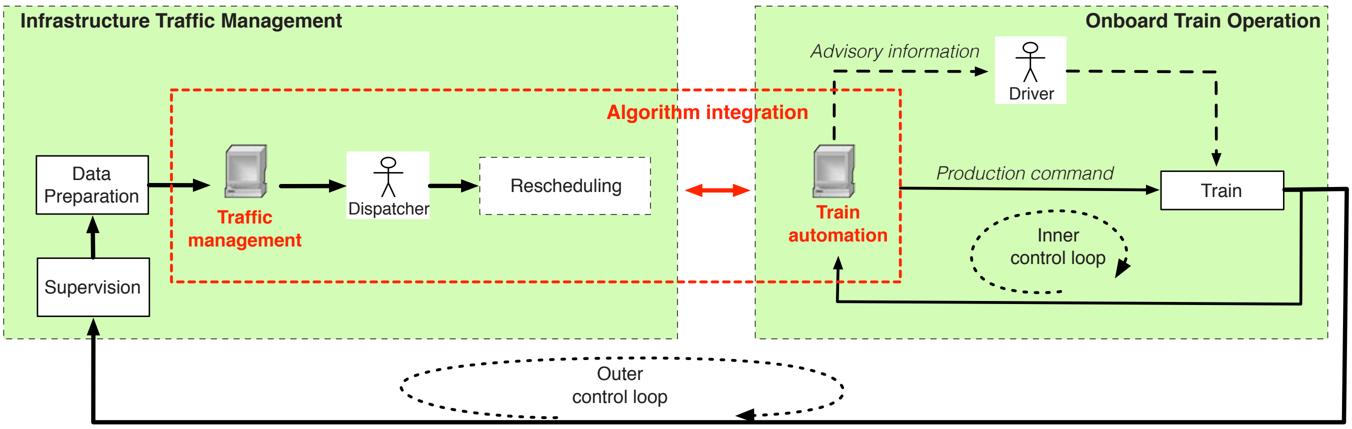

Figure 2 – A basic concept of the integrated optimisation model.

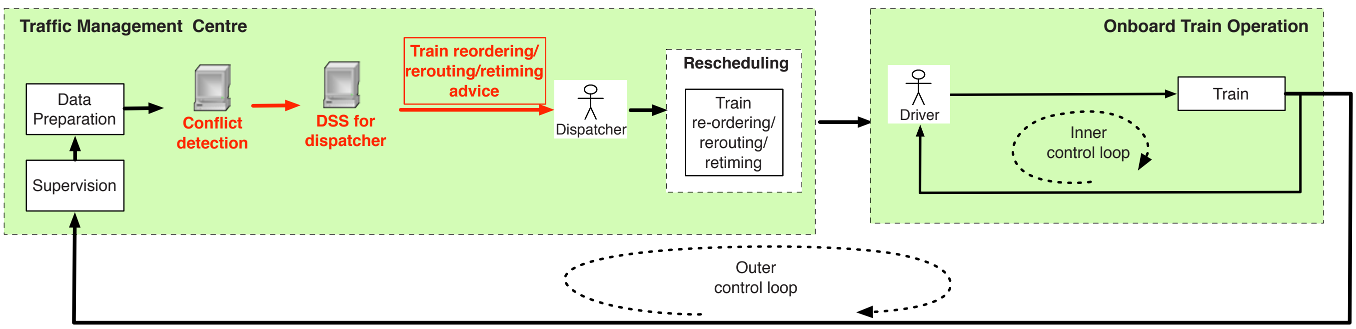

Figure 3 – Optimisation with the Decision Support System (DSS) for dispatchers.

has multiple undertakings and it varies in infrastructure topology, signalling system, locomotive types, timetable and many other aspects. Therefore, interoperability is important for introducing ATO to the main line railway.

Review and classification of railway optimisation schemes

Before introducing the new integrated optimisation model, we need to review and compare current railway optimisation schemes systematically. The comparison results will explain the necessity of combining traffic management and train automation for the main line railway.

