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Coupling Multi-criteria Analysis And Machine Learning For Agent Based Group Decision Support:
Spatial Localization

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Abstract: The land use management context is known for its spatial complexity. It is a multidimensional problem influenced by several criteria of dissimilar importance. This kind of problem involves many decision-makers (individuals and institutions) with often conflictual preferences. The authors' contribution consists of designing and developing a web intelligent multi-criteria group decision support system (WIM-GDSS), which combines four tools so that the shortcoming of one tool is complemented by the strength of the others. These tools are Multi-Agent System, Geographic Information System, Multi-Criteria Analysis methods (TOPSIS and AHP) and Machine Learning techniques (Linear Regression). The current study aims to assist decision-makers in choosing the most adequate alternative that best meets certain criteria. The chosen solution has to satisfy the majority of the involved decision-makers. In this perspective, WIM-GDSS will be enriched with a coordination protocol, allowing the agents to properly collaborate to find a compromise solution using multiple criteria analysis methods and prediction models.

Keywords: Group decision support, Multiple criteria analysis, TOPSIS, Linear regression, Web decision support, Prediction models, Machine learning, Collaborative decision.

1. Introduction

Decision-making consists of evaluating a set of alternatives (possibilities) for ranking, selecting, or classifying them according to several criteria. Single criteria cases deal with problems that have only one criterion, making them unsuitable for real-world requirements. Due to the latter fact, researchers and scientists are more interested in multi-criteria decision support to handle the lack of dimensionality, by allowing decision-makers to select and rank solutions based on their importance, while taking into account the influence of multiple criteria. In real-world organizational decision- making problems, decisions are often taken in meetings, where several members around the table are part of the final decision, which makes group decision support systems (GDSS) more efficient compared to single-actor decision support systems. Many companies are becoming multinational organizations as a result of globalization, and their managers are traveling around the world to different (distant) places with different time zones, making them unavailable to participate in decisional meetings. To address this issue, many GDSSs are being adapted by using a web-based architecture, which allows decisions to be taken properly regardless of location. The current study concerns territory planning problems, where the need to locate a territory zone that best meets certain criteria for a given construction project. The main objective is to design and implement a web-intelligent multi-criteria group decision support system called WIM- GDSS, that aims to help a group of decision-makers to find a compromise solution (best solution) that satisfies the majority of them (or ideally all of them), while taking into consideration their preferences (often conflictual), and their distant locations. The WIM-GDSS is dotted with a prediction mechanism (using linear regression) that allows it to predict the outcome (the final ranking of alternatives) of any given territory-planning problem. The prediction model was trained using a multi-criteria analysis method (TOPSIS and AHP) on a dataset containing real data, and it demonstrated its efficiency, robustness, and resistance to changes in dimensionality (number of criteria) and number of alternatives.

The paper is organized as follows: Section 2 contains the related works. Section 3 highlights our contribution. Section 4 describes the proposed model and its different modules and components. In Section 5, a case study is presented,

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illustrating the proposed model with an example of a real-world decisional problem. In section 6, we illustrate the limitations of the proposed system. Finally, the paper is closed with a conclusion and perspectives.

2. Related Work

The quality of decisions made is one of the most important factors that determine the success of an organization. Therefore, decision support has a great impact on the world of organizations. In the decision support domain, several systems that treat different types of decision-making problems have been developed over the years. However, this domain can be divided into two broad categories:

- Single actor decision problems- the problem concerns only one decision-maker who forms an alternative (solution) based on his personal opinion and values (preferences)
- Multi actors' decision problems-the problem involves several deciders (decision-makers) to reach an agreement (compromise solution) every one of them with his personal preferences often conflictual compared with others.

