Appliance of Intelligent Transportation Systems within the Moving Block Technology

Hrvoje Haramina
Faculty of Transport and Traffic Sciences
University of Zagreb
Vukelićeva 4, 10000 Zagreb, Croatia
haramina@fpz.hr

Milivoj Mandić
Faculty of Electrical Engineering and Computing
University of Zagreb
Unska 3, 10000, Zagreb, Croatia
milivoj.mandic@fer.hr

Edouard Ivanjko
Faculty of Transport and Traffic Sciences
University of Zagreb
Vukelićeva 4, 10000 Zagreb, Croatia
edouard.ivanjko@fpz.hr

Abstract. *Train control methods based on Moving Block technology are known several years but still represent an undeveloped area regarding appliance of Railway Intelligent Transportation Systems. Namely, instead of currently used train control methods which imply train separation in fixed track blocks defined by their absolute braking distance on a certain railway line, in Moving Block technology trains are following each other in the relative braking distance calculated for every specific pair of trains during their movement on the line. Usage of this train control method instead of traditional ones offers an additional possibility for improvement of railway transport efficiency especially by means of energy efficient train driving, improvement of timetable stability and track capacity. In this paper new possibilities of Intelligent Transportation Systems implementation within the Moving Block technology are presented and its applicability in high density railway lines control systems is analyzed.*

Keywords. Railway intelligent transportation systems, train control system, moving block.

1 Introduction

Railway transportation systems have been constantly improved to increase they transport capacity as an interconnection of two places. Today's improvement emphasis is no longer solely on building railways to interconnect various places, cities or states. Other factors such as safe and clean driving, travel comfort, train-driver assistance, energy consumption reduction, and optimal usage of railway transport infrastructure are becoming more and more significant. Hence, to ensure better usage of railway transport capacity, the Moving Block technology is developed. Further development of this technology is mainly based on optimal train driving methods considering railway timetable stability and energy efficient train driving. Thus, in this paper the potential benefits of usage of Intelligent Transportation Systems (ITS) within the Moving Block Technology are presented and analyzed.

This paper is organized as follows. Second chapter describes principles of Moving Block technology followed by the third chapter that gives an analysis of possible railway control improvement. Fourth chapter describes possibilities of energy savings by means of ITS methods in more detail and following fifth chapter presents first simulation results regarding energy consumption reduction obtained on a small segment of the Croatian railroad network. Paper ends with conclusion and authors ideas for future work.

2 Moving Block technology

Unlike the separation of vehicles in road transport, in regular railway operation movements procedures for train separation are required that work independently from the train driver visibility range. Main reason for this is the fact that braking distances of trains, concerning their bigger masses and lower adhesion between train wheels and rails, are much longer than braking distances of corresponding road vehicles. There are two main principles of train separation during their operation on an open railway line: (i) train separation in fixed block distance (with discrete or continuous influence on the train); (ii) train separation in absolute braking distance i.e. "Moving Block".

When an open railway line is divided into several fixed blocks that can be controlled regarding occupancy by railway vehicles, the length of spacing distance depends on the necessary length of the blocks that maximally meet the requirements for safe and efficient operation of rail traffic. Rule is that the minimal length of the block has to be equal at least to the longest stipulated train braking distance value on this particular railway line section [4]. Longest stipulated train braking distance depends on maximum permitted speed on a certain railway line. In the case of train separation in fixed block sections there is a rule that one block section can be occupied by only one train. Usually, in normal conditions the distance between two following trains is two fixed blocks. This principle of train separation has several marked drawbacks that cause lack of flexibility of railway traffic. Namely, in this case block length is set to the same value for all the types of railway vehicles regardless of their different running speeds and braking characteristics. Thus large safety distances of the fixed block as required by fast trains with longer braking distances are unnecessarily imposed for the slower trains also. This happens since fixed block minimal length, among other things, is determined by the needs of the longest minimally necessary braking distance of trains that can operate on a certain railway line. Result is predimensioned length of block distances and dependency on the very costly wayside train detection equipment.