Optimisation schemes in traffic management

Traffic Management System (TMS) comprises all functions necessary for enabling trains to run safely and efficiently on the railway infrastructure (Lochman, 2009). With the growing demand for transportation, more trains are expected to be in service. It is a challenge for the main line railway to increase rail capacity and improve service quality at the same time. A more functional TMS is required to reduce the impact of traffic conflicts by applying different real-time automatic solutions.

To take this challenge, two optimisation schemes are implemented. The first is Decision Support System (DSS), which is prevalent today and shown in Figure 3. DSS is used to reschedule the traffic when the current timetable is detected with a conflict. The solution is to find a new conflict-free schedule by train reordering, re-routing or re-timing.

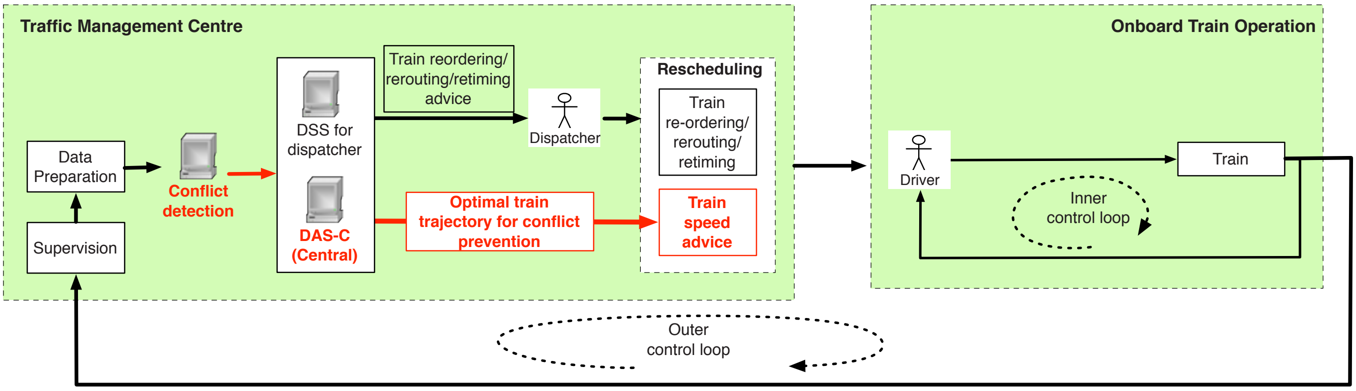

Figure 4 – Optimisation with Driver Advisory System - Central (DAS-C).

The second is Driver Advisory System - Central (DAS-C), as shown in Figure 4, which is another solution to reduce the impact of traffic conflicts by generating train speed advice for the driver. DAS-C computes the optimal train running trajectory to avoid the predicted unplanned train stops. Based on the trajectory, a series of train speed advice is generated and sent to the train. The speed advice can inform the driver to reduce train speed in anticipation of the conflict detected ahead, and to increase train speed in anticipation of the conflict resolved. Therefore, the driver's knowledge of traffic conflict is extended to avoid predicted unplanned train stops by optimising train speed.

It is noted that the unplanned train stops can be discovered earlier than train delays at destinations or route conflicts between trains within block sections. This provides possibilities to resolve potential traffic conflicts by optimising train speed without changing the current schedule.

So far, DAS-C has often been seen as supplementary to DSS but not a substitute for it. A practical example of DAS-C is the commercial product Automatic Function (AF) applied in the Lötschberg Base Tunnel in Switzerland. This application increases capacity and saves energy costs (Mehta et al., 2010). To our knowledge, this is the first practical application of DAS-C in a mixed-traffic main line railway.

Optimisation schemes in train automation

Train automation is applied to reduce the loss of capacity due to manual train operation. The basic functions of train automation include automatic train speed control (accelerating, braking, cruising and coasting), precise train parking and door control.

The International Association of Public Transport (UITP) defines the Grades of Automation (GoA) depending on the distribution of responsibilities between the staff and the train automation system itself. However, it seems that those definitions tend to fit better for metro railway, but less so for main line railway, where train drivers can be supported by Driver Advisory System (DAS). DAS is actually an automation level between GoA 1 and GoA 2. It provides drivers with additional driving advice to keep the train at the optimum speed. Therefore, an updated GoA table is proposed in Table 1.

