Multi-agent Simulations in Decision Support: Specifics of the Biological Incident Management

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Abstract: - Dealing with complexity and limited cognitive skills of human decision-makers during management of biological incidents represent a research challenge. Several models have been already developed, based on various principles such as partial differential equations or Markov chains. Multi-agent technologies have been used for modeling of different types of systems for several years. The paper presents model utilizable for the management of biological incidents created in the NetLogo environment. Its main contribution to the scientific field consists of characterization of specifics related to a certain type of decision-making process. Also, in the paper model description is provided, parameterization is explained, and areas for further research are depicted.

Key-Words: - biological incident, decision support, epidemiology, multi-agent technologies, NetLogo, simulation

1 Introduction

The management of biological incidents represents the unstructured problem. For the purposes of its resolution, a vast amount of various real data must be considered. The determination of the appropriate combination of available reactions and suitable countermeasures should be supported by the data describing both the environment, where the incident proceeds, and the biological agent, which has spread within the environment. Therefore, it represents a noticeable potential for scientific research. This should provide for example with the answer to a question how to ensure the qualified decision support in certain situations which would enable relevant output acquisition applicable in practice.

Nevertheless, the problem complexity is not the only reason. Another motivation to examine this realm is the fact that such decisions are crucial, because they influence human lives. Moreover, these are performed by humans who are not absolutely reliable. Therefore, it is suitable to support the reliability by the employment of appropriate modern technologies. The ability to find the scenarios describing the incident development and their simulation represents a particular area which deserves attention. These can ensure better resource planning and their more effective utilization. Likewise, they guarantee faster response to the certain incident and higher accuracy and adequacy of particular steps of countermeasures during the incident management process. At the general level, the decision making process during the biological incident management can be divided into the under-mentioned phases. After the identification of the incident and its description, it is necessary to create the scenarios of its further development. The set of countermeasures which will be realized in practice must be determined after the choice of the most pessimistic, most optimistic and most probable scenario. The entire system for the decision support based on the simulation of the biological incident should comprise the following parts:

1) module for the description of the emerging incident,
2) module for the creation of potential scenarios of further development,
3) module for the support of countermeasures selection.

Therefore, the paper aims to describe the second module, the subsystem supporting the scenario creation, and to propose the appropriate technology utilizable for these purposes.

2 Simulation as a Scientific Method

The simulation represents the examination of characteristics and behavior of a particular system on the basis of the experiments realized on the mathematical model of this system [8]. Similarly to other scientific methods, the simulation utilizes explicitly given presumptions. It does not aim to prove their validity, but it focuses on data generation on the basis of the accurate rules. Even from the essential presumptions, the unexpected results might arise.

According to [2], there is a mutual relation among the simulation, induction and deduction. While the induction serves the general knowledge revelation from the specific particularities (for example the description of new relations discovered on the basis of the empirical data collected from the questionnaire survey), the deduction leads to the certain conclusion derivation on the basis of general knowledge (for example new statements about a particular case based on the given presumptions and valid axioms). Likewise the deduction, the simulation is based on the set of explicitly given presumptions which however do not lead to the verification of the certain conclusions. Within this context, the simulation results primarily in generation of data which are suitable for further analysis by the induction method. It is crucial that this process of such data generation follows accurate rules. Therefore, the data acquired by the simulation are absolutely different than the data collected and consecutively processed by the induction method.

During the biological incident management, the induction method is utilizable only to a limited extent. It can be employed in the phase focused on the prevention of potential problems. In case of existing problems it is necessary to utilize the simulation which eliminates the problem complexity due to the previously created model (for example by induction method). Moreover, also the demands on the decision maker decrease noticeably. Furthermore, the scenario development enables better preparation for the incident consequences thanks to the modeling of real situation development according to the given parameters. Evidently, it is thus easier to plan the utilization of the technical, human, time as well as financial resources more effectively. Biological incidents can be characterized as high open and at least high dynamic environments which include the uncertainty. Therefore, the application of multi-agent approach is worthy [8]. Such attitude ensures:

- the reduction in time necessary for the solution (thanks to the possibility of parallel and asynchronous procedures),
- the elimination of demands on the communication (specialized agents solve their assignments and deliver the results of their actions among themselves),
- the higher flexibility (the possibility to maintain the count of team agents),
- the higher reliability (everyone is replaceable, the loss of one member does not threaten the operation of the whole system),
- lower costs regarding the fact that each component (agent) is simpler and therefore cheaper than the whole system [12].

