Modelling Human Behaviour at Work using Fuzzy Logic: The Challenge of Work Teams Configuration

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Abstract

One of the first steps in the planning of a new engineering project in industry is its partition into subtasks and the configuration of a work team to execute it. This decision making process is typically performed by a project manager based on his/her past experience and the available (though frequently scarce, uncertain and dynamic) information about the cognitive and personal characteristics of the available team members. This paper presents our first results in the development of a knowledge-based tool that aims to help project managers in their decision-making process. Software agents are used to model social human behaviour at work, where human characteristics are represented by a set of fuzzy values, and fuzzy rules model the interaction between the agents to generate the possible performance of a work team. As a first validation step, a comparison of the results predicted by our model with the performance of an engineering team in a real industrial project is made.

1. Introduction

The correct selection of people to integrate a work team in order to execute an industrial project is not a trivial task because it must account not only for technical competence and availability aspects, but also for the personal and social characteristics of each potential team member. Often, a good working environment depends on the personal characteristics of each worker. They are even more important in a project, where the interaction and communication between team members are fundamental for the achievement of the final objective. In addition to social factors, emotions play a critical role in rational decision-making, perception, human interaction, and human intelligence [20].

Since one of the goals of Artificial Intelligence is to design and implement systems that simulate human intelligent behaviour, we propose that some of its techniques can be very useful to support the configuration of work teams. More specifically, we think that the Multi-Agent Systems (MAS) could help to simulate human behaviour within a team given their capability to account for characteristics such as autonomy, co-ordination and communication [23].

We have proposed an agent-based model to simulate the interaction of a team member with other team members and with the tasks of a project [13]. In our model, we propose that each software agent represents a real person by configuring a set of relevant human characteristics at work within each agent. Several simulations can then be run with the hypothetical team to get estimates of the team performance in charge of a specific project.

The model we are proposing uses fuzzy logic to represents the agent internal characteristics and some of the project characteristics. This paper focuses on these fuzzy characteristics and on how the team behaviour can be modelled from the agents and project characteristics also using fuzzy logic. In Section 2 we describe the set of human characteristics that we consider important when a person is at work. Section 3 presents a brief review of others approaches that use fuzzy logic to model human behaviour. Section 4 presents the fuzzy values used for our agents and those used to represent some characteristics of the tasks in a project. In Section 6 we describe how the human behaviour at work can be modelled through fuzzy rules. Finally section 7 presents a case study where an initial validation of our proposed model was done by comparing its results with those obtained from a real work team within an industrial environment.

2. Modelling Human Capabilities at Work

Modelling human behaviour is a great challenge due to "human nature", i.e. humans are unstable, unpredictable and capable of independent action. The performance of individuals will fluctuate depending not only on their ability, training and education, but also on their physiological and psychological states and traits [9]. However, models and techniques are emerging within the military or social science domains that clearly indicate that some useful modelling of human performance is possible [21].

Three main challenges in capturing complex patterns of human behaviour in agent-based simulations have been identified in [11]:

(a) humans are not limited to one identity or any common set of emotions;
(b) humans are not limited to acting in accordance with predetermined rules;
(c) humans are not limited to acting on local patterns.

At first sight, such challenges look daunting. Clearly, it is difficult to consider all scales of human awareness simultaneously, instead it is possible to choose one circle of influence when devising mental models to represent human behaviour in a specific context. Furthermore, on further reflection these challenges may not be critical for simulating certain social collectives [2].

We propose that it is possible to simulate part of the human behaviour in the context of a work team in charge of a specific project. The first step to achieve this team behaviour simulation is to identify the set of relevant human characteristics that we consider affect the performance of a person in this specific context. They can be grouped into cognitive capabilities, personality trends, emotional states and social characteristics.

Cognitive Capabilities. Human cognitive capabilities involve several brain processes such as learning and memory among others. Modelling these brain processes and their interactions to generate an intelligent behaviour has been one of the main goals of Artificial Intelligence but it is out of the scope of this research. Nevertheless, in our model, the cognitive capabilities of a person were defined as his/her degree of expertise in a particular domain. Thus, to represent the technical knowledge of a person within a team, a set of six cognitive classes was set: *Project Manager*, *Co-ordinator*, *Specialist*

Sr., *Specialist Jr.*, *Technician* and *Assistant*. In addition, every team member has two other independent parameters: *experience level* and *creativity level*.

Personality Trends. We have taken into account two different psychological approaches to identify the personality trends that influence the behaviour of a person when performing his/her work. The first approach is based on the CLEAVER technique, used to identify the predominant personality trend of a person [5]. The CLEAVER technique is applied to the candidates through several questions about his/her likely actions in front of different work situations. The result of this questionnaire is a numerical value between 1 and 99 for each of the following personality trend parameters (DISC):
Drive –leadership; capability to achieve results, overcome challenges and display high initiative.
Influence –capability to interact with people and motivate them to improve their behaviour.
Steadiness –capability to follow routine and continuous activities without large variations in behaviour.
Compliance –capability to execute work following established rules and procedures.

The other approach is from Schubert [3]. Schubert proposes four general personality trends that may influence behaviour of a person: *Amiable*, *Driver*, *Expressive* and *Analytical*. These four personality trends are closely related to the CLEAVER trend parameters: *Drive – Driver, Influence – Expressive, Steadiness – Amiable,* and *Compliance – Analytical*. We therefore consider that the parameter with the highest value from among the CLEAVER parameters defines the Schubert personality type.

Emotional State. From the large set of basic emotions [18], we select a small set of four basic emotions to model the agents' emotional state at work. Two of them are positive emotions and the other two have a negative influence over performance:

- **Positive emotions:** *Desire* and *interest* of a person to execute a specific task in a given moment.
- **Negative emotions:** *Disgust* and *anxiety* generated by a specific task in a given moment.

In addition to these four basic emotions, we also consider the *stress* parameter as part of the internal state of the agents. The stress is not an emotion, but its influence over the performance of a worker is recognised in several studies [4, 22]. In our model, the difference between the basic emotions and the stress parameter is given when the behaviour of the agent is generated.

Social Characteristics. Human relations are important to achieve a good communication and co-ordination among the group members. In a work team in particular, an environment with good human relations is crucial to achieve common goals. The modelling and analysis of human relations within groups and teams (such as competitiveness, trust, co-operation, etc.) is the main goal of several research areas such as social psychology, social sciences and organisational behaviour. Inclusion of all these characteristics within our model is out of the scope of this research. Nevertheless, we consider a small set of social characteristics (in a similar fashion to the set of basic emotions) to influence the agents' behaviour. The following social characteristics are considered in each of the agents: *Introverted/Extroverted* and *Prefers to work alone/Prefers to work in a team.*

Once the characteristics that affect performance at work are identified, the next step is to determine how to model the interaction between the internal characteristics of the different team members for the generation of overall behaviour. The following section explains our proposal to confront this challenge through the use of fuzzy logic.

3. Fuzzy Logic to Model Human Behaviour

Once we have related specific parameters to each of the internal characteristics of a person, the following step is to decide how these characteristics will be represented and measured. All the characteristics are closely linked together, so they need to be combined to model the global behaviour of a person. Our goal was to build a simulation tool in which we would be able to:

- Modify the parameters (i.e. change their value within a given range).
- Combine parameters.
- Measure and evaluate the effects that one parameter has over the others.

The behaviour of a person, i.e. the simulation of his/her performance within the project individually and as a team member, is generated by the combination of all the previously mentioned characteristics. It is difficult to accept that a numerical value could be used to measure the intensity of either human emotion, experience or creativity level. However, we frequently use qualitative attributes to describe properties of human moods, features and emotions. Expressions as "she is *very* experienced", "you seem a *little* tired", "I feel *less* stressful today" are commonly used. Following this fact, we believe that it is more natural and intuitive to associate qualitative values to the person's internal parameters. We can talk in terms of *low, medium* and *high* values. For example, we can say that a person has a *high level of experience*, *low level of stress*, a *medium desire* to develop his/her task, *high level of creativity*, etc.

