Autonomous driving trains to pass in bidirectional crossing loop preventing stops

Osmar B. Dordal* , Bráulio C. Ávila

*Pontifícia Universidade Católica do Paraná, Rua Imaculada Conceição, 1155, Curitiba, 80215-901, Brazil

Abstract

This study presents an intelligent approach based on software agents capable of conducting and coordination trains in stretches of single railway track, aiming to optimizing the utilization of railway and reduce environment impacts. In the Brazilian rail modal, due to the low duplication of tracks, trains that journey on single railways should accomplish required halts, in order to wait for other trains to use the crossing loop safely. The technological evolution resulted on the appearance of new railway traffic system control. However, systems that rely on software agents are not well explored yet. Therefore, this study elaborated a Intelligent System capable of simulating railway environment using agent drivers and agents with a highest level in managing the railway tracks. The behaviour of agents was based on specialized rules of conduction and his proactivity is based in obtain a sage driving with informations of position and time limit to the end of journey. The coordination between them occurs through message exchanges, always aiming to avoid halts during the journey. Results have shown an strong average reduction of 22.5% in journey time and 25.5% in fuel consumption when compared to journeys using the traditional method of conduction. The reduction, not only on the journey time, but also on the fuel consumption, entails on the decrease of CO2 emission.

Keywords: Artificial Intelligence; Intelligent System; Coordination; Reactive Agents; Driving of Trains.

1. Introduction

In this study, we propose the use of an intelligent system for controlling the rail modal freight trains from Brazil, which has simple lines in most of its stretch. As demand increases production, railway systems reached its exhaust linked to rail capacity1. This request led to some problems that have become more obvious, such as high fuel consumption; traffic congestion on the simple railways; increase travel time and appearance of judgements relating to the movement of other trains. On this context, the study offers an alternative to solve the fuel consumption problem and optimization of railways, using a reactive intelligent system capable of driving trains on a section with a crossing loop. In this context, the solution avoids the need for trains to make unnecessary stops, one of the causes of high fuel consumption2.
The proposed control area, the agents are inserted according to their expertise, they are: Driving Agent, License Agent and Environment Agent. Driving Agents are experts on the conductor rail. They are able to perceive by the sensors and the exchange of messages with the License Agent. Regarding perceptions, Driving Agents are able to calculate many variables related to the movement of trains, such as strength calculations, the point with the acceleration of the lowest consumption, calculating stopping distance, time travel or approaching the calculation, the calculation of consumption, among others. The exchange of messages are performed to Driving Agent perception information linked to other trains on the same stretch and to obtain the license for circulation.

Regarding the management of stretching, the License Agent is specialized on the issue. It is the agent responsible for controlling a small section containing at least one passage in crossing loop, providing stretch of licenses. The License Agent detects Driving Agents next to the entrance that stretches fields. Therefore, the License Agent checks the amount of train that already have a license released in special sections and decides whether to discharge the entry of a new train on this section. This procedure follows the rules relating to the management of each train, its entry position and size. Only after checking several, it is able to inform if crossing loop can support the amount of trains on the section.

The License Agent, control a small piece. The other agent that controls the railway is called Environmental Agent. In this study, the environmental agent executes the exchange of information on the section with the License agent. The agent’s environment will not be discussed in this study because of its creation linked to the future expansion of the system. The main objective of this study will be the coordination between license and driving Agents.

2. Trains Driving and Coordination

Actually, freight trains on a railway line obey different safety standards. The standards used in Brazil follow an old system based on the Block Sections (BSs). A BS is a fixed length or variable length way one train can enter both. In this system, when a train enters the station, it closes and prevents further entry of trains. Therefore, the BS release is realized only when the train leaves the BS rest.

However, the increased demand for the use of the track, more passive permissions to a train entering a specific BS have been introduced. These permissions are not safe, as with the growing number and speed of trains base stations tend to become smaller. For added security, trains travelling in the same direction must keep the BS free, reducing the line capacity. This type of traffic is given the name Multi-Aspect Signalling Systems (MASS). In this standard colour lights (red, yellow and green) say the train driver if he can or can not enter a BS: A green light means that the train can enter the next BS; yellow sign indicates that the driver must enter with a lower speed; Finally, the red sign means the driver must stop the train, because after the semaphore is another train, which can cause a rear-end collision.

Other signalling systems have been used, especially in light rail systems, where a high level of security is necessary. These methods have been improved through new technologies such as global positioning satellite and wireless communications. Such technology is known under the name Communications-Based Train Control (CBTC) and uses systems such as Global Positioning Satellite (GPS) and Global Navigation Satellite Systems (GNSS). Communication using towers near the railway line was built in CBTC and led to the establishment of Positive Train Control (PTC) and Wireless Positive Train Control (WPTC).

