

The State of the Art about Energy-efficient Railway Traffic Control

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Abstract The real-time traffic control has an important impact on the efficiency of energy utilization in the modern railway network. In order to develop an energy-efficient railway traffic control system, we firstly conducted a review so as to find out interesting ideas and approaches. Details of the review work are given with two topics: the railway disruption management and the train synchronization. The former aims to retrieve the disrupted train timetable in an energy-efficient way while the latter is mainly concerned with the interaction between different trains in order to minimize the global energy-consumption of the targeted network. In general, an optimal synchronization between trains in the railway system should not only introduce the fewest stops for trains during their journey but also maximize the re-utilization rate of the energy produced by the dynamic braking.

Key words: railway traffic control, railway disruption management, train synchronization, energy-efficient

1 Introduction

In modern railway system, most of the energy required by trains is supplied by the electric network. Since the efficiency of the electric network depends on real-time states of trains during their journeys, it is important to construct an energy-efficient traffic control system to manage the trains' real-time operations. As startup of this work, an overview of the existing work on energy-efficient traffic control is firstly made in this study. The aim is to find out interesting ideas that will lead to the achievement of our final objective: developing a decision-making tool for the dispatching center to manage the real-time railway traffic in an energy-efficient way.

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Before going further, a brief introduction of the railway traffic control system is given in section 2. In the rest of this review, details are given in two topics: stated in section 3 is the work about railway disruption management, and presented in section 4 are results about train synchronization management.

At the end of the paper, some discussions will be made on possible ideas and methods for future researches.

2 Railway Traffic Control System

Supported by the railway traffic control system, the railway traffic control is a dynamic process. Its main objective is not only to avoid conflicts between trains but also to restore the disrupted railway network as soon as possible whenever necessary. In recent years, the third objective has arisen: to synchronize trains' real-time operations so as to reduce the railway energy consumption in a dynamic perspective.

Although it seems that the traffic control center is not a major energy-consuming part of the railway system, it plays an important role in railway energy consumption management because the decisions made by dispatcher(s) impact directly on real-time operations of running trains considered as the biggest energy-consuming units. What's more, it is only the traffic control centre that could make the decision on both global and dynamic perspectives so that train drivers would be able to "synchronize" their actions for not only avoiding unnecessary energy consuming but also reutilizing the energy produced by the dynamic braking nearby.

The work presented below are based on all papers on energy-efficient traffic control, which have been published in recent years besides those interesting papers cited in some related review work (Huisman et al (2005); Törnquist (2005); Acuna-Agost (2009)).

3 Railway Disruption Management

Railway disruption management is "the joint approach of the involved organization to deal with the impact of disruption in order to ensure the best possible service for the passengers"(Jespersen-Groth et al (2009)).

3.1 Railway Disruption

In general, daily trips of trains are organized according to the schedules defined at the tactical level. These schedules are periodically readjusted in order to take account of important changes in demands and political decisions.

Unfortunately, the pre-defined schedules cannot always be followed because there are often real-time disturbances in the railway network. Although those periodical schedules are able to absorb some tiny disturbances as they are designed to be, most of the real-time disturbances cannot be neglected and some of them, especially the busy ones, may spread throughout the railway network. Because of those significant disturbances, some trains can no more follow their pre-defined schedules and therefore real-time traffic control decisions must be made to both guarantee the railway security and reduce the network operating cost.

3.2 Review of Methods

According to the literature, various approaches have been applied for modeling the railway disruption management problems. These are analytical models(e.g. Walker et al (2005); Törnquist and Persson (2007)), graphical models(e.g. D'Ariano et al (2008); Corman et al (2009)), constraint programming models(e.g. Mladenovic and Cangalovic (2007); Rodriguez (2007)) and logical expressions(e.g. Lova et al (2007); Tazoniero et al (2007)).

With regard to the applied methods, most of the studies were interested in using meta-heuristics and their hybridizations (Törnquist and Persson (2007); Rodriguez (2007); D'Ariano et al (2008) et al.). Some exact methods were used to seek optimal solutions for some simplified problems (Walker et al (2005); D'Ariano et al (2008); Corman et al (2009) etc.). Some heuristics, especially those based on expert knowledge, are used for quickly solving problems (Lova et al (2007); Mladenovic and Cangalovic (2007); Tazoniero et al (2007), etc.).

