A Multi-Agent Geo-Simulation Approach for the Identification of Risky Areas for Trains

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ABSTRACT

The identification of risky areas along the railroad in the context of a railway system is a complex problem. A railway system is spatially and functionally distributed; its subsystems have a high degree of autonomy, and are in constant interaction with each other and with their geographic environment. In order to identify risky areas in the vicinity of rock falls zones we need to model and simulate the train behaviours in large scale geographic environments. Such a process involves coping with a variety of dynamic variables including the train characteristics, the environment properties as well as the weather conditions. The traditional mathematical and statistical modelling techniques which are usually used for the identification of risky areas do not satisfy all the requirements of such a complex process where spatial constraints are of high importance. In this context, m*ulti-Agent geo-Simulation* provides a flexible approach that can be used to easily simulate complex systems in large scale georeferenced environments. The purpose of this paper is to present *Train-MAGS*, an agent-based geosimulation tool which simulates train behaviours and identifies risky areas in large scale geographic environments. We show how agent-based simulation opens interesting perspectives regarding the development of new functionalities to improve risk assessment in the transportation field, more particularly for railway networks.

Keywords
Agent Based Simulation, Geosimulation, Train Derailment, Large-Scale Geographic Space, Risk Assessment.

1. INTRODUCTION

Our literature review showed that the agent paradigm and multi-agent systems in traffic and transportation are used to address several issues in various fields including *traffic modelling*, *decision support systems for better transportation*, *logistics planning*, *sea freight transportation*, *vehicle dispatching*, and *railway transportation traffic and scheduling* [1-3].

In this paper we focus on transportation and traffic systems. While most of works in this domain concern transportation infrastructures (road or networks) which do not really depend on geographical constraints, we are interested in large railway systems which are highly constrained by the geographical environment. Indeed, we use Agent-Based Simulation (ABS) with the purpose of predicting and analyzing potential perturbations which are not only related to the transportation infrastructure (here, tracks and trains) or to its users' behaviours (here train conductor) - as previous works do - , but also to the real environment (particularly the geographic space) in which the transport infrastructure is situated. We thus aim at showing how ABS can solve complex problems in large railway systems.

In this paper we present the Train-MAGS project, an agent-based geosimulation prototype. Geosimulation is a modelling approach which is concerned with the construction of high-resolution spatial models. These models are used in order to explore ideas and hypotheses about how spatial systems operate when developing simulation software and tools to support agent-based simulation, and applying simulation to solve real problems in geographic contexts [4]. In this project, we aim at investigating the contribution of the multi-agent geosimulation to help identify risky areas in the vicinity of rock falls zones in large scale geographic environments. We thus use agents which have an enhanced knowledge with respect to the virtual geographic environment [4]. Moreover, we examine how our agent-based approach can be applicable to a wide range of complex transportation systems' simulations where the spatial dimension is of major importance. The rest of the paper is organized as follows. Section 2 introduces the problem of the identification of risky areas in large scale railway systems. Section 3 presents the multi-agent geosimulation approach for the modelling and simulation of complex system in spatial environments. Section 4 highlights the main characteristics of Train-MAGS: the proposed multi-agent geosimulation simulator for trains. Section 5 presents the main functionalities of the Train-MAGS tool and how the simulation results are assessed. Section 6 presents future perspectives and extensions of the Train-MAGS platform. Finally, Section 7 concludes with some summary discussion.

2. IDENTIFICATION OF RISKY AREAS

Canada has a large railway system, with 49,422 kilometres, that today primarily transports freight [5]. There are two major privately owned transcontinental freight railway systems, the

Canadian National and Canadian Pacific Railway. These companies operate hundreds of freight and passenger trains each day over some of the world's most rugged terrain, and in some of the world's worst weather conditions. Train derailment constitutes a major problem for these companies. In 2007, 465 derailments were reported in Canada. Apart of their high cost, these accidents may lead to the release of hazardous materials, and to property and environment damage [5].

Train derailment, which is prone to uncertainty, is influenced by a large number of constraints such as the geologic state of the terrain (which can cause rock falls), weather conditions (e.g. rain, snow, fog), human behaviours (e.g. fatigue of the conductor), and train characteristics (e.g. braking system, weight). In this paper, we define a *risky area* as a portion of the rail track that precedes a possible obstacle (e.g., a rock fall) and on which the train should limit its speed so that it can avoid derailment if the probable obstacle is confirmed. Even if some special sensors can be used (e.g. sensor spots are currently used to detect rock falls), monitoring a very large railway system remains impossible because it would be too expensive. However, developing software to help identify risky areas could help railway companies to optimize the train traffic by setting adequate speed limits in these areas and allowing higher speeds elsewhere. The stakes for railway companies are high since they are committed to deliver on time the freight to their customers. Any delay implies penalties that increase the railways' operating costs. In such a context, any way of diminishing the risks of train derailment may be invaluable. In this project, we are particularly interested in rock fall hazard zoning [6], and the identification of risky areas in the vicinity of such zones that are prone to various types of rock falls. The traditional way of identifying such risky areas consists in having an expert follow the tracks on a special car in order to visually inspect the landscape surrounding the tracks in order to visually identify the areas where there is a higher probability of rock falls. Then, for each risky area, the inspector needs to assess the maximum speed of the train that would enable a train operator to brake in time in order to stop the train before reaching a possible obstacle on the tracks. Indeed, the distance required to bring a train to a complete stop depends on the capacity of the train's operator to detect the obstacles on the tracks, on the train's speed and on the tracks' conditions (i.e. slipperiness, presence of snow). The inspection of risky areas[1] is complex, requires a scarcely available expertise and can be only carried out on certain portions of an extended railway network and at certain times. Moreover, the procedure should be done under several different circumstances (e.g., different weather conditions). Hence, there is a significant interest to develop simulation software that may help practitioners to identify such risky ares under different conditions.

