Simulating Future Crisis Scenarios with Multi-Agent Systems

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ABSTRACT

In order to reduce the impact of bad situations as well as getting the most of profiting periods, it is vital to research in the field of methods, techniques and tools that allow us to simulate and foresee the future. Although this problem is common to any area, an urgent solution is required to those with critical social repercussions. Fields like national security, demography or economy are examples of areas in which prospective techniques are applicable.
Technical prediction, with procedures like Prediction or Projection, is very common but in most cases not very efficient. It is not usual to find a critical social system which evolves according to predictable guidelines. For instance, the collapse of transports, economic crisis, natural disasters or terrorist attacks are examples of scenarios of crisis difficult to estimate with techniques of Prediction and Projection.
This paper presents a solution to model human expert's opinion with the aim of simulating possible future scenarios. Our approach consists of obtaining an applicable technology which enables us to be aware of possible crisis scenarios before they actually materialize, allowing us to analyse them and come up with appropriate risk mitigation strategies.
This paper includes the description of a specific methodology to elaborate the opinion of human experts by using fuzzy logic and the development of multi-agent systems (MAS) to automate the creation of such scenarios.
The method and tools are being validated with a real case study by the Spanish Institute for Strategic Studies (Ministry of Defence).

ABOUT THE AUTHORS

José Miguel Castillo is the Director of the Information Systems Division at the 'European Virtual Engineering' EUVE Tech. Center. In 2001, he earned his PhD in Telecommunications from the Universidad Politécnica in Madrid. The same year he was awarded with the 'General Fernández Chicarro' prize by the Spanish Ministry of Defence for his work on operations research. In 2007, he obtained his PhD in Computer Science from the Universidad Rey Juan Carlos in Madrid. In June 2007, he was awarded with the prize on research by the Spanish Ministry of Defence. In the same year he received a prize for his research on crisis prevention by the Spanish Sub-directorate of Civil protection and Emergencies. His educational and professional background includes military studies at the Military Academy in Zaragoza, where he graduated in the year 1985 with the rank of lieutenant. After twenty seven years of service in the Army, he passed to the reserve situation with the rank of lieutenant colonel. Currently, he is associate professor at the 'Universidad Pontificia de Salamanca' in Madrid (Spain). His main areas of interest are: Simulation and Applied Artificial Intelligence. He is the author or co-author of three books and almost fifty articles in his areas of interest.

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Brigadier General **Miguel Angel Ballesteros** was appointed as Director of the Spanish Institute for Strategic Studies on April 2009, coming from the Superior Center of Studies of Defense (CESEDEN) as the Head of Strategy and International Relations Directorate of the Superior School of the Armed Forces (ESFAS) in Madrid Spain.
Besides his military qualifications, the General holds a Bachelor in Operational Research by the University of Valencia, he made diverse courses in Paris and Toulouse (France) related to the recognition satellites (System Helios) and obtained a Diploma of Advanced Studies from the "Pontifical University of Salamanca – Faculty of Political Science and Sociology Leon XIII".
During his military career he commanded several artillery units, he was working in the division of Intelligence of the Spanish Joint Staff, he was the first head of the Spanish Center of satellites and head of the development equipment in the multinational Program HELIUMS and was titular professor in the Spanish CESEDEN where he became head of Directorate.
The Director of the IEEE is a fellow professor in the Pontifical University of Salamanca in Madrid from 1994.

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OVERVIEW

This paper presents a solution to model human expert's opinion with the aim of generating future and possible scenarios. Although the problem of foreseeing the future is common to any area, an urgent solution is required to those with critical social repercussions. Fields like national security, demography or economy are examples of areas in which Prospective techniques are applicable.

The goal of our current research is to obtain an applicable technology which enables us to be aware of possible critical scenarios before they actually materialize, allowing us to analyse them and come up with appropriate risk mitigation strategies. The project includes the application of a specific methodology [5] to foresee possible future scenarios of crisis based on the opinion of human experts and the development of multi-agent systems (MAS) [13] to automate the creation of such scenarios.

Getting results in this field will enable the achievement of a new technology, and also a suitable methodology for the development of automated environments for the prevention of scenarios of crisis.

