

# Evolutionary Algorithms in Embedded Intelligent Devices Using Satellite Navigation for Railway Transport

Anatoly Levchenkov, Mikhail Gorobetz and Andrew Mor-Yaroslavtsev  
*Riga Technical University  
Latvia*

## 1. Introduction

Nowadays, the most widely spread type of a computer is an embedded system. The embedded systems consist of the following hardware (i.e. nano-electronic components) – programmable microcontrollers or microprocessors; transmitters, including the receivers of global positioning information systems, which demonstrate the state and measuring parameters of a controlled object, and which relay that to the programmable microcontroller; actuators, which receive a signal from the programmed microcontroller and relay it to an antenna, a display or an electro-drive device; and communication devices, including wireless communication with other devices and the software with algorithms of artificial intelligence (Russel, Norvig, 2006).

Railway traffic flow is limited by safety criteria. Therefore, routing and scheduling task is actual for a railway transport. As well an optimal braking control and safety of braking process are very important (Luo, Zeng, 2009). The analysis of human behavior and simulation of train's braking are investigated (Hasegawa et al., 2009). An intelligent transport control system gives a possibility to make traffic control safer and more cost-effective (Gorobetz, 2008). It may find an optimal solution to a conflict faster than a human as a decision support system (Levchenkov et al., 2009). In addition in case of emergency it may prevent crashes and accidents without human intervention.

Authors propose the intelligent braking control device, which warns the driver about the necessity of starting the working braking, taking into account the signal of the traffic light. If working braking has not been started the controller activates emergency brakes with a purpose to stop before the beginning of the next block-section if it is possible, or to choose a free way with enough free distance to stop without a crash. The primary task of the diagnostics device is to separate dangerous situations in braking system by critical values of sensor measurements from the regular states of the system, to detect and to warn about changes in the system and to prevent emergencies immediately. The system allows stopping the train timely before the problem has occurred.

## 2. Problem formulation

Railway safety is an actual and important task. Nowadays a human factor is the main reason for 74% of railway accidents and crashes. This problem is actual as in Latvia as all over the world. Various crashes like in Riga (Latvia) in February 2005, in Ventspils (Latvia) in December 2008, in Aegvidu (Estonia) in December 2010, in Brussels (Belgium) in February 2010, in Magdeburg (Germany) in January 2011 prove the necessity of finding the problem solution.

The main reason of railway accidents is a human factor, when

- train driver does not stop a train on the restrictive signal
- incorrect decisions were made by signalmen (station-on-duty) in extraordinary situations

Therefore, auxiliary embedded electronic devices are needed

- to help a train driver and station signalmen to make the best decision faster
- to prevent accidents if a human does not react

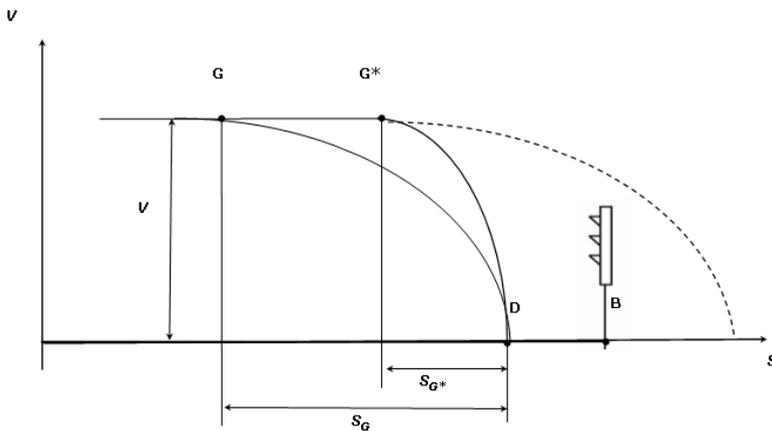


Fig. 1. Graphical representation of the task.

The primary task is to stop the train before the restrictive signal. For this task a warning point  $G$  should be detected, where regular braking still may be applied (Fig. 1.). The point  $G^*$  is a marginal point and also must be defined, where only emergency braking may be applied to stop the train before the signal. Using of regular braking in  $G^*$  follows the passing of the restrictive signal.

The purpose of the research is to develop a prototype of a new control command and a signalling track-side and on-board locomotive's devices to improve train movement safety.

The following functions of the on-board locomotive's embedded device are required:

- receiving location and other necessary data from satellite navigation system
- reception of the data from the server about railway infrastructure (tracks, points) and control points (signals, section points) in the location of the train;
- selecting the necessary signal on the way;
- establishing the wireless connection with the selected signal (Fig. 2.)

- receiving the data from a track-side signal
- checking if the train has reached the route control point;
- detecting the acceleration of the train
- detecting the regular braking distance;
- detecting the emergency braking distance;
- detecting the speed limitation;
- detecting the starting point of regular braking;
- starting emergency braking process
- a module for checking the reaching of the starting point of regular braking;
- warning about the necessity to start regular braking;

The following functions of the track-side embedded device are required:

- establishing the wireless connection with the train
- transmitting signal value to the locomotive's device
- detection of the safest state of the station points using evolutionary algorithms to avoid the collision (Fig. 3.).

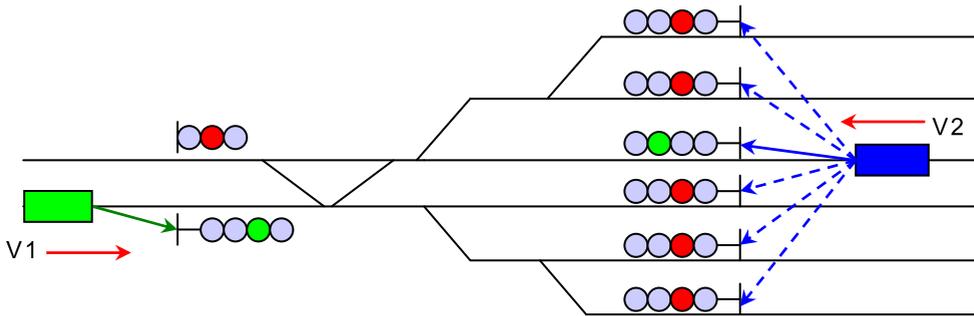


Fig. 2. Selection of the necessary signal on the way.

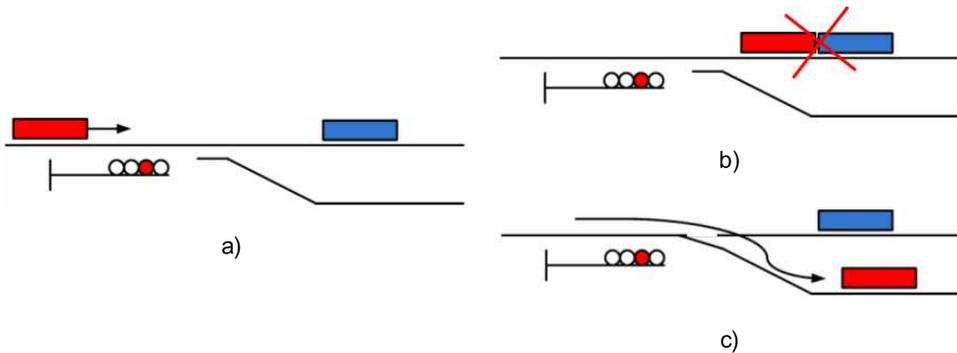


Fig. 3. Detection of the safest state of the station points to avoid the collision.  
 a) Initial state, b) Collision is possible, c) Collision is avoided.

There are many embedded transport control systems on the market which are designed to provide safety for a vehicle, its passengers or cargo, and other traffic participants.