Apart from the DAS-C scheme in traffic management, Driver Advisory System - On-board (DAS-O) is a similar scheme but installed onboard. ATO is another optimisation scheme onboard including GoA 2, GoA 3 and GoA 4, which controls train speed automatically.

DAS-O, as illustrated in Figure 5, is an alternative approach to generate train speed advice for the driver. DAS-O which is installed on the train concentrates on improving train driving behaviour rather than resolving traffic conflicts. DAS-O has a predefined train speed profile, which is a standard driving guidance for riding accuracy, riding comfort, energy saving and other onboard optimisation goals. DAS-O can generate a series of speed advice to minimise the deviation between the predefined train speed profile and the observed train states (train position, speed and time).

Grade of Automation	Type of train operation	Train speed control	Train stopping	Train door control	Operation in event of disruption
GoA 0	On-sight by driver	Driver	Driver	Driver	Driver
GoA 1	ATP with driver	Driver	Driver	Driver	Driver
GoA 1.5	DAS	Driver with advice	Driver with advice	Driver	Driver
GoA 2	STO	Automatic	Automatic	Driver	Driver
GoA 3	DTO	Automatic	Automatic	Train attendant	Train attendant
GoA 4	UTO	Automatic	Automatic	Automatic	Automatic

ATP *Automatic Train Protection*
STO *Semi-automatic Train Operation*
DTO *Driverless Train Operation*
UTO *Unattended Train Operation*

Table 1 – Grades of Automation (upgraded).

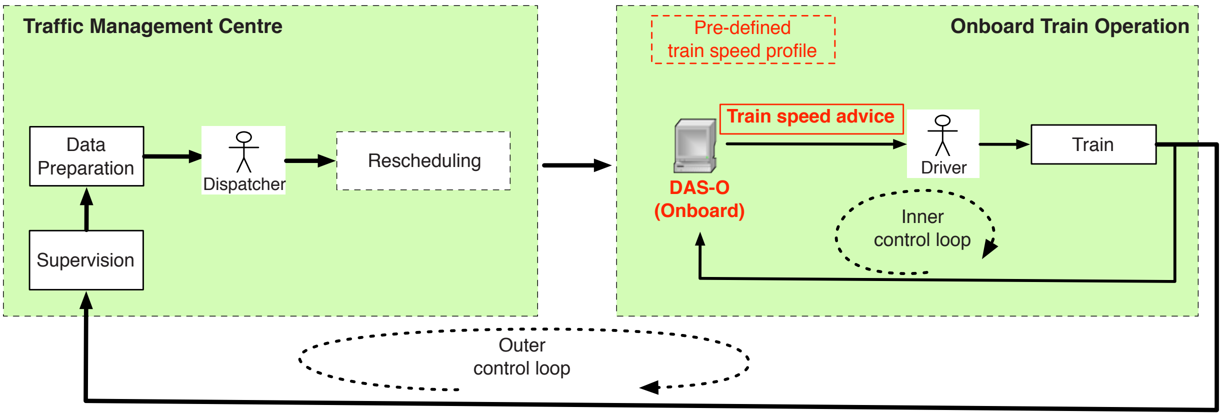

Figure 5 – Optimisation with Driver Advisory System - Onboard (DAS-O).