In the context of single-actor decision support, several decision support systems in TP (Territory Planning) have caught our attention. There is a summary of some of them in the work of Hamdadou in [1] from which we cote: *"The author in [2] presented a decision-making procedure for water management in a city while in [3] , the authors offered some decision-making tools for local communities to handle water management issues. Bensaid In [4], For geospatial localisation of regions under intense human pressure, multi-criteria analysis was utilized as a decision-making technique. In the same publication, a case study of the Algerian department of Naama was offered. For management and decision-making in territorial challenges, a variety of decision support systems with spatial tools and multi-criteria analysis methodologies have been created (water, air, natural areas, transportation, energy, waste, health planning, risk management...) [5]. All these systems couple multi-criteria analysis tools with GIS at various levels, but they treat the criteria as separate entities which make them unable to simulate any interaction between them (interchangeability, correlation, preferential dependence ...). The inclusion of correlation criteria in MCDA approaches, notably "ELECTRE TRI," was studied extensively In [6]. The authors introduced the Choquet integral (rather than the arithmetic sum) as an aggregation operator."*. However, traditional decisional models adapted to the single decision-maker case are not consistent with organizational reality. Collective decision support, group decision support, or multi-participant decision, treats processes in which multiple decision-makers are involved. According to Smoliar and Sprague in [7] decision processes in organizations usually involve several actors interacting with each other. For Hamdadou [8] a GDSS can facilitate and record group communication processes and should take into account the likelihood of communication taking place outside of the system. Therefore traditional decision models that are based on single decision-maker are often not suited for real-world organizational problems. Below are some of the systems that have been developed in the context of multi-actor decision support. Bars in [9] developed a simulation tool dedicated to helping with the process of negotiation of decision- makers involved in water management problems, in [10] the authors studied a water management problem and developed a platform for decision support, based on a hybrid approach MAS-GIS, dedicated to the problem mentioned. The work in [8], has been conducted to treat and solve group decision allocation problems, encountered in crisis management applications, using a multidimensional, multilateral negotiation protocol, based on cooperation, In [11] the authors Proposed a multi-criteria group decision support system for parks conception and attribution while taking into account the protection of the environment from global warming, the system is modeled by a set of interacting agents to retrieve users preferences, a negotiation protocol is used to help to choose a space with multiple attributes, Tayyebi in [12] proposed SmartScapeTM, which is a web-based spatial decision support system(SDSS) that aim to help decision-makers to evaluate and assess cultural changes, on a variety of ecosystem services in agricultural landscapes, Reddy in [13] presented and implemented an information decision support system(IDSS), that is dedicated to helping decision- makers(construction engineers) execute a new transmission line project efficiently, Nugent in [14] proposed an integrated dynamic web-based framework for an urban climate adaptation tool called UrbanCAT, its main objective is to help cities plan possible risks, that affect urban infrastructures and population due to climate changes. Several decision support systems for territory Planning were developed and improved within our research team "Modeling spatial-temporal and artificial vision: from Sensor to decision ". The most important are: In [8] the authors proposed a decision support system for the control of space process, a multi-criterion approach, and a negotiation approach, two components were combined in this model multi-agent system dotted with a negotiation protocol to ensure group decision process and geographical information system to treat spatial data, the authors in [1] designed and implemented an interactive multi-criteria decision support system in Territory Planning for punctual spatial location based on the contract net protocol and multi-criteria method ELECTRE III, Oufella in [15] proposed a spatial multi-criteria group decision support system modeled by a multi-agents system, the author used protocol of negotiation based on argumentation approach, which allows agents (decision-makers) to exchange complex justification positions rather than just simple proposals, the authors in [16] proposed a web-based platform of communication for a group decision support system using web services for territory planning, the system is modeled by a set of interacting agents using a negotiation protocol based on mediation and multi-criterion analysis, Hamdani [17] proposed a multi-criteria group decision support system using web services, the authors used a multi-agent system to represent the decision-makers doted by a negotiation protocol based on monotonic concession using CONDORCET and BORDA voting methods, The authors in [18] proposed A Temporal Distributed Group Decision Support System Based on Multi-Criteria Analysis for solving spatial localization in territory planning problems, the authors used a multi agent system to model the agents using a negotiation protocol to reach an acceptable compromise solution before fixed deadlines time expire. The systems mentioned above are not dotted with intelligence mechanisms, the authors in most cases used reactive agents to represent the decision-makers except for Oufella [15] where the authors used BDI (beliefs, desires, intentions) agent's architecture, to our knowledge, there has not been a lot of intelligent systems developed in the context of territory planning using MAS and GIS combination based on multi-criteria analysis, the work presented in [19] consists of proposing a decision-making model for territory planning combining Geographic Information systems and artificial neural network but the authors didn't use MAS architecture nor multi-criteria analysis, in [20] the authors proposed a model for shopping center site selection problem using a combined fuzzy multi-criteria decision making (fuzzy AHP and fuzzy TOPSIS) approach to treat uncertain values, In [21] the authors proposed an intelligent decision support system for classifying industrial sites according to quality criteria estimated by exploiting a geographic information system, expert knowledge, and machine learning techniques. The proposed system is based on a geographic information system for generating location alternatives and a hierarchical neuro-fuzzy approach for site classification, the neuro-fuzzy method is based on a knowledge base designed by experts in the field. In [22] the authors proposed a grape disease detection network based on multi-task learning and attention features, but their detection mechanism falls within the scope of medical area, and it did not use multi-agent systems.