Unlike the train separation in fixed block, in the moving block train separation principle the protected section for each train is not statically defined. It depends on actual position and speed value of two successive trains [13]. Beside that, moving block train control system does not require train detection devices such as track circuits or axle counters in order to determine the position of the trains and their integrity. It relies on the continuous two-way digital radio communication between every controlled train and the control center as well as on the train onboard equipment which checks its integrity. To achieve needed safety margins regarding wireless digital communication, studies have been made by several authors to analyze its reliability. Measured average probability of datagrams delivery was about $99.5\ \%$ as it can be seen in [8]. Such high datagrams delivery probability makes digital wireless communication reliable enough for implementation in train control systems. Studies also revealed that some terrain configuration can be problematic reducing probability of datagrams delivery. Such terrain configurations can be detected and equipped with additional communication equipment improving probability of successful datagrams delivery.

In case of a moving block system application, railway lines are usually divided into control areas [2]. Each control area is controlled by means of a computer installed at the traffic control center with transmission of train movement authorities using a radio based communication system. Beside this data, every train transmits also data about its identity, position, direction of movement and speed to the computer that controls the control area in which a certain train is positioned. Based on gathered data, computer at the traffic control center performs calculations of the necessary gap length between the trains that are within its control area. Radio communication connection between each train and the computer at the traffic control center is continuous. So computer at the traffic control center has all the data on the position of all the trains within its control area at any moment. The computer forwards to every train data regarding the position of the train it follows and stipulates every train's braking curve necessary to stop the train before it catches up with the train ahead as it can be seen in Fig. 1.

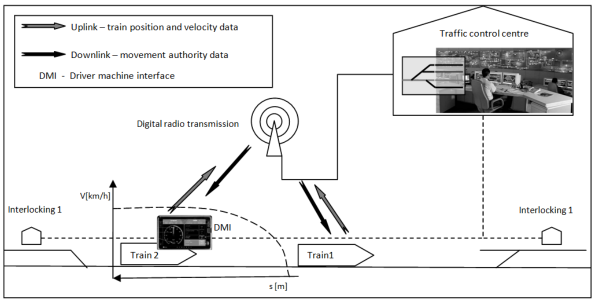

Figure 1: Basic principles of a moving block system

So basic advantage of the moving block system over the fixed block systems lies in the fact that the position and length of the moving blocks is adapted to the required running method to meet the planned objectives of traffic control. Traffic control objectives are determined on the basis of position, dynamic characteristics and actual train speeds on a certain railway line section. Another important advantage of moving block system is reduction of line side equipment for track occupation detection resulting with significant cost reduction.

3 Impact of Moving Block on Rail Traffic Efficiency

The most significant improvements of appliance of moving block operation method in comparison with methods based on separation of trains in fixed blocks regarding efficiency of rail traffic are: (i) rail line side train detection equipment reduction, (ii) increase of the railway line capacity, (iii) better possibility for energy efficient train driving methods usage, and (iv) the ride comfort improvement for railway passengers.

Rail line side train detection equipment has direct impact on railway system efficiency. Crucial part of such equipment is the signalling equipment and infrastructure. Costs for the signalling infrastructure represent a significant part of overall railway infrastructure life cycle costs. Namely, this part of railway infrastructure requires a large amount of expensive line side hardware equipment which is exposed to variable climatic conditions, wear, vandalism, theft and heavy usage. This results in high maintenance requirements regarding labor force and spare parts. With the usage of moving block technology signalling infrastructure costs can be reduced thanks to following cost saving factors:

- Removing train detection and integrity equipment from track to train;
- Minimizing signal cables by controlling elements via radio communication;
- Minimizing maintenance costs of track side equipment.

Another very important benefit of using moving block technology is its impact on capacity of railway lines. Regarding a higher possibility for influence on the train movement characteristic during the moving block train operation, better traffic fluidity with more regular traffic flow can be achieved. Considering this fact an amount of regular recovery and buffer times needed for railway timetable stability can be decreased and thus more train paths in a particular dedicated time window can be added. In this way the moving block technology can increase the capacity of a railway line, especially in case of high density lines with significant heterogeneity of traffic.