Among the advantages of the model utilization the following can be mentioned [8]:

- emergency capture - behavior which are not revealed by the local examination because these are not intuitive and predictable
- common tool for the investigation of the systems of a certain type - for example the modeling of emergency exits location in a building
- flexibility - the possibility to model the moving entities, define their relations and networks, etc.

The model utilization is naturally linked with particular disadvantages which follow:

- the model is created for a special purpose and with a specific level of detail - therefore, both these facts must be correctly interpreted
- modeling of irrational behavior, subjective viewpoints and complex systems is always difficult
- some variables are not quantifiable
- the created models cannot be verified, etc.

3 Simulation Prototype of Biological Incident Development

The simulation prototype of biological incident development can be perceived as an important part of the entire system for scenario creation. On the basis of created model, it is possible to simulate the agent spread within the environment. The aim of the simulation is the evaluation of the incident impact on the population and the appropriate focus and suitable coordination of preventive countermeasures and eventually rescue works. It is important to notify that the prototype described within this paper serves the purposes of technology verification and demonstration of its functionality. The input to the simulation is the subset of parameters defined in the table of information availability created by research

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team. Generally, these embrace domain knowledge about the certain agent and the up-to-date data about the environment. The domain knowledge is derived from the elaborated ontology which was created on the basis of semi-structured interviews with domain experts from fields of biology, medicine and epidemiology. The outputs of simulation are values of particular parameters in a certain time.

3.1 NetLogo Model

The model utilized for the biological incident simulation is based on the multi-agent technology [5]. This technology was chosen regarding the character of the biochemical incident where a lot of various factors with defined attributes and specific intended behavior emerge. Thus, the interaction of autonomous agents occurs within the defined environment. Therefore, such modeling enables to deal with the complexity of the progress of the particular incident management.

For the purposes of the described model and regarding its realization, the NetLogo environment which can be downloaded for free is used [10]. Moreover, the system requirements are not demanding. The NetLogo environment allows the observation of natural and social phenomena as well as the modeling of complex systems which develop over time. Additionally, the NetLogo environment provides with the library of pre-defined models which enable the simulation of pre-set situations from various areas (for example biology, mathematics, chemistry, system dynamics or computer science). Therefore, the environment offers the introduction of its options and functions to the users. Another advantage is the environment interactivity and flexibility which allows the input parameters setting as well as their adjustment. During the model creation, three basic types of elements are available - these are buttons, switchers and sliders. The user interface offers also the utilization of extensive dictionary of built-in constructs and mathematical operations [8]. Furthermore, various output formats can be selected. A range of quite a few extensions is also available. These include for example the addition of sound, the access to MySQL databases or the connection to Geographic Information System.

Considering the purpose of the simulation, which is to verify the technology and demonstrate the required functionality, the selected environment is adequate and sufficient. Nevertheless, for more complex and complicated simulations it would be more suitable to utilize an advanced environment. Java Agent DEvelopment Framework is mentioned as an example [6].

3.2 Model Description

The prototype is primarily focused on the simulation of the spread of the agent transmissible through the air and its impact on the population. The basic agent classification corresponds to this fact. The agents are divided to these representing the population and the second group describes the contaminated cloud.
The entire model uses with a few layers. The first layer represents the environment within which the simulation proceeds. The second layer embodies the people considered for the model purposes. In addition to the initialization of people's characteristics (see code below), the rules determining their random movement within the environment are set.

```
to setup-people
  set-default-shape people "person"
  create-people people-count
    [ setxy random-xcor random-ycor
      set color blue
      set sick-count 0
      set immune? false
      set sick? false
      set will-survive true
      set size 10

       ]
  end
```

The people are divided into two groups. In the situation of the model initialization, only healthy persons are present. During the simulation progress, some healthy people become infected. In case of death, the particular person disappears from the simulation. This model of behavior described in discussed model is adapted according to the model called 'Virus' which is available in the Biology section in the Models Library of the NetLogo environment [10]. The people impacted by the contaminated cloud are infected regarding to the level of infectability. The infectability is highest at incident location and decreases gradually with the distance. The level of the infectability is determined by the distance from the incident location and the spread intensity.