FORESEEING THE FUTURE

Before facing a future scenario, the first and fundamental phase is to foresee it. It is better to be prepared for future scenarios rather than suffer their consequences. After figuring out the possible future scenario of crisis, the second phase consists of analyzing all elements or factors which should be modified in order to avoid the scenario to materialize.

The scenarios of crisis are mainly created inside a social environment. A social environment evolves as a dynamic system, with phases of stability, instability, or even worse, of a chaotic nature.

The creation of future scenarios based on stable dynamic systems uses technical prediction techniques in which tendencies of historical data are applied. However, inside the field of security it is hard to meet a stable dynamic system which generates scenarios based on predictable guidelines. The collapse of transports, economic crisis, natural disasters and terrorist attacks are just a few of many examples of scenarios of crisis which are difficult to estimate with techniques based upon Prediction and Projection. Normally, the scenarios of crisis are born due to an accumulation of events that would otherwise be ineffective in isolation; however when occurring together they create an unsustainable and critical scenario.

In our every day lives there are many events, from domestic economy, incidence of criminality, social integration, to radical terrorist attacks. All these events belong to a specific scenario in which we are involved. We can study the future as the development of past and present events through the time.

The objective of strategic planning initially consists of analysing the events that have a direct influence over the entire scenario. For example, the scenario that occurred on Sept. 11th was the result of a determined number of events.

From a conceptual point of view, our research is going to be developed under Prospective proceedings (instead of technical prediction techniques like Prediction and Projection). The final aim is to develop a technology which is able to identify and alert on the generation of possible social scenarios of risk or crisis.

PROSPECTIVE: A POWERFUL TOOL

Nowadays, the current use of Prospective is more related to the field of social sciences. Prospective tries to create an image of the future, reducing the consideration of the past, but never actually forgetting it. The prospective methods which correspond to an imaginative and intuitive exploration of the future, lie on structural premises based on the past but open constantly to changes [8]. The opinion of groups of experts is used for the creation of future scenarios. The classical prospective method consists of [3]:

-Submission of a questionnaire to the expert group to grade the probability of each event.

-Achievement of the common criterion of the group by using the Delphi method.

-Use of the cross impact technique to modify the conditional probability of each event.

-Elaboration of the cross impact technique to obtain the most probable scenarios.

-Analysis and interpretation of the most probable scenarios.

Initially, a group of analysts select the area of study and identify a list of possible events related to a future scenario.

After studying the events that are linked to a scenario, a human expert group has to research the influence each event has on the others. This enables a more thorough study in terms of probabilities. The Delphi method (Dalkey [6]) is used to bring the group to a common conclusion. Hence, we are referring to conditional probabilities the Bayes theorem has to be taken into account and the isolated probabilities for each event have to be adjusted. After weighing probabilities, analysts have to produce a set of scenarios with their consequent probabilities. Those scenarios with higher probability will be chosen for a detailed sensitive analysis.

We can follow a similar process in analysing different contexts, like those related to banking, commerce, military operations, industry, disruptive technologies, security, etc. After the application of the method we obtain a matrix with future scenarios graded by their probabilities. The following figure shows an example of a matrix with ten possible scenarios. In the first column the events that can be involved in the scenario are listed. In the bottom line the probability for such scenarios to happen is given.

Ev	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8	Sc 9	Sc1 0
1										
2										
3										
4										
5										
6										
7										
8										
Prob	6.77	3.22	2.87	2.79	2.78	2.55	2.21	2.20	2.13	1.44

Cells in grey: the event doesn't exit

Figure 1. Example of a matrix with probable scenarios

IMPROVING PROSPECTIVE CLASSICAL METHODS WITH AI.

There are some critics to the classical prospective method that we have to take into account before facing a new development in the field of multi-agent systems. These critics are the following:

- Each expert has to describe his opinion in terms of probability. The probability is a way to express relative variables for comparison that are repeated in the past. Regarding a future scenario based on different and non-related variables, the use of probability does not seem to be the most accurate procedure.
- The Delphi method usually leads the group to a common response. Experts are some times conditioned to the evolution of the group response.
- Adjusting conditional probabilities due to the Bayes theorem is not widely accepted by the expert group.
- Many times it is difficult to decide which is the most probable scenario, since the difference among many of them is insignificance in terms of probabilities.
- The method doesn't include an analysis or the critical events that have major influence on the scenario.