In the commercial railway transport segment an example of such a safety system is KLUB-U, currently used on Russian Railways. It is installed in the locomotives and by interacting with existing signaling systems and its own modules provides information about the train's and its closest neighbors' coordinates, diagnostics of the brakes, current railway segment profile and maximum allowed speed, and controls the vigilance of the locomotive driver. Still, despite the wide array of features, it lacks automation and many decisions require manual operation.

A significant component of the whole safety system is the circuits, engines and brakes diagnostics complex. While the most complete diagnostics can be performed only in the technical service environment, most failures can be detected during its operation using circuit integrity indicators and different sensors designed to uncover electrical mechanical damage.

All kinds of damages which could lead to failures can be combined into distinctive value sets, thus recognizing them in the stream of incoming data allows early identification of problems in the engine.

Artificial immune systems (AIS) were mentioned in some papers in mid 1980s but became a subject in its own right in 1994 in the papers on negative selection (Forrest et al., 1994, Kephart, 1994). Currently the systems are actively explored for possible use cases. For example, there are studies on a real-valued negative selection algorithm for an aircraft fault detection (Dasgupta et al., 2004).

### 3. Structure of proposed system for railway safety tasks

The chapter will demonstrate some issues of design and modelling of a part of a modern embedded system for a rail transport (Fig. 4.). This embedded system is intended for managing the rail transport's electrical drive and the traffic lights, and it consists of the microcontrollers, the developed software and the information system, the wireless communication possibilities and the global positioning system.

Fig. 4 illustrates a complete scheme of a structure of the rail transport's embedded system. In the figure, the brown colour shows the train's embedded devices; the green colour stands for the devices of the traffic lights' embedded system; the purple colour – the devices of the crossing's embedded system; the yellow colour – coordination embedded system devices; the light blue colour – software which provides operation of the network of the wireless embedded system, operation of the communication network of the wireless devices and which is responsible for making operational decisions.

The device receives the signal from the defined traffic light and defines its position using a wireless communication network and has data storage with route control points as well.

Artificial immune systems use evolutionary data processing paradigm based on biological immune systems. It differs from computational immunology which models biological immune systems. Immune algorithms are mainly used to solve anomaly recognition, data collection and analysis tasks. From the computational point of view the most interesting features of the immune systems are self-learning, diversity maintenance and memory.

The problem is represented as an antigen and a solution candidates as antibodies which are randomly generated from the library of available solutions or genes. The evaluation of affinity

or degree of binding between the antigen and the antibody is similar to complementarity level in biological IS and it defines the fate of each individual antibody as well as the termination of the whole algorithm. Individual antibodies are replaced, cloned and hypermutated until a satisfactory level of affinity is reached. Partial replacement of the solutions' population with fresh randomly generated candidates maintains diversity which allows solving a wider set of problems. The probability of cloning or hypermutating a candidate depends on its affinity.

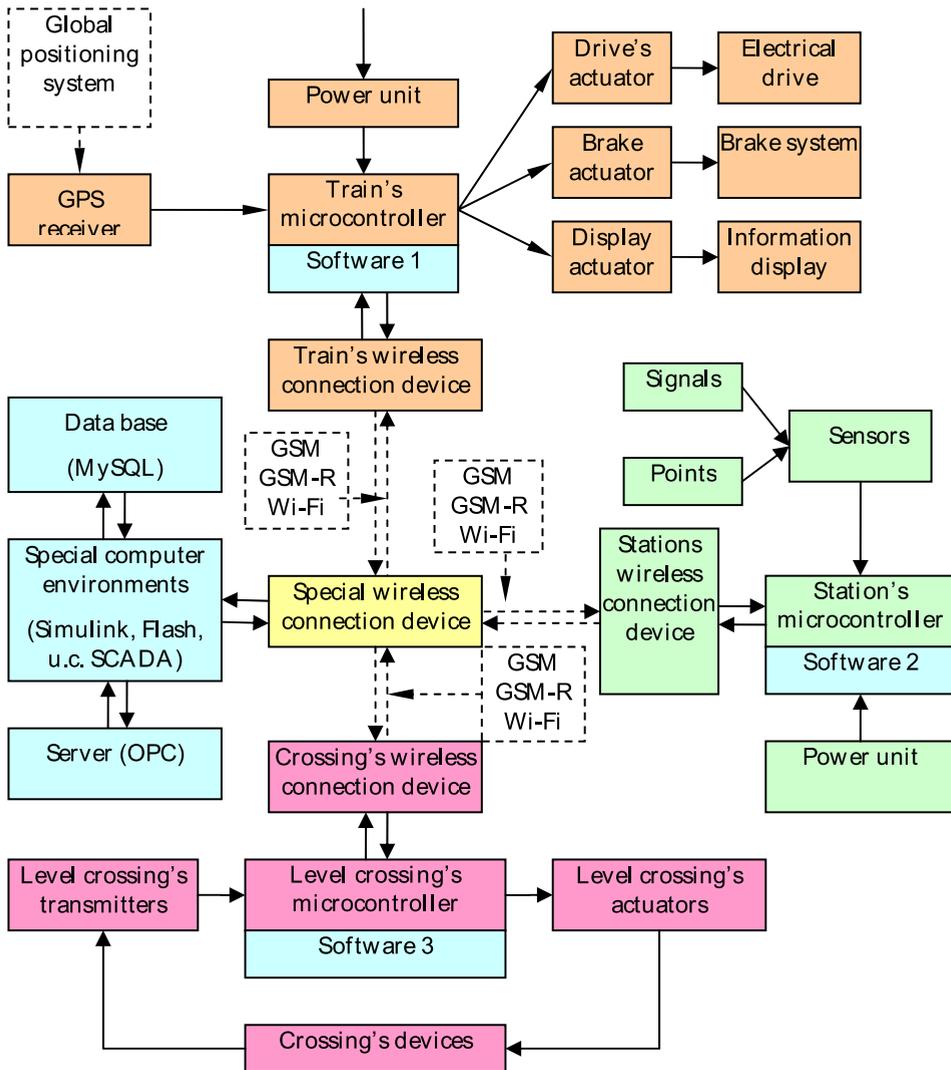


Fig. 4. Wireless network structure's scheme of embedded devices for a rail transport

In the rolling stock safety system (Fig. 5) (Mor-Yaroslavtsev, Levchenkov, 2011), the invading object *I* is picked up by sensors *S* and the data is transmitted to the nearest cell

tower *CT*, which relays it to the control center *CC* and the nearest locomotives wireless modems *M*. Through the same modem the locomotive *L* receives data about the closest neighbors' rolling stock position and status, railway segment profile and maximum allowed speed.

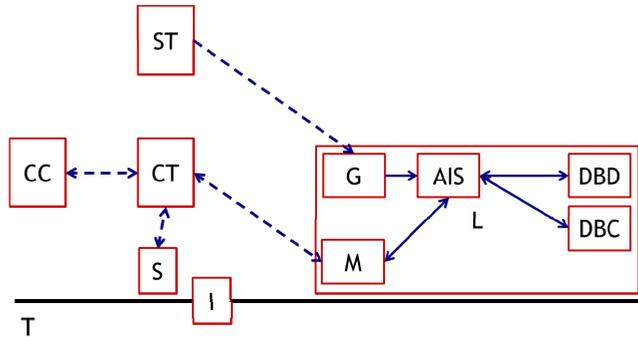


Fig. 5. The intelligent rolling stock safety system functional design

*L* also hosts: a positioning receiver *G* which receives data from a positioning satellite *ST*; data analysis module *AIS* which communicates to the immune detector database *DBD* and control cell database *DBC*. Depending on the results of control cell maturation the module makes a decision and executes it by sending a control signal or displaying an alert to the driver.

Analogous to the hybrid IDS (Powers, He, 2009) the most feasible way to implement such a system would be through the two phases of anomaly detection and determination of their type to draw a conclusion. In this case the incoming data from the sensors is the set of antigens. The data includes but is not limited to speed, acceleration, voltage, rotation, temperature, and presence of smoke.