Few papers have addressed problems related to the simulation of train behaviours from an analytical point of view [7-10]. However, the increase of the parameters that must be considered to achieve a realistic train operator's perception of obstacles leads to a complex mathematical system. Moreover, the formulation of a mathematical model, which includes various factors such as the geologic state of the terrain, weather conditions, human behaviours, and train characteristics, seems complex and not obviously feasible. The complexity of the formulation and the resolution of such analytical models motivated us to find an alternative approach that addresses the simulation of train behaviours while taking into account the abovementioned parameters and factors. In addition, other modelling and simulations capabilities are required if we want to plausibly address the problem of obstacle perception. We need to create geosimulations (simulation of phenomena taking place in virtual geographic spaces generated from georeferenced data) involving autonomous agents that are '*spatially-aware*' in the sense that they are able to perceive the terrain characteristics of the virtual geographic world.

Agent technologies started to penetrate the transportation domain only recently [3, 11]. Agents are able to represent various kinds of entities in the transportation domain. Agents may simulate users involved in traffic, means of transport (trucks, trains, planes, ships), or elements of the traffic infrastructure. Agents can also be used to simulate the behaviours of such entities as well as their interactions with each other and with their geographic environment [12]. Thanks to the flexibility provided by the agent paradigm for the characterization (attributes, capabilities, and behaviours) of trains in their context, agent technology is an appropriate choice for modelling trains in the transportation domain [13].

3. GEO-SIMULATION AND MULTI-AGENT SYSTEMS

Geosimulation is a modelling approach which is concerned with the construction of high-resolution spatial models. These models are used in order to explore ideas and hypotheses about how spatial systems operate when developing simulation software and tools to support agent-based simulation, and applying simulation to solve real problems in geographic contexts [4]. Geosimulation differs from conventional urban simulation in its constituent 'elements'. Geosimulation models operate with human individuals and infrastructure entities, represented at spatially non modifiable scales such as households, homes, or vehicles. Many of these entities are animated (visually and dynamically) [14]. Geosimulation is a useful tool to integrate the spatial dimension in models of interactions of different types (economics, political, social, etc.) [15]. The GIS plays an important role in the development of geosimulation models. New methodologies for manipulating and interpreting spatial data developed by geographic information science and implemented in GIS have created added-value for this data [16].

[4, 14, 16] presented *Multi-Agent Geo-Simulation* as a coupling of two technologies: the Multi-Agent Based Simulation technology (MABS) and the Geographic Information systems (GIS). Based on the MABS technology, the simulated entities are represented by software agents that can be autonomous in their behaviours. They can interact with other agents and with the spatial environment. They may be reactive, proactive, mobile, social or cognitive [16]. Thanks to the agents' capabilities, we can use them to model and simulate complex entities or systems. Using the GIS technology, spatial features of geographic data can be introduced in the simulation.

[1] In this paper we only consider rock falls as a potential direct risk.

Multi-agent geosimulation is a powerful concept that can be used to simulate complex systems in georeferenced environments. According to our literature review, there exist a small number of multi-agent geosimulation candidate platforms that can be used to simulate systems in geographic environments using the agent paradigm. As examples, we can cite the platforms CORMAS (*Common-pool Resources and Multi-Agent Systems*) [17] and MAGS (*Multi-Agent Geo-Simulation*) [16]. In our work we use the MAGS platform to simulate the train behaviours in large scale geographic environments [16]. Our objective is to show how multi-agent geosimulation opens interesting perspectives regarding the development of new functionalities to improve risk assessment in the transportation field, more particularly for railway networks.

4. THE TRAIN-MAGS APPLICATION

In this section we first present an overview of the Train-MAGS application design. Next, we focus on the system architectural features as well as the involved agent types.

4.1 Design Overview

The Train-MAGS application can be thought of as a layered architecture as illustrated in Figure 1 (rectangles on the right side). We briefly present the four layers of our architecture in general as well as its application to the identification of risky areas in the vicinity of rock falls zones for trains in large scale geographic environments. This design philosophy is inspired by the layered simulation model proposed in [4]. It aims at building a parallel between the real world (rectangles on the left side, Figure 1) and the *Virtual Geographic Environment* VGE (right side).