3. Contribution

Group decision-making support consists of finding a compromise decision (solution) among multiple decision makers (actors) while taking into consideration the different points of view of each one of them. To tackle these kinds of problems, authors usually used a combination of techniques such as negotiation [1], voting [16], argumentation-based systems [15], monotonous concession [17], consensus protocols [23], to achieve a satisfactory solution for all the decision-makers involved. In this work the authors were inspired by the PROMETHEE GDSS method (Figure 4) proposed in a three-phase procedure by [24], to build their coordination protocol. The major deliverables of the current paper is:

- A web group decision support system (WIM-GDSS).

The main contributions within the latter system are as follows:

- Design and implement a web intelligent multi-criteria group decision support system.
- The web architecture allows geographically dispersed decision-makers to participate and resolve a decision-making problem wherever they are.
- This system uses a coordination protocol to deal with decision makers' multiplicity. It is based on a PROMETHEE II GDSS procedure.
- The proposed system is modeled using a multi-agent system known for its distributed architecture, capacity, and efficiency, allowing it to better represent and preserve decision-makers' human autonomy.
- The decision-makers in this system are represented by virtual cognitive agents that are dotted with an intelligent mechanism that predicts and recommends individual and global solutions to the users (decision-makers) using a linear regression model. The latter is based on a TOPSIS method, its main goal is to predict TOPSIS outcome on a given multi-criteria problem.

4. The Proposed System

The proposed system WIM-GDSS is based on web architecture. It contains two levels, the client level, and the server level. The client level is composed of two modules namely : the web user interface and the geographical information system (GIS). The server-side contains the webserver incorporating the multi-agent system (MAS) and the database system, physically, there are three possible modes to integrate GIS and other decision support systems; loose, tight and full integration [25].
The authors chose the loose coupling (the two systems will exchange files but run independently) due to its simplicity and low development cost. The research in [26] could be of great support improving the dashboards within the proposed system, since it was conducted to *"identify the feel for dashboards, how they can be used, and the various technologies that can complement each other to get the success of a prescriptive dashboard"* [26].

A. *Identification of The Involved Actors*

In WIM-GDSS, two roles could be identified (Figure 1) Each one has its own panel of login to the platform. The first one is the Administrator role and the second one is the user (decision maker) role. When a user logs in to their account, two other sub-roles are assigned based on the status of the decisional problem; the user who initiates the problem is referred to as Initiator, and the users who are invited to participate are referred to as Participants. The authors introduce these profiles (roles) in Figure 1 along with use cases for each role.
The administrator can manage the users' accounts in the platform by adding new users (decision makers), updating existing information, managing the database system (he has the ability to add delete update tables, configure the database system . . .) and training new prediction models.

