EMPLOYING SOFTWARE MULTI-AGENTS FOR SIMULATING RADIOLOGICAL ACCIDENTS

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Abstract: Through agent based systems we can build scenarios of radiological accidents that enable us to evaluate the consequences of accidental contaminations. The incidental release of radionuclides in an environment might cause the contamination of areas and people. So, it is necessary to make use of tools that allow us to foretell the effects of the exposition of the population and to evaluate the consequences and to suggest measures of protection. In this paper we introduce the use of software multi-agents systems immersed in a geographical representation of the world, as a viable option to simulate radiological accidents and assess doses.

1 INTRODUCTION

Radiological accidents can result in significant radiation exposures of workers and of the public.

These accidents usually occur as a consequence of human activities in military, industry, medicine, agriculture and research, involving the use of radiation and radioactive substances that cause radiation exposure in addition to the natural exposure. Study the impact of radiological accident in society and learn the lessons for the future it is a way to prevent further accidents.

So, planning immediate answers and actions to emergency situations is a critical factor to establish security policies. Simulation models incorporating software agents are one of the tools that can be successfully employed in these tasks. They can mimic the "real world", and the interaction among people, materials and radioactive sources. Through computational simulation of agent-based models, people can perceive, with details, the effect of radioactive contamination in case of accidents, what makes easy the understanding of the risks involved and the damages caused in such situations.

In this article we'll show how to create an environment where software agents simulate radiological accidents. Our agents will have some properties, as: mobility, reactivity and objectivity. People and radioactive sources and elements will be also represented by software agents, In this way, through agent-based simulation, we intend to study, analyse and manage these complex systems (radiological accidents).

Here we use the following definition, of agent (Franklin, Graesser, 1997): "A system situated within a given environment, that senses that environment through its perception mechanism and acts on that environment and/or on other agents, as time flows, in pursuit of its own agenda, plans or beliefs. Eventually the agent´s perception/action mechanism evolves with time".

In this study it is necessary that multi-agent systems can provide a computational platform where the dynamic of spatio-temporal systems can be analysed and the agents can interact ones with others through communication mechanisms (Wooldridge, 2002) .

2 RADIOLOGICAL ACCIDENTS

Radiological accidents are accidents that occur in nuclear or radioactive installations and are characterized by the existence of intense fields of not intentional radiation, not controlled release in the environment of amounts of radioactive material, and involve exposition or contamination of human beings or the environment, being able to cause serious damages or death.

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The incidental release of radionuclides in the environment might cause the contamination of areas and people. So, it is necessary to make use of tools that allow us to foretell the effects of the exposition of the population and to evaluate the consequences and to suggest measures of protection (IAEA, 1996).

First of all, we need to identify the amount of contaminated people, degree or dose of radiation received and a more elaborate map (georeferenced information) from the areas impacted (Agape, 2005).

A radiological accident can affect the public transportation system, generate zones of exclusion in the contaminated areas, leading to the displacement of people, damage the water supply, and overcrowd hospital services, causing serious social problems (Agape, 2005).

For the evaluation of the dose received for individuals it is necessary to take in consideration the release rate of the radioactive source, its exact distance from the exposed individuals, the existence of materials (shield) between the radioactive source and the exposed individuals, and the time of exposition of the individuals. Through the following formulas we can determine the dose:

$$A=A_0e^{\lambda.t} \quad (1)$$

Where: A is the activity of a radioactive source, A_0, is the activity at time t=0, and λ is the constant of disintegration, meaning the rate in which disintegration proceeds.

$$X = \Gamma.A / d^2 \quad (2)$$

Where,
X = exposition rate, in R/h (Roentgen / hour)
A = source activity, in Ci (Curie)
d = distance between the source and the point of measure, in meters.
Γ = a characteristic constant of each radioactive source, also known as factor gamma, in (R.m^2) / (h.Ci)

$$D = X.t \quad (3)$$

Where,
D = absorbed dose, in Gray (Gy)
X = exposition rate, in R/h
t = time, in hours (h)

$$DE = D.FQ \quad (4)$$

Where,
DE = dose equivalent , in Sievert (Sv)
D = absorbed dose, in Gray (Gy)
FQ = quality factor of radiation, for gamma radiation FQ equals 1

3 ARCHITECTURE OF AGENT-BASED SYSTEMS TO SIMULATE RADIOLOGICAL ACCIDENTS

The goal of our agent-based system is to furnish useful information related to a given radiological accident. This class of information is usually related to: i) the quantity of persons that were esposed; ii) the effective dose they received; iii) determination, localization and extension of contaminated areas.

