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Train Control System Without Interlocking

short report

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Obhajoba dizertačnej práce sa koná ....
pred komisiou pre obhajobu dizertačnej práce v odbore doktorandského štúdia, vymenovanom predsedom spoločnej odborovej komisie 9.2.7. Kybernetika, na Ústave robotiky a kybernetiky, Fakulta elektrotechniky a informatiky, Slovenskej technickej univerzity v Bratislave, Ilkovičova 3, 812 19 Bratislava

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1. Introduction

The aim of this PhD thesis is to show how railway system performance could be substantially enhanced by using existing railway infrastructure with a new control philosophy. There is a growing need for train services due to the increasing demand for transportation services. With increasing train frequency, existing infrastructure with the existing control strategy is utilised to the limits. More and more often, it is becoming impossible to improve the service offered to railway customers under the current system of train control due to a lack of infrastructure. Options do in fact exist for running a substantially greater number of trains using the existing railway infrastructure. Such options are based on a new control system without the current limitations. These limitations are based on the idea of the train safety and control methodology, which during the existence of the railway, was using many generations of interlocking systems. The main characteristics and current limitations are:

1. Cost expensive interlocking and block systems, which ensures safety and the train control.
2. Each fix block section on the railway allows only a single train to be present.
3. Existence of signals for controlling trains to enter each fix block section, as well as train stations.

The new idea allows a higher number of trains to run in succession. In other words, there are no more fixed block sections and no interlocking system needed. The new proposed control methodology is characterised by:

1. Monitoring of all vehicles and infrastructure elements from a central point of a railway region.
2. Control of routes of all vehicles as well as their distances from other vehicles (or vehicle speeds respectively) and ensuring the safety of all vehicles without the interlocking system.
3. Maximisation of the railway infrastructure utilization using efficient train scheduling optimisation methods.

The information for such a control system – “Train Control System Without Interlocking” (TCWI) is provided by all infrastructure elements and vehicles within the defined region e.g.: balises (fixed monitoring points located on the railway), cross switches, on-board (train) computers, safe communication systems, etc. All necessary infrastructure elements are controlled including railway crossings and all trespassing vehicles. The control and safety of all vehicles is ensured by the: central (regional) control system, local control systems, on-board control system, railway infrastructure without interlocking systems and communication systems. Under the control system we can understand computer systems with control software and control algorithms. The most important differences to the current system (using interlocking systems) are as follows:

1. More than one vehicle is accepted within one and the same section in the same direction.
2. No (light) signals for train control are used.
3. No cost expensive interlocking technology is needed.

The thesis could be divided into five core parts. The motivation of the thesis and a simulation-based analysis of a fixed-block-less railway management are presented in the second chapter. Within Chapter 3, the basic principles and foundations of train control were described, as well as the conceptual description of interlocking-less systems and its underlying paradigms including the advantages of the idea. Within Chapter 4 the background of the current mode of operations within the rail domain is discussed, followed by the technical conception of the TCWI and the comparison to current, related implementations of concepts within the specific rail market – here ETCS Level 3. Within Chapter 5 the developed interlocking-less concept is set in context to recent studies within the field. Next the railway operation optimisation using genetic algorithms is proposed. Within the last chapter an impact analysis tries to highlight core entites which might change, if the TCWI system approach would be implemented on a super-national level.

2. Simulation-based comparison of the interlocking-based train control and the TCWI

The aim of the the simulation-based experimental analysis is to compare the difference in operating efficiency of the railway infrastructure using two various approaches. As mentioned above, let us consider the two cases:

A. The current situation, where fix block sections exist, which are controlled by light signals. Only a single train can be present on a section, independently on its direction. This control and safety philosophy is based on the interlocking systems.

B. The control system according the TCWI, where no fix block sections exist. Trains can move in save distances in the same direction in all sections and their positions and speeds are controlled by the central (regional) control system. No interlocking system and no light signals are needed. *Remark:* in this study constant speed of all trains is considered.

In the following simulations let us consider a simple railway model according Fig.1. Consider such situations on it:

I. The trains are moving in both directions from L to R and from R to L in each time and each direction it is possible (whenever the way is free).