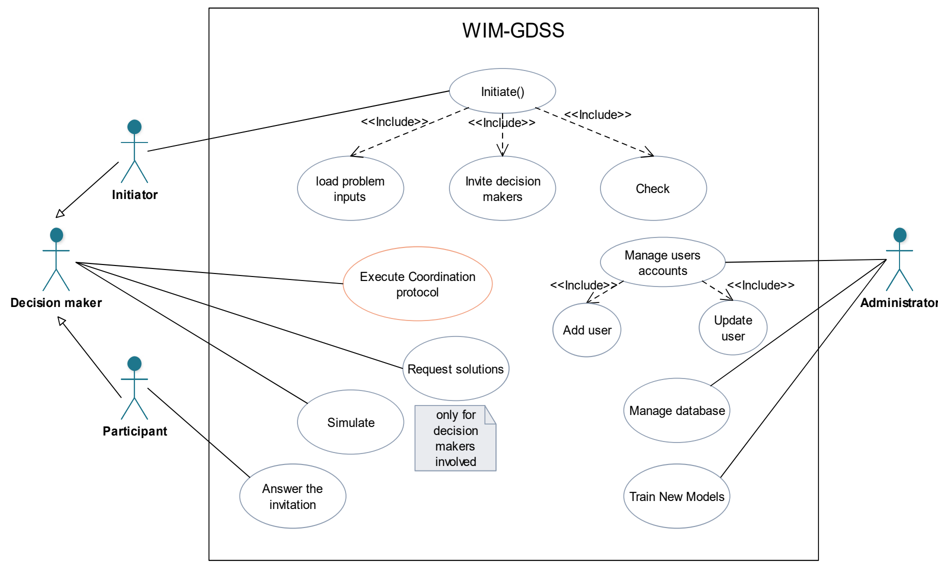


Figure 1. Use case diagram of the proposed system

For the initiator, he can initiate a new problem by introducing all the information and documents necessary for the execution and inviting the decision-maker involved in the process and finally receiving the answers and checking whether the problem should be launched or aborted. The participants have the ability to answer to the initiator invitation by responding with accept or refuse.
In addition to the use cases mentioned above, there are others shared between the initiator and the participants, such as the execution of the coordination protocol (requires coordination to perform), requesting solutions to a specific problem (participation required), and simulation.

B. Description of WIM-GDSS modules

The global architecture of WIM-GDSS is highlighted in Figure 2. Below is a brief description of the different components:

1) **The Web User Interface:** Users can interact with content or software running on a remote server via a web browser using the web user interface or web app. This content or website is downloaded from the web server and the user can use a web-browser that serves as a client to interact with the content.
2) **The Web Server:** It is a service provider that constitutes a set of software computers with a primary objective to comply with client's requests (HTTP)
3) **The Web Database:** It is an application that is accessed and managed via the internet and contains data collection (often structured). The web server operators can manage and use this data to satisfy client's requests.
4) **The Geographic Information System Module:** According to the authors [27] 80% of the data used by decision-makers for industrial site selection (which is a territory planning problem) is geographical (spatial). Therefore the importance of GISs for this kind of problem, GISs are mainly used to [28] capture, store, query, analyze, display, output spatial information.
5) **The Multi-agent System Module:** The multi-agent paradigm is a powerful tool known for its ability to model and deal with the multiplicity and diversity of decision-makers involved in the decision-making process. This modelization will preserve the autonomy and valuable intelligence and knowledge provided in face-to-face meetings, effectively compensating for GIS's shortcomings. There are several tools for implementing such a framework in the literature, depending on what is required and which development language is used. In this paper, the model used for the agents is based on the work proposed by Javier Palanca [29], which is a python-based framework called SPADE (Smart Python Agent Development Environment). The innovation of the current study is that these agents are provided with additional modules (Figure 3) to help solve the problem by using multi-criteria