Not always it is possible to determine *who* where the persons exposed, neither their exact number. This would be the case, for example, of a terrorist attack with a radioactive source in the public system of transportation, for example in a train or in a subway. Notwithstanding it is very important for the public health system, to have a estimate of the people involved and of the effective dose they received, in order to calculate the medical resources that will be need to face the problem, to warn the population against the risks of exposure, and also to manage the entire situation, all the risks involved, descontamination procedures, etc.

Our model is based on the formula of radioactive dispersion in the air (equation 2), leading in account the radionuclide and its activity, the distance of the people exposed to the radioactive element, the time of exposition, as well as possible shields. We also consider eventual movements of persons and of radioactive sources. Both of them are represented by very simple agents, People agents suffer the effects of radioactive source agents, based on equation 2, and these effects are registered on the state variables of people agents. Shield effects could, as well, be incorporated into the model.

The source agent has the following state variables: i) The source Id; ii) Its position, given by a tuple of coordinates (x, y, z); iii) Its activity A; iv) The factor Γ for the specific source; v) The quality factor (FQ), a factor used to weight the absorbed dose with regard to its presumed biological effectiveness. A typical agent, representative of a person, has the following state variables: i) Person Id; ii) Its position, given by a tuple of coordinates (x, y, z); iii) Time of exposition; iv) Shield effect; v) The absorbed dose; vi) The effective dose.

In our model we need also a representation for the space, the environment from where our agents take sensory inputs and produce as output actions, that is, their movements. Normally Geographical Information Systems (GIS) use raster or vector structures to represent space in bi-dimensional models. In some cases a third dimension is represented through digital elevation models (dem) of a terrain. Given a GIS spatial representation (a *shape file,* for example), we'll add to it software agents and the structure of a dynamic spatial model, in order to simulate the dynamic of radiological accidents. The GIS spatial representation is the environment or locus, where agents of our Agent-Based Models will operate.

For each specific phenomenon, we are interested, only, in particular information about the environment. So, considering the geographical space where the phenomenon develops, we need to filter only the aspects of the environment we are interested in, that is, the features that will compose the environment as seen by the agents, and where all the process will be simulated. This is not a difficult task, for data is organized on GIS in different layers, such that: utilities, river and lakes, roads and rails, soil maps, land parcels, etc. We need to select only the layers we are interested in. Objects that are not of interest must be discharged, for an environment full of superfluous objects would unnecessary complicate the implementation and reduce the simulation performance. So, depending on the problem, we can simplify considerably the simulation, as we´ll see below in our case study (Farias, Leite, 2005).

4 CASE STUDY: THE RADIOLOGICAL ACCIDENT AT COCHABAMBA, BOLÍVIA

We will take as our case study the radiological accident occurred in Cochabamba, Bolivia, in 2002. This accident was minutely documented and *physicaly reconstructed* by the IAEA (IAEA, 2004), *and the assessment of doses estimated.* So, we have a valuable data to compare with the results of our agent-based simulation and to validate our model.

In April 2002 an accident involving an industrial radiography source containing ^{192}Ir occurred in Cochabamba, Bolivia, some 400 km from the capital, La Paz. The source, in a remote exposure container, remained exposed within a guide tube, although this was not known at the time. The container, the guide tube and other equipment were returned from Cochabamba to the headquarters of the company concerned in La Paz as cargo on a passenger bus. This bus carried a full load of passengers for the journey of about eight hours from Cochabamba to La Paz. The equipment was subsequently collected by company employees and transferred by taxi to their shielded facility. Routine radiation measurements made there established that the source was still exposed and actions were then taken to return the source to its shielded container (IAEA, 2004).