II. As in case 1, but the condition is that the direction L to R and R to L is changing alternately.

III. The trains are coming in randomly generated times and in random directions (from both sides L to R and R to L).

IV. The trains are moving only from L to R, whenever it is possible.

The speed of all trains is not controlled and not optimised, it is constant 60 km/h in our experiments. The distances between the trains are not limited, the size of each train is 500m. The distance between stations R and L is 100 km and the time interval of time-table is 10 hours. In Fig.2. results for the situation I are shown. On the horizontal axis is the operation time which duration is 10 hours. On the vertical axis is the total number of trains, which are present on the railway at each moment. The statistics of all simulations is in Tab.1. It is evident, that the railway infrastructure utilisation is much higher using the new control strategy B than using A. The same is valid also for the rest of experiments. The remaining results for situations II-IV are presented in the PhD Thesis. The simulation results shows, that the control strategy B is more effective than the currently used strategy A.

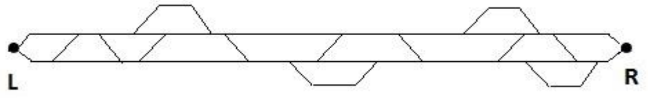

Fig. 1. The considered simple railway model.

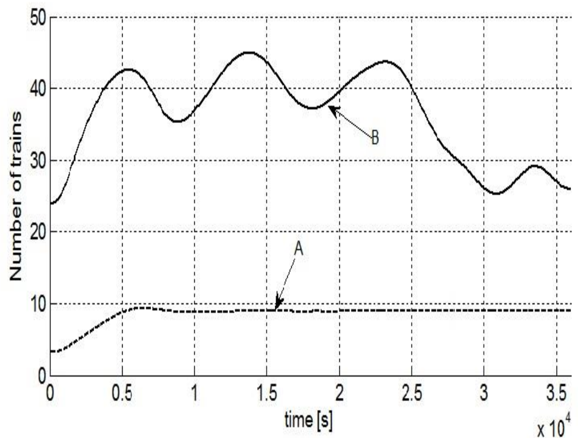

Fig. 2. I. The trains are moving in both directions from L to R and also from R to L in each time and each direction when it is possible (whenever the route is free).

TABLE 1. Simulation statistics

case	**maximum trains on the railway**	**average trains on the railway**	**sum of all trains on the railway during 10 hours**	**increase of B against A (B/A)**
I-A	*10*	*8.9189*	*48*	
I-B	*48*	*36.1019*	*201*	*4.19*
II-A	*9*	*6.6029*	*37*	
II-B	*42*	*26.8753*	*172*	*4.65*
III-A	*8*	*6.4324*	*35*	
III-B	*21*	*11.7505*	*69*	*1.97*
IV-A	*10*	*8.9584*	*47*	
IV-B	*66*	*55.4678*	*284*	*6.04*

3. The Train Control System Without Interlocking (TCWI)

The purpose of the developed new concept of TCWI is to demonstrate how railway system performance could be substantially enhanced by using existing railway infrastructure with a new control philosophy. There is a growing need for train services due to the increasing demand for transportation services. With increasing train frequency, existing infrastructure with the existing control strategy is utilised to the limits. More and more often, it is becoming impossible to improve the service offered to railway customers under the current system of train control due to a lack of infrastructure. Options do in fact exist for running a substantially greater number of trains using the existing railway infrastructure. Such options are based on a new control system without the current limitations. These limitations are based on the idea of the train safety and control methodology, which during the existence of the railway, was using many generations of interlocking systems. The main characteristics and current limitations are:

- Cost expensive interlocking and block systems, which ensures safety and the train control.
- Each fix block section on the railway allows only a single train to be present.
- Existence of signals for controlling trains to enter each fix block section, as well as train stations.

The new idea allows a higher number of trains to run in succession. In other words, there are no more fixed block sections and no interlocking system needed. The new proposed control methodology is characterised by:

- Monitoring of all vehicles and infrastructure elements from a central point of a railway region
- Control of routes of all vehicles as well as their distances from other vehicles (or vehicle speeds respectively) and ensuring the safety of all vehicles without the interlocking system.
- Maximisation of the railway infrastructure utilization using efficient train scheduling optimisation methods on a supervised control level.