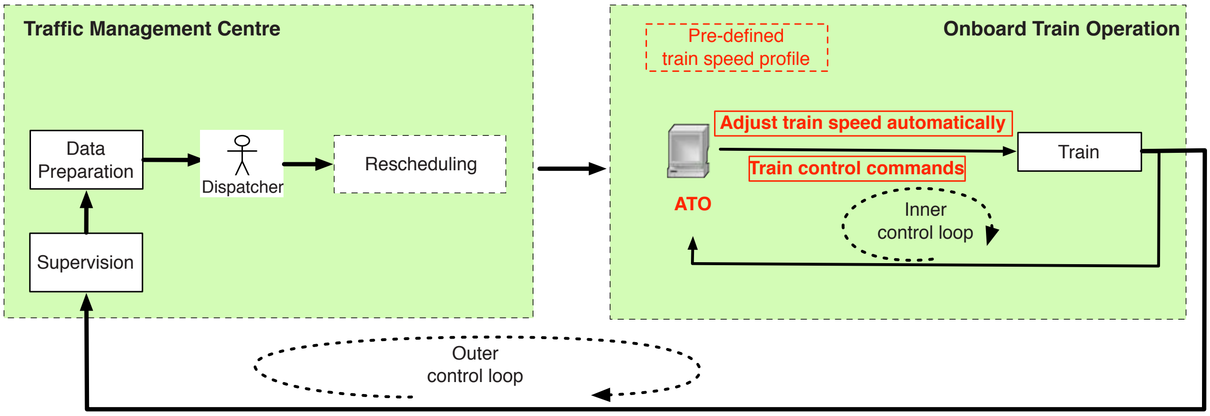

Figure 6 – Optimisation with the Automatic Train Operation (ATO).

DAS-O is often used as a complement to the driver training system for practising and improving driving skills. Currently, most existing DAS belong to DAS-O with the focus on energy-efficient driving, such as Computer Aided Train Operation (CATO) system in Sweden (Yang et al., 2013), InLineFAS in Germany (Albrecht and Dasigi, 2014) and GreenSpeed in Denmark (Bergendorff et al., 2012). In short, DAS-O can be seen as an interim step to achieve ATO.

ATO, as illustrated in Figure 6, generates a series of train control commands to adjust train speed directly, rather than the speed advice for the driver. The train control command can decide how much train force (tractive and braking force) is inserted. Moreover, ATO has to resolve the Multi-objective Optimisation Problems (MOPs) with two or more (often conflicting) objectives. This can be achieved with various intelligent control algorithms, such as fuzzy logic control, expert control, predictive control, neural network control, genetic algorithm, differential evolutionary algorithm and integrated intelligent control methods (Rao et al., 2012).

Comparison of optimisation schemes

In order to better distinguish these schemes, Table 2 overleaf compares their features in several aspects.

DSS and DAS-C are installed in the traffic management centre so that they can prevent traffic conflict by analysing the traffic network data. However, DSS and DAS-C offer no improvement for onboard functionality as the dynamic calculations for all trains are carried out in the traffic management centre. When the conflict case grows to a certain extent, there will be a concern about whether traffic management centre can handle such a heavy computing workload. Additionally, the computation of DSS and DAS-C is based on the transmitted data in the outer control loop. In this regard, another concern is about whether the transmitted data is complete, accurate and updated in real-time. Therefore, the lack of advanced onboard functionality and the quality of transmitted data are seen to be the main obstacles for the further development of traffic management.

DAS-O and ATO are installed in each train with enhanced onboard functionality. Each train carries on with its own dynamic calculation. The train states are measured and transmitted in real-time in the inner control loop. Therefore, the increased onboard computing power and the improved quality of data transmission are seen as the advantages of DAS-O and ATO. However, DAS-O and ATO cannot avoid unplanned train stops because they need external support for traffic conflict prediction.

The comparison result shows that the optimisation schemes applied in traffic management (DSS and DAS-C) and train automation (DAS-O and ATO) are complementary. Therefore, we propose to integrate their optimisation advantages into a new optimisation model. This model is expected to have bidirectional communication between traffic management and train automation. Trains can avoid potential traffic conflicts by reacting to the proposals from traffic management, while traffic management can improve its calculation according to the real-time feedback from train automation.

Optimisation scheme	Non-optimised operation	DSS for dispatcher	DAS-C	DAS-O	ATO
Figure	Figure 1	Figure 3	Figure 4	Figure 5	Figure 6
Traffic management by re-ordering, re-routing, re-timing	No	Yes	Yes	No	No
Traffic management by optimising train speed	No	No	Yes	No	No
Optimised onboard functionality	No	No	No	Yes	Yes
Automatic speed control	No	No	No	No	Yes
Progress	- Widely applied	- Efficient traffic management - Conflict prevention		- Improved train driving performance - Enhanced onboard functionality	
Remaining problems	- Low efficiency	- Lack of advanced onboard functionality - The quality of transmitted train data - No guarantee that each conflict resolution can be executed accurately		- Need additional onboard support for train's over-speed protection - Need additional infrastructure support for traffic regulation - Not widely applied for dense and mixed-traffic mainline railway	
Application domain	- Most existing Main line railways	- Dense and mixed-traffic lines (e.g. mainline railway)		- Homogeneous traffic lines (e.g. metro railway)	

Table 2 – Comparison of railway optimisation schemes.