It is possible to express the intensity of the above mentioned parameters through the use of *Fuzzy Logic* [24]. In classical logic a statement is either true or false. This principle of *truth* or *falsehood* was formulated by Aristotle some 2000 years ago as the Law of the Excluded Middle, and has dominated mathematical logic ever since until the first half of the XX century. The idea that things must be either *true* or *false* is in many cases uncertain. Is the statement "my child is good", completely true or completely false? Probably neither. How about "I am rich"? Or "she is beautiful"? The idea of *gradations of truth* is familiar to every one. Fuzzy logic offers a more flexible way of representing reality. In fuzzy logic, a statement is true to various degrees, ranging from completely true through half-true to completely false.

Fuzzy Logic has been used in several applications for diverse purposes, typically in control devices [26], and in other research areas such as pattern recognition [19, 25] and social complexity [1, 6]. In recent years a growing interest in the use of fuzzy logic to model some characteristics of human behaviour has emerged. In [8], fuzzy logic is used to model emotions that can be implemented into intelligent agents. This model uses fuzzy logic to map events and observations to the agent emotional state.

Fuzzy logic models have been applied to mobile robots. In [16], fuzzy logic is used to extend the capabilities related to behaviour-based systems. The main goal of this research was to design a unified control architecture able to combine the interesting properties associated to "intelligence", such as reactivity, planning, deliberation and motivation. Another work is presented in [7], where a fuzzy emotional agent for decision-making in a mobile robot is described. The model deals with three negative emotions: fear, pain and anger.

These models of agents with fuzzy logic, also known as *fuzzy agents,* have been applied to human behaviour simulation. According to [10], fuzzy agents are agents that can perform qualitative uncertainty reasoning with *incomplete and fuzzy knowledge* in some environment that contains linguistic variables. In [17], neural fuzzy agents are presented for profile learning and adaptive object matching. Another interesting work is presented in [10], where fuzzy agents with dynamic personality for the simulation of human behaviour are described. In this research, fuzzy sets are defined for personality traits and facets and the resulting representation of personality is processed through fuzzy logic.

In the following two sections we present how we employ fuzzy logic to model the human characteristics at work described in Section 2. We use fuzzy agents to simulate a set of plausible global behaviours of a team of real people at work. We have built a software simulation prototype as a support tool for the configuration of work teams in charge of a specific project [14].

4. Identification of the Fuzzy Parameters

The first step in the use fuzzy logic within our model is to identify the parameters that will be *fuzzified* and to determine their respective range of values. An intuitive but helpful idea of set in mathematics is simply a collection of things. Things either belong to the set or not, similarly to the idea in logic that statements are either true or false. In 1965, Lotfi Zadeh [24] proposed the idea of a *fuzzy set*, where objects can belong to the set with different *degrees of membership.*

Fuzzy sets (FS) are used to parameterise the main aspects in modelling human behaviour at work:

1. **Agent internal characteristics.** Every internal characteristic of the agents (see Section 2) is represented by a fuzzy parameter value.
2. **Tasks.** FS are used to represent the project task parameters: *difficulty* and *type* (two of the eleven task parameters).
3. **Agent performance.** The result of an agent performance is represented by a set of fuzzy parameters associated to that agent.
4. **Modelling human behaviour.** FS are used to model the interaction between the agent's internal parameters with the task and team-mates parameters. The final result of this interaction is the value for each performance parameter.

We now describe in more detail each of these aspects of the model.

4.1. Internal characteristics

Each internal characteristic is fuzzified by using a Gaussian-shaped membership function for its corresponding fuzzy set. For the *emotion, cognitive* and *social* characteristics, three *intensity fuzzy sets* were defined. The range of values for these fuzzy sets is from 0 to 100. The first fuzzy value represents a *low_intensity* and covers a range of values from 0 to 35. The second fuzzy value ranges from 25 to 75 and represents a *medium_intensity.* Finally, the third fuzzy value ranges from 65 to 100 and represents a *high_intensity* for each parameter, see Figure 1. The ranges of values, as well as the shape of the fuzzy curves were set empirically, but can be changed by the user as described in Section 6.

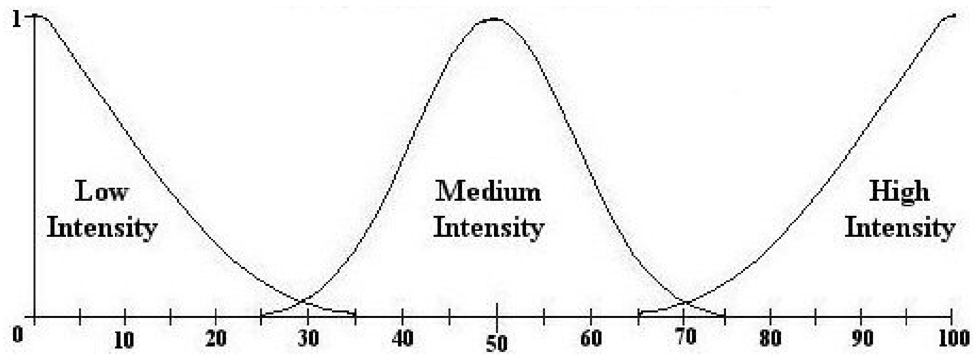


Figure 1. Fuzzy set values for emotional, cognitive and social parameters.

The range of values for the *stress* parameter is a little different: a heavier weight is set up to the stress parameter than to the basic emotions, as we believe that the stress has a greater effect over a person performance at work. Thus, the *low, medium* and *high intensity* fuzzy set for this parameter has, respectively, a range of values from 0 to 25, 20 to 80, and 65 to 100.

Despite the fact that the CLEAVER questionnaire (used to get the personality trends values) output is a set of numerical values [5], fuzzy sets were also used for the CLEAVER parameters due to the implementation of fuzzy rules for the modelling of human behaviour. Fuzzy rules facilitate the combination and measurement of all the internal parameters of a person. The fuzzy sets for each CLEAVER parameter have the same range of values from 0 to 100. The fuzzy set for a *low_intensity* ranges from 0 to 40, the *medium_intensity* set ranges from 20 to 80, and finally, *high_intensity* ranges from 60 to 100. This last fuzzy value corresponds to the dominant personality associated with each personality trend.

In addition, we have defined *increase/decrease fuzzy sets* for the emotion intensity, calculated as a result of firing behaviour rules through the simulation process. The range of values for these sets is from -30 to 30. The *high_decrease* set ranges from -30 to -15, the *low_decrease* set ranges from -20 to 0, the *stay_equal* set ranges from -10 to 10. The *low_increase* set ranges from 0 to 20, and finally, the *high_increase* set ranges from 15 to 30, see Figure 2.

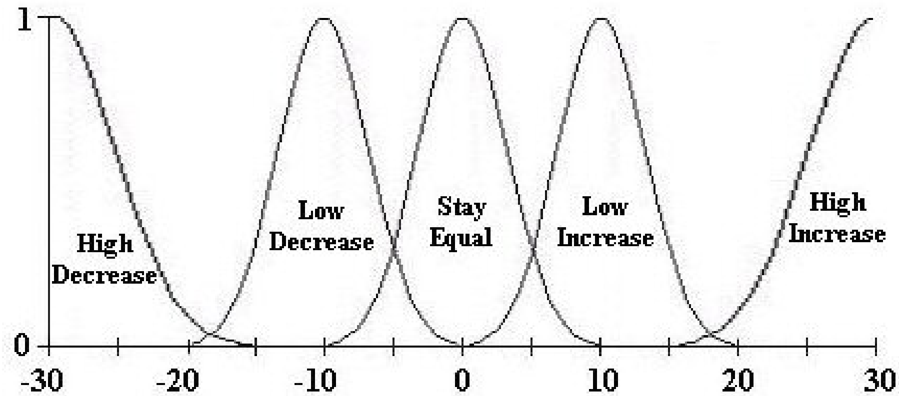


Figure 2. Fuzzy sets used to increase / decrease the emotional and stress intensity.