Our aim consists of giving a solution by using a MAS-oriented architecture, that achieves the same objectives as classical prospective method pursuits, but avoiding the problems mentioned in the above paragraphs.

ELICITING EXPERTS' INFORMATION

One of the key points of the process is to establish the method to elicit the information from each member of the expert group.

In order to extract the information from the expert group and with the intention of developing a MAS as a new solution, we suggest to follow the following steps:

- To select the expert group. The number of experts depends on the problem and the level of expertise they have. Usually a number of experts between 10 and 15 is accepted. If they actually are experts, to add more members to the group would produce redundant information.
- To generate a set of questionnaires comprising the whole field of different future scenarios.
- The experts will answer the questionnaires by using specific adjectives from the natural language instead of probabilities.
- Most likely each expert will have a particular view about the proposed scenario. Consequently, there will be different opinions inside the group of experts. From a technical point of view, the aim is to elicit the information from each expert and to develop a knowledge module able to give a response about future scenarios like the group of experts as a whole.
- Analysis of the most possible future scenario produced by the MAS as a result of the information given by the group of experts.
- Study and identification of the events that have a major influence in creating the scenario.

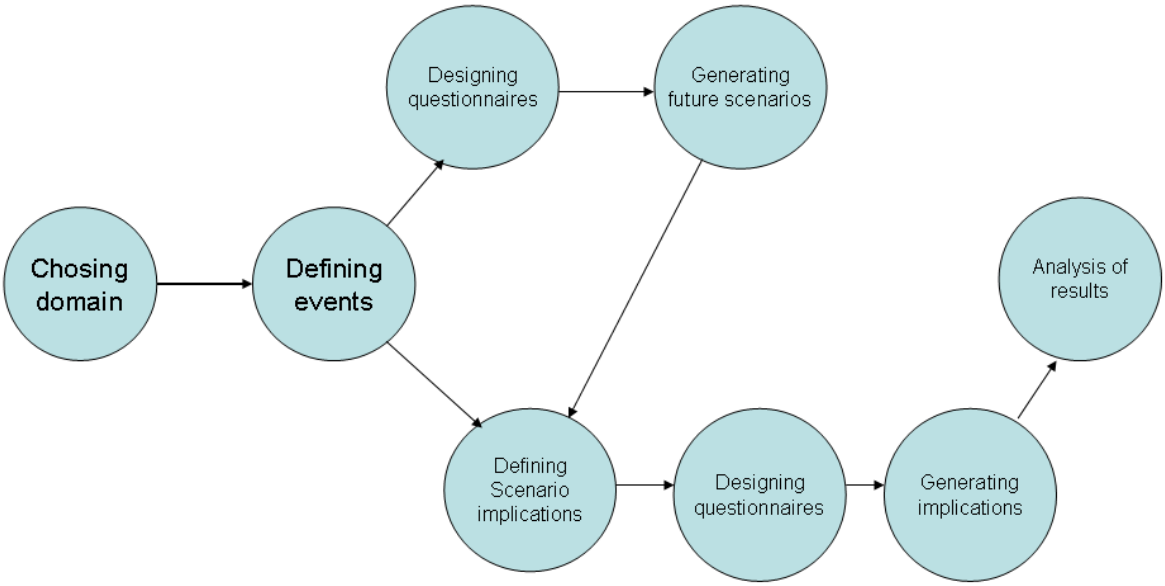

Figure 2. Map of processes

The objective of the prospective study can be simple, only to know the most possible scenario; or complex, to avoid or to confirm its creation.

Figure 2 shows the map of processes when applying an AI solution. The chart has two different branches, the upper one indicates how to get the most possible scenario, as the lower one expresses how to analyse it.

MODELLING FUTURE SCENARIOS. A TECHNICAL APPROACH

In this section, we illustrate our Multi-Agent System approach within this class of domains. The objective consists of the construction of a model that faces the problem of modelling future scenarios from a different perspective from the classical statistical prospective methods. We use possibilities graded by linguistic tags instead of probabilities, we take a different track towards the problem compared to classical methods.