Although the various technologies developed have been in service, the trains still stop because of BSs (red) halt signs. The lack of a system to coordinate and provide information on the use of a synchronized base stations means that the trains are forced to stop and ensure that the Operational Control Center (OCC) check the position of other trains on the same section in the opposite direction. The OCC must allow a stopped train to travel or not after these checks have been performed. These security checks are currently performed by the OCC with the above mentioned systems, but do not manage to avoid the need to stop the trains.

In the authors propose a system known under the name Advanced Automatic Train Control (AATC) to replace the current fixed automatic locking system. In the long term, it is expected that the AATC system is able not only to ensure safe operation of short progress, but also to facilitate the coordinated train control and management of energy, using an approach collaborative agent and wireless communication. has developed a framework for a basic intelligent agents transport system and set up an experimental environment to investigate further.

In, the authors developed an intelligent agent to help train drivers. The main objective of the study was to infer rules using data from previous driving trips.
energy efficiency in driving trains. Both methods have given good results and are suitable for use in trains. In an experience that defines a train drive plane generator based on a high level Believe Desire Intention (BDI) architecture was achieved. Discusses the results of a development software agent named S-Driver, which is able to drive a long distance freight train safely, economically and quickly. The S-Driver runs a small set of instructions, called: reduce, maintain or increase the acceleration point and start to break. In systems were developed with a capacity to carry trains driving through on case based reasoning. These systems reuse of human conductors driving data.

In it was considered a training mission for a heavy diesel truck. With the help of a database on the slope of the road map in combination with a GPS unit, information on road geometry for the extraction of data previously.

3. Architecture of the Agents

The simulator offered in this study involves the above three agents: Driving Agent, License agents and Environment Agent: Driving Agents are responsible for the process of conduction; License Agent for licensing and control of sections with at least a crossing loop; and the Environment Agent is responsible for the railway.

The Driver Agent is responsible to make the trip in an allotted time. By communicating with the other stretching agents, driving agents receive information from the license of the agent, saying that they will go through the crossing loop on the line or the main loop. In Fig. 1, the area of the crossing loop will completely marked as gray and consists of BSs 5 and 6, and BS6 is the crossing loop and BS5 is in the same main line as the other stations.

The main objective of this system is to coordinate all Driving Agents, they move in opposite directions or not, to ensure safety, savings and coordinated driving along a section containing a crossing loop. The crossing loop allows vehicles travelling in the opposite direction (i.e., to different destinations) under the control of two or more agents through.

The Environmental Agent, in turn, has a diagram of the rail network and transmits information on the different sections of the railway line in the agent network license. The license of the agent is able to interact with the agent of the environment in search of sections where there might be a conflict, such as a crossing loop, passing or yard. It also transmits messages between agents involved, arbitrating the inputs of these agents in the section that has a perception. The Licence Agent is also responsible for checking the stretch of capacity under its control and whether to allow other trains on the stretch.

The architecture of the agent and the conduct of modules based on licensing agents, as shown in Fig. 2. The perception module is responsible for collecting information from the environment. The calculation module is responsible for the management of the information used in the simulation to drive trains, such as speed, strength,
Algorithm 1: trainAhead()

\[
p \leftarrow \langle \text{Idt}, V_t, W_t, P_t, L_t \rangle;
\]

while not endJourney() do

\[
p \leftarrow \langle \text{Idt}, V_t, W_t, P_t, L_t \rangle;
\]

\[
m \leftarrow \langle \text{Idt}', V_t', W_t', P_t', L_t' \rangle;
\]

\[
d \leftarrow \text{calculate}(p, m);
\]

\[
r \leftarrow \text{rule}(d);
\]

apply(r);

end while

Algorithm 2: test checkLicense()

Require: TD \leftarrow <d_0, d_1, ..., d_n >

\[
\text{TD} \leftarrow \text{perception}();
\]

\[
t\text{Size} \leftarrow \text{trainsSize(TD)};
\]

\[
c\text{Size} \leftarrow \text{sizeCrossingLoop}();
\]

if fullCrossingLoop(tSize, cSize) then

\[
denyLicense();
\]

else

\[
grantLicense();
\]

end if

Algorithm 3: notCommunication()

while not endJourney() do

if not communication() then

\[
c \leftarrow \text{contingence}();
\]

\[
r \leftarrow \text{rule}(c);
\]

apply(r);

else

\[
\text{end if}
\]

end while

Fig. 3: Three algorithms of system.

braking force, displacement and time as specified in. The reasoning module has different functions. The conduct of agents is responsible for safety rules, such as verification of speed, distances and the rules of use of the crossing loop, according to the Algorithm 1 (Fig. 3). In the licensing agent, reasoning module is responsible for managing the capacity of the line and the use of the line by driving various agents (Algorithm 2, Fig. 3).