As mentioned above, within the simulation there are also agents representing the particles of the contaminated cloud. The spread of a certain agent is characterized by particular parameters which comprise two interlinked phases. The initial phase represents the cloud expansion when its size grows according to the spread intensity (see code below). For the description of the cloud spread, the color differentiation is utilized. It demonstrates the infectability intensity expressed by the various color tones of red where denser tone represents higher intensity. The cloud is divided into two parts, the inside and the edge, where only the edge spreads. Progressively, the cloud moves according to the wind direction and its consecutive dispersion. Simultaneously, the number of infected and dead people increases according to the fatality of given agent or eventually according to the probability of the transmission from one person to another. The coloring of the cells (Environment Agents) proceeds in the wind direction. Nevertheless, this process runs only in case of cells in the neighborhood of already colored ones. Each time unit during the spread period, a cell in angle from -45 to +45 degrees is randomly chosen and colored.

```
to spread-cloud
   ifelse ( current-spread-period > 0)
  [
    ask cloud-line
    [
        if(random-float 100) < spread-
        intensity
        [ ;;ask neighbors with [(count
        turtles-here) = 0]
          ;; [ infect ]
          let angle 90
          repeat 3 [
              ask  patch-left-and-ahead
              angle 1 [
          if (count turtles-here) = 0
              [ spread ]]
              ask patch-right-and-ahead
              angle 1 [
          if (count turtles-here) = 0
              [ spread ]]
          set angle angle - 45
          ]
      ]
      set breed cloud-inner
    ]
  ]
  [ask cloud-line [die]]
end
```

Within the second phase, the diffusion process prevails. The progressive spread of the harmful agent is observable. This process is logically separated also in the code (see the description of this phase below). Nevertheless, during both phases the cloud moves according to the given wind speed and wind direction.

```
to diffuse
  ask cloud-inner
      [ if   (random-float   10000)   <
        age
        [ set pcolor green
          die ] ]
end
```

The exemplification of a prototype describing the agents' spread is illustrated on the pictures in the Figure 1.

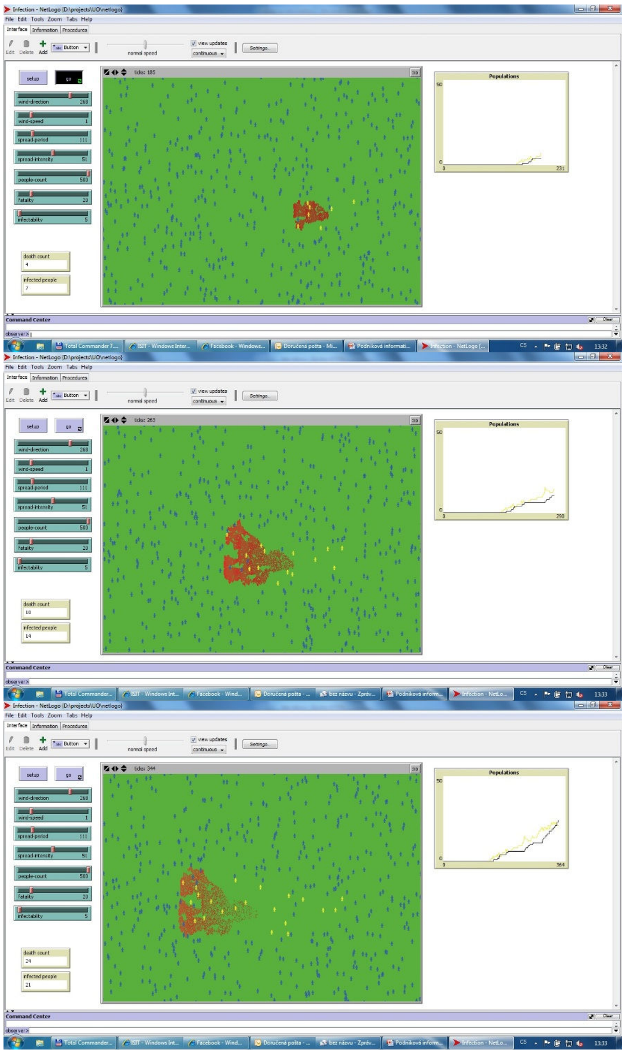

Fig.1: Agent-based scenario development (authors' research)