## 4. Mathematical models for problem solution

### 4.1 Model of differential positioning system

Differential satellite navigation systems are used to increase precision of the positioning systems that is very significant for safety-critical systems, such as transport.

Differential satellite navigation systems (Fig. 6.) contain the following object types:

- S - satellite;
- M - base station;
- R - receiver.

Each satellite *S* is described by the following parameters:

- $\alpha$  - slope of the satellite's orbit to the equator plane;
- $\Omega$  - slope of up-going node of the satellite's orbit to the Greenwich meridian;
- $\omega$  - perigee angle from up-going node
- *t* - time of crossing perigee or up-going node of the satellite's orbit;

- $e$  – eccentricity of the satellite’s orbit:

$$e = \sqrt{1 - (b/a)^2}, \tag{1}$$

where  $a$  and  $b$  are half-axes of the ellipsoid orbit;

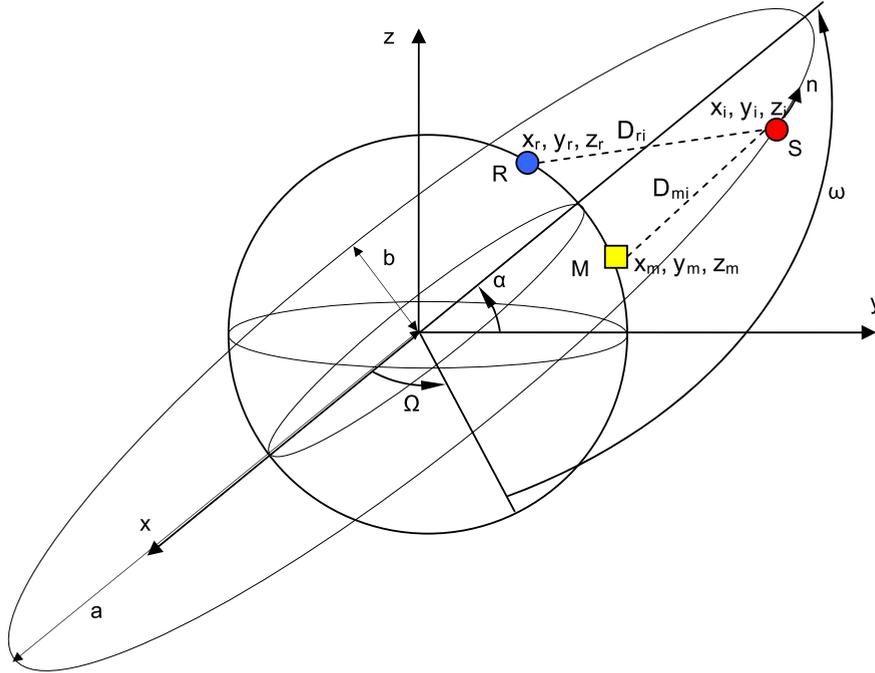


Fig. 6. Differential satellite navigation system elements

- $n$  – angular velocity of the satellite,

$$n = \sqrt{\mu / a^3}, \tag{2}$$

where  $\mu$  – Earth gravimetric constant.

- $x, y, z$  – coordinates of the satellite

Base station M parameters:

- $x_m, y_m, z_m$  – coordinates of the base station
- $D_{mi}$  – known distance between  $i$ -th satellite and base station  $m$ :

$$D_{mi} = \sqrt{(x_i - x_m)^2 + (y_i - y_m)^2 + (z_i - z_m)^2} \tag{3}$$

- $\rho_{mi}, \Delta\rho_{mi}$  – distance measurement result and necessary correction between measured and real distance:

$$\Delta\rho_{mi} = \rho_{mi} - D_{mi} = \varepsilon_{m,sat} + \varepsilon_{m,con} + \varepsilon_{m,rec} + c \cdot \delta t_m, \tag{4}$$

where  $\varepsilon_{m,sat}$  - satellite apparatus error, satellite clock error,  $\varepsilon_{m,con}$  - control error, incorrect ephemerid forecast,  $\varepsilon_{m,rec}$  - receiver's error, ionosphere, troposphere and other noises,  $\delta t_m$  - base station clock deviation from satellite clock,  $c$  - light speed.

-  $\rho_{ri}$  - corrected distance measurement between recipient and satellite:

$$\rho_{ri} = D_{ri} + \varepsilon_{r,sat} + \varepsilon_{r,con} + \varepsilon_{r,rec} + c \cdot \delta t_m - \Delta\rho_{mi} = D_{ri} + \varepsilon_r + c \cdot \delta t_{mr} = \sqrt{(x_i - x_r)^2 + (y_i - y_r)^2 + (z_i - z_r)^2} + \varepsilon_r + c \cdot \delta t_{mr}, \tag{5}$$

where  $\varepsilon_r$  - receiver's result segment error,  $\delta t_{mr}$  - combined clock deviation,

$x_r, y_r, z_r$  - coordinates of the receiver.

### 4.2 Model of railway station

The model of the station may be described with the following sets of objects:

- $V = \{v1, v2, \dots, vn\}$  - set of trains;
- $M = \{m1, m2, \dots, mn\}$  - set of train goals;
- $L = \{l1, l2, \dots, lk\}$  - set of signals;
- $P = \{p1, p2, \dots, pq\}$  - set of points;
- $R = \{r1, r2, \dots, rw\}$  - set of routes.

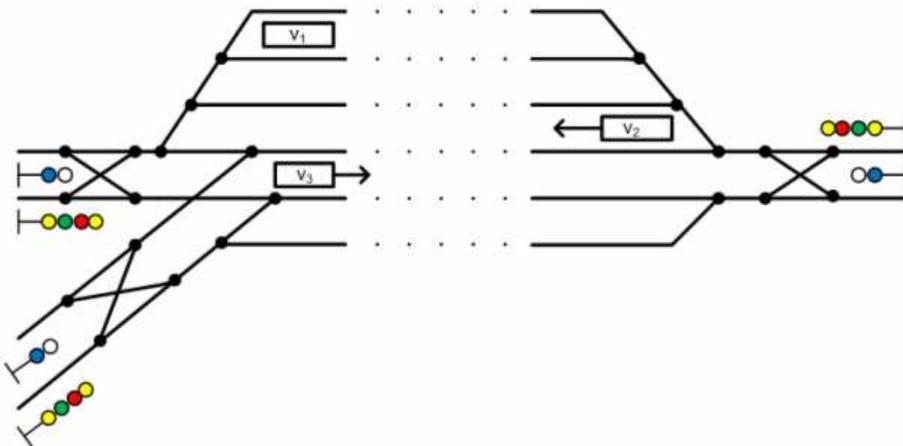


Fig. 7. Graphical interpretation of station model

### 4.3 Model of braking of rolling stock

The braking way consists of preparation and real segments:

$$S_T = S_p + S_D; \tag{6}$$

where  $S_T$  is the braking distance,  $S_p$  – distance of moving during the preparation of braking system,  $S_D$  – real braking distance

The braking power of the train should be defined taking into account a real force of the braking chock influencing the train wheels. A real friction factor depends on the braking chock material.

The following factor characterises the braking chock made of cast iron:

$$\varphi_K = 0,6 \frac{16K + 100}{80K + 100} \cdot \frac{v + 100}{5v + 100}; \quad (7)$$

The cast iron braking chocks containing phosphorus of 1,0-1,4% are characterised with the factor

The mentioned above factor for braking chocks of composite materials can be defined with the following expression :

$$\varphi_K = 0,44 \frac{K + 20}{4K + 100} \cdot \frac{v + 100}{2v + 100}; \quad (8)$$

The calculations of braking force of the chocks also depend on a type of chocks.