Methodology steps

We present a methodology [5] that permits to solve a wide range of planning problems. In general, we can assume that the way in which we apply the method depends on a thorough analysis of the results obtained at each step. In certain circumstances, it is necessary to go back to previous states if the desired results are not obtained at a specific step.

From a technical point of view to get to a solution with MAS, we have implemented the methodology, as follows:

Statement of the Problem

Our purpose is to construct a planning system based on MAS, with capacity to generate future scenarios by using prospective methods. Thus, this new approach helps us overcome the limitations and criticism pertinent to the classical Prospective technique [10].

Establishing the System Limits

An expert group will be in charge of defining the events that belong to a specific scenario. By applying fuzzy logic procedures, linguistic tags can be defined in order to identify each event's intensity. The system will yield a scenario as a result of such events.

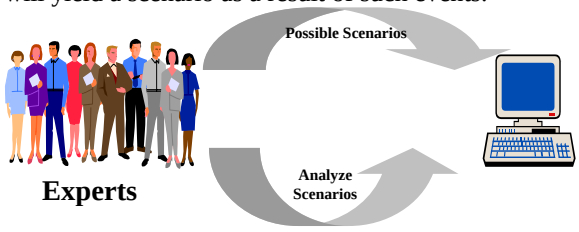

Figure 3. Knowledge extraction

Objectives Identification

The objectives that we are pursuing are summarised as follows:

-To provide a scenario as a result of the set of events and their intensities as given by the expert group.

-To perform a sensitive analysis in order to determine which events can have a major influence on the scenario and how to obtain an ideal scenario by changing as few events as possible.

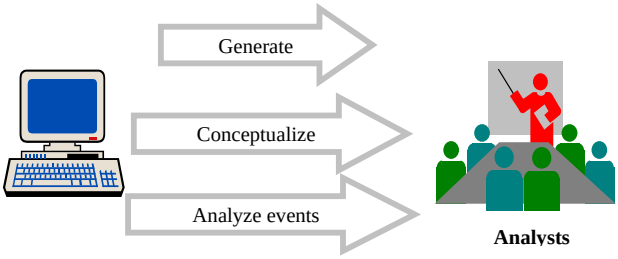

Figure 4. Knowledge exploitation

Data identification

The input of our planning system will be the set of events for a specific situation. These events will be graded for their relevance. The input will be provided by a group of strategic analysts.

The output of our planning system will be the global description of a scenario composed by several items and their corresponding relevancies. They will be defined by using linguistic tag variables [17].

Initially the output that matches a specific set of events will also be defined by the group of analysts.

The user could define an ideal scenario by modifying the relevance of the scenario items. The planning system will respond with a list of possible solutions by describing the events to be modified.

Rules Identification

We can identify two main processes in this model:

-Matching events and their relevancies to scenarios defined by items and their intensities.

-Prospecting the range of possible events we can modify in order to obtain the ideal scenario.

Selection of Agents

We have used a neuro-fuzzy network [9] [17] aimed at reproducing human knowledge and experience in order to create a scenario by studying the influence among events. Thus, we talk about possibilities instead of probabilities and avoid using complex probabilistic techniques which are in most cases unclear for the human expert group.

We have implemented an intelligent search to make the sensitive analysis of variables (events) that can help us to arrive at an ideal scenario.

Model Building

We have built two agents in the MAS-oriented model: the Classifier agent and the Analyser agent. *The first one* will obtain the scenario after analysing the proposed events.

Each agent of the MAS has been developed to carry out a specific function; all of them are based on Artificial Intelligence procedures [12] [14].

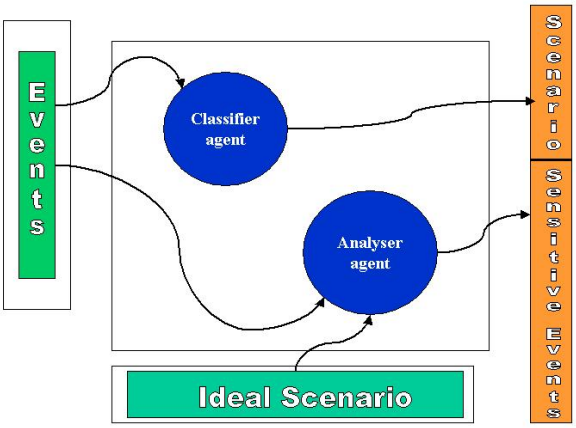

Figure 5. Strategic Planning Model

The knowledge extracted from the expert group will be used to train the Classifier Agent. Once the Classifier Agent has been trained, it can be used to generate new scenarios by presenting it with a set of events never used in the training phase. Thus, the knowledge of the expert group has been transferred to the Multi-agent System (MAS).