The proposed integrated optimisation model

Overview

Based on the review of different optimisation schemes, the new integrated optimisation model combines four optimisation schemes (DSS, DAS-C, DAS-O and ATO) into one, as shown in Figure 7.

DSS is mainly applied in 'condensation' zones (i.e. with high traffic density) to deal with major disruptions, while DAS-C is mostly applied in 'compensation' zones (i.e. with low traffic density) to prevent potential traffic conflicts at an earlier phase. In compensation zones, the choice of appropriate train speed profiles is the most important degree of freedom to be exploited (Caimi, 2014). Therefore, the focus of DAS-C is to explore the flexibility in generating different train running trajectories to prevent potential traffic conflicts. Based on the trajectory, a series of control-target points (position, time and speed) can be generated as discrete information sent to the train in real-time, rather than sending a complete train running trajectory or sending only train speed advice (Rao, 2016).

The choice of DAS-O or ATO depends on the practical requirements of GoA. The core function, optimised train speed control, is the same for both DAS-O and ATO. The deviation between the received control-target points and the observed train states is calculated onboard. According to the deviation, DAS-O can generate corresponding advice for the driver (either train speed advice or additional train control command advice), while ATO can implement train control commands directly to adjust train speed automatically.

Highlights

The proposed integrated optimisation model has two important highlights. The first is the decision-making procedure to decide the most attractive output from the set of optimal trajectories and the set of train control commands (Rao, 2015). The second is the bidirectional communication between traffic management and train automation, as illustrated in Figure 8. The function of traffic management delivers the control targets to train automation, while the function of train automation provides real-time feedback of train dynamics information to traffic management. The importance of this bidirectional communication was discovered during a case study. The details can be found in Rao (2015) and Rao (2016).

Conclusions

For the current main line railway, there are two focuses for traffic optimisation. The first is to improve the efficiency of traffic management by providing conflict resolutions, while the second is to improve train driving behaviour by providing driver assistance or introducing train automation. This paper reviewed and classified these two focuses into different optimisation schemes. Based on this classification, this paper proposed combining the optimisation methods of traffic management and train automation into an integrated optimisation model.

Insight into the future railway optimisation

Figure 9 gives an insight into the future optimisation. It describes the development of railway optimisation from the current situation to the visions of future railway optimisation.

Today's railways are improving the efficiency of traffic management and train operation separately. The two will work collaboratively in the very near future, because there will be more and more demands for such collaboration. For instance, conventional rail lines will be updated with new systems, which will ask for optimisation of train behaviour based on the enhanced onboard computing power. The high-speed lines will no longer be dedicated lines but mixed with conventional lines, therefore, the traffic conflicts are foreseen to be increased and the traffic management will be highly required. Moreover, the strict limits between metros and main line railways tend to disappear, which will require an integration of train automation and traffic management.