For the standard cast iron braking chocks:

$$K_p = 2,22K \frac{16K + 100}{80K + 100}; \quad (9)$$

The cast iron- phosphorus braking chocks:

$$K_p = 1,85K \frac{16K + 100}{52K + 100}; \quad (10)$$

For the braking chocks of composite materials:

$$K_p = 1,22K \frac{K + 20}{4K + 20}; \quad (11)$$

The total braking factor:

$$g_{PO} = \frac{\sum K_p}{Q + P_u}; \quad (12)$$

The main force resistive to the motion in idle running

$$W_{Ox} = W_{O1} + N \cdot W_{Oc}; \quad (13)$$

where  $N$  - quantity of the carriages.

Locomotive without the train:

$$W_{0l} = 24 + 0,11v + 0,0035v^2; \quad (14)$$

Cargo carriages:

$$w_{0c} = 7 + \frac{a + v + 0,025v^2}{q_0}; \quad (15)$$

Passenger trains:

$$w_{0c} = 12 + 0,12v + 0,002v^2. \quad (16)$$

As within the time interval  $\Delta t$  the braking force and the opposite self-resistive force  $\omega_{Ox}$  to the motion of the train are assumed as constant values then the increasing of the speed can be calculated according to :

$$\Delta v = \frac{\xi(b_T + \omega_{Ox} + i_c)\Delta t}{3600}. \quad (17)$$

The speed of the braking force distribution is a braking wave:  $v_t = \frac{L}{t_t}$ ; where: L is the length of the train;  $t_t$  - time from the moment when the driver turns the handle of the hoist till the pressure appears (?) in the braking cylinders; air wave :  $v_v - 20\sqrt{T}$ ; where:  $T = 273 + t^\circ C$  - absolute temperature of gas.

The preparation braking distance:

$$S_p = 0,278v_0t_p = \frac{v_0t_n}{3,6}. \quad (18)$$

Real braking distance:

$$S_D = \sum \frac{500(v_N^2 - v_K^2)}{\xi(w_{ox} + b_m + i_C)}; \quad (19)$$

Thus the total braking way:

$$S_T = \frac{v_0t_n}{3,6} + \sum \frac{500(v_N^2 - v_K^2)}{\xi(w_{ox} + b_m + i_C)} \quad (20)$$

#### 4.4 Model of railway infrastructure and command and control system

Rail ways can be represented as a graph  $R = \{C, S\}$ , where rails are divided into sections S, and each section  $s \in S$  is connected with each other by two connectors  $s = \langle c_i, c_j \rangle$ .

Each section  $s \in S$  has a constant length  $l_s$ , a curve  $a_s$ , and a speed limit  $v_s^*$ .

Each point  $p \in C$  has a connecting set  $W$  of three or more sections and a set of possible states of point  $D_p$ , where  $d_p^m = \langle s_i, s_j \rangle$  means opened in both directions from  $s_i$  to  $s_j$  and from  $s_j$  to  $s_i$  is following for different point types:

single point:  $D_p = \{ \langle s_i, s_j \rangle, \langle s_i, s_k \rangle \};$

dual point:  $D_p = \{ \langle s_i, s_j \rangle, \langle s_i, s_k \rangle, \langle s_i, s_m \rangle \};$

cross point:  $D_p = \{ \langle s_i, s_j \rangle, \langle s_i, s_k \rangle, \langle s_m, s_j \rangle, \langle s_m, s_k \rangle \}.$

Each state of point  $d_p \in D_p$  has a speed limit  $v^*_{d_p}$ ; maximal each point's  $d_p \in D_p$  switching time:  $t_{d_p}$ .

Railway signal  $G$  is an object with fixed coordinates  $x_0, y_0$  connected to the fixed position on the track.

Each signal  $g \in G$  has the following states of signals  $L_g \subseteq \{R, Y, YG, G, V, W\}$ , where "R" - red, and rolling stock must stop before the signal; "Y" - yellow, can move and be ready to stop, the next signal is red; "YG" - yellow and green, next two sections are free; "G" - green, "V" - violet, "W" - moonlight white.

Each signal sets up speed limits for the next block-section:  $v_{def}$ - maximal predefined speed on the section,  $v_0$ - 0 kmh, stop;  $v_1$ - < 50 kmh, movement on turnouts 1/9 and 1/11 types;  $v_2$ - < 80 kmh for movement on turnout 1/18 type;  $v_3$ - < 120kmh for movement on turnout 1/22 type.

### 4.5 Assessment functions

Multi-criteria target function for braking:

$$\left\{ \begin{array}{l} F^{br}(DL, CL, EL, \Delta) \rightarrow \min \\ DL = \Delta S \rightarrow 0 \\ CL = \varepsilon(t) \rightarrow \varepsilon^* \\ EL = \frac{d\varepsilon}{dt} = const \\ \Delta \rightarrow \{\bar{0}, C_1, C_2, \dots\} \\ \Delta = |\Phi(t) - E(t)| \\ E(t) = \{g_p, S_B, \varepsilon_i, t_m, \tau, I_{dcp}, Q_v\} \\ \Phi(t) = \{g^f, S_B^f, \varepsilon_i^f, t_m^f, \tau^f, I_{dcp}^f, Q_v^f\} \end{array} \right. \quad (21)$$

- $\Delta S$  - distance between the closed section and rolling stock - danger level criteria (DL)
- $\varepsilon(t)$  - deceleration of rolling stock
- $\varepsilon^*$  - optimal deceleration for passengers - comfort level criteria (CL)
- $d\varepsilon / dt$  - changes of deceleration and braking torque - optimal energy consumption criteria (EL)

- Fbr – function for braking process optimization
- $\Delta$  – difference/similarity vector, which defines the difference between the estimated and the actual values.
- $\vec{0}$  – Zero vector, which means a compliance with the normal situation, where the estimates and the actual value of the difference is zero;
- $C_i$  – situation of danger classes, according to differences between estimated and the actual values;
- $E(t)$  – vector of estimated values;
- $\Phi(t)$  – vector of actual values;
- $f$  – index, which represents the actual values.

The routing task for accident prevention consists of a generation of a new route and schedule for rolling stocks  $V$  moving on points  $P$ .

The target function for scheduling and routing is to arrange points for each train to reach a destination and assigning of time moments  $t$  to each train and each point.

- Train's schedule:  $\sigma_v : P \rightarrow \{t_{v1}, t_{v2}, \dots, t_{vs}\} \subset \mathfrak{R}$
- Point's schedule:  $\sigma_{p^1} : V \rightarrow \{t_{p1}, t_{p2}, \dots, t_{pm}\} \subset \mathfrak{R}$

The target function for an optimal point state on the station is the following:

$$T_{\Sigma} = f(t_1, t_2, \dots, t_n; x_{11}, x_{12}, \dots, x_{1q}; \dots x_{n1}, x_{n2}, \dots, x_{nq}) \rightarrow \min \quad (22)$$

$t_i$  – the  $i$ -th time moment of switching points

$x_{ij}$  – state of the  $j$ -th point in the  $i$ -th time moment

## 5. Evolutionary algorithms for problem solution

### 5.1 Fitness function for genetic algorithm

Step 0. Initialization

$T_{i \text{ sum}} = 0$  – for each  $i$ -th train summary time

$G_i = 0$ , for each  $i$ -th train goal achievement

$i = 1$  – selected train number

Step 1. Moving the time calculation of the  $i$ -th train on the  $j$ -th railway section,  $t_j^i = S_j / v_i$  where

$S_j$  – length of the  $j$ -th section,

$v_i$  – current  $i$ -th train speed

Step 2. Check if the  $j$ -th section ends with signal.

Step 2.1. Check the occupancy of all tracks to the next signal.