We can obtain the crisp value corresponding to a set of fuzzy values by applying equation 1.1 to obtain the *centre of gravity (COG)* [12]. Through the simulation process the crisp values of the *increase/decrease fuzzy values* are added to the crisp values of the *intensity fuzzy values* for the corresponding emotion according to the triggered rules. The result of this addition is then fuzzified to get the new emotional state of the agent (using the *emotional intensity fuzzy sets*). This process will be detailed in Section 5.

$$u^{crisp} = \frac{\sum_i b_i \int \mu_{(i)}}{\sum_i \int \mu_{(i)}} \quad \text{eq. (1.1)}$$

In equation 1.1 u^{crisp} is the defuzzified value; b_i denotes the centre of the membership function, and $\int \mu_{(i)}$ denotes the area under the membership function $\mu_{(i)}$.

4.2. Task parameters

The behaviour of the work team is modelled through the interaction between the team members and their assigned project tasks. The tasks of the project must be also modelled for this reason. We have modelled the tasks by setting values to 11 selected parameters:

1. Number of participants in the task.
2. Estimated duration (measured in days).
3. Sequence (sequential or in parallel).
4. Priority within the project.
5. Deadline.
6. Cost.
7. Quality.
8. Application domain.
9. Task description
10. *Difficulty.*
11. *Type (required specialisation level)*.

The last two parameters are fuzzy parameters. The *Type* parameter represents the required specialisation level to achieve the task. For both parameters, the fuzzy values range from 0 to 100 divided into 3 fuzzy sets: *low_(type/difficulty)* ranges from 0 to 35, *medium_(type/difficulty)* from 25 to 75, and *high_(type/difficulty)* from 65 to 100. The fuzzy graph is similar to the intensity fuzzy sets depicted in Figure 1. These fuzzy task parameters will be used to generate the agent behaviour by firing fuzzy rules (Section 5).

4.3 Agent performance parameters

The agent performance at work is evaluated by analysing his/her capability to perform the assigned task as well as his/her interaction with the rest of team members: both, the ability in performing a task and the personal social skills affect the team performance. The next parameters have been proposed to assess the agent performance at work:

1. Goals achievement.
2. Timeliness.
3. Quality of the performed task.
4. Team collaboration level.
5. Individual contribution level.
6. Required supervision level.

These six parameters were taken from the formats used by project leaders of the Mexican Institute of Petroleum (IMP), the institution that provided the case study (see Section 6*)*. The project leader fills this performance format for each team member in the project. In our model, the fuzzy sets for the corresponding parameters use the same Gaussian-shaped membership function in each fuzzy set. For the member performance parameters the values range from 0 to 100, divided into five fuzzy sets: *very_low* (0 - 30), *low* (25 - 65), *minimum* (45 - 75), *acceptable* (65 - 95) and *satisfactory* (90 - 100), see Figure 3.

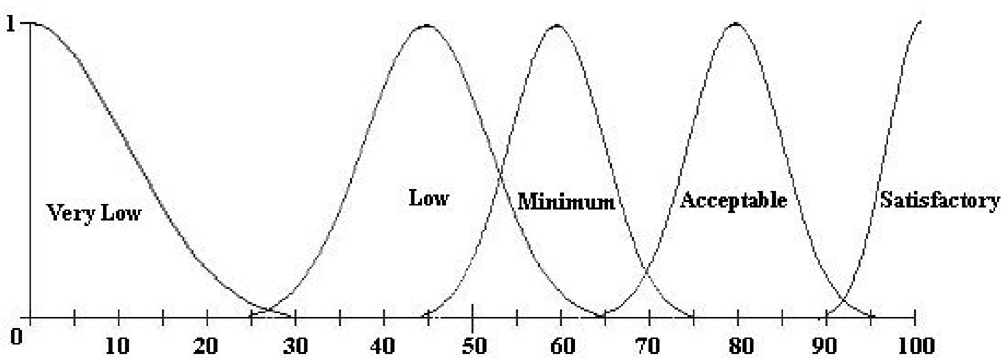


Figure 3. Fuzzy sets used to represent the person performance.

The *timeliness* parameter is defined with a different range of values from –30 to 30 with the following fuzzy values: *excellent* (–30 to -10)*, high* (–15 to 0)*, acceptable* (–5 to 5)*, regular* (0 to 15) and *low* (10 to 30). These fuzzy values allow us to set a *delay* or *advance* value for the tasks done by the team. Thus, negative values mean that a task is ahead of time whereas positive values represent delays. All these values are configurable as different projects require different parameters to measure their quality. Given the same value for a parameter its fuzzy values may be different, what is acceptable for a project may be disastrous for another.

4.4 Fuzzy sets to model human behaviour

Fuzzy rules are used to simulate how the project participant might perform in a particular situation. Fuzzy rules require as input fuzzy values that represent the agent internal characteristics and some of the task parameters. When the rules are triggered, the parameters that evaluate the agent performance over his/her assigned task are modified (see Section 4.3). The values that modify these agent performance parameters are also fuzzy values.

The fuzzy values that modify the timeliness parameters when the corresponding fuzzy rules are fired range from –20 to 20 (see Figure 4) with the following fuzzy values: *high_advance(* from –20 to –5), *medium_advance(from* –10 to 0), *normal (from* –5 to 5), *medium_delay* (0 to10) and *high_delay (5 to 20).*

Take as example the agent A1 in charge of task T1. When a fuzzy rule is triggered and one of these fuzzy values has been asserted, then a crisp value is obtained by defuzzifying that fuzzy value. As a consequence, the crisp value is added to the *estimated duration* parameter of T1. The result of this sum is fuzzified in each of the five fuzzy sets presented in Section 4.3. This is the result of the performance of A1 with respect to T1 in terms of the *timeliness* parameter.

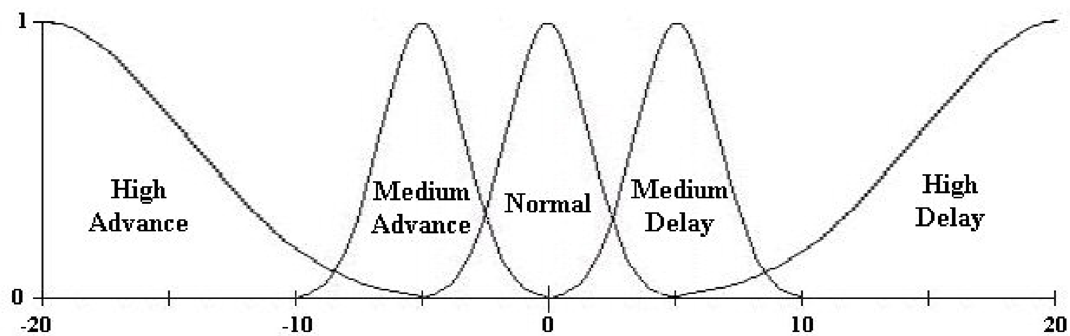


Figure 4. Fuzzy sets used for the advance / delay of the timeliness parameter.

Similar fuzzy sets are defined for the other team member performance parameters (goals achievement, quality of the assigned task, team collaboration level, individual contribution level and required supervision level) and the same method is applied to modify their values. The fuzzy set for each parameter has the same range of -50 and 50: *high_decrease* (-50 to -25); *low_decrease* (-30 to 0); *normal* (-15 to 15); *low_increase* (0 to 30) and *high_increase* (25 to 50).