In Algorithm 2 (Fig. 3), License Agent has a perception of Train Drive (TD), which contains the data of all driving agents to stretch. It checks the length, direction and the number of trains in its sector and compares these data with the data of the crossing loop. The License Agent can therefore control the ability of loop crossing in the stretch under its control using the fullCrossingLoop(tSize, cSize) rule, which can grant or deny a license to enter the sector. The rules module has a set of rules that allows different behaviours for each agent: For drivers agents were developed driving rules and calculations forces; to the license agent verification rules were developed to provide and validate licenses and observe situations of risk in just one stretch of the railroad; and the environment agent rules were developed to map and observe a whole railroad.

The message module is responsible for communication between agents. Finally, the actuator module is responsible for making the change in control of the train.

The basic travel cycle, which involves calculations, perceptions and selection rules and actions can be seen in.

In Algorithm 1 (Fig. 3), \( p \) is the perception of the process inputs that the agent of conduct must lead. The data \( p \) refer to code \( \text{Idt} \), speed \( V_t \), weight \( W_t \), position \( P_t \) and the size train \( L_t \). Similarly, \( m \) are seen as data from the messaging module. Data \( m \) refer to another train on another part of the line, in \( d \) calculations are performed and a rule \( r \) is selected and applied. In the case of Algorithm 1 (Fig. 3), it is assumed that the selected rule is looking for an ideal speed \( T_3 \) to reach a safe position \( sp_{T_3} \) simultaneously \( t_{T_1} \) as \( T_1 \) travelling in front reaches the safety position \( sp_{T_1} \) as shown in Fig. 4. Equation 1 is used to calculate the ideal speed for \( T_3 \) so that \( T_3 \) and \( T_1 \) arrive at their safety positions at the same time (Fig. 4).

Fig. 4 show how the Equation 1 is used by a Driving Agent

\[
V = \frac{S_{sec} + L_{T_1} + S_{sp_{T_1}} - S_{sp_{(T_1-T_3)}}}{t_{T_1}} \times 3.6
\]

where:
• $S_{sec}$ is the safety distance between the locomotive of $T3$ and the last wagon of $T1$ (in meters) calculated using the equation:

$$S_{sec} = \text{haltDist()} + \text{haltDist()} \times \text{secLevel()}$$

(2)

• $L_{T1}$ is the length of $T1$ (in meters);
• $S_{spT1}$ is the distance from $T1$ to its position of safety $spT1$ in the crossing loop (in meters);
• $S_{spT1-T2}$ is the difference between the distance from $T1$ to its position of safety $spT1$ and the distance from $T3$ to its position of safety $spT1$ (in meters); and
• $t_{T1}$ is the time $T1$ takes to arrive at its position of safety (in seconds).

The safety positions mentioned in the Equation 1 are shown in Fig. 4. In the calculation to determine $S_{sec}$, the $\text{haltDist()}$ has been used as shown in22 and an empirical value of 20% of result for $\text{haltDist()}$ has been used for $\text{secLevel()}$. This percentage was sufficient for the experiments described here.

Algorithm 3 (Fig. 3) shows other rules that may be selected in an emergency, for example if there is no more communication between the train driver and the license agent. Driving agents could enter a rule of contingency, and its speed would be reduced to an emergency speed, in other words, all driving agents would reduce their speed to 10 km/h up communication with licensing agent could be restored. Speed of 10 km/h is used, as with this speed, both the recovery of the cruise as a full stop, it would lead to waste and the use of extreme braking force, respectively. In case of no settlement on messages, Driving Agents would travel on emergency speed until the end of each of the security points, as seen in Fig. 4, so the judgement. Only after the return of communication, the trains could move again.

Consumption for a trip has been calculated according to the Equation 3 and measured in Litters per Transported Gross Tonnage (LGT T)

$$\text{LGT T} = \left(\frac{CA}{P \times \frac{CD}{1000}}\right) \times 1000$$

(3)

where:

• $CA$ is the cumulative consumption in liters for the whole journey;
• $P$ is the weight of the train (in tonnes); and
• $CD$ is the cumulative distance for the journey (in meters).