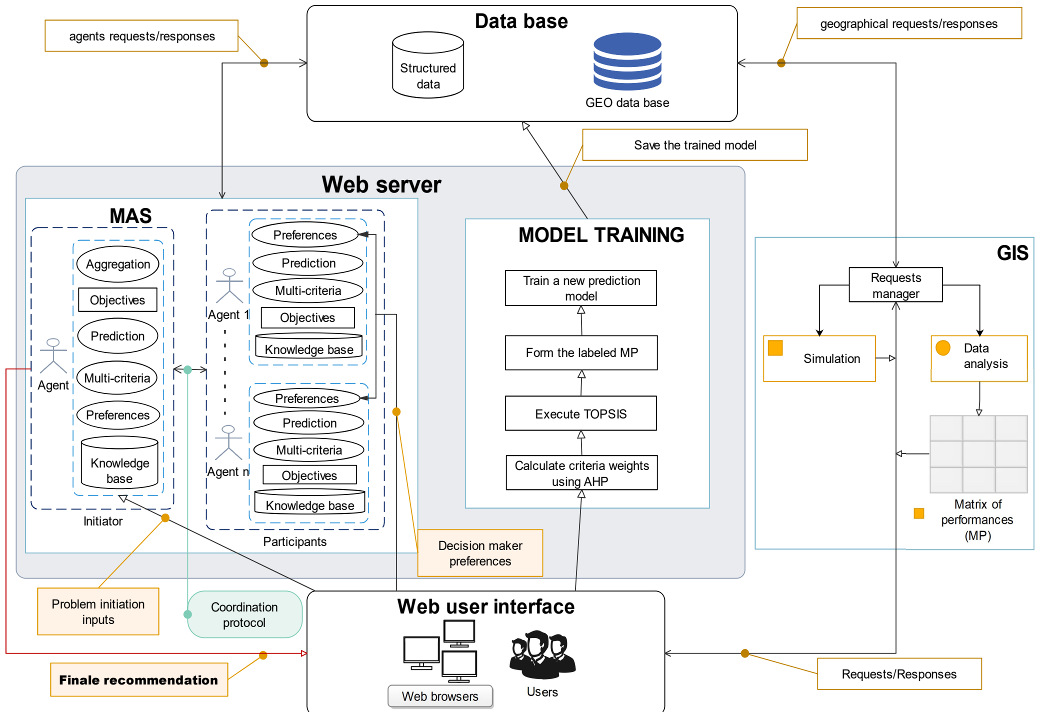


Figure 2. Global architecture of WIM-GDSS

approaches and machine learning techniques. As shown in Figure 3, the agent is made up of several modules, including a connection module, a message dispatcher, behaviors, a knowledge base, a prediction module, a multi-criteria module, and an aggregation module.

For details on the default components of the SPADE model agent, refer to [30]. The additional modules are described below.

1) The Multi Criteria Module

Used to address the problem's multitude of criteria, which are frequently in conflict. The outranking family methods of the multiple criteria decision aid are the focus of this article. The key reason for this option is to assist decision makers by providing them with a global view of the degree of preference between alternatives, allowing them greater flexibility and clarity when making decisions.
There are two levels of using the multi criteria method:

- Local level; where it is used by every agent separately to calculate its objectives.
- Global level; the method is used to calculate the group solution of the given problem after forming the global matrix of performances.

The used methods are TOPSIS [31], [32] and AHP [33] respectively.

1) **TOPSIS Method:**
Topsis is a straightforward multi-criteria decision analysis method (MCDA), its name stands for "Technique of order preference similarity to the ideal solution". It was presented by [31], [32], and can be considered as one of the classical MCDA methods that has received a lot of attention from researchers and scientists. The concept behind this method is to determine an ideal solution and an anti-ideal solution and comparing the distance of each of the alternatives to those. Table I adopted from [34] presents the distribution of papers on TOPSIS by application areas.

TABLE I. distribution of papers on TOPSIS by application areas. Source [34]

Area	N	%
Supply chain management and logistics	74	27.5
Design, engineering, and manufacturing systems	62	23
Business and marketing management	33	12.3
Health, safety, and environment management	28	10.4
Human resources management	24	8.9
Chemical engineering	14	5.2
Water resources management	7	2.6
Other topics	20	7.4
Total	269	100