When all these values are defuzzified, the calculated crisp values are added to the corresponding parameters. In every simulation, when the fuzzy rules are triggered the value of each parameter can increase or decrease. At the end of all simulations each agent has values for each of its performance parameters with respect to each assigned task. The resulting performance of each agent is measured by all these values, and a plausible global team performance can be gleaned by studying the performance of all the agents involved in the project.

5. Fuzzy Rules for Modelling the Human Behaviour

Once the fuzzy parameters have been identified and defined, the next step is to build the fuzzy rules required to simulate the agent behaviour. This process is described in the three steps shown in Figure 5.

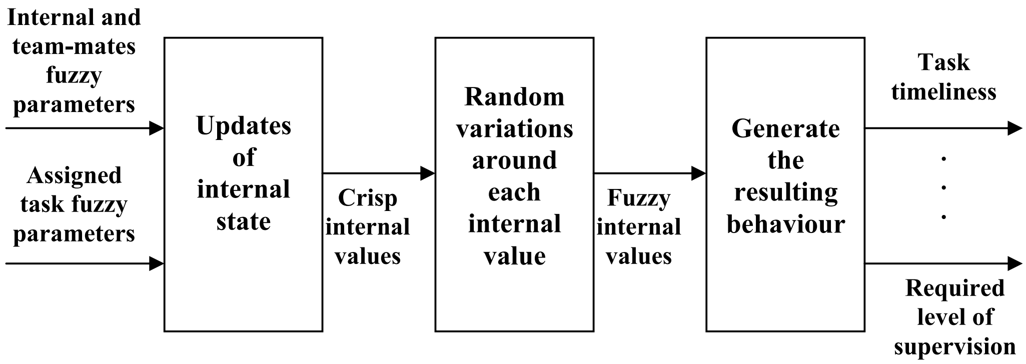


Figure 5. Agent behaviour generation process.

Three sets of fuzzy rules are involved in this process:

1. *Fuzzy rules to modify the agent internal state.* Emotion and stress parameters are modified by the interactions with the assigned task and the team-mates internal state.
2. *Fuzzy rules to generate the agent performance.* The performance of an agent is calculated by assessing its emotional state and personality trends.
3. *Fuzzy rules to update the agent internal state.* When a team member finishes his/her assigned task, a result of this behaviour is generated. This result is used to update the emotional state and the stress parameters of the agent.

5.1 Modifying the internal state of the agent

In our model the project manager selects, according to his/her own experience, an initial set of possible team members; assigns the tasks to each team member, and then, the process of simulation starts.

The first step in the generation of an agent's behaviour is the setting of its emotion and stress values taking into account the internal state of its team-mates and the characteristics of its assigned task. Table 1 shows the internal and external factors that influence the initial emotional state of an agent.

External Factors: assigned tasks and team-mates
Advance/delay of the assigned task
Task difficulty
Task specialisation level
Team-mates internal characteristics
Internal Factors: personal characteristics
Cognitive: experience level and role within the team (i.e. project manager, co-ordinator, specialist Sr., specialist Jr., technician and assistant).
Social: (introverted/extroverted, prefers to work alone/prefers to work in a team).
Personality trends (CLEAVER): drive, influence, steadiness and compliance.

Table 1. Internal and external factors that affect the initial emotional state of an agent

In this research work we assume that all the team members have a *medium* intensity value in all the emotions at the beginning of the simulation. This means that the initial emotional state of each team member is in a *neutral state* until the simulation process begins. According to the values of both, the internal and external factors, the corresponding fuzzy rules are triggered, and as a result the intensities of the agent's emotions and stress are modified –and reflected in the parameter changes. Each emotion and stress modification is induced according to the fuzzy sets described in Section 4.1. Examples of these fuzzy rules (paraphrased in English) are shown below:

Given the agent A1 in charge of task T1,

IF T1 presents a *high_delay* AND A1 has a *driver* personality with *high_intensity* THEN
The *desire* emotion will have a *high_increase*
The *interest* emotion will have a *high_increase*
The *disgust* emotion wills *stay_equal*
The *anxiety* emotion will have a *low_increase*
The *stress* will have a *low_increase*

IF A1 is *introverted* AND in T1 must interact with other people THEN
The *desire* emotion will have *high_decrease*
The *interest* emotion will have a *low_decrease*
The *disgust* emotion will have a *high_increase*
The *anxiety* emotion will have a *low_increase*
The *stress* will have a *low_increase*
…

For rule matching we use the Mamdani fuzzy rule-based model to represent the minimum operator "AND" in the premise, and the implication [12].

When all fuzzy rules are triggered the result of the emotion and stress changes are defuzzified. Then, random variations on each of the agent emotional parameters are introduced. The introduction of random variation intends to account for the non-deterministic nature of human behaviour. Random variations generate different results for each simulation even if the same team is working on the same project. We generate these random variations using a normal distribution curve (see Figure 6). After the application of random variations all emotion and stress parameters are fuzzified to set the new emotional state of the agent.

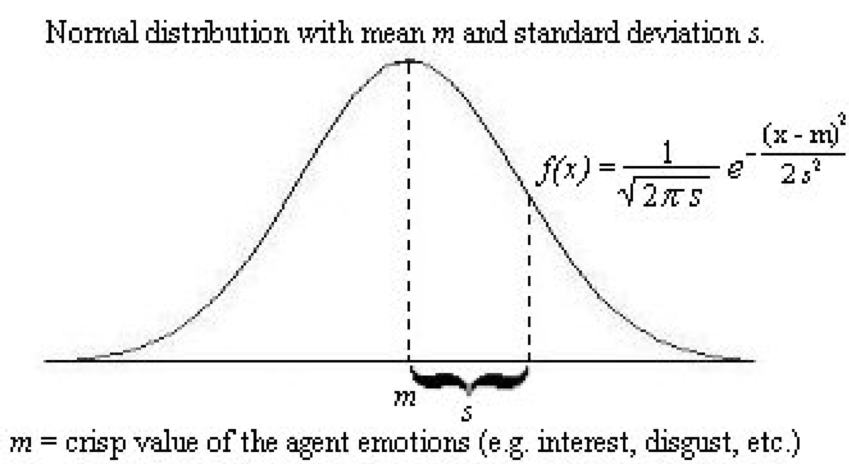


Figure 6. Normal distribution curve to generate random values for internal parameters.

5.2 Generating the agent performance

The next set of fuzzy rules involves the modelling of the agent performance. As a result, the rules setting the agent performance parameters for each assigned task are triggered. Note that even if two people have the same intensity for the same emotions their behaviour over their assigned tasks may not be the same. In this step of the simulation the different personality trends and the characteristics of the assigned task affect the agent performance. The result of this behaviour is measured through the parameters described in Section 4.3. Table 2 shows the characteristics that influence the agent performance.

Assigned task characteristics
Difficulty level.
Specialisation level.
Personal characteristics
Cognitive: experience and creativity level.
Emotional: desire, interest, disgust and anxiety.
Stress
Personality types (CLEAVER): drive, influence, steadiness and compliance.

Table 2. Factors that influence the agent performance

Similarly to the initial neutral state for the intensity of emotions, we assume that five of the six agent performance parameters have the *acceptable* value at start of the simulation. The *timeliness* parameter is slightly different, and its initial value will be the *estimated duration of the task*. According to the value of the factors listed in Table 2, fuzzy rules are triggered to modify the value of the performance parameters. The result of the triggered rules is the association of a *high_decrement*, *low_decrement*, *normal*, *low_increment* and/or *high_increment* (fuzzy sets described in Section 4.4) for the values of each agent performance parameter. Examples of these fuzzy rules (again, paraphrased in English) are:

Given the agent A1 in charge of task T1,

IF A1 has a *high creativity level*; A1 has a *driver* personality with *high_intensity* AND T1 requires a *high specialisation level* THEN
The *goals achievement* is *normal*
The *timeliness* has a *medium_advance*
The *quality* has a *medium_increase*
The *team collaboration level* is *normal*
The *individual contribution* has a *medium_increase*
The *required supervision level* is *normal*

IF A1 has a *low experience level* AND T1 is a *high difficult* task THEN
The *goals achievement* has a *medium_decrease*
The *timeliness* has a *high_delay*
The *quality* has a *medium_decrease*
The *team collaboration level* has a *medium_decrease*
The *individual contribution* is *normal*
The *required supervision level* has a *medium_increase*
…

When all the performance fuzzy rules are triggered, their resulting crisp value is added to the previous crisp value of the performance parameter. The result of this addition in each parameter is then fuzzified to set its current fuzzy value. This is the result of the team member performance over his/her assigned task.