Step 2.2. If any of sections in Step 2.1 is busy and the train is moving, then recalculate time with braking conditions and Goto 4.

$$S_b^i = \frac{-v_i^2}{2\varepsilon}; \quad S_r = S_j - S_b; \quad t_r = \frac{S_r}{v_i}; \quad t_b = \frac{v}{\varepsilon}; \quad t_j^i = t_r + t_b; \quad v_i = 0$$

Step 2.3. If train is already stopped then check If all sections in Step 2.1 are free, then recalculate time with acceleration conditions

Step 2.4.  $j = j + 1$ , select next section of the route

else if the  $j$ -th section is not a signal then  $j = j + 1$ , select the next section of the route

Step 3. Check if the train reached the goal, then  $G_i = 1$

Step 3.1. Check if all trains reached the goal then  $T_\Sigma = \max(T_{SUM}^1, T_{SUM}^2, \dots, T_{SUM}^n)$

Step 3.2. Function STOPS

Step 4. Update summary time of  $i$ -th train  $T_{SUM}^i = T_{SUM}^i + t_j^i$

Step 5. Check if the summary time is less than the next point switching time  $T_{SUM}^i \leq t_p$  ?

Step 5.1. If  $T_{SUM}^i \geq t_p$  then  $T_{SUM}^k = \min(T_{SUM}^1, T_{SUM}^2, \dots, T_{SUM}^n)$

Step 5.2 If  $k = i$  then Goto 6, else  $i = k$ , Goto 1

Step 6. Check occupancy of tracks in switching moment

Step 6.1. Recalculate position of the train  $S_{beg}^i = v_i \cdot (T_{SUM}^i - t_j^i - t_p)$

Step 6.2. Find "tail" of the train  $S_{end}^i = S_{beg}^i - L_i$

Step 6.3. Check the occupancy of all tracks.

If switching points are busy, then  $T_\Sigma = \infty$ , algorithm ENDS; else Goto 1

## 5.2 Genetic algorithm

A genetic algorithm for the task solution may be described with the following steps.

1 step: Initialize random set of possible solutions:  $S^{(0)} = \{s_1^{(0)}, s_2^{(0)}, \dots, s_{s_{\max}}^{(0)}\}$ ;

2 step: Evaluate each solution with a target function:  $V^S = \{F(s_1), F(s_2), \dots, F(s_p)\}$ ;

3 step: Arrange solutions by evaluation:  $\bar{S} = \{\bar{s}_1, \bar{s}_2, \dots, \bar{s}_p\}$ ,  $F(\bar{s}_1) = opt(V^S)$ ;

4 step: Duplicate the best solutions in the elite set:  $S_E \subset \bar{S}$ ;

5 step: **Selection.** Select from the set of solution pairs according to the defined selection:  $S_C = \bar{S}$ ;

6 step: **Crossover:** Generate a new population from the set of the solution pair according to the defined crossover algorithm:

$$\bar{s}_i \Pi \bar{s}_j \rightarrow s'_i = s_{ij}; s'_j = s_{ji}, \quad i, j = \overline{1, p}; \quad (23)$$

7 step: **Mutation:** Random change of one of solution parameter that helps to find a global optimum of the function:

$$x_j^{s'_i} = x_j^{s_i} + 1, \quad s'_i \in S', \quad j = \text{rand}(\overline{1, k}), \quad i = \text{rand}(\overline{1, p}); \quad (24)$$

8 step: Evaluate the new population using the target function:

$$V^{S'} = \{F(s'_1), F(s'_2), \dots, F(s'_p)\}; \quad (25)$$

9 step: Arrange the new population by the evaluation values:

$$\bar{S}' = \{\bar{s}'_1, \bar{s}'_2, \dots, \bar{s}'_p\}, \quad F(\bar{s}'_1) = \text{opt}(V^{S'}); \quad (26)$$

10 step: Add the new population of solution to the elite set:  $S = (S_E + \bar{S}')$ ;

11 step: Delete the last solutions from the population  $S$  if its size exceeds predefined population size  $p$ :  $S = S / \{s_{p+1}, s_{p+2}, \dots\}$ ;

12 step: Algorithm stops by time, generation, convergence or by another predefined criteria. If stop criteria is false then repeat the algorithm from step 4. If true then the result of the algorithm is solution  $s_1$ .

### 5.3 Algorithm for an artificial immune system

#### 5.3.1 Shape-space concept

AIS are modeled after biological IS and carry the terms of antigens and antibodies. They can be modeled using the shape-space concept (see Fig. 8.) (Musilek et al., 2009). The shape-space  $S$  allows defining antigens, receptors and their interactions in a quantitative way.

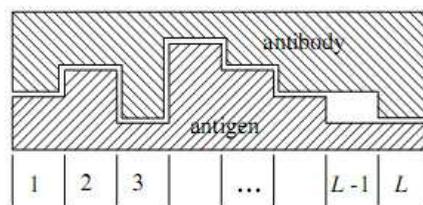


Fig. 8. A shape-space model of an antigen and an antibody.

Like chromosomes in the evolutionary algorithms, depending on a problem being solved it also could be a set of integers or binary numbers -  $m \in Z^L$  or  $m \in \{0, 1\}^L$ .

The affinity of an antigen-antibody pair is related to their  $\epsilon$  distance in the shape-space  $S$  and can be estimated using any distance measure between the two attribute strings. The distance between an antigen,  $Ag$ , and an antibody,  $Ab$ , can be defined, for example, using a general class of Minkowski distance measures:

$$D_M(Ag, Ab) = \sqrt[p]{\sum_{i=1}^L |Ag_i - Ab_i|^p}$$

By varying the value of the parameter  $p$  a suitable measure of distance can be obtained.

### 5.3.2 The negative selection algorithm

Negative selection is the paradigm describing the evolution of the T-lymphocytes where they are randomly generated and learn to recognize all except the self structures, specific to the host. Negative selection algorithms need training samples only from one class (self, normal), thus, they are especially suited for the tasks such as novelty, anomaly or change detection including those in engines and other devices.

The key advantage of anomaly detection systems is their ability to detect novel attack patterns for which no signature exists, while their most notable disadvantage is a larger false positive rate.

The algorithm:

Step 1. Define a set  $S$  which needs to be monitored and the set  $P$  of the known self  $m = \langle m_1, m_2, \dots, m_L \rangle \in S^L$  elements in a feature space  $U$ . The set  $U$  corresponds to all the possible system states,  $P$  - normal states and  $S$  - the current state which changes in time.

Step 2. Generate a set of candidate detectors  $C = \{c_1, c_2, \dots, c_n\}$ .

Step 3. Compare each candidate  $c_i$  to the set of known good elements  $P$ .

Step 4. If a match occurs, discard the individual  $c_i$ , otherwise store it in the mature detector set  $D$ . Or, to maximize the nonself space coverage with a minimum number of detectors, move the matched candidate away from the closest element  $p_j$ , then store it in  $D$ .

Step 5. Monitor  $S$  for changes by continually matching it against the detectors in  $D$ . If any detector matches, the change which has occurred most likely is dangerous, as  $D$  is designed not to match any normal system state.

This algorithm produces a set of the detectors capable to recognize non-self patterns. The action following the recognition varies according to the problem under consideration. In the case of transport safety control system it could be an alarm or issue of an immediate stop signal depending on the detected fault.

The detectors and the caught fault conditions are stored in an immune memory for further processing and to provide further information about the consequences of the attack and possible future actions instead of simply reporting the incidents.

## 6. Computer experiments

### 6.1 Computer experiment of genetic algorithm

The task of the experiment is to minimize idle time of trains on the station and to minimize the risk of their collision.

The station (Fig. 9) with 4 points  $p_1, p_2, p_3, p_4$  is given and two trains  $V_1$  and  $V_2$  are approaching. Railway tracks of the station are split into the sections, where start and end of each section is a point or a signal. The length of the trains  $L_{v1} = 500$  m and  $L_{v2} = 300$  m is given.