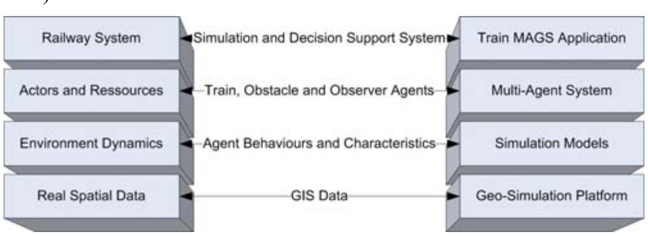

Figure 1: The Train-MAGS Design Overview

1st Layer: It is the software platform which is in charge of reproducing the real geographic world in the VGE. A GIS is essential to reproduce real spatial data in the simulation environment. In addition, human users need a visual tool to supervise the geographic environment. It is thus necessary to transform GIS data into a simulation software platform which is visual for human users and navigable for software agents. Therefore, the Train-MAGS application embodies, at each cell of the simulated environment, information elevation, percentage slope, slope direction, etc. This information is relevant to the simulation of train and conductor's behaviours.

2nd layer: It is responsible of modelling the dynamic factors influencing the real world. In fact, a GIS cannot describe all the spatial data that influence the environment. External factors such as atmospheric phenomena and weather conditions make the environment much more dynamic and unpredictable. Complementary models (such as rock falls) have to be used to simulate this dynamism. Data used by these models should first be captured from the real world and then continuously updated. The model can thus provide a reliable and progressive simulation of the environment. In our example, there is a need to model dynamic data.

3rd layer: This is the multi-agent layer. It represents actors (those who perform actions in the real terrain) of the real world. There is a need for software agents situated in the terrain (Concretely, these could be sensors or electronic devices which sense their neighbourhood and in which agents are embedded). We also need agents in the VGE. Agents within the real world may then communicate with agents within the VGE, which guarantees a better coherency between data collected from both the real and the VGE. Each actor should have a software agent as a representative within the VGE. In our example, an actor is a *Train* which would possess a mobile platform in which an agent (*Train Agent*) is embedded. This train interacts with the *Train Agent* via an interface and communicates with its representative in the VGE via remote messages. Before they can act (navigate, perceive, etc.) within the VGE, software agents need to be coherently linked to real world actors.

4th layer: It represents the functionalities which are domain-specific. Actually, the three previous layers provide a foundation for applications aiming to help decision makers as well as users of the simulation platform with the goal of better strategic decisions. These applications are located in the fourth layer. For our example, the goal of the simulation of the train behaviours is to identify risky areas and to propose recommended speed limits in the vicinity of rock falls zones.

4.2 Architecture

The Train-MAGS architecture includes the simulation core engine (corresponding to the 1st layer, Figure 1) which interacts with several simulation models (2nd layer) such as the physical model (weather conditions: rain, snow, fog), the model of risk (rock falls frequency and location), and a braking model which represents the braking process of the train in case of obstacle detection. The simulation engine also exploits a VGE built from GIS data. Finally, the Train-MAGS tool enables us to create two types of agents (forming the 3rd layer):

- Mobile (moving) agents with navigation, perception and decision making capabilities [16]. These mobile agents are immersed in the VGE and processed by the simulation core engine. In Train-MAGS, the *Train Agent*, which represents the train, is a mobile agent.
- *Observer Agents* which do not represent any real entities. They are responsible for collecting data (see sub-section 4.2.3).

All these agents are spatially-aware in the sense introduced in Section 2. Figure 2 illustrates the conceptual architecture of the Train-MAGS application. All the elements mentioned above are detailed in the following sub-sections.

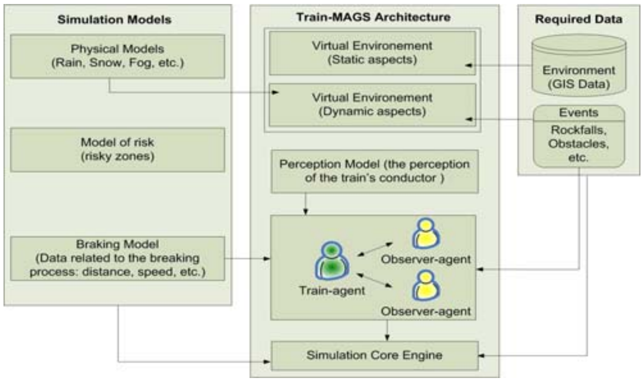

Figure 2: The Train-MAGS Conceptual Architecture.

4.2.1 Virtual Geographic Environment (VGE)

The VGE is a grid (bitmap) which is created from topographic data of a portion of the *Albreda region* (Canada), a digital elevation model and a data base providing the characteristics of the rail tracks. In addition, a module of the Train-MAGS system generates a set of other bitmaps [16] which are used by the *Train Agent* to get information about the space surrounding it and to simulate its perception process [11]. First, the system generates an *Elevation Map* which provides agents with data about the grades and slopes in the simulated area (at each cell of the grid). Next, it generates a bitmap called *Ariadne Map* from GIS data [16]. This map represents the rail track which is followed by the *Train Agent* (see Figure 3). The spatial information is recorded in a raster mode which enables the *Train Agent* to access the information contained in various bitmaps that encode different kinds of information about the terrain characteristics (e.g. slope, elevation) and the objects contained in the VGE (e.g. bridge, tunnel).