Two out of these six parameters affect directly the team-mates performance and thus the global behaviour of the team. These two parameters are *quality* and *timeliness*. Consider as an example agents A1, A2 and A3 working on task T1; and QT1 and TT1 the *quality* and *timeliness* values for task T1. To get QT1 we take the *minimum* value of the quality parameters of A1, A2 and A3. For example: if quality of A1 is *acceptable*, quality of A2 is *minimum* and quality of A3 is *satisfactory* then the crisp value will be taken from the minimum fuzzy set. This crisp value is the final quality result for T1, which will be then fuzzified again. To get TT1 we use a similar process, the difference is that we use the *maximum* crisp value (representing a task delay) the timeliness of each person over T1.

5.3 Updating the internal state of the agent

Once the behaviour of a team member is modelled, the corresponding parameters are used to update his/her emotions and stress. We consider that the performance of a person affects his/her internal state: a success will be reflected in increasing his/her confidence and motivation; a failure will have a negative impact on his/her stress and motivation. To model this characteristic we assume that the person knows (or makes an internal evaluation of) his/her performance once his/her assigned task is finished (though this exact situation does hardly occur in real life). The updating of the agent's emotions and stress is very similar to the process described in Section 5.1. The difference resides in the parameters used in the premises of these fuzzy rules as can be seen in Table 3.

Agent performance results
Goals achievement
Timeliness
Individual contribution level
Quality
Internal characteristics
Personality types (CLEAVER): drive, influence, steadiness and compliance.

Table 3. Factors that influence the updating of an agent emotions and stress values.

Given the agent A1 in charge of task T1,

IF A1 has a *driver personality* with *high_intensity* AND the calculated *quality* over T1 is *high* THEN
The *desire* emotion will have a *medium_increase*
The *interest* emotion will have a *medium_increase*
The *disgust* emotion wills *stay_equal*
The *anxiety* emotion wills *stay_equal*
The *stress* will have a *low_decrease*

IF A1 has an *influence personality* with *high_intensity* AND the calculated *timeliness* over T1 is *low* THEN
The *desire* emotion wills *stay_equal*

The *interest* emotion wills *stay_equal*
The *disgust* emotion will have a *medium_increase*
The *anxiety* emotion will have a *high_increase*
The *stress* will have a *high_increase*
…

The triggered rules update the agent's emotions and stress parameters by increasing or decreasing them. These new emotions and stress intensity will be part of the new agent's internal state, and thus part of the input for the next assigned task. The process described in Sections 5.1, 5.2 and 5.3 is repeated for all the team-members in all their assigned tasks until the project finishes and the global team behaviour is generated.

5.4 Implementation of the prototype

Fuzzy agents have been used to implement the model described in the previous sections (detailed descriptions of the multi-agent platform can be found in [14, 15]). Each fuzzy agent aims to simulate a real project team member by setting this person internal characteristics. The JADE framework was used to build the Multi-Agent System (see http://jade.tilab.com/); the JESS (see http://herzberg.ca.sandia.gov/jess/) and FuzzyJess (http://www.iit.nrc.ca/IR_public/fuzzy/fuzzyJToolkit2.html) rule engines were used for the implementation of the fuzzy sets and the reasoning mechanism used to simulate the agents performance. The prototype was developed with the following assumptions and limitations:

a) The software agents do not work to solve any real project but they only simulate their interaction with other agents and with their assigned task(s).
b) A plausible set of global behaviours of a team is obtained by averaging its behaviour over a statistically significant number of simulations.
c) The most suitable team configuration can be obtained by comparing the sets of global behaviours for several possible team configurations.
d) We cannot foresee the future, so we cannot guarantee that the team will behave exactly as the simulations suggest, but we aim to generate information about possible performance patterns. This information can be particularly useful in the identification of undesirable performance patterns and their relation to the team configuration and task assignment.

6. Case Study

The following test and validation of the model was completed at the Mexican Petroleum Institute (IMP, www.imp.mx), a research and technological development centre. At the IMP as in other organisations, the configuration of the project team is fundamental to success in large and complex projects. Furthermore, team configuration may be even more important for *critical* projects or for working in critical circumstances.

Given the interdisciplinary nature of the institution, projects at the IMP require professionals with different backgrounds, e.g. petroleum, chemical, or computing engineers; psychologists, sociologists and economists among others. People can be involved in diverse projects for exploration, production, design, management and training among others. There are projects in which only few people are required (3 to

15) and projects in which many team members need to work together (from 10 to 100 or even more).

In order to test and validate the model, we had to adapt it first to the idiosyncrasies and culture of the IMP, and then compare the generated results against the results measured from a real team that worked in a recent project at IMP.

An Information Technology project was selected for the validation due to the availability of the project manager, the accessibility to documents related to the evaluation of performance of some of the team-members, and its recent date of completion. In particular, the project consisted on the development and implementation of a Geographical Information System (GIS) for internal use at IMP.

6.1 Adapting the agent-based model to the IMP

We first interviewed project managers in order to establish how they select people that work in a project. An interesting outcome of these meetings was that the characteristics used in our original model to represent team members were quite similar to the characteristics that they take into account when they select people.

The use of the CLEAVER parameters was added because most of the people involved in IMP projects were applied CLEAVER questionnaires as part of their staff development programmes. This information was quite valuable for us, as we were able to know the personality trends for the case study. The agents' roles were the same roles used in the GIS project.

Additionally, a number of new fuzzy rules were configured. We were able to define 485 fuzzy rules divided into:

- 101 fuzzy rules to modify the agent internal state.
- 144 fuzzy rules to generate the agent performance.
- 240 fuzzy rules to update the agent internal state.

All these rules were built in conjunction with an IMP psychologist given her background and experience in the area of human behaviour.

6.2 Implementation of the GIS/IMP project

The agents and tasks in our model were configured by getting the available information on the people involved and the GIS/IMP project specifications. The work team consisted of 23 people and the project was divided (coincidentally) into 23 tasks. The characteristics of the people are shown in Table 4 (the participants have been made anonymous because of confidentiality issues). The project tasks and their characteristics are shown in Table 5, and their sequence in Figure 7.

Person	Role	P1	P2	P3	P4	P5	P6	P7	P8
Agent 1	Project Manager	HE	HT	H	H	H	MH	H	MH
Agent 2	Co-ordinator	M	HT	H	H	H	M	MH	MH
Agent 3	Technician	M	M	ML	M	L	L	L	L
Agent 4	Specialist Jr.	M	M	ML	M	L	L	M	MH
Agent 5	Specialist Sr.	M	M	MH	H	M	L	M	M
Agent 6	Technician	HE	HT	L	M	L	ML	L	L
Agent 7	Specialist Sr.	HI	HA	MH	H	ML	M	M	M
Agent 8	Specialist Jr.	M	M	M	H	L	M	M	M
Agent 9	Specialist Sr.	HE	HT	H	H	ML	H	H	H