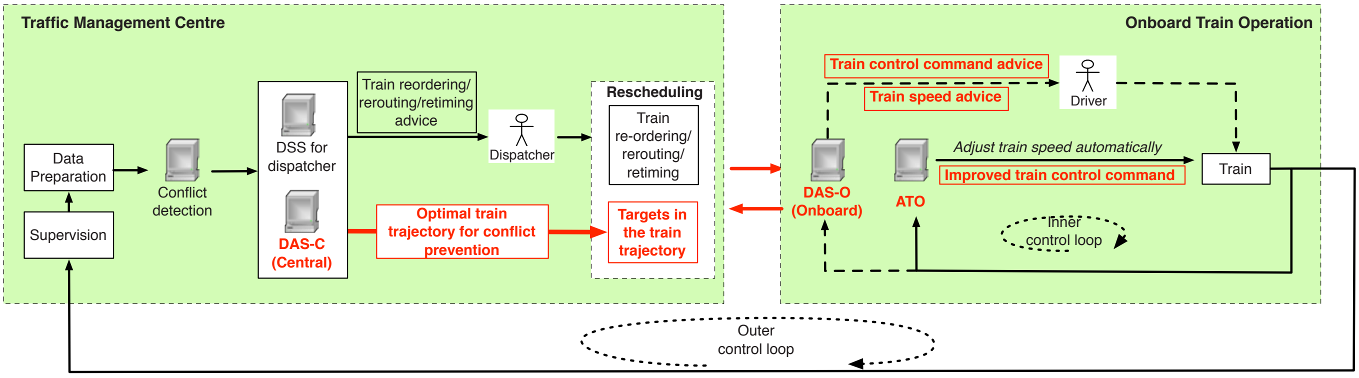

Figure 7 – The integrated optimisation model combining optimisation schemes of DSS, DAS-C, DAS-O and ATO.

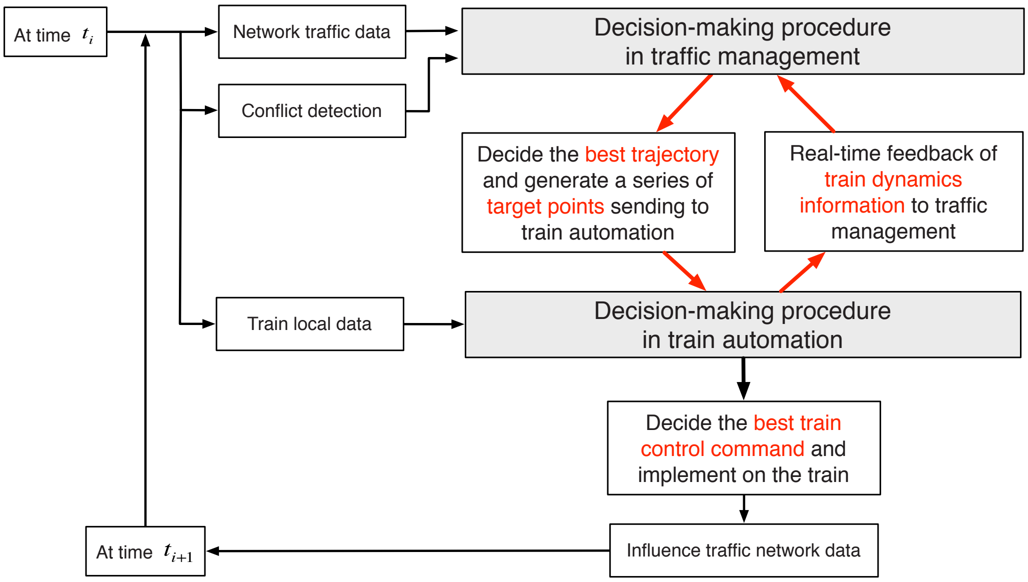

Figure 8 – The highlights in the integrated optimisation model: the decision-making procedure and the bidirectional communication between traffic management and train automation.