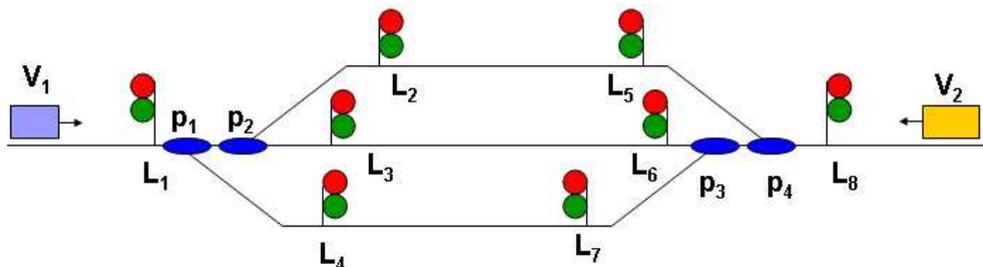


Fig. 9. Structure of the station for the computer experiment

Generation 1	Generation 12
0) 0011000010010010000101000100	0) 1000110001001101000001000100
$f(x) = 610.47947316824; T_1 = 379, T_2 = 564$ Points states: 0 1 0 0   0 1 0 0	$f(x) = 270; T_1 = 96, T_2 = 406$ Points states: 0 1 0 0   0 1 0 0
1) 0011000010010010000101000010	1) 1000110000000101001001000100
$f(x) = 610.47947316824; T_1 = 379, T_2 = 564$ Points states: 0 1 0 0   0 0 1 0	$f(x) = 270; T_1 = 94, T_2 = 160$ Points states: 0 1 0 0   0 1 0 0
2) 0110010000001101000101000100	2) 1000111000000101000001001111
$f(x) = 639.47947316824; T_1 = 781, T_2 = 408$ Points states: 0 1 0 0   0 1 0 0	$f(x) = 270; T_1 = 109, T_2 = 156$ Points states: 0 1 0 0   1 1 1 1
3) 0011101001011101000101001111	3) 1000110010000101010101000110
$f(x) = 686.47947316824; T_1 = 455, T_2 = 908$ Points states: 0 1 0 0   1 1 1 1	$f(x) = 270; T_1 = 98, T_2 = 166$ Points states: 0 1 0 0   0 1 1 0
4) 1100111101111000110101000100	4) 1000110000001010101001000100
$f(x) = 850.47947316824; T_1 = 619, T_2 = 775$ Points states: 0 1 0 0   0 1 0 0	$f(x) = 270; T_1 = 94, T_2 = 332$ Points states: 0 1 0 0   0 1 0 0
5) 0101110101110101000101000100	5) 0001000010011010000101000110
$f(x) = 960.47947316824; T_1 = 729, T_2 = 830$ Points states: 0 1 0 0   0 1 0 0	$f(x) = 270; T_1 = 129, T_2 = 814$ Points states: 0 1 0 0   0 1 1 0
6) 110110101100001110001011101	6) 1000110010000101010101000010
$f(x) = 100000; T_1 = 709, T_2 = 55$ Points states: 0 1 0 1   1 1 0 1	$f(x) = 270; T_1 = 98, T_2 = 166$ Points states: 0 1 0 0   0 0 1 0
7) 0110110101000011011010100000	7) 10001100010011010101000100
$f(x) = 100000; T_1 = 854, T_2 = 105$ Points states: 1 0 1 0   0 0 0 0	$f(x) = 270; T_1 = 96, T_2 = 410$ Points states: 0 1 0 0   0 1 0 0
8) 1100110000101010110001100101	8) 1000110111000101010001000100
$f(x) = 100000; T_1 = 594, T_2 = 336$ Points states: 0 1 1 0   0 1 0 1	$f(x) = 270; T_1 = 107, T_2 = 164$ Points states: 0 1 0 0   0 1 0 0

Fig. 10. Results of Genetic Algorithm - a) first iteration, b) last iteration

The fitness function and the algorithm are realised in the program and the following parameters for genetic algorithm are used:

- Crossover rate - 0.8;
- Mutation rate - 0.01;
- Population size - 50
- Random parent selection
- Single point crossover

Table 1. shows the dynamics of genetic algorithm. The algorithm is performed in 2 seconds and the algorithm converges completely in the 12th generation, where an average value of the population is equal with the best value.

Generation	Average	Best
1	88087.15753678	610.47947316824
2	82128.38630517	413.47947316824
3	70197.754252487	270
4	50320.950968194	270
5	32391.38814628	270
6	26405.504351969	270
7	14391.055583579	270
8	2366.4284573351	270
9	2332.525484097	270
10	329.57671570692	270
11	307.08794731682	270
12	270	270

Table 1. Average and best values of fitness function on each generation

## 6.2 Computer experiment for an artificial immune system

### 6.2.1 Collecting the location data

One data set for the experiment was taken from the two PLCs in the field attached to a vehicle and a level crossing. The data collection scheme is presented in Fig. 11.

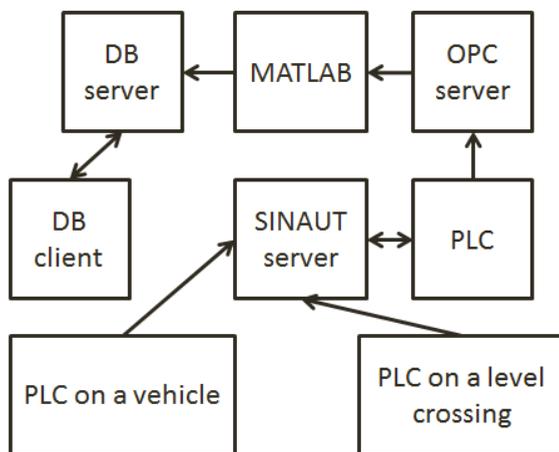


Fig. 11. The location data collection scheme.

The communication between the PLCs is facilitated by GPRS modules and a server running on a PC. Through the chain of software tools the data is piped from the PLCs to DB tables.

The data was collected into two tables for records related to a vehicle and a level crossing. The report (Fig. 4) contains this data cross-matched using the date and time – as all the data was simultaneously recorded with discrete steps of 1 s, the matches are 1:1.

This provides a set of data for test runs of the algorithms.

## 6.2.2 The real-value negative selection algorithm

The RNS detector generation starts with a population of candidate detectors, which are then matured through an iterative process. In particular, the center of each detector is chosen at random and the radius is a variable parameter which determines the size of the detector in  $m$ -dimensional space. The basic algorithmic steps of the generation algorithm are given in 5.3.2.

The whole detector generation process terminates when a set of mature (minimum overlapping) detectors are evolved which can provide significant coverage of the non-self space.

A detector is defined as  $d = (c, r_d)$ , where  $c = (c_1, c_2, \dots, c_m)$  is an  $m$ -dimensional point that corresponds to the center of a hypersphere with  $r_d$  as its radius. The following parameters are used (Fig. 12):

- $r_s$ : threshold variation of a self point;
- $a$ : variable movement of a detector away from a self sample or existing detectors;
- $\xi$ : maximum allowable overlap among the detectors, allowing some overlap can reduce holes in the non-self coverage.

Settings:

- Maximum self-element variation: 0.2
- Maximum detector overlap: 0.1
- Dimensions (sensors): 4
- Maximum detector population: 10
- Number of tests: 20
- Next generation after 5 tests
- Number of top detectors to clone: 2

### Problem space

Dimension	Minimum	Maximum
1. Train speed, km/h	0	100
2. Crossing car speed, km/h	0	150
3. Distance from the train to the rendezvous, m	-100	1000
4. Distance from the car to the rendezvous, m	-10	1000

### Self elements

- [0, 5, 1000, 0]
- [50, 30, 900, 10]
- [20, 30, 600, 2]

Fig. 12. A screenshot from the computer program running a real-valued negative selection algorithm showing the initial settings for training the detector set.