4.2.2 Train Agent Characterization

The *Train Agent* actually represents both the train and its operator. As the train representative and similarly to a real train, it follows the rail tracks, adjusts its speed according to the terrain's characteristics (mainly according to the grade of the terrain), and simulates the braking system. The *Train Agent* uses its navigation capability (see sub-section 4.2.2.2) to achieve its goals. As the operator's representative, it mainly simulates the perception of the operator (see sub-section 4.2.2.1).

The *Train Agent* (as all agents in the MAGS Platform [16]) is characterized by a number of variables whose values describe the agent's state at any given time. We distinguish static states and dynamic states. A static state does not change during the simulation and is represented by a variable and its current value. For example, the train category (e.g., passenger train, freight train) is a static characteristic which does not change during the simulation. A dynamic state is a state which can possibly change during the simulation. For example, the *Train Agent*'s speed and its braking distance to stop can change during the simulation depending on the context. Using both static and dynamic variables, the system simulates the evolution of the *Train Agent* in the VGE and triggers behaviours depending on changes of its states and on the achievement of its goals [16].

4.2.2.1 Perception

Perception is an important agent's ability which must be carefully simulated in a VGE if we want that agents exhibit plausible cognitive spatial behaviours. The *Train Agent* simulates both the displacement of the train and the perception of its operator who checks for potential problems on the rail tracks ahead of the train position. By analogy to human spatial perception, we identified several perception modes for the *Train Agent*: 1) perception of terrain characteristics (elevation and slopes) in the area surrounding the agent; 2) perception of the landscape surrounding the agent (including trees and static objects such as rocks on tracks); 3) perception of other mobile agents navigating in the agent's range of perception (pedestrians or cars crossing rail tracks, other trains); 4) perception of "*dynamic areas*" with specific properties such as foggy areas.

Several research works have already tried to address the problem of simulating perception in an environment represented using a height map. The goal of these techniques was to determine the visibility of all the cells of the height map which are in an observer's field of vision. They use lines of sight in order to test the cells' visibility (labelled as visible or not) from the observer's location.

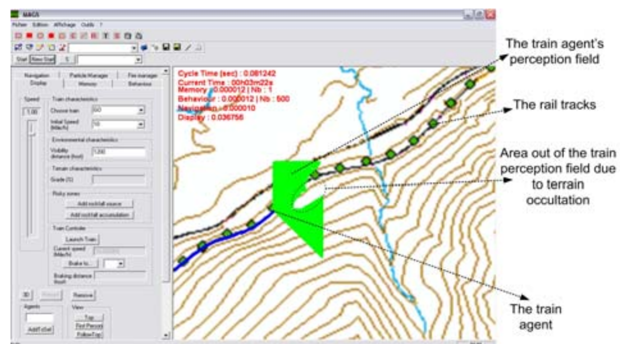

Figure 3: The *Train Agent* Field of Perception.

In MAGS [16] we use an approach extending Franklin's algorithm in a way that enables agents to perceive the environment as well as other agents in real time [16]. The *Train Agent*'s perception field is represented by an isosceles triangle, the main vertex being at the agent's location, the congruent sides of the triangle limiting the perception field and the bisector of the main angle corresponding to the agent's direction of movement. The length of the bisector corresponds to what we call the *Perception Radius* (PR). The angle of perception is a parameter that can be adjusted (currently set to 160 degrees to mimic conductor's perception in the front of the train) (Figure 3). Since perception takes into account the terrain elevations, an area which is hidden by an elevated portion of terrain will not be perceived (obviously) as shown in Figure 3.

4.2.2.2 Navigation

In order to optimize the agent's navigation function, we exploit the *Ariadne Map* (Figure 3). The *Train Agent* can directly access it in order to determine which cells around it correspond to its path (rail tracks). The *Train Agent* navigates using a *following-a-path mode* [16] which consists in forcing the agent to follow a predefined path in the VGE corresponding to the rail tracks. The Train-MAGS's navigation module is able to access the *Ariadne* Map's portion which is perceived by the agent. Data extracted from the *Ariadne* Map is then used to compute the agent's next move. Moreover, depending on the terrain's characteristics, the *Train Agent* adjusts its speed in the VGE in order to reflect the real situation.

4.2.2.3 Objective-Based Behaviours

In Train-MAGS an agent is associated with a set of objectives or goals that it tries to reach. The objectives are organized in hierarchies, which are trees composed of nodes representing composite objectives and leaves representing elementary objectives that are associated with actions that the agent can perform. Each agent owns a set of objectives corresponding to its needs. An objective is associated with rules containing constraints on the activation and the completion of the objective. Constraints are dependent on time, on the agent's states, and the environment's state. The selection of the current agent's behaviour relies on the priority of its objectives. Each need is associated with a priority, which varies according to the agent's profile. An objective's priority is primarily a function of the corresponding need's priority. It is also subject to modifications brought by the opportunities that the agent perceives or by temporal constraints [16].