It is important that solutions should be found as soon as possible for solving real-time traffic disturbances. Therefore, heavy computation requirements tackle the exact methods over the problems with serious disturbances. Heuristics can normally give the quickest response, but the decisions are often far from optimal. In consequence, as a reasonable compromise between the solution quality and the required calculation time, meta-heuristics and their hybridizations could be regarded as proper methods for railway disruption management. In some case, hybridizations between different kinds of methods may give the most proper traffic control solutions.

4 Train Synchronization Management

Train synchronization management is mainly concerned with the interactions between different trains in order to minimize the total energy consumption of the targeted railway network.

4.1 Train Synchronization

An ideal train synchronization solution should respect at first necessary constraints, such as the network security and train punctuality, and meanwhile it should also minimize the network energy cost from a global perspective.

In the modern railway network, most of the trains are equipped with electric braking equipment, which is used to slow down the train rather than stop it. During one dynamic braking period, the electric braking equipment produces electric energy that can be either fed back into the electricity network (named as regenerative braking) or dissipate by a resistor equipped on the train (named as rheostatic braking). When the regenerative braking is realized, the current generated by the regenerated electric energy can be utilized by the trains running in the same substation. In consequence, it is important to dynamically synchronize operations of trains running in the same substation so as to benefit from as much as possible the regenerated energy.

4.2 Review of Methods

The modeling approaches mentioned in the previous section are theoretically applicable to the train synchronization management because it is concerned with combinatory optimization problem as well. However, considering the dynamic characteristic of the real-time train synchronization problem, optimal solutions in static perspectives are no more practical in this domain and almost all problems should be dynamically modeled. That's why it is regarded as one of the most difficult management problems.

As one of the most lately raised topics in the railway management, no clear definition can be found in the literature and few publications are dealing with the exact problem. Nevertheless, some published results are found with similar objectives: minimization of the energy consumption for several interrelated trains or for a targeted network (Albrecht (2004); Dorfman and Medanic (2004); Albrecht (2009); Caimi et al (2009); Ding et al (2009) etc.).

In the literature, most of the studies just dealt with sub-problems, such as distributions of trains' running periods along their lines (e.g. Dorfman and Medanic (2004)), the construction of conflict-free schedules for junctions (e.g. Albrecht (2009)) etc. The global problem, i.e. conflict-free schedules for the whole network with detailed velocity profile for each train under control within an objective of minimizing the network energy consumption, were solved by either decomposition methods (e.g. Albrecht (2004); Caimi et al (2009)) or heuristics (e.g. Ding et al (2009)).

Sub-problems were mainly solved by meta-heuristics and their hybridizations (e.g. Albrecht (2004); Caimi et al (2009); Dorfman and Medanic (2004) etc) while heuristics were also used in some studies (e.g. Albrecht (2009); Ding et al (2009) etc.). It should be emphasized the method proposed in (Albrecht, 2004) is the only

one found in the literature that tries to take into account the impact of the regenerated energy.

5 Conclusions and Perspectives

A review work of energy-efficient railway traffic control has been performed in this study. It is observed that most of the related publications are concerned with the train timetable restoration under disturbances though few of them focus on energy-efficient train synchronization.

In fact, the railway energy-efficient traffic control is also one of the most difficult optimization problems because not only the velocity profile for each running train should be dynamically defined but also all mandatory constraints keep changing. That's why there is no room for time-consuming method in this case and most of the researchers are interested in meta-heuristics or heuristics.

Till now we have observed that most of the traffic control problems are solved without taking into account the on-board train operations, i.e. the train performances are regarded as parameters rather than decision variables though the drivers' actions can never be neglected in real traffic control system.

In one word, although some good papers are published for solving simplified problems, no well-developed work has been published for solving the whole problem. Some primary analyses have been launched in real-time energy-efficient traffic control problem. The decomposition idea looks efficient but the problem raised is how to reduce the error-amplification during the resolution procedure. What's more, it is important to find an efficient decomposition perspective.

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