During the straightforward detection process the matured detectors are continually compared to new test data samples. The distance  $D$  between a sample pattern  $p = (c_p, r_s)$  and a detector  $d = (c_d, r_d)$  is computed in the same way as in the detector generation phase. If  $D < (r_s + r_d)$  then the detector  $d$  gets activated indicating possible fault.

#	Centre	Radius	Overlap	Over max	Score
1	[45.66, 40.56, 810.52, 663.2]	659.19916560457	11.712630436924	yes	4
2	[3.5377912542611, 122.88340464607, 832.85177432791, 102.2142227637]	154.21666004677	6.3919845832792	yes	0
3	[2.5695947048491, 55.544483105892, 626.76977100429, 818.4035867151]	816.98189370543	6.3486551611765	yes	5
4	[27.187694470002, 7.383584927742, 834.12094957612, 165.16710031129]	171.35523483706	1.6998396082232	yes	0
5	[2.4970453904292, 107.56920206545, 147.79921302734, 600.96580139848]	754.27876623534	1.4457514612364	yes	9
6	[-333.39525695325, -33.332929255992, -551.13755538503, 1176.2567277667]	636.717573631	1.0569522747208	yes	8
7	[41.257027357444, 43.532006533725, 972.66947431812, 415.34266049214]	412.06540262312	12.106804100201	yes	2
8	[-246.31283775086, 22.874262963601, -500.71681310562, 933.80196469498]	665.99707917402	0.633326326294142	yes	5
9	[89.731672862793, 90.455627923196, 650.94499861178, 713.53201403252]	719.01647151605	0.8099069742284	yes	9
10	[94.182276086748, 244.90184263729, -312.34914808896, -15.984607496821]	496.19048469929	6.9579249445827	yes	4

Fig. 13. The first generation of detectors with unscaled values.

#	Centre	Radius	Overlap	Over max	Score
1	[-333.39525695325, -33.332929255992, -551.13755538503, 1176.2567277667]	754.27876623534	0.16176065722673	yes	3
2	[-246.31283775086, 22.874262963601, -500.71681310562, 933.80196469498]	496.19048469929	1.8652038367886	yes	2
3	[94.182276086748, 244.90184263729, -312.34914808896, -15.984607496821]	496.19048469929	6.9579249445827	yes	4
10	[-246.31283775086, 22.874262963601, -500.71681310562, 933.80196469498]	754.27876623534	0	no	0
9	[-333.39525695325, -33.332929255992, -551.13755538503, 1176.2567277667]	496.19048469929	0	no	0

Fig. 14. The fourth generation of detectors after running several suppressions.

#	Antigen	Result	Generation #
1	[60.06, 126.02, 978.89, 427.11]	Alarm!	1
2	[94.81, 125.18, 859.17, 743.68]	Alarm!	1
3	[52.6, 107.84, 421.43, 204.17]	Alarm!	1
4	[42.88, 9.89, 700.14, 28.52]	Alarm!	1
5	[10.83, 146.65, 80.78, 34.18]	Alarm!	1
6	[69.71, 141.42, 182.66, 172.82]	Alarm!	1
7	[17.43, 5.43, 377.09, 72.29]	Alarm!	2
8	[49.87, 143.89, 156.74, 168.58]	Alarm!	2
9	[8.02, 122, 819.52, 693.07]	Alarm!	2
10	[75.09, 60.43, 344.95, 944.64]	Alarm!	2
11	[1.85, 41.12, 91.18, 882.67]	Alarm!	2
12	[25.76, 6.93, -52.54, 313.08]	Alarm!	3
13	[82.26, 83.93, -34.98, 594.2]	Alarm!	3
14	[32.93, 40.11, 100.63, 897.77]	Alarm!	3
15	[82.7, 35.2, 952.59, 465.22]	OK	3
16	[86.71, 112.21, 250.6, 758.03]	OK	3
17	[5.75, 65.84, 106.16, 465.41]	OK	4
18	[18.47, 73.92, 604.71, 450.33]	OK	4
19	[78.26, 3.03, 679.72, 340.8]	OK	4
20	[90.77, 148.39, 265.3, 284.15]	OK	4

Fig. 15. Test runs with a sample of antigens on each detector generation with detection results.

The testing of the algorithms on a 2-dimensional space proves that the detectors show good coverage of the non-self space and a stable detection of non-self antigens. Fig. 13. shows the coordinates, radii, overlap and detection score of the first detector generation. The population should stay the same but after 3 generations the detector population decreased (Fig. 14.) but still detected the pathogens (Fig. 15). The chosen actions did not differ much probably because of the implementation which needs further research and improvement.

### 6.3 Computer simulation of the railway station

For the experiments the program for programmable controller was implemented. The controller performs all the calculations and controls the electric drive and traffic lights on the functional prototype.

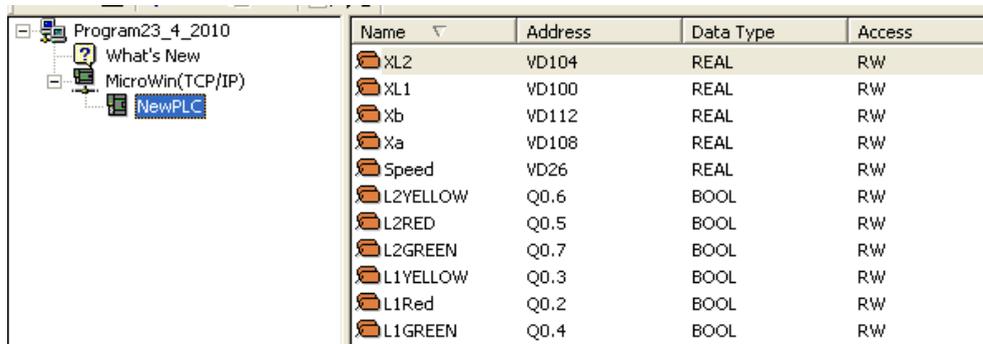
The computer model is created to show the results of controller's operations to perform an emergency stop before the red signal of the traffic lights.

The specific environment is developed by the authors for the modelling of railway system for safety improving algorithms (Fig. 16).

The data from the specific memory addresses of the controller is read by the server (Fig. 17.) and transferred to the model.



Fig. 16. Simulation environment



Name	Address	Data Type	Access
XL2	VD104	REAL	RW
XL1	VD100	REAL	RW
Xb	VD112	REAL	RW
Xa	VD108	REAL	RW
Speed	VD26	REAL	RW
L2YELLOW	Q0.6	BOOL	RW
L2RED	Q0.5	BOOL	RW
L2GREEN	Q0.7	BOOL	RW
L1YELLOW	Q0.3	BOOL	RW
L1Red	Q0.2	BOOL	RW
L1GREEN	Q0.4	BOOL	RW