Also a lot of research has been undertaken in the last decades to develop smart control strategies for driving trains from the starting point to the destination point with minimal energy consumption while satisfying a strict set of time and safety constraints [9]. Energy efficiency effects can be achieved through general optimization of driving style and traffic flows. Modern signalling systems are being deployed across Europe as part of the European rail traffic management system (ERTMS) programme, which, among other parts, includes wireless communication between trains and central control centers. These wireless links can be used to measure energy consumption and send instructions to trains to significantly reduce energy consumption. Reduction up to $20\ \%$ can be achieved depending on the used technology. On Croatian rail road networks authors achieved maximal energy consumption reduction of 14%. Average value of energy consumption reduction is about 10%, [5].

Basic assumption for such control systems is that energy efficient driving profiles for each route can be calculated at the control center based on track features, particular train speed and acceleration characteristics, and availability of track resource. Driving recommendations can then be sent using wireless communication to the train, helping the driver to conserve energy. For stationary trains, energy consumption resulting from lighting, heating and other services can be minimized with control center intelligence. Since the traffic control center has macro level knowledge of the actions of each train, it can shut-down non-essential services more quickly than existing "load shedding" systems. For example, if the system knows a train will be stationary for several hours the auxiliary services can be shut down immediately when it stops, rather than waiting for on-train electronics to time out [7]. Driving energy consumption minimization approaches will be explained in more detail in the next chapter.

Additional component of railway control improvement area is ride comfort combined with energy saving [3]. Namely, as it will be explained in the next chapter, energy savings in railway traffic are achieved by prolonging the train coasting phase and adjusting optimal velocity values on a particular rail section. Abrupt train velocity changes or non-smooth changes between train running phases significantly deteriorate ride comfort. In order to prevent this, velocity change smoothing around running phase change point is applied. Depending on required timetable, piecewise sinusoidal function or quadratic programming optimization can be used. Hence, the transition time between different running phases and allowed transition distance is too short and fixed in railway control systems, quadratic programming optimization is more suitable for railway control. Using speed smoothing around running phase changes results with significant ride comfort increase are achieved while negligible increasing energy consumption and train traveling time between two stations. Hence, train control systems always have a safety margin regarding time and distance, quadratic programming optimization procedure has the advantage that it can consider this values.

4 Energy saving and ITS

Railway service is now the major transportation mode in most of the countries around the world. With increasing population and expanding commercial and industrial activities, a high quality of railway service is highly desirable. In general, time and energy demand are the two main parameters for the train service regulation in railway engineering and they are usually complement with each other. To achieve a flexible and efficient train schedule with limited available resources, dwell time and coast control are the two measures currently applied in most railway system. With rapid development of the railway traffic, the moving block signalling system (MBS) method has become more and more important for increasing the track capacity by allowing trains to run in a shorter time-headway while maintaining the required safety margins [3].

To minimize energy consumption of train operation where certain compromises on the train schedule are allowed, coast control is an economical approach to balance run-time and energy consumption in railway operation. Crucial assumption is that time is not an important issue, which is particularly fulfilled at off-peak hours.

All modern methods for energy efficient train driving usually use some sort of a driving support system. In this case its purpose is to inform the train driver about the current optimal train speed value and when to start the coasting phase. Energy-saving control can so be divided into four phases: traction, speed holding, coasting and braking as illustrated in Fig. 2. Energy consumption is largest in the traction phase when the train is accelerated. Smallest energy consumption is in the coasting phase when only train onboard systems like control electronics, lighting, heating or cooling systems are powered. Regarding energy consumption reduction, this phase should be the longest one.