The information for such a control system – "*Train Control System Without Interlocking*" is provided by all infrastructure elements and vehicles within the defined region e.g.: balises (fixed monitoring points located on the railway), cross switches, on-board (train) computers, safe communication systems, etc. All necessary infrastructure elements are controlled including railway crossings and all trespassing vehicles. The control and safety of all vehicles is ensured by the: central (regional) control system (CCS), local control systems, on-board control system, railway infrastructure without interlocking systems and communication systems. Under the control system we can understand computer systems with control software and control algorithms. The most important differences to the current system (using interlocking systems) are as follows:

- More than one vehicle is accepted within one and the same section in the same direction.

- No (light) signals for train control are used.
- No cost expensive interlocking technology is needed.

The safety of all vehicles is ensured exclusively by the control infrastructure: Central computer + remote computers + on-board computers + railway infrastructure, without interlocking.

3.1 TCWI Levels

The main levels of the TCWI are shown in Fig.3 and consist of following components:

- **Control station (CS) level -** The Central Control System is housed in a central facility. This facility also houses a control station (CS) which consists of the setting and control equipment. In normal operation, TCWI is operated by means of a train control system. This system, which is programmed based on the operating program, controls the entire area assigned to the CC without human assistance. All of the functions relating to setting and control are displayed at the CS. Specific operator activities are only required when irregularities occur

- **Central computer and control system level (CC) -** A clearly defined area of railway infrastructure, including tracks, points, crossings etc., is assigned to the CC environment. The term “CC environment” is used to designate this area. The entire infrastructure within this area is recorded, concentrated, managed and stored in the CC. The CC tracks the position of all trains, controlling them as well as the railway infrastructure within the CC environment.