Fig. 17. Input data from PLC to computer model

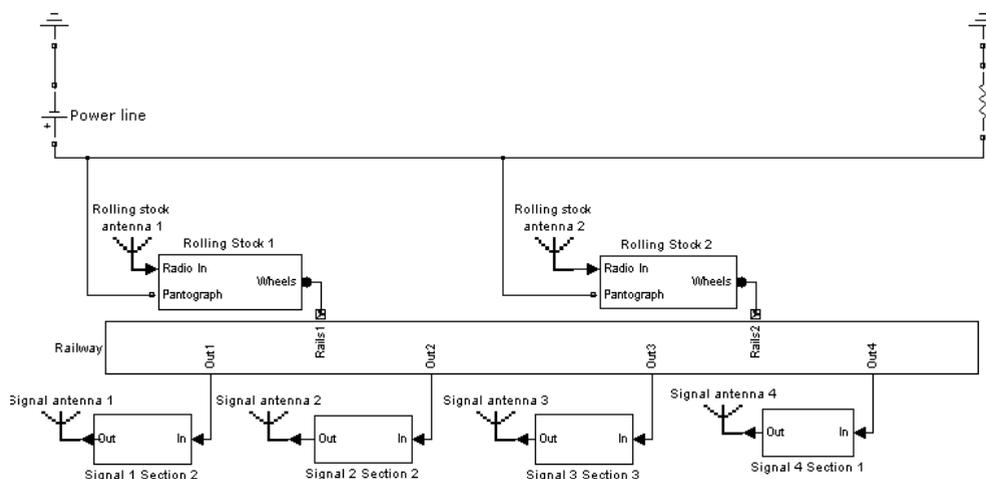


Fig. 18. Model of the railway system

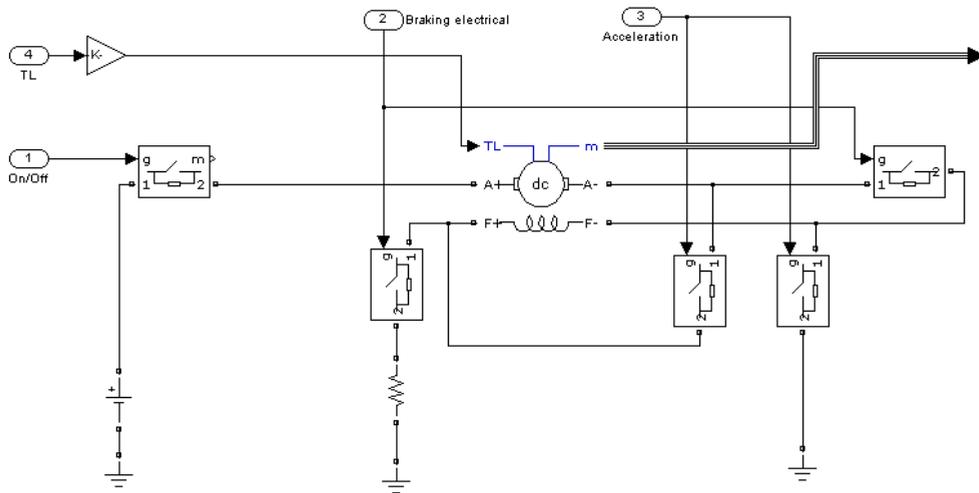


Fig. 19. Fragment of the electrical part of the computer model of the rolling stock

The current experiment is proposed for modelling of crash prevention of two trains moving towards each other. The model consists of 3 series block-sections; 2 rolling stocks; 4 railway signals (Fig. 18.).

Each rolling stock and signal is equipped with receiving and transmitting devices that give a possibility in a multi-agent system.

Electrical part of the model (Fig. 19.) consists of a DC drive with characteristics of 8 DC motors, 1 switch to connect or disconnect the electric drive from the electric contact network, and 2 pairs of switches for acceleration and for braking that changes direction of field current  $I_f$  flow. A braking branch contains braking resistance. An output of a DC drive is an electrical torque which handles the mechanical part of a rolling stock.

## 7. Experiments of prototype in real conditions

The result of this work is a train emergency braking device. The invented device is proposed to increase safety on railway transport. It gives possibility to stop rolling stock automatically before a closed signal timely.

In contrast to the known devices that actuate brake only after the passing of a closed signal, the invented device provides a train emergency braking and stopping before a closed section, even if it is not equipped with automatic locomotive signalling. The device also provides a distance control and an emergency braking way calculation.

The detector of the regular braking distance determines an emergency braking distance, but the detector of the starting point of regular braking defines the point on the route when braking should be started. The module for checking the reaching the starting point of regular braking evaluates location of the train, defines starting point of regular braking and operates braking signalling device in the cabin, the module for controlling starting of

regular braking evaluates whether the regular braking is started. The device warns the driver about the necessity of starting process of the emergency braking taking into account the signal of the traffic light and speed limitation and allows to perform an automatic operation of the emergency braking in time and stops the train preventing trains collision at any sector of a railway.

Fig. 20. presents the demonstration of this device that can be installed on the train. Two traffic lights; the electric motor; sensors and wireless communication equipment are installed on the demonstrator.

According to the traffic light signal the controller selects the appropriate engine speed. When the red light is on, the control system automatically stops the engine. In response to the light sensor, the control unit in addition to the fan is turned on and switches to another mode of operation. Remote monitoring and control of the processes is possible using wireless communication. In a real system, it could be dispatching control centres, from which it is possible to switch both signals and also take over control of the train speed.

Taking into account the pieces of advice and the recommendations from the State joint stock company "Latvian Railways" (Latvijas Dzelzceļš/LDz) specialists, the prototypes of the locomotive and the signal devices have been created. Both inventions were issued Latvian and International Patents No. LV13978 B, LV14156 B, LV14187 B, WO 2011/115466 A2, PCT/EP2011/067474.



Fig. 20. Functional prototype and information screen with satellite navigation data

The authors and the LDz staff had tested the prototypes of the devices in real service conditions. A non-busy section of the railway was chosen to play the role of a proving ground. During the experiment all the devices were working steadily and without troubles, thus the experiment proved that the ideas adopted in the devices can be implemented into practice.

The task of the locomotive's embedded SAFE-R 3 device and the traffic lights' embedded SAFE-R 4 device, which was designed by the RTU and LDz, is to stop the train automatically at the restrictive signal of the traffic lights, in those cases when a driver does not react to this restrictive signal. It is provided that these devices will also work in unencoded railway sections, where the automatic locomotive signalling did not work.

## 8. Conclusions

Advantages of the proposed device are the following: The device is not using rail circuits and works independently of automatic locomotive signalization system. The proposed device is an alternative or auxiliary to existing safety systems. As opposed to existing systems the new device uses wireless communication network and may work in railway sections without an automatic interlocking system. The possibility to prevent a dangerous situation and a crash corresponding to the condition of the braking system of rolling stock allows stopping the train before dangerous failure time point; possibility of using of already existing measurement devices and sensors together with the new sensors.

The results of the experiment show the possibility to use the proposed system as an auxiliary safety device to prevent breaches of red signal and crashes on the railway.

The most relevant features of immune algorithms are self-learning, diversity maintenance, memory about the past decisions, and detection of previously unknown but related elements, noise rejection and classifying ability.

An intelligent rolling stock safety control system could benefit from using a combination of both an immune negative selection algorithm and a clonal selection algorithm. A fault detection system for railway electric transport could benefit from using an immune negative selection algorithm.

The most feasible way to implement a railway electric transport safety control system would be through the two phases of anomaly detection and determination of their type to draw a conclusion about further action.

Single string data encoding is better suited for use on PLC. The PLC program needs a data buffer to eliminate the risk of data loss due to unstable radio signal.

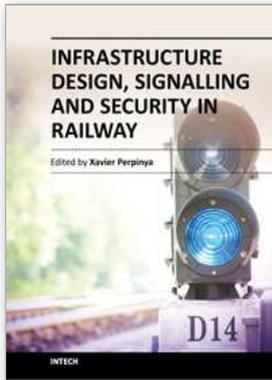
The authors need to assess the possibility to run the data analysis using these algorithms in real time. The detector maturation and control cell selection processes need improvement.

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## **Infrastructure Design, Signalling and Security in Railway**

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Railway transportation has become one of the main technological advances of our society. Since the first railway used to carry coal from a mine in Shropshire (England, 1600), a lot of efforts have been made to improve this transportation concept. One of its milestones was the invention and development of the steam locomotive, but commercial rail travels became practical two hundred years later. From these first attempts, railway infrastructures, signalling and security have evolved and become more complex than those performed in its earlier stages. This book will provide readers a comprehensive technical guide, covering these topics and presenting a brief overview of selected railway systems in the world. The objective of the book is to serve as a valuable reference for students, educators, scientists, faculty members, researchers, and engineers.

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Phone: +86-21-62489820  
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