3.3 Parameterization

The parameters represent the input values of the simulation model. Therefore, especially because of the model accuracy and reliability, it is important to pay attention to these parameters and unambiguously determine them. NetLogo offers the input parameters' amendment according to the user's needs and thereby provides with the option to observe the agent behavior as well as environment

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changes under various conditions. The number of both parameters and autonomous agents is not practically limited.

For the purposes of the discussed simulation, the parameters fatality, infectability and the way of transmission from one person to another are considered. Particular values of these parameters depend on the chosen agent. These are acquired from the modeled domain knowledge in subsystem modeling the incident. This knowledge is adopted from the Biological and Chemical Agent Characteristics [3] compiled on the basis of data from the Committee on Toxicology [4] and U.S. Department of the Army [14]. Moreover, the population size can be chosen. Within the described model, the population size can be selected from 0 to 500. Such extent is sufficient for the illustrative purposes of the simulation. Higher population size unnecessarily increases the demands on the computational complexity and proportionally decreases the simulation speed. This problem might be eliminated by the employment of various methods (for example Parallel Computing [11]). Furthermore, the characteristics of the environment can be adjusted. These noticeably influence the agents' spread. Especially, the influence of weather and climate conditions in the impacted area is considered. Within the depicted model, the parameters relating to wind are reflected because of the fact that the mentioned agent is transmissible through the air.

For this particular simulation the following parameters are used. These can have under-mentioned values.

- Wind Direction: 0-360 degrees
- Wind Speed: 0-10 points per time unit
- Spread Period: 0-500 time units of the simulation; time period of the cloud spread during the simulation
- Spread Intensity: probability of the infection spread within the cloud further into the environment (the edge of the cloud)
- People Count: 0-500
- Fatality: probability of death of an infected person; such person disappears from the screen after death
- Infectability: probability that the cloud infect a person.

4 Further Research

The further research covers a lot various areas. First, the discussed model itself can be furthered and developed. Second, the connection of the model to other applications is possible. As an example, the objects influencing the wind direction or movement of defined population can be inserted or maps can be connected to the current model [7].

Further precision and specification of the simulation can be reached through the employment of the suitable epidemiological models of agent spread - for example see [1], [9], [13]. Moreover, the real data can be added, eventually utilized for more accurate illustration of the actual situation. Such data and information can be acquired from relevant sources. Among others, demographic data, strategic documents or medical and epidemiological systems are mentioned. Likewise, the inclusion of more parameters describing the environment especially in terms of weather conditions should be considered due to the importance of their influence on the agent spread. These data and information are available in various hydro-meteorological institutes.

Generally, it is possible to extend the amount and the details of the input parameters. However, this possibility is connected with higher demands on both the user who input the data and their availability as well as format. The entire model can be consequently more accurate, but also less clear and comprehensible. Therefore, this fact should be taken into account since the begging of the model creation. Moreover, the parameters should be optimized according to the purpose of the model and the needs of its users. Prospectively, the prioritization of the selected input parameters can be considered because of the fact that each parameter in the model bears different level of reliability during the incident modeling and each parameter is diversely important for the incident development.

5 Conclusion

Biological incidents remain an unstructured and very complex issue. Considering the sophistication of potential aggressors, the increasing value of impacted assets and growing demands on humans who make decision under pressure with limited resources and cognitive skills, the readiness for the biological incident management needs to be supported. This paper confirms that the computer-based scenario simulations, if correctly managed and interpreted, represent a useful tool for decision support during such situations. Therefore, the discussed multi-agent based technology can be recommended and employed to improve the impact elimination, resource planning or future preparedness for similar incidents.

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