4.2.3 Observer Agents

In the MAGS platform, an *Observer Agent* is an agent whose behaviour is dedicated to data collection during the simulation process [16]. The *Observer Agents* are immersed in the VGE at specific geo-referenced locations in order to closely observe particular phenomena. Their perception and memory capabilities are basically used to perform data collection. This data is then analyzed in order to better understand the observed phenomenon. In the context of train behaviours' simulation, we use *Observer Agents* located in the obstacles' surroundings in order to observe the changes of the train's behaviour when it detects the obstacle. The train position, added to obstacles' positions, the braking distance, and the terrain grade are used to assess the capability of the train to brake before hitting the obstacle. *Observer Agents* are located at the intersection of rail tracks and rock fall zones which are represented graphically by nested ellipses as shown in Figure 5. The simulation process, when the *Observer Agent* perceives *Train Agent*, it starts collecting data related to the context such as the *Train Agent*'s position, the terrain topology, and the risk level of the area. On the basis of this data the system carries out an analysis in order to assess the *Train Agent* behaviour in the vicinity of risky areas. The result of such an analysis is presented in Section 5.

4.2.4 Obstacle Agents

In the Train-MAGS platform, obstacles are introduced in the simulation scenario using a specific type of agent called *Obstacle Agents*. *Obstacle Agents* represent physical obstructions in the real world. This type of agent may be *stationary* or *mobile* [16]. *Stationary Obstacle Agents* (SOA) include landslide, fallen trees, significant quantities of concrete materials, and equipment or freight fallen from other trains as well as any object that is liable to pose a danger to the safe passage of trains. On the other hand, *Mobile Obstacle Agents* (MOA) include farm livestock or other animals that have entered upon the track as well as road vehicles at a level crossing. These agents can be immersed in the VGE by the user at simulation run time at specific geo-referenced locations. In the current version of the Train-MAGS platform, only *Stationary Obstacle Agents* are implemented. The integration of *Mobile Obstacle Agents* is part of the future works as discussed in section 7.

4.2.5 Weather Conditions

Certain gaseous phenomena such as smoke and fog are related to the VGE's atmosphere and cannot be modelled using agents. They are associated with areas or volumes whose properties (boundaries, local density, etc.) change dynamically under the influence of external forces like the wind. A good way to simulate such phenomena is to use particle systems. The MAGS platform provides such tools which have been used to simulate tear gas in crowd simulation in urban areas [16]. However, in the current version of the Train-MAGS tool, atmospheric phenomena such as fog, rain and snow, are not yet included since we did not get the corresponding data yet for the area in which we conducted our experiments. Weather conditions need realistic data to be modelled and simulated.

4.3 Operating Modes

The Train-MAGS is a two-phase project which aims at providing a multi-agent geo-simulation platform which is able to operate in two different modes: ***Pre-execution mode*** and ***Real-time mode***. The *Pre-execution mode* is already supported by the current version of this simulation tool, while the *Real-time mode* is under implementation.

4.3.1 Pre-execution Mode

A decision maker may use the Train-MAGS platform in order to analyze and assess different situations by simulating various scenarios involving stationary and mobile obstacle agents. The *Train Agent*'s behaviours are thus evaluated by the decision maker and speed limits are defined with respect to the to the risk identification process. Using Train-MAGS in the *Pre-execution* the user can achieve the following goals:

- Identification of risky areas;
- Elaboration of a table which summarizes the recommended speed limits with respect to the identified risky areas in large scale geographic environments.

4.3.2 Real-time Mode

The Train-MAGS system's architecture can be coupled to a real-time monitoring system. Hence, the Train-MAGS application may be used for different purposes taking advantage of its simulation capabilities. Indeed, this tool could first keep track in the simulation environment of the effective moves of the train in the real world using a GPS (*Global Positioning System*) tracking system. Second, it could periodically update the information regarding the geographic environment using the data sent by sensors and actuators located at specific geo-referenced positions. Finally, the Train-MAGS could suggest possible strategies as soon as an unexpected event is reported. Possible events include detection of stationary or mobile obstacles along the rail tracks. The proposed suggestions consist in modifying the train behaviour such as reducing its speed. The *Real-Time mode* is a challenging objective since it aims at exploiting the Train-MAGS platform as a monitoring system for trains. This topic will be discussed in Section 6.

5. SIMULATION AND RESULTS

In this section, we discuss the implementation of the *Pre-execution mode*. The Train-MAGS application, which corresponds to the 4th layer in Figure 1, enables a user to create the VGE and to specify the train's characteristics (category, speed, perception radius, etc.). It also offers the possibility to create two different types of simulation scenarios: the *interactive scenario* and the *modelling rock fall Probabilities scenario*.