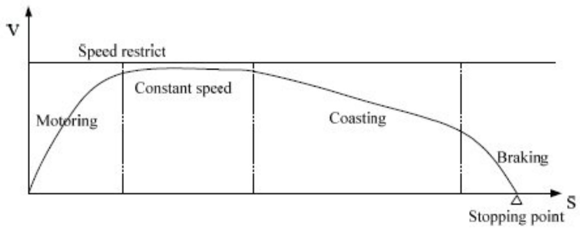

Figure 2: Speed curve of a typical inter-station run

In [10] new energy saving driving strategies for trains' tracking control are proposed. They can be implemented by Automatic Train Operation (ATO) system or as the reference speed for driving assistance systems. Nonlinear Sequential Quadratic Programming (SQP) method is used to optimize the energy saving speed trajectory of the following train. This is an iterative method, in which each iteration solves a square sub-problem, and it tries to transform a non-linear constraint into a linear one.

As described above most efficient methods of reducing energy consumption in train operation is by optimizing the speed profile of the trains. Regarding commuter train operation, main energy saving strategy is coasting, i.e. switching off traction as early as possible before stations [6]. Another approach is to compute optimal train speed profile by means of a multiparametric quadratic program [14]. Train running phases are then interchanging during traveling according to computed train control lock-up table. Such approach defines the non-linear train energy consumption problem with a piecewise affine approximation so no gridding of optimal train speed profile has to be done in the saved control lock-up table. It can take into consideration ride comfort, train section characteristic, fixed arrival times, train breaking system characteristics (regenerative or non-regenerative), and influence of wheatear conditions (tail or chest winds, rain, snow, etc.) on energy needed to drive the train. Resulting control lock-up table is available for all feasible train speed profiles ensuring also in case of a disturbance minimal energy cost in the remaining travel time. It has to be noticed here that no additional time consuming computations during train travel are needed. Only traversed path on a particular rail section and current train speed are needed to obtain optimal reference train speed and speed profile phase from pre-computed lock-up table.

For optimization procedure code implementation, Optimization Toolbox [10] and Multi-Parametric Toolbox [14] within the Matlab numerical software package, was selected. During the optimization process, an overview of the development of optimization variables vectors values for each iteration is enabled, and finally, optimal objective function value is presented. The initial vector values of the optimization variables are of medium-velocity of individual sections, obtained from the total length of all the sections and given time needed to cover all section distances.

Additional benefit or parameters from ITS for optimal on-line train speed profile computation can be obtained from train delay estimation [11] and passenger flow on stations prediction systems [12]. It has to be noticed that trains operate in a time and space frame influenced by other trains on the same rail section. Trains stop at stations to interchange passengers and freight. In case of existing time table safety margins, estimated and predicted values of precursor train delay and time needed to interchange passengers on a station can be used to adapt train speed profile with respect to ride comfort and energy consumption. Namely, in case of precursor train delay controlled train can begin its travel from the station some time later than planned and achieve a smaller maximal velocity in the motoring phase. In case of an expected larger passenger number, controlled train can use train section characteristics with respect to minimal energy consumption to arrive at the station some time earlier to prolong passenger change time. Needed estimation and prediction systems can be made using artificial neural networks, multiple regression, fuzzy logic, Petri nets, and similar techniques from ITS making them applicable in various control systems and regulation areas. Of course always fulfilling all safety margins defined in railway systems.

Described approaches generate an optimum coast control based on riding comfort and energy consumption. They also have potentials for on-line implementation for producing the train speed profile control lookup table for each interstation run before the train sets off. Optimal energy coast, obtained in an off-line procedure is available for all feasible arrival times and therefore it may be used to optimally weigh between the optimal energy coast and the overall travel time coast. Whence optimization procedures are used, different restrictions and additional parameters can be always included in optimization restrictions or cost function.

5 Application on Croatian railroad network

Croatian railroad network does not currently enable usage of wireless transmission of optimal train velocity reference. Different drive regimes have to be computed off-line and then used during train ride according to current time table and traffic conditions. For this purpose a train movement simulator has been developed [5]. Its interface is shown in Fig. 3. Basic functionality for coasting phase duration optimization regarding longitudinal profile of test rail line is implemented without the passenger ride comfort restrictions.