4. Experiments

The experiments were performed on a line of 19 km of rail length. The stretch of railway line used was based on data for a real line, and a long crossing loop 1 km was added. Nineteen kilometers were sufficient to show the three trains that travel this stretch, as shown in Fig. 5. A crossing loop of 1 km was chosen to ensure that there would be three trains in the loop, and thus simplify the experiments. We added to stretch at speeds impede the pipe produced by various conducting agents, which increases the degree of difficulty for these agents.

This 19 km railway was set up on a flat and straight, because the main purpose of this study is to demonstrate that the load trains, when conducted in the traditional way increases fuel consumption, because of stopovers in places near a crossing loop2.

Fig. 5 shows the safety position conduct agent and calculate the trains can arrive safely at the crossing loop. In the case shown in Fig. 5, $T1$ calculates how long it will take to reach its safety position $a$ using an Equation 1. However, the calculation to determine whether it will be able to arrive at exactly the same time as agents perform to $T2$ and $T4$ is based on the fraction line (shaded field in Fig. 5). Fig. 5 shows the simulation environment of experiments in which one can check the displacement tree trains crossing loop. For a better understanding, the trains running in the positive direction (left to right) are odd, and trains travelling in the negative direction (from right to left) in the same number in the index. Thus, travelling in train $T1$ to $T2$ and $T4$ travel trains and positive in the negative direction.
Only three trains were allowed in the simulation that the restriction imposed by the licensing agent on the basis of the rule in the Algorithm 2 (Fig. 3) ensures that the number of trains is not large enough to exhaust the capacity of the segment, particularly in since the loop through the size is concerned.

Trains run along the same lines are also subject to a security policy that allows for remote emergency stop. The calculation of this judgement is always performed depending on the actual speed and the size of the train. Therefore, the train moves to the other side, is limited to that distance. The safety distance also increases the capacity of railways, given that two trains running next to each other on the same way may be considered as a single train. This principle is established by many researchers on the realization of the increase of this capacity. The safety rule for trains running on the same track is not only the responsibility of the driving agent, leading the train that runs behind, but also a relationship between him and the agent that leads to the train forward. While the train was a heavyweight it would require a long distance to be able to stop. If the axle drive agent before must make a quick change of speed or even an emergency stop, these actions will be communicated to the rear drive axle agent, so as to establish a new security speed or even start an emergency break coming, avoid to a collision.

Our results are based on the pipe method used for freight trains to Brazil that train drivers travelling in the same or opposite directions must obey the BSs signalling. Fig. 7 shows the road consumption graph for the three trains T1, T2 and T4. The trains were made in the traditional way and stopped BSs 3, 8 and 10 respectively. The number of base stations of Fig. 7 and Fig. 10 correspond to the base stations shown in Fig. 5.
The vertical sections of the plots for the three trains, as Fig. 8 correspond to the judgements in the BSs. The trains are stopped in those base stations with their engines while they wait for the authorization of the OCC. The dots in Fig. 7 of abutment are shown in Figs. 8 and 9 as a graph of the time and speed, respectively. It is at this stage of the travel fuel consumption increases. It can also be considered as T4 remained a stop BS9 left space BS between her and T2, which moves in the same direction. T1, which moves in the opposite direction, is maintained at a judgement of the crossing loop in BS8, because it is the only train travelling in the opposite direction to the other two trains, and should enter the crossing loop over the loop line at a speed below 15 km/h.

The trains used in the experiment were configured with 15 units, consisting of a locomotive and wagons 14. Each unit was 20 m long, giving a total length of 300 m and the total weight of 1,289.70 tons per train. The three trains used in the experiment were the same, the goal was to show that the trains on a railway line coordinated save fuel and travel time.

Fig. 8: Time of trains using the traditional method.

Fig. 9: Speed of trains using the traditional method.

Fig. 10: Consumption of trains led by agents of the system.

Fig. 10 is possible to check the consumption of lower content, in which the LGTT for the three trains was 1.844 compared to 2.355 for the traditional method in Fig. 7. This corresponds to an average consumption of difference
LGTT of about 22%. This reduction is due to the non-existence of stops on the part added to the conduction based on the average speed calculated for the first time for the Security arrived, located in the area of travel by full-time crossing loop. Therefore, there was also a reduction of around 24% on travel time.

A note in point is the difference between the fuel consumption. In the graphs of Fig. 10, the axis of reference of the consumer a range between 0.0 and 0.6, being lower compared to the graphs in Fig. 7, with between 0.0 and 6.0.