In our case study, due to the source characteristics, the effect of the radiation was relevant only to people situated a few meters from the source, that is, for people inside the bus. If we look at the exposition rate, absorbed dose and dose equivalent (effective dose) formulas, we'll see that all these measures - given a specific source - are dependent only of the relative position between the source and the people exposed and of the time of exposition. So, in this very special case, it doesn't matter the path followed by the source in its journey from Cochabamba to La Paz. Assuming that all passengers, after entering the bus, didn't change their seats, what is relevant to assess doses is: i) the distance between each passenger and the radioactive source that remained fix during the entire journey; ii) the exposure time.

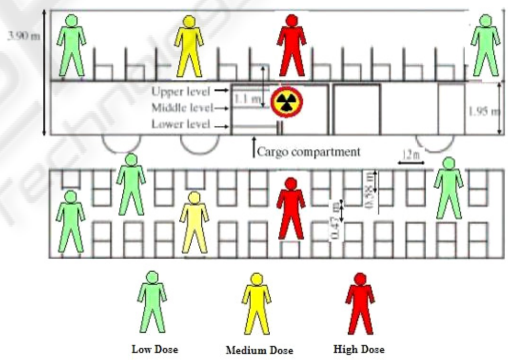

Figure 1: Bus passenger.

Figure 1. shows the relative distance between the passengers and the source, as well a classification of doses received.

"The time frame of the exposures of the bus passengers is reasonably well defined. For most of the passengers on the bus that day, this is an eight-hour period from 16:00 to 24:00. There are some variations on this; for example, the duration would have been 30 minutes shorter for those passengers picked up at Quilacollo and it would have been longer for those passengers from Cochabamba who spend some time on the bus before it departed. Also some time would have been spent off the bus during a meal stop" (IAEA, 2004).

In our Agent-Based simulation we employed essentially the same formula (equation 2) for doses estimation. However, we summed 14 cm to the seat heights, for the whole body dose may be better represented at an eight of about one third of the way up the torso (see table 1).

The received dose (d) for the passengers, after reconstruction of the dose and technical analysis conducted by an IAEA technical mission, was calculated between a minimum 10mGy (~DE = 10mSv) to a 190 maximum mGy (~DE = 190 mSv) for 8 hours of the bus trip (See table 2). The dose received annually for the worldwide population due to natural radiation is calculated in 1,12 mSv/year and in the case of a source of ^{192}Ir, it is necessary only 4 seconds of exposure to surpass the limit of annual dose (1,12mSv/year).

As we can see from tables 1 and 2, the simulation gave us upper limits for doses absorbed, basically for not considering shield effects.

Table 1: Ranges of estimated doses (Gy) to the bus passengers by Software Agent Simulation.

Seat number	High Dose (Agent simulation)
1–4	0.02
5–6	0.03
7–10	0.04
11–14	0.07
15–18	0.13
19–22	0.31
23–26	0.85
27–30	1.08
31–34	1.00
35–38	0.40
39–42	0.16
43–46	0.09
47–50	0.05
51–55	0.03

Table 2: Ranges of estimated doses (Gy) to the bus passengers based on the dose reconstruction performed by the IAEA team (IAEA, 2004).

Seat number	Upper	Lower
1–6	0.010	0.001
7-10	0.015	0.002
11-14	0.025	0.005
15-18	0.040	0.010
19-22	0.070	0.020
23-26	0.160	0.040
27-30	0.190	0.050
31-34	0.160	0.040
35-38	0.070	0.020
39-42	0.040	0.010
43-46	0.025	0.005
47-50	0.015	0.002
51-55	0.010	0.001

5 CONCLUSIONS

Trough this case study we could have a first idea of the magnitude of the radiological accident and its impact.

Simulating the number of people contaminated by agent-based systems we can estimate the absorbed doses, its spatial distribution and possible physical consequences by the effect of the radiation.

The researcher can simulate a non-natural radioactive dispersion, building an environment, in a delimited area, where he can find parameters for analysing and studying the phenomenon.

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