Agent 10	Specialist Jr.	M	M	M	M	L	M	M	M
Agent 11	Technician	M	HA	M	H	L	L	M	M
Agent 12	Specialist Jr.	HE	HT	M	M	L	ML	M	M
Agent 13	Specialist Jr.	HI	M	H	MH	MH	H	H	H
Agent 14	Technician	HE	HT	H	H	MH	H	H	H
Agent 15	Specialist Sr.	M	M	MH	H	M	M	M	MH
Agent 16	Specialist Jr.	M	M	M	M	L	L	M	L
Agent 17	Specialist Sr.	HI	M	MH	H	M	M	MH	MH
Agent 18	Technician	HE	M	ML	ML	L	L	ML	M
Agent 19	Specialist Jr.	M	M	M	M	M	M	M	M
Agent 20	Specialist Jr.	M	HA	M	ML	M	L	M	M
Agent 21	Specialist Jr.	M	M	ML	MH	M	M	MH	M
Agent 22	Technician	M	HT	M	ML	L	M	H	M
Agent 23	Specialist Jr.	HE	HT	H	MH	M	M	H	MH

Parameter	Value
P1: Introverted/Extroverted **P2:** Prefers to work alone/Prefers to work in a team **P3:** Creativity **P4:** Experience **P5:** Drive **P6:** Influence **P7:** Steadiness **P8:** Compliance	**HE:** High extroverted **HI:** High introverted **HT:** Highly prefers to work in a team **HA:** Highly prefers to work alone **H:** High **M:** Medium **L:** Low **MH:** Medium high **ML:** Medium low

Table 4. Parameters and initial internal state of the people involved in the GIS/IMP project.

Task	Type	Difficult	Assigned to:
Task Management: *Asignar tareas*	H	H	Agent 1
Spatial information analysis: *Análisis de información espacial*	H	H	Agent 4
SAP Administrative Support*: Apoyo en la administración SAP*	L	L	Agent 19
Personal Assistant: *Apoyo en actividades de oficina*	L	L	Agent 6
Technical Data Revision: *Revisión de datos técnicos*	ML	ML	Agent 20
Task Coordination: *Coordinación de Tareas*	H	H	Agent 14 Agent 17 Agent 21
Support for the Quality Assurance Plan Requirements: *Apoyo en la integración de los requerimientos del Sistema Institucional de* Calidad	M	M	Agent 11
Project Manager Personal Assistant: *Apoyo a la jefatura de proyectos*	L	L	Agent 11
Coordination of the design and programming of functions: *Coordinación en el diseño y programación de funciones*	ML	ML	Agent 2
Data Standards coordination: *Coordinación en la homologación de datos*	M	M	Agent 2
Object Oriented Analysis and design: *Análisis y diseño orientado a objetos*	H	H	Agent 3 Agent 5 Agent 10 Agent 12 Agent 13 Agent 14 Agent 16 Agent 21 Agent 22 Agent 23
Data Bases Analysis and Design: *Análisis y diseño de bases de datos*	H	H	Agent 7 Agent 9 Agent 17
Implementation: *Programación en VBA*	MH	M	Agent 3 Agent 8 Agent 10 Agent 12 Agent 14 Agent 16 Agent 18 Agent 21 Agent 22 Agent 23

Design of SQL queries: *Diseño de consultas en SQL*	MH	MH	Agent 14 Agent 21
Design of HCI: *Diseño de interfaces de usuario*	M	ML	Agent 3 Agent 10 Agent 12 Agent 16 Agent 17 Agent 22 Agent 23
Construction of Spatial elements: *Construcción de elementos espaciales*	H	M	Agent 4
Implementation of SQL queries (1): *Programación de consultas SQL*	ML	ML	Agent 8 Agent 18
Implementation of SQL queries (2): *Diseño y programación de consultas SQL*	M	M	Agent 3 Agent 10 Agent 12 Agent 16 Agent 22 Agent 23
Database implementation: *Construcción de bases de datos*	M	M	Agent 7 Agent 9 Agent 17
DB Validation: *Coordinación en la adecuación de bases de datos*	M	M	Agent 2
Spatial Elements validation: *Coordinación en la creación de elementos espaciales*	M	ML	Agent 2
Software connection: Conectividad entre equipos	M	M	Agent 7 Agent 9
SAP and invoice management: *Administración del SAP y facturación del proyecto*	M	M	Agent 15

Parameter	Value
Type: Specialised **Difficult:** Complexity	**H:** High **MH:** Medium High **M:** Medium **ML:** Medium Low **L:** Low

Table 5. Characteristics of the tasks of the GIS/IMP project

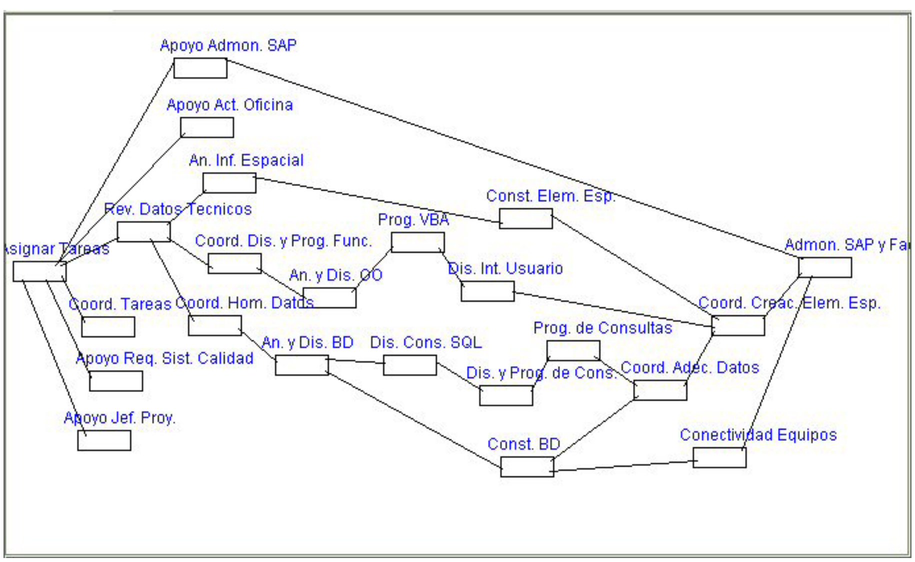
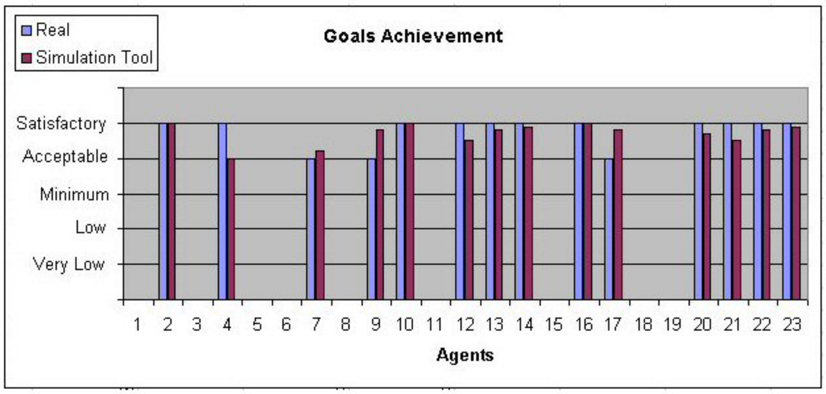


Figure 7. Task sequence for the GIS/IMP project

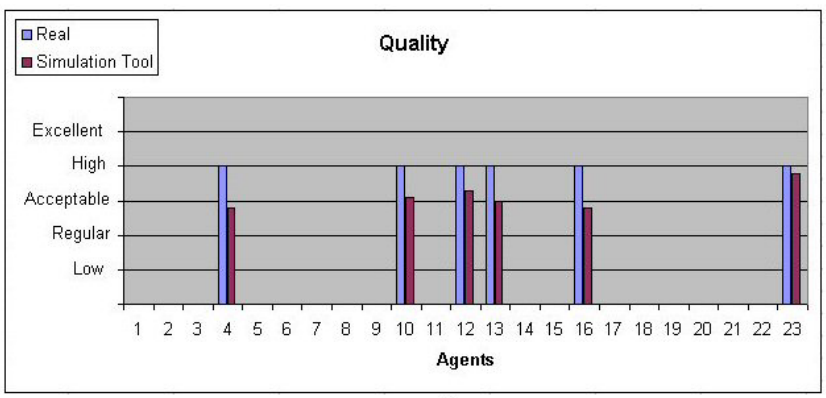
Once we configure our simulation tool with the available information, simulations were run to observe the results. A standard deviation parameter of 10 was set for the degree of randomness affecting the emotional state of team members (see Section 5.1). With this standard deviation we noticed that after 35 simulations, the variation in performance parameters for every person with respect to previous predictions was minimal. The results shown in the following section are obtained after performing 40 simulations.