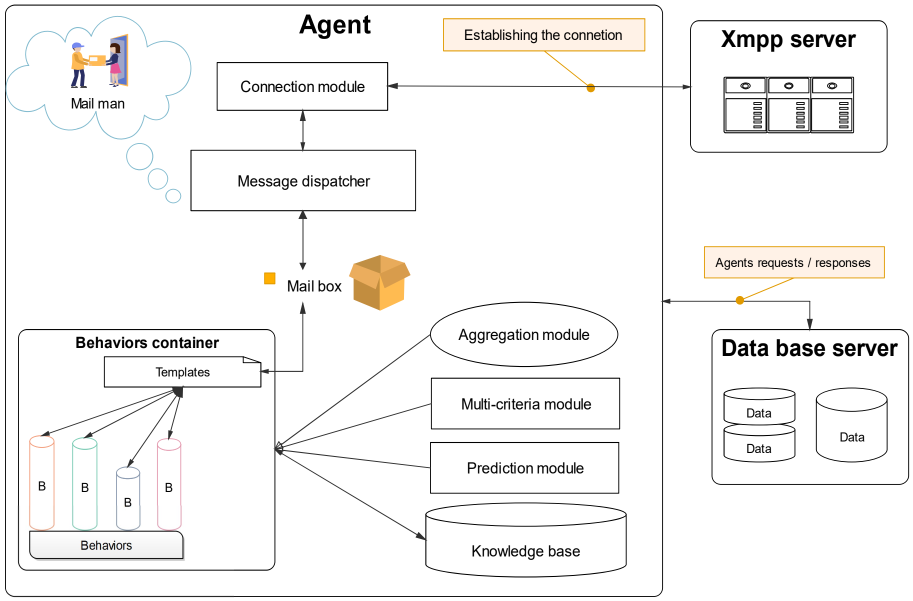


Figure 3. Agent's architecture

Initially it is assumed that a decision matrix with m alternatives and n criteria is formulated first, where each alternative is evaluated against each of the criteria separately. These evaluations form the decision matrix X. a vector of the criteria weights is also needed where:

$$\sum_{j=1}^{n} w_j = 1, j = 1, 2, ..., n \quad (1)$$

Where w_j is the weight of the jth criterion. The TOPSIS algorithm is composed of the following steps:

- **Normalization of the decision matrix:** This step consist on scaling the values of the decision matrix, in order to be able to compare different kinds of criteria and make them dimensionless [35], the choice of the normalization method can be tricky, since it affect the final outcome of TOPSIS method, the authors in [36] presented a detailed analysis on the impact of normalization process on a case study based on TOPSIS, they found out that *"vector, linear and logarithmic normalization are three suitable normalization methods for TOPSIS"*. The normalized values of each performance x_{ij} is calculated using vector normalization method as:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, i = 1, \ldots, m, j = 1, \ldots, n \quad (2)$$

- **Calculation of the Weighted Normalized Decision Matrix:** In TOPSIS, the criteria's weights are the only subjective parameters (unlike other MCDA methods), this step consist on multiplying the normalized decision matrix with the weights associated to each one of the criteria (1) to form the weighted normalized decision matrix where v_{ij} are the weighted normalized values

$$v_{ij} = w_j r_{ij}, i = 1, \ldots, m, j = 1, \ldots, n \quad (3)$$

- **Determination of the Ideal (Zenith) and Anti- ideal (Nadir) Solutions:** In this step, the distances of each of the alternatives from the ideal (4) and anti-ideal (1) solutions

$$D_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}, i = 1, \ldots, m, j = 1, \ldots, n \quad (4)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, i = 1, \ldots, m, j = 1, \ldots, n \quad (5)$$

- **Calculation of the Relative Closeness to the Ideal Solution:** The relative closeness $C_i^*$is always between 0 and 1, the closer the value to 1 the better. It is calculated as follows:

$$C_i^* = \frac{D_i^-}{D_i^* + D_i^-} \quad (6)$$

- **Ranking of the Preference Order:** Finally, the alternatives are ranked from the best to the worst, depending on the value of the relative closeness (the higher the better).

2) **Why TOPSIS:** The authors chose this method due to the following reasons [35]:
   - It has been applied and approved by researchers in a variety of application areas (Table I).
   - It has been successfully applied to group decision problems.
   - Its simplicity and Straightforwardness, (simple to understand and to code).
   - It doesn't have a lot of parameters that could influence the final result.
   - The final score of each alternative could be calculated separately and independently from other alternatives.
   - Its capacity to deal with a large number of alternatives.
3) **Why AHP:** Criteria weights reflect the importance of each one of the criteria constituting the decisional problem, it is very imperative to properly assign these weights because of the impact on the final result, the method used for this purpose is AHP. The AHP acronym stands for analytic hierarchy process, it is a widely used MCDA methodology proposed by Saaty [33], The Analytic Hierarchy Process (AHP) is a method of *"measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales"* [37]. *"It has been one of the most widely used multiple criteria decision-making tools."* [38]. *"It is used by decision makers and researchers, because it is a simple and powerful tool"* [39].

2) The Prediction Module

Artificial intelligence strategies and approaches can