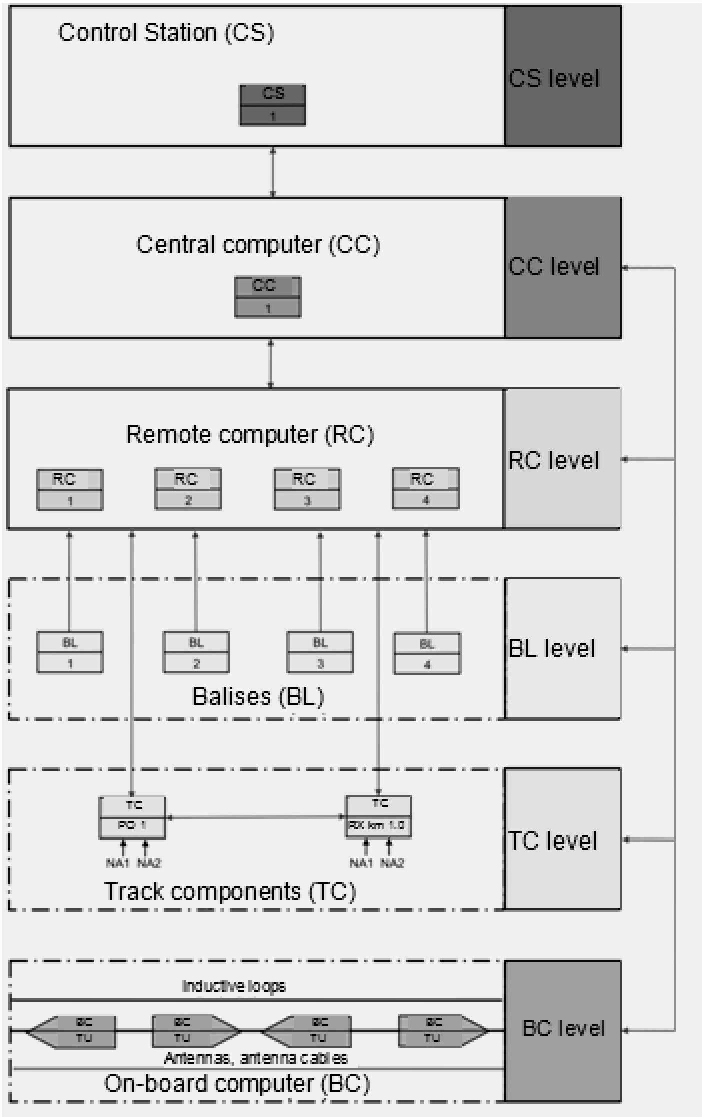

Fig.3 Block scheme of the TCWI

- **Remote computer (RC) level -** The field elements in the immediate environment of a remote computer are assigned to that RC. The RC receives commands from the CC. The RC reports to the CC the execution of the commands. A continuous information exchange takes place between the RC and the CC. In the event of an emergency, the RC can take over certain CC functions within the RC environment.

- **Balise (BL) level ([3], Eurobalise [4], fixed data balise [5])** Balises are installed in defined distances at the rail at specified spots in the tracks and points, at the centre of the track (track axis). A message is sent to the traction unit (TU) when a vehicle moves over a balise. The balises have the function of detecting with absolute precision the location of the TU and of communicating the position to the RC or CC. A balise of this type is referred to as a fixed data balise (a kind of electronic milestone). Although the entire CC area is modelled in the data and the positions are identified and recorded in the system, the balises nonetheless monitor the position of the TU with centimetre precision. The balise is a component that is programmed only once with its exact position data. The balise functions with complete autonomy after that. It does not require a power supply. The power required for data exchange between the TU and the balise is supplied by wireless means, specifically by the on-board computer of the TU, in the form of a vertical magnetic field with a frequency of 27,095 MHz. When the TU passes over the transponder, the magnetic field induces current in a coil located within the Eurobalise. The balise runs on this energy. The distances between balises define the resolution of the grid, which represents the precision of the train location.

- **Track components** represent the all necessary equipment on the rail and it is connected to the CC.

- **On-board computer** is controlled by the CC and ensures the safe operation of each train, its current position and speed.

4. Optimisation level of the TCWI

As already mentioned, the TCWI is able to ensure a higher efficiency of the railway infrastructure utilisation. The goal is to maximise the number of vehicles on the existing railroads. Next we propose a method for optimal train scheduling. Without loss of generality let us consider the following task. Let a fixed time-table of personal transport is a-priori defined. The task is to propose such a time-table of cargo trains, which use the same railway infrastructure as the personal transport and maximises the number of cargo trains using the remaining railway capacity.

4.1 Genetic algorithm for the train time-table optimisation

Genetic Algorithm (GA) [43, 44] is a powerful optimisation/search approach which is able to solve complex practical problems in many application domains. The GA is able to find the (sub)optimal solution of a problem in the defined space of possible solutions. GA work over a set (population) of individuals - candidate solutions [46]. Each individual (called string or chromosome) contains a set of parameters (genes) of the optimised object, which characterise a potential solution. The essential part of the optimised problem is the fitness function (or cost function). It is a performance measure of each individual of the population and it has to be maximised or minimised. Fitness may have the form of a function, which is to be calculate, but it also may consist of complex computation (modelling, simulation, etc.) procedures, and performance measure evaluation. The operators, which are responsible for change of the individuals, are the crossover and mutation. Crossover combines random selected parts of two or more parent individuals to produce one or more offspring. Mutation modifies randomly selected genes of a parent to produce a new offspring. The GA principle can be described in following steps:

1. Initialisation of the population of individuals *Pop* by random.
2. Evaluation of the fitness for all individuals.
3. Selection of a set *P* of parent individuals (stochastic universal sampling was used for selection [43, 44]). Better individuals have higher probability to be selected. Selection of a set of best individuals *B* and

slection of a set of individuals which will remain unchanged *U* (random selection).
4. Crossover and mutation of parents *P* → children *C*.
5. Creation of a new population consisting of best individuals, new children and unchanged members of the old population (*Pop= B+C+U*).
6. Testing of terminating conditions, jump to the Step 2 or end.

In our experiments the size of the population was set to 50 individuals, size of *B* was 2 individuals, size of *C* was 30 individuals and the size of *U* was 18 individuals.