It has been necessary to develop the classifier agent by means of fuzzy logic, since most of the times we express data in terms of adjectives. It is very common to define the relevance of the events or objectives in terms of linguistic tags. In this environment, Fuzzy Logic [15] provides a set of powerful tools.

The *second agent* is useful in determining which events can be influenced by us in order to arrive to the desired scenario. It is possible that the scenario doesn't match our expectations. In this case, the Analyser Agent is responsible for looking for the events which are to be influenced in order to get closer to an ideal scenario.

We have used intelligent search as an Artificial Intelligence procedure to construct the Analyser Agent.

In Figure 5, we can observe the inputs to the model, the Agents we have designed to build the model, and the results we can obtain after its use. The model can be used for two purposes: to obtain a scenario as a result of the events, or to present an ideal scenario and look for the events that we have to influence in order to obtain such scenario.

In summary, the Classifier Agent receives the events and yields a scenario, while the Analyser Agent receives an ideal scenario and the original set of events and provides the list of events to be modified in order to obtain the ideal scenario.

CASE STUDY 1: THE IMPACT OF MIGRATIONS IN EUROPE

As a result of the application of the MAS-oriented model, we have developed a software prototype to validate the model in a real prospective problem. The prototype can be used to accomplish three different objectives: to produce the most possible scenarios, to foresee the result of a specific scenario, and finally to analyse which events should be modified to get an ideal scenario.

As an example, we are going to solve a strategic planning problem that deals with the future migratory movement in central Europe. The events and scenarios are fictitious. We want to know the possible influence of a set of events to create a political and social scenario.

The events are:

1-Higher restriction to obtain the nationality in the EC
2-Eastern Europe countries are accepted in the EC
3-Racial riots happen in European Cities
4-Worldwide financial crisis
5-Negative birth rate in Europe
6-Strong epidemic in Africa
7-European measures to support African economies
8-Economic instability in Russia

As a result of this study we can get the following:

-Set of the most possible scenarios.

-Consequences of the most possible scenarios regarding two general variables: intensity of migrations and level of social stability.

-Introduction of an ideal scenario.

-Events that should be influenced or modified to obtain the ideal scenario.

A group of strategic analysts have created a set of ten questionnaires to be studied by the expert group, who have to qualify them with adjectives like 'Very possible, Possible, Not possible'.

Ev	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8	Sc 9	Sc1 0
1										
2										
3										
4										
5										
6										
7										
8										
VP,P,NP										

Cells in grey: the event doesn't exit

Figure 6. Possible events questionnaire

The answers from the expert group are treated with fuzzy logic procedures. The extracted knowledge is fed into the Classifier Agents. The software prototype is ready to be used. It yields the list of the most possible scenarios. The prototype found a total of 49 highly possible scenarios that can be displayed or printed.

The group of strategic analysts has to decide whether to choose all of them or whether to choose only the most relevant. The group decides that the scenario in which all events are present has to be analysed in depth (Sc1).

The analysts submit a new questionnaire to the expert group with ten possible scenarios. They will grade the possible results in terms of intensity of migrations and level of social stability.

Ev	Sc1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8	Sc 9	Sc1 0
1	H	M	L	H	H	H	M	M	L	L
2	H	H	H	L	M	M	H	M	H	H
3	H	H	M	H	M	M	M	H	L	H
4	H	H	H	H	M	M	L	H	L	H
5	H	B	H	L	H	M	M	M	H	L
6	H	H	L	H	M	L	M	H	M	L
7	H	H	H	H	H	M	H	M	M	H
8	H	H	H	H	M	L	L	H	L	H
Migration										
S. Stabili										

H=High; M=Medium; L=Low

Figure 7. Possible scenario questionnaire

The answer of the expert group is treated with fuzzy logic procedures, and again the extracted knowledge is forwarded to the Classifier Agents.