6.3 Initial Results

The results generated by our simulation tool were compared with the evaluation reports provided by the project manager. Unfortunately, we only got access to the reports for 6 out of the 23 people involved in the project (with the exception of the *goals achievement* parameter, where the data for 14 people were available). Each one of the predicted performance parameters was compared with its corresponding value obtained from the evaluation report. Figures 8, 9 and 10 show this comparison.



a)

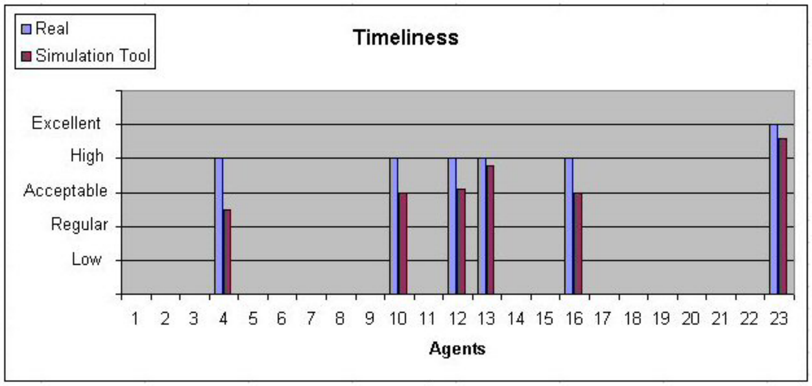


b)

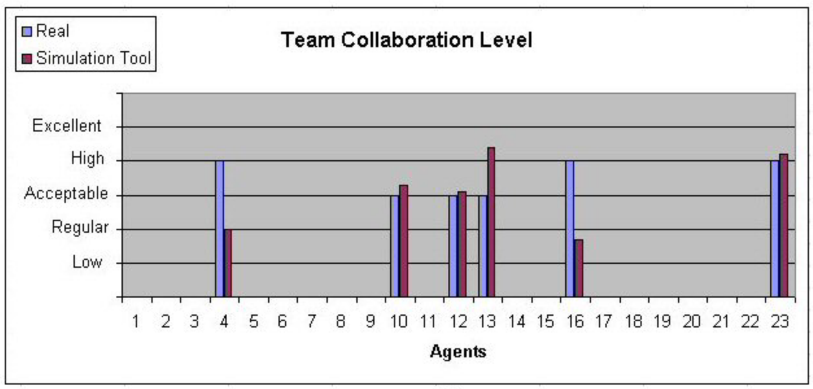
Figure 8. Comparison for the *"Goals Achievement"* and *"Quality"* parameters among team members and agents performance results

The bars in light blue in Figures 8, 9 and 10 represent the results obtained by the real team (according to the evaluation records for each team member) and the bars in dark red represent the results predicted by the software simulation tool (i.e. the average of the 40 simulations for each agent).

For the "*Goals Achievement*" parameter we can observe that for 11 out of 14 people the result was very close; the values for "*Goals Achievement*" (Figure 8a) were between acceptable and satisfactory for both real and simulation tool results. In the case of the other five parameters we only had the evaluation results for six team members, and we made the comparison with them. The evaluation for the "*Quality*" parameter (Figure 8b) for the six people was high, whereas the results generated by the simulation tool present differences and only in two out of the six we got similar results (agent 12 and agent 23).



a)



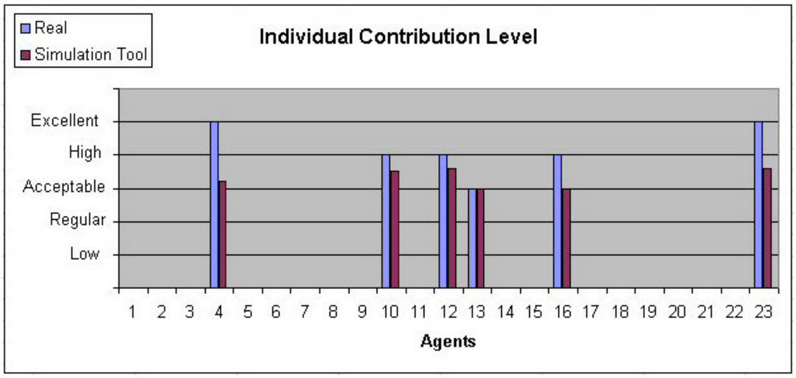
b)

Figure 9. Comparison for the *"Timeliness"* and *"Team Collaboration Level"* parameters among team members and agents performance results

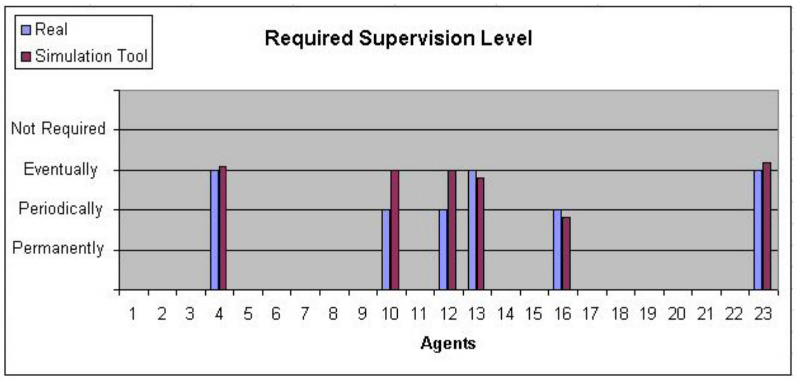
For the "*Timeliness*" parameter the results for two of the six agents were close (agent 13 and agent 23). In the evaluation records, five people presented a high degree of timeliness and only one presented an excellent result (team member 23). For this person the result generated by the simulation tool was very similar.

The difference between the data provided by the project manager and the simulation tool for the "*Team Collaboration Level*" parameter was higher than for the other parameters, as can be seen in Figure 9b. For three out of the six agents the results were close (agent 10, agent 12 and agent 23). On the other hand, for three of the six team members the results for the *"Individual Contribution Level*" parameter were quite similar (agents 10, 12 and 13, Figure 10a).

The "*Required Supervision Level*" parameter showed the closest values between real and simulation results. In four out of six agents the difference among them was very small (agents 4, 13, 16 and 23). In both cases the range of values for this parameter was from "Periodically" to "Eventually".