The *interactive scenario* allows the user to introduce, at simulation run time, geo-referenced rock fall hotspots in the VGE. The *Train Agent* can perceive rock fall hotspots using its perception function. When an obstacle is detected on the tracks, the *Train Agent* triggers its braking process. The braking process is a complex computation model which takes into account several variables such as the train category, the speed, the terrain characteristics, and the state of the rail track. These variables are collected thanks to the *Observer Agents*. The braking process is launched after the train's conductor perceives the obstacle. Thus, the simulation of the braking process strongly depends on the *Train Agent*'s perception (it also depends on the response time of the conductor, but this parameter is not considered here for simplification reasons). The objective of the *interactive scenario* type is to determine the capacity of the simulated train to brake at a safe distance from the perceived obstacle, given the aforementioned parameters.

Modelling Rock Fall Probabilities Scenario enables the user to simulate the risk instead of the event (rock fall zones instead of obstacles detection) (Figure 4). Thanks to data generated by statistic models of the rock fall phenomenon, rock fall probabilities are modelled by nested ellipses and introduced in the VGE as shown in Figure 5. Ellipses are used instead of the original non regular shapes for simplification reasons. Each ellipse represents a probability level. The probability increases towards the centre line of these ellipses. Thus, the smallest ellipse represents the highest probability of rock fall. From the *Train Agent*'s point of view, a higher probability of rock fall corresponds to a higher level of risk. The *Train Agent* uses its perception field and computes the minimum distance from which the operator may perceive a possible rock within the zone delimited by the ellipse while taking into account the elevation of the terrain (*grade*) measured by the *Observer Agents*.

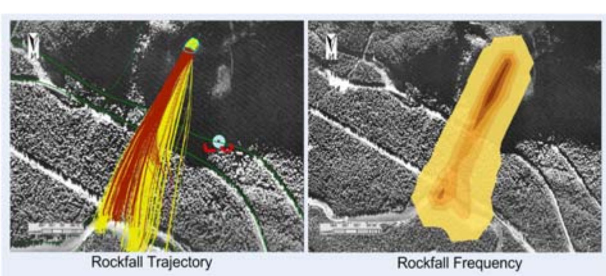

Figure 4: The distribution of rock fall probabilities **in key areas of the *Albreda* region (Canada). The map was generated by statistic models and built upon GIS layers for areas of special interest around railway traffic corridor, with layers depicting rock fall risks.**

Given this distance, the Train-MAGS application determines (using heuristic data provided by Canadian National) the maximum speed which is allowed for the train in order to be able to brake on time if an obstacle is perceived inside one of the ellipses.

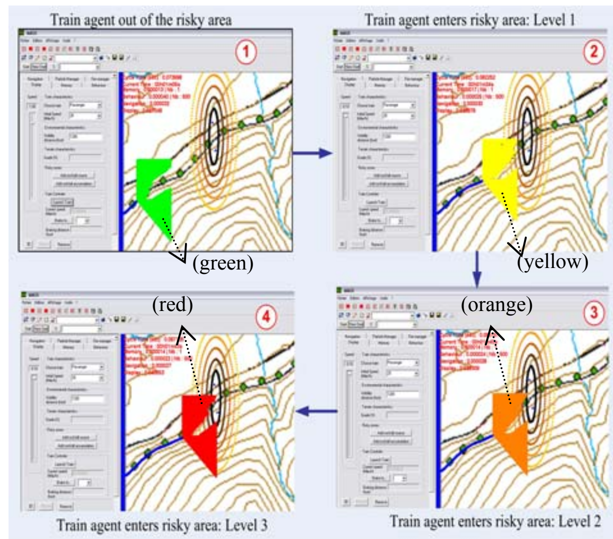

Figure 5: Perceiving the Rock fall Zones .

In order to determine the risk level (from the *Train Agent*'s point of view) depending on the train's position, the *Train Agent*'s perception field is coloured ranging from green to red, where the green colour warrants a safe area and the red colour indicates that the train is in a risky area (a risky area, defined in Section 2, is thus the distance between the current position of the train and the ellipse's perimeter). Figure 5 presents the changes of the colours of the *Train Agent*'s perception field as a consequence of the risk level of the area crossed by the train. The computation of the braking distance to the obstacle can also be used to determine the maximum allowed speed in order to enable the train to stop before reaching the rock fall zone. This speed depends on the perception distance (which depends on several constraints including the weather conditions and curves), the terrain topology (grade of the tracks), and the distance between the *Train Agent* and the rock fall zone. The Train-MAGS system generates for each rock fall probability other output such as a table indicating the maximum allowed speeds for a given region (Table 1).

Table 1: Recommended Speeds for a risky area (the considered train weights 24 tons: 3 locomotives+196 cars).