Compared with the traditional travel, travel executions by Driving Agents is shown in Figs. 10, 11 and 12. First in Fig. 10 were avoided consumption peaks related to that arrest produced in the traditional method. Also in Fig. 11 not seen vertical lines indicating stop trains. The agents of conduct got coordination across buckles avoiding stops. In the end, Fig. 12 shows that T2 and T4 remained constant speeds, keeping this kind of behaviour, T2 and T4 trains have got better mileage than T1.

In Fig. 6, the License Agent receives messages from any sender Driving Agents and distributes them from a central point to each recipient Driving Agent using the policy module to check that the train is the closest to the other. The number of messages sent by Driving Agents is directly proportional to the distance between trains and/or near the crossing loop. Driving Agents travelling in the same direction for exchanging messages every 20 meters, or for each new reading of the track, because they must always aim to keep a safe distance of at least one defined by computer emergency stop while keeping an appropriate distance to travel through the region of the flow loop. This distance must be maintained, as when they go through the train passing area must behave as if they were a train thus increasing the line capacity. In the experiments, the Driving Agents travelling in the same direction had a safe distance between 400 and 700 meters and an interval between 100 and 140 seconds.
Driving Agents are specifically designed for safe and efficient driving. Fig. 11 shows the rates of these agents obtained 19 km long in this experiment. We can see from this figure that the agents are trying to reach a constant speed and avoid unnecessary fuel consumption. Due to excessive speed changes the speed curves for T2 and T4 before reaching the crossing loop zone are substantially compliant with this type of speed curve, trains can reach lower fuel consumption and avoid unnecessary stops. Curve T1 was different because it was moving at high speed to achieve a crossing loop in time. This rate was calculated by taking into account the decrease in the rate estimated 10 km/h necessary to comply with the speed limit at the entrance to crossing loop over the loop line.

Fig. 13: Comparison of trip times and mean fuel consumption with the average LGTT among the three trains.

Nine trips have been generated in the experiment with T1 moving in a positive direction and T2 and T4 in a negative sense. On one of these movements, the conventional driving method was used, while on the other hand, the Drivers Agents (DA) was used. Eight trips were then made with T1 and T2 travelling in a positive direction and T4 moving in a negative direction. Fig. 13 shows the average consumption of three LGTT trains and the corresponding time route based on the time taken by the last train to complete the trip on that section of line.

The graph in Fig. 13 shows that driving under DA travel control T01.3.DA resulted in an average of 1.663 LGTT and the total duration of 43 minutes ride, compared to an average of 2.355 LGTT and total time 47 minutes trip using traditional driving on the trip T.Tradit.1. The trip T1.8.DA had an average of 1.844 LGTT and a total time of 36 minutes ride, compared to an average of 2.355 LGTT and the total duration of 47 minutes ride on the road T.Tradit.1. Thus, for the first comparison, DA has made the reduction of high fuel consumption in LGTT approximately 29% and a reduction of about 9% of travel time, while for the second comparison, the reduction in consumption fuel LGTT was about 22% and the reduction of approximately 23% of travel time.

In another configuration, DA control on the trip T2.6.DA resulted in an average of 1.563 LGTT and the total duration of 40 minutes, compared to an average of 2.110 and ride LGTT total time 49 minutes using the traditional travel behaviour T.Tradit.2. The trip T2.7.DA the Driving Agents achieved an average LGTT of 1.663 and a total trip time of 38 minutes compared to an average of 2.110 LGTT and the total trip time of 49 minutes on the road T.Tradit.1. Thus, for the first comparison of the reduction DA got high fuel consumption in LGTT approximately 26% and a reduction of approximately 18% travel time, while for the second comparison, the reduction in consumption fuel LGTT of fuel was about 13% and reduced about 22% of travel time.

In Fig. 13 trip J.2.6.DA was better from an economic viewpoint T.2.7.DA because the Driving Agents were able to coordinate faster trips, or the arrival time at the safety positions in the area of fastest crossing loop were calculated for T.2.6.DA that T.2.7.DA.

5. Conclusions

This study contributed to the design of an intelligent system capable of coordinating the trains in a railway section with a crossing loop. The system allows all trains in a coordinated manner, avoiding unnecessary stops. The network’s objective of this study was to create driving agents with a high level of proactivity. Agents there, just with information about the position and the driving period, could coordinate the trains to a crossing loop. In this way, another contribution were obtained: creating conduction rules, increased rail capacity, security, strong reduction in consumption and travel time were indeed the results of this study expressed. With these results, it is also possible to expect the benefits
of the reduction of pollutants associated with the combustion of fossil fuels and also a reduction in transport costs, which can be transferred into the final product.

References