Once the events that belong to the scenario are defined, the group of strategic analysts presents one situation which is the most possible or perhaps the one which will result in the worst case scenario. Inputs are introduced in the prototype.

Eventos	Influencia
Higher restriction to obtain the nationality in the EC	Medium
Eastern Europe countries are accepted in EC	High
Racial riots happen in European Cities	High
Worldwide financial crisis	High
Negative birth rate in Europe	Low
Strong epidemic in Africa	High
European measures to support African economies	High
Economic instability in Russia	High

Figure 8. Possible events

The classifier agent will produce a global scenario definition in terms of intensity of migrations and level of social stability.

Escenas	Intensidad
INTENSITY OF MIGRATIONS	Medium
LEVEL OF SOCIAL STABILITY	Low

Figure 9. Expected scenario

The group of strategic analysts decides that it is dangerous to permit the creation of a social

environment with a low level of social stability, so they introduce an ideal scenario with the intention of knowing the events that should be modified.

Escenas	Intensidad
INTENSITY OF MIGRATIONS	Medium
LEVEL OF SOCIAL STABILITY	Medium

Figure 10. Ideal scenario

The prototype has generated a great number of solutions in a short period of time. The solutions are sorted and listed according to the number of events to be modified.

	Descripción del evento a modificar.	Grado de Influencia.
Solución..1...		
	Strong epidemic in Africa	Low
Solución..2...		
	Higher restriction to obtain the nationality in the EC	Low
	Negative birth rate in Europe	High
Solución..3...		
	Higher restriction to obtain the nationality in the EC	Low
	Negative birth rate in Europe	Medium
Solución..4...		
	Higher restriction to obtain the nationality in the EC	High
	Strong epidemic in Africa	Low

Figure 11. Events to modify

In summary, given a specific set of events that are considered as most possible, we have obtained a scenario in which social stability is low. To get a medium level of social stability we should act according to one of the solutions generated (e.g. to reduce the possibility of 'a strong epidemic in Africa').

CASE STUDY 2: THE FUTURE OF THE EC POLICY OF SECURITY AND DEFENCE

In this section we present a current work that is being developed by the Spanish Institute of Strategic Studies and the 'European Virtual Engineering' Tech. Center.
The objective is to foresee the future of the European Policy of Security and Defense under the horizon of the year 2020. The project is still in progress. The initial processes have been completed, such as the definition of the domain, the creation of questionnaires and the consultation to the expert group. Currently, we are working on the technical part of the project by analyzing the information extracted from the experts and constructing the knowledge module. Before the end of year 2010, we will finish the project by presenting the most possible future scenario and its implications, paying special attention to those events that can be critical or the special importance to facilitate or to hinder the scenario creation.

Defining the domain

A group of analysts from the Spanish Institute of Strategic Studies chose the domain in which we should develop a prospective study. In this particular case, the objective consists of envisioning the future of the European Policy of Security and Defense in the year 2020.

Defining events

The same group of analysts with the assistance of a group of technical experts from EUVE defined the general events that are related to the domain. We chose the list of events paying special attention to their independence among them. A number of seven events were identified and are listed below:
Event 1: The public opinions of the member states press its governments for a major development of the PCSD.
Event 2: the structures are rationalized to promote the planning and execution of the missions of the PCSD, with an integrated employment of the civil and military capacities.
Event 3: a change takes place in the architecture of euro Atlantic security as consequence of a redefinition of the roles of the NATO and EU, and a change in the position of key actors as the USA and Russia.
Event 4: The PESC develops of coherent form in accordance with the instruments foreseen in the Lisbon Treaty.
Event 5: The European Council decides for unanimity to implement a common European defense, in the terms established in the article 27.2 of the Lisbon Treaty.
Event 6: The Capabilities Headline Goals (military and civilian), which are established by the EU to substitute those of 2010, are accomplished.
Event 7: The EC constitutes a number of forces adequately trained and equipped, and ready to be used by flexibility in crisis management.