Visibility (m)	Train Position (X,Y)		Perceived Rock fall zone (X,Y)		Risk Level	Distance to Rock fall zone (m)	Grade	Recommanded Speed (Km/h)
450	48	780	73	767	1	280	0,000	20
450	48	780	78	762	2	350	0,089	23
450	48	780	83	757	3	410	0,093	24
450	52	779	88	753	4	440	0,098	24
450	60	776	93	748	5	430	0,103	24
450	69	770	103	740	4	450	0,097	27
450	89	751	108	737	3	230	0,093	16
450	90	751	113	735	2	280	0,088	20
450	103	740	118	734	1	160	0,084	15
450	111	736	123	733	0	0	0,000	50

Using such a table, the train behaviour may be changed by reducing its speed in order to be able to brake on time in case of an obstacle is detected (e.g., perceived by the conductor). In this table we suppose that the conductor has a limited visibility (450m) and that the train is approaching a curve. The zone between (73,767) and (123,736) is a zone where rock falls are possible. Since this zone is partially hidden -due to the topology of the area (the curve)-, a conductor may see (according to our simulation) the beginning of this zone only from position (48,780), i.e. at a distance of 280m (even if the visibility is 450m). However, later and once he is at position (60,776), he may see the rock fall zone with the highest risk (level 5) at a longer distance 430m (probably because at this position, the conductor has a better view of the rail track, i.e. no curve). The recommended (maximum allowed) speeds are calculated given the distance between the train and the rock fall zone (e.g., 280m, 430m), the risk level (from 1 to 5), and the terrain grade measured by the *Observer Agents* (in Table 1, grades are positive, which indicates an uphill rail portion. Recommended speeds would have been lower if grades were negative). In Table 1, the risky area, defined in Section 2, is the rail track portion between (48,780) and (111,736) (1st and last rows of Table 1). Beyond this area, the risk level is "0" and the train can have a higher speed (e.g., 50Km/h in the last row of Table 1).

6. TOWARDS REAL TIME RISK ASSESSMENT

The Assessment of risk through the identification of risky areas is achieved using the Train-MAGS platform in the *Pre-execution mode*. Moreover, with advances in computation, telecommunication, and sensing technologies, it is nowadays possible to monitor large spaces and particularly the geologic state of a given portion of the terrain [6].

The next phase of the Train-MAGS project aims at synchronizing the simulation environment with the real world in order to assess risk in *Real-time mode*. To this end, the VGE is synchronously coupled with the real environment [9], which means that the VGE should reflect in real-time what is actually happening in the terrain. Therefore, we suppose that trains are equipped with GPS devices and that specific sensors and actuators are deployed in critical zones to measure certain geologic parameters (which are used to monitor certain geologic parameters that could indicate a potential rock fall) [6]. The *Train Agent* is synchronously linked to the real train and keeps track of its effective moves within the VGE. Each sensor device deployed in the terrain has its representative in the VGE: *Sensor Agent*. *Sensor Agents* are thus in charge of receiving data from the physical sensors which are deployed in areas of interest. In this case they are considered as situated agents who are not really proactive. Nevertheless, *Observer Agents* communicate with these *Sensor Agents* to collect, filter and fuse data, and derive potential risks of rock falls. Hence, the *Observer Agent* that detects a danger notifies the *Train Agents* which are concerned (those which, according to their current geo-referenced positions, are in the vicinity of and heading to this risky zone) by this potential threat. Each *Train Agent* modifies autonomously its behaviour by adjusting its speed when approaching the risky area. This briefly summarized our vision of a real-time risk assessment system for trains.

7. DISCUSSION AND CONCLUSION

Modelling and simulating the train behaviours including the geographic environment, the train's characteristics, the train operator's capabilities (perception and decision making), and the obstacles along the track, is a complex process. Several simulation tools have been developed to simulate train behaviours ranging from the game industry, to the physical dynamics of the train [8, 9] ending with traffic analysis and the performance assessment of the railway traffic [3, 10]. These simulators are generally built using mathematical and statistical models. In general, the complexity of these mathematical models leads to a trade-off between simplicity and accuracy of the model. Increasing the complexity usually improves the fit of a model. However, it can also make the model difficult to understand and to work with, and can also raise computational problems such as numerical instability. For example, when modelling the train's behaviour, we may include different parts and sub-systems of the train (the train, the tracks, etc.) in the model and would thus get a more detailed view of the system. However, the computational cost of adding such a large amount of details would effectively inhibit the usage of such a model. Additionally, the uncertainty would increase as a result of an overly complex system, because each separate part induces some amount of variance in the model. It is therefore usually appropriate to make some approximations to reduce the model to a sensible size. Engineers often can accept some approximations in order to get a simpler model. However, in the context of the identification of risky areas in large scale geographic environment, we need to model and to simulate the train's behaviour as well as its interactions with the spatial environment. Fortunately, the multi-agent geo-simulation approach provides an efficient tool for the simulation of complex systems while taking into account the spatial dimension. This approach gives a particular attention to the specific features of geographic data which can be introduced in the simulation and be accessible for agents. Hence, we used such a multi-agent geosimulation approach to model and to simulate the train behaviour using *spatially aware* agents in order to identify risky areas in large scale geographic environment.