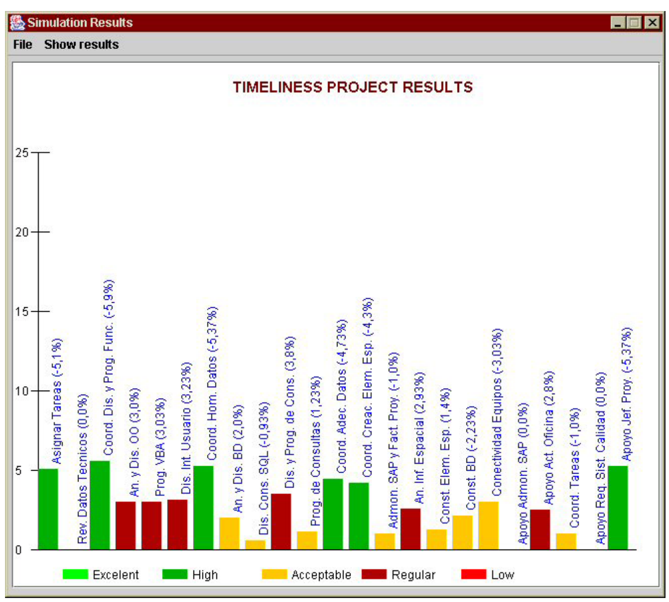
a)



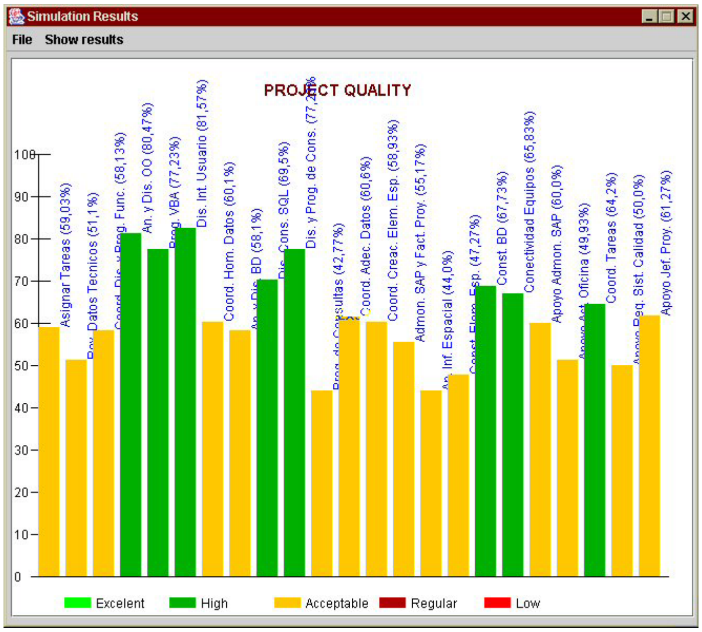
b)

Figure 10. Comparison for the *"Individual Contribution Level"* and *"Required Supervision Level"* parameters among team members and agents performance results

Figure 11 shows the global results of the team through the "*Timeliness*" and "*Quality*" parameters for each of the 23 tasks. For this team configuration the quality of the performance has values from "Acceptable" to "High". In terms of timeliness, the values were from "Regular" to "High".



a)



b)

Figure 11. Global results: *"Timeliness"* and *"Quality"*

6.4 Discussion

The people (and agents) performance is strongly affected by the values of the CLEAVER parameters. Low values for these parameters generate low values in most of the other evaluation parameters (see, for example, agent 16). On the other hand, high values of CLEAVER parameters and high values in the parameters related to the social characteristics give rise to a better performance (see agent 23).

The *difficult of the task* parameter influences the team member behaviour. Agent 11 was in charge of 2 tasks (without team-mates in both tasks), and one of these tasks was of medium difficulty. The result of its behaviour for each of the six parameters was better for the low difficulty task than for the medium difficulty task (see Figure 12).

It can be argued that most of the results depend on the rules configuration, despite that, in most cases, the simulation and the GIS/IMP project results were similar. Nevertheless, we must take into account the following:

- Unfortunately, we could not access the information for all the team members involved in the project. Nevertheless, the GIS/IMP project was completed during 2003, and we had the opportunity to talk with the project manager and some of the people who worked in the project. Their comments were that, given the software limitations (absence of some of the policies of the institution, such as involvement of the client and manager services among others), the initial predictions can be considered useful and resemble a part of the reality.

- The project manager filled the evaluation documents where the results of the team-members performance are recorded. This evaluation is according to the project manager perception and, in many cases, he/she did not work directly with some of the team members. In these cases, the project leader evaluated the person according to the client satisfaction over the project final delivery.

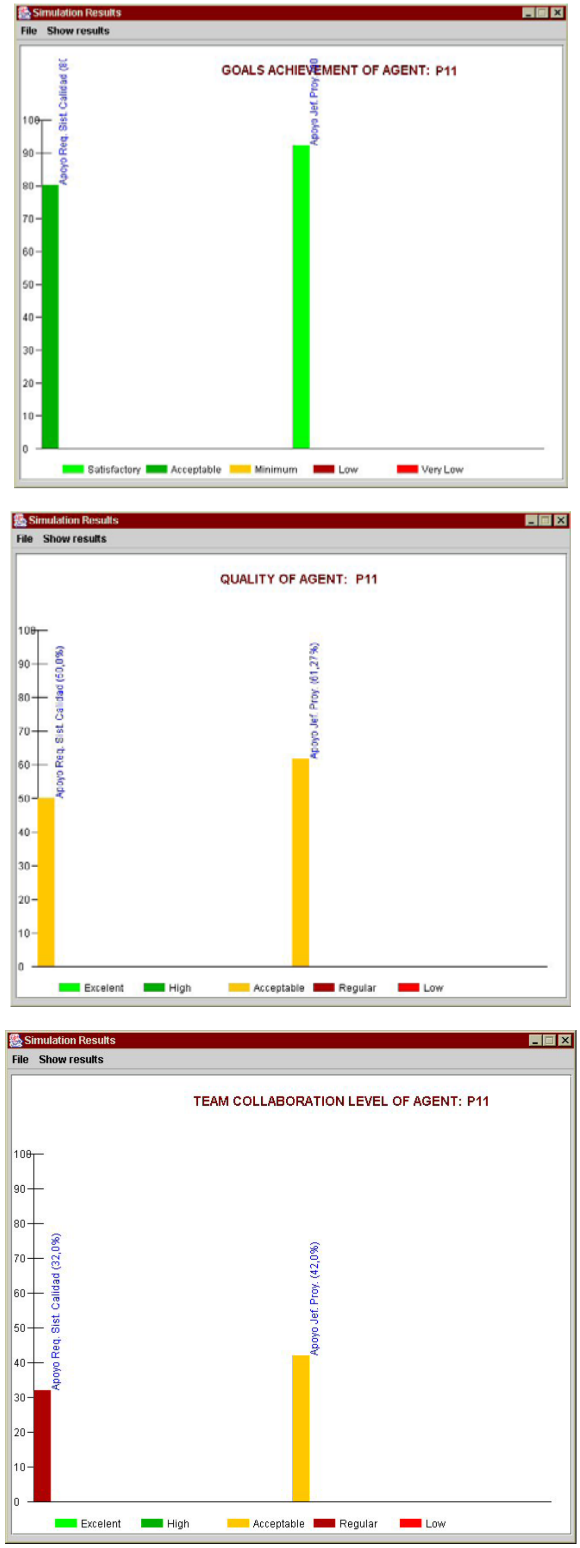


Figure 10. Effect of the type of task on the performance of an agent

- The personality type parameters for each agent were set according to the results of the application of the CLEAVER technique. Nevertheless, the values of parameters such as *creativity* and *experience* were configured according to the perception and experience of one of the project co-ordinators regarding his/her interaction with the other team members.

We have compared the results for only one project. As a result of these initial results, the managers of IMP have shown a huge interest in applying this model for more projects. Once the new information becomes available, we plan to use it for further comparisons and validation (IMP plans to finish this job in the next 8 months).

7. Conclusions

We have presented the use of fuzzy logic to model human behaviour at work. Fuzzy logic is used to represent a set of selected human characteristics that influence the performance of people when assigned to a job. From this set of human characteristics, we model the human behaviour as a consequence of the interactions between team members and with their assigned project tasks. We use fuzzy rules to model this behaviour and predict the possible performance of each person over his/her assigned task and a set of plausible results from the performance of the whole team. An initial validation of this proposed model is also presented and the results obtained are discussed.

Even with the set of encouraging results of the initial validation, it is patent that more tests with other case studies are necessary to improve the overall validation of the model. At the moment, the institution where we developed the initial case study is interested to apply this model to more internal projects and integrate it as part of a knowledge management system.

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