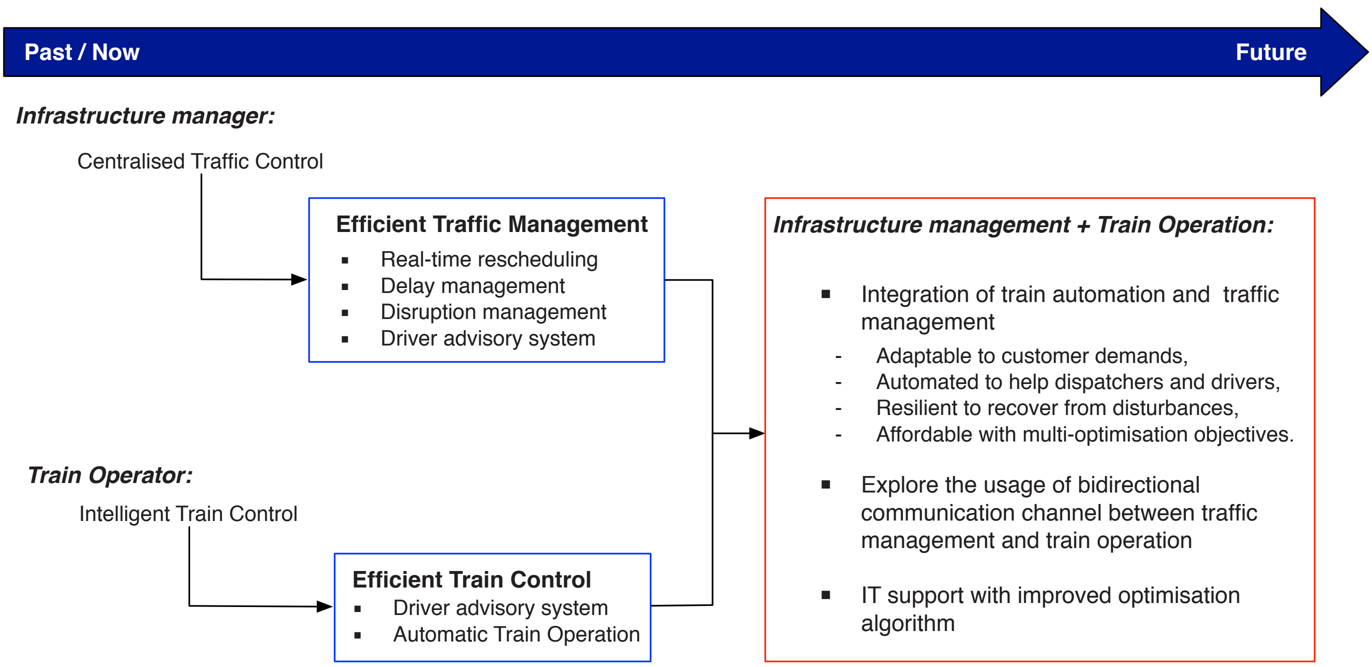

Figure 9 – Insight into the development of railway optimisation.

Since it is almost certain that the integration of train automation and traffic management will happen in the future railway optimisation, the arising interest would be how to fully utilise the bidirectional communication channel between train and traffic management in order to reduce the cost for optimisation. Moreover, it is expected that more and more Information Technology (IT) will be introduced into railway systems to support various optimisation algorithms in the near future.

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Pesa and Bombardier sign ERTMS framework

[RGI] POLAND: Bombardier Transportation has signed a five-year framework agreement to supply rolling stock manufacturer Pesa Bydgoszcz with its EBICab 2000 automatic train protection equipment for installation on new vehicles for the Polish market. The equipment will be delivered from Bombardier's Katowice site.

In 2015 Bombardier became the first supplier to obtain Polish certification for both lineside and onboard ERTMS equipment. It currently has four ERTMS projects completed or underway in the country.

"As the first approved ERTMS onboard safety system supplier in Poland, we look forward to delivering our integrated technology which will improve services for passengers", said Sławomir Nalewajka, Bombardier's Head of Rail Control Solutions, Poland, on 2 March.

Frauscher joins Alstom Alliance

FRANCE/AUSTRIA: Frauscher and Alstom deepen their relationship in a long-term leading supplier agreement. Frauscher has joined the Alstom Alliance, the strategic partnership program of Alstom. The charter was signed by Olivier Baril, CPO Alstom, and Michael Thiel, CEO Frauscher Sensor Technology. Alstom Alliance acknowledges around 30 companies who work closely with Alstom in terms of business development, industrial excellence as well as products and innovations.

"It is a key objective of Alstom to fulfill customer's expectations of quality, excellence, innovation and costs. Therefore we are sure that it is more important than ever today to attract and develop jointly rewarding, long-term partnerships with suppliers who have proven ability in the increasingly competitive global railway market. Companies who are known to deliver the highest quality, most innovative and cost-efficient products to market in a reliable, ethical and timely fashion are acknowledged and supported through Alstom Alliance. Frauscher fits perfectly with these requirements and we are looking forward to a close cooperation", said Olivier Baril.