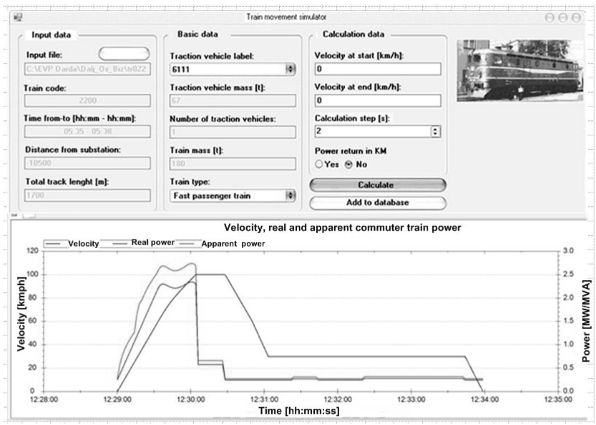

Figure 3: Train movement simulator graphical interface

A part of the railway line Dugo Selo - Zagreb GK is modeled and first simulation for algorithm testing was performed on selected interstation distance between two adjacent stations Maksimir and Zagreb GK. Three train driving regimes were defined: (R1) minimum driving mode in which a train in the shortest travel time possible, travels the distance between two passenger stations and this regime does not involve the application of driving with coasting; (R2) is the initial mode of running, which implies a certain proportion of coasting depending on the time table and traffic condition; and (R3) implies a larger share of coasting driving presenting the regime with longest interstations travel time and smallest energy consumption.

The initial vector values of the SQP-method optimization variables consist of medium-velocity of individual sections, obtained from the total length of all the sections and given the time needed to cover the distance. The regimes have been determined in such a way as to correspond to the commuter train travel times on a certain interstation distance rounded to a full minute. In doing so, each of the driving modes (R) means the driving time that can deviate up to 20 seconds from the running time determined by the timetable adjustment. This discrepancy is the result of the timetable rounding adjustment to a whole minute with real train driving conditions. The appropriate driving time for the specific situation in the transport process will be selected in the process of schedule adjustment to the real traffic condition. The driving modes R2 and R3 have been defined with the aim of optimizing the operational energy consumption with regard to the planned travel times.

In Table 1, the results of energy consumption are given for the considered cases of input (not optimized) vectors. First column denotes preferred driving regime, second column initial (not optimized) value of energy consumption, and the third column shows the reduction

Running mode	E_{in} (kWh)	E_{opt} (kWh)	ΔE (%)
R1	34.5	32.1	6.9
R2	30.9	27.3	11.7
R3	32.2	27.6	14.3

Table 1: Optimization results of energy consumption reduction on a Croatian railroad section

of energy in percentages after applying the SQP-method for different driving regimes optimization. The results show that coasting driving can save in average about 10% of consumed energy for the traction supply of electric passenger trains.

6 Conclusion and future work

This paper describes possibilities of ITS appliance in rail transport with special emphasis on Moving Block technology. Major common benefit for railway companies and passengers are ride comfort and increased traffic flow density in a railway section. Railway companies have additional benefits regarding reduction of needed signalling infrastructure and energy consumption. Also a higher utilization of railway infrastructure can be achieved especially when a path for a non-scheduled train has to be found or such a train has to be controlled.

Modern railway stations, especially urban and suburban railway stations, have the possibility of monitoring passenger numbers. Archived data of connected railway stations passenger numbers can be used to estimate and predict passenger flow during a day or a year using ITS methods. Obtained values can be used for major or minor on-line train timetable adaptations. As described, results are energy consumption reduction and passenger ride comfort improvement. First simulation results are encouraging and justify usage of the implemented optimization procedure. So appliance of ITS within the moving block technology presents a win-win situation for railway companies and passengers.

In future work authors plan to implement described approaches for energy consumption reduction augmented with parameters for ride comfort improvement on larger sections of the Croatian railway network. Making of simulation models of larger Croatian rail network sections for OpenTrack planning and simulation software for railway operations is in progres including detailed data on rail section characteristics like slope, speed restrictions, available equipment properties, etc. Also Matlab optimization procedures are being augmented to adopt restrictions and cost functions to Croatian rail network characteristics including new parameter of ride comfort.

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