Designing questionnaires

Once the domain and the events were defined, EUVE designed the questionnaires to be answer by the expert group. The number of questionnaires cannot be numerous and have to represent the whole range of possible scenarios.
The group of experts was chosen by the Institute of Strategic Studies. A number of fourteen experts on international policy were selected.
In order to facilitate the knowledge extraction process a website was develop for the experts to answer on-line the questionnaires (www.escenariosprospectiva.info).

Figure 12. Website of the prospective exercise

Generating future scenarios

After having studied the whole set of questionnaires, a number of fifty nine rules have been indentified as the main elements to be treated as part of the multi-agent system. Namely, these fifty nine rules will be the core of the classifier agent. Currently, this task is still in process.

Figure 13. Rules generated by the experts

As describe in figure 2, the upper part of the map of processes is about to be completed. There are two tasks left to complete: the identification of the most possible scenario and the validation of the whole process.

Shortly, we are going to start with the lower part of the 'Map of processes' to study the implications of the most possible scenario and the analysis of factors to support the creation of the scenario or to prevent it from happening.

PREVENTING CRISIS SCENARIOS IN SECURITY

The technology presented in this paper is applicable to any field; especially in those that prevention plays an important role. That is the case of security in which when preventing a crisis or undesired scenario is crucial to avoid negative or fatal repercussions.

By treating adequately the opinion of human experts groups, it is possible to envision critical or undesired scenarios in the field of security. For example, this technology could be applied to detect emerging scenarios of terrorism in which different social events are involved.

Combining this technology with others like pattern recognition, tracing human groups' behaviour or analysis of tendencies most of the prevention activities in the field of security would be covered.

We are available to collaborate with any research group or governmental institution to validate the result of this research work for preventing future scenarios in the field of security.

RELATED WORKS

The problem that we address consists of the construction of agent-based models to solve a specific operational problem such as foreseeing future undesired social scenarios. We tackle this problem with a methodological approach, with the aim of preventing undesired future scenarios from happening.

Consequently, the two main fields that are related to this paper are:

- Simulation with MAS-oriented architectures
- Prospective planning methods

The concept of agent generation is not new and has been addressed in many publications such as in [11], [16] and [7]. Agents have to be constructed under a specific objective. There are many papers related to methodologies in this field; however, most of them are targeted at obtaining efficient communication among agents as in [1], [2] and [4]. This paper tackles the specific construction of MAS-oriented models to solve strategic planning problems in the field of security.

Prospective is a well-known technique based on statistical methods, as described in [8] and [3]. In this work a new solution is given on the basis of a MAS-oriented architecture. The model is built by using a methodological approach [5].

FUTURE WORKS

In order to validate the architecture and new approach showed in this paper, in 2010 we are developing some prospective studies together with the Spanish Institute of Strategic Studies. The initial scenario on which we are working is:

- Future scenarios for the Policy of Security and Defence in the European Union

The final result of this work will be published at the end of 2010.

We are also planning to work on the following subjects:

- The strategic and political future of Afghanistan
- The future of the North Atlantic Treaty Organization

We are also preparing a large scale European Project under the FP7 (Framework Programme 7) to validate the concept of MAS-oriented architectures for prospecting in field of security.

CONCLUSION

In this paper we have presented the idea of applying Prospective as a useful tool to envisage future and possible scenarios of crisis or risk. We have illustrated the use of Prospective in domains where crucial decisions need to be taken.

One of the most important advantages that this work can offer is the possibility of foreseeing future scenarios with computer aided control based on a MAS-oriented architecture. This characteristic implies the automatic reorganization in real time if the scenario changes or new biased events show up unexpectedly as time goes by.

Furthermore, by comparing our work with classical methods, we found the following advantages:

- A natural use of linguistic tags instead of probability to define the possibility or intensity of events.
- The achievement of a common criterion of the expert group without using the Delphi method.
- The study of the future scenario implications through an analysis of the events that should be modified in order to obtain an ideal scenario.

Finally, we have illustrated the application of this technology with two examples. The first one related to the impact of migrations in Europe and the second one deals with the future of the policy of defence and security in Europe.

ACKNOWLEDGMENT

We really thank the Spanish Ministry of Science and Innovation to support partially the project under grants PID-520100-2009-1, TIN2009-13839-C03-02 and CSD2007-0022, and the General Directorate of Armament and Materiel of the Spanish Ministry of Defense. Without their support we would never have started this project.

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