Railway transportation is a complex system that may benefit from artificial intelligence techniques towards the development of 'intelligent transportation systems' [33]. In this paper we showed how certain characteristics of this system may be adequately modelled using autonomous agents and multi-agent systems. The Train-MAGS platform is a proof of concept of the proposed agent-based geosimulation prototyping approach which relies upon the agent's capabilities and the geographic environment built upon reliable GIS data. This simulation tool provides the possibility to build a table of recommended speeds in the surroundings of risky areas. This table may help to inform the train's operator about the vicinity of risky areas along the rail tracks. The Train-MAGS experiment also demonstrates the importance of using realistic GIS data in order to build the VGE as well as the identification of risky areas. We also showed how agent-based geosimulations can contribute to identify risky areas in large scale geographic environments. As a result of this kind of modelling, one could also meet the growing interest in making traffic and transportation more secure, efficient, resource-saving and ecological. Besides, only few research works have been found addressing the effects of weather condition on train behaviours, we still need to analyze train behaviours under various weather conditions. Indeed, the breaking model as well as the *Train Agent*'s perception, navigation, and decision making capabilities are deeply related to such factors. Therefore, we are currently working on the integration of particle systems in order to extend the *Train-MAGS* capabilities to support gaseous phenomena simulation. Such capabilities will allow us to simulate atmospheric phenomenon including heavy rains, fog, and snow.

8. ACKNOWLEDGEMENT

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9. REFERENCES

[1] Gambardella, L. M., Alessandrini, A., and Epifani, C. 2000. "The Use of simulation in the socio-economical evaluation of the management of an intermodal terminal," In Proc. of the Maritime & Industrial Logistics Modelling and Simulation, Portofino, Italy.

[2] Ezzedine, H., Kolskia, C., and Péninou, A. 2004. "Agent-oriented design of human–computer interface: application to supervision of an urban transport network," *Engineering Applications of Artificial Intelligence*, vol. 18(3), pp. 255-270.

[3] Cuppari, A. 1999. "Prototyping Freight Trains Traffic Management Using Multi-Agent Systems," In Proc. of the Proc. of the 1999 International Conference on Information Intelligence and Systems, pp. 646-653.

[4] Sahli, N. and Moulin, B. 2006. "Agent-Based Geo-simulation to Support Human Planning and Spatial Cognition," LNCS, Springer, vol. 3891, pp. 115-132.

[5] TSBC. 2007. "The Transportation Safety Board of Canada," TSB Canada July 2007.

[6] Vařilová, Z. and Zvelebil J., 2005. "Sandstone relief geohazards and their mitigation: rock fall risk management in the Bohemian Switzerland National Park," In Proc. of the Sandstones Landscapes in Europe, FERRANTIA, Luxembourg 25-28 Mai, pp. 53-58.

[7] Malay, A. D. and Lawrence, P. J., 2001. "Simulation modeling at union pacific railroad," in Proc. of the 33nd conference on Winter simulation. Arlington, Virginia, IEEE pp. 1048-1055.

[8] Jeong, D., Perlman, B., and Chris, P. 2006. "Dynamic Simulation of Train Derailments," In Proc. of the International Mechanical Engineering Congress and Exposition, Chicago, IL 5-10 Nov..

[9] Durali, M. and Bahabadi, M. M. J. 2004. "Investigation of train dynamics in passing through curves using a full model," In Rail Conference, Proc. of the 2004 ASME/IEEE Joint, pp. 83-88.

[10] Lewellen M., and Tumay K., 1998. "Network simulation of a major railroad," In Proc. of the 30th conference on Winter simulation, Washington, D.C., United States, IEEE pp. 1135-1138.

[11] Davidsson, P., Holmgren, J., Kyhlbäck, H., Mengistu, D., and Persson, M. 2006. "Applications of Agent Based Simulation," In Proc. of the Multi-Agent-Based Simulation VII, Hakodate, Japan, Springer LNCS 3891, pp. 15-27.

[12] Cuppari, A., Guida, P. L., Martelli, M., Mascardi, V., and Zini, F. 1999. "An Agent Based Prototype for Freight Trains Traffic Management," In Proc. of the FMERail'99 Workshop (satellite event of FM'99), Toulouse, France.

[13] Zhu, K. and Bos, A. 1999. "Agent-based design of intermodal freight transportation systems," In Proc. of the NECTAR Conference, Delft.

[14] Benenson, I. and Torrens, P. 2003. "Geographic Automata Systems: A New Paradigm for Integrating GIS and Geographic Simulation," In Proc. of the GeoComputation conference, pp. 24-30.

[15] Mandl, P. 2000. "GeoSimulation- Experimentieren und Problemlösen mit GIS-Modellen," Angewandte Geographische Informationsverarbeitung XII, pp. 345-356.

[16] Moulin, B., Chaker, W., Perron, J., Pelletier, P., Hogan, J., and Gbei, E. 2003. "MAGS Project: Multi-agent geosimulation and crowd simulation," In Proc. of the COSIT'03 Conference Spatial Information Theory, Ittingen (Switzerland), LNCS 2825 pp. 151-168.

[17] Bousquet, F., Bakam, I., and Proton, H. L. P., C. 1998. "Cormas: Common-Pool Resources and Multi-Agent Systems," LNAI, pp. 826-838.

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