Each individual represents the complete information of a potential solution: the trajectories of all trains on the railway during the 10 hour time interval. The fitness function consists of a simulation of all trains on the railway and from the cost function evaluation. The cost function, which is minimised during the GA evolution is in form

$$Cost = N+\alpha F+\beta B-T; \quad \alpha = 10; \beta = 3; \qquad (1)$$

F - number of frontal collisions o trains
B - total size of back collisions of all trains (size of overlaped segments of all trains in collision)
T - number of all transported trains during the 10 hour time interval
N – desired number of cargo trains in defined directions.

No crossover operation is used in our application. We consider following mutation operations:

a) Small random shift of the starting time of a random selected train (maximum 1 hour).
b) Large random shift of the starting time of a random selected train (maximum 9 hours).
c) Removing of a random selected train.
d) Addition of a new random train.
e) Random change of the route of a random selected train.

4.2 Experimental results

In Fig. 4 graphs of cost function evolution for 8 independent optimizations are shown. Each point of a graph is the currently best value of the cost function of the population in the actual generation. In our example the evolution is terminated after the cost function reaches the value 0. That means we found N cargo trains in defined directions without collision with other cargo trains and personal trains. In the presented examples N was set to 20 (10 in each direction). Among 8 runs of the GA (each with 5000 generations) the algorithm was unable to find a collision-free solution in two cases (dashed line).

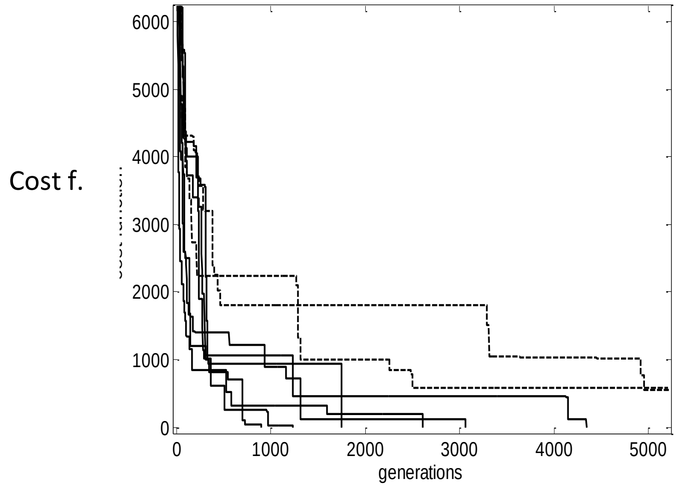

Fig. 4. Evolution of the cost function for 8 independent GA runs

The result of the GA-procedure is a time-table for 20 cargo trains which can be safety operated simultaneously with the 20 a-priori defined personal trains. If more cargo trains have to be operated, the same GA-based optimisation procedure can be used with higher value of N. The approach is effective and able to solve also more complex cases. The only limitation is the computation time, which is higher in comparison to conventional approaches.

5. Conclusion

The goal of this thesis was to demonstrate how railway system performance could be substantially enhanced by using existing railway infrastructure with a new control philosophy. Options do in fact exist for running a substantially greater number of trains using the existing railway infrastructure.

We introduced an alternative idea of railway operation control methodology - TCWI, which is based on a centralised train monitoring and processing and control without the use of interlocking systems and without the use of light signals. A simulation model of the current as well as the new proposed methodology has been created. The statistics of our simulation experiments shows, that the railway infrastructure utilisation is much higher using the new proposed approach. Additionally it is possible to replace the use of the extremely cost-expensive interlocking systems by other automation, communication and computer technology. Next, a new method for train scheduling optimisation is presented, which is based on genetic algorithms. The goal is to maximise the number of vehicles on the existing railroads. This method requires a high computation effort, but it is able to generate time-tables for train operation (also using the TCWI) with a high efficiency of the railway capacity utilisation.

The proposed methodology shows new principles how to utilise the existing infrastructure with a higher efficiency and partially shows also the technical equipment and technology, which is used also today and which can be utilised in the new strategy. But not all technical details which have to support these ideas are solved and proposed in this work. But this exeeds the scope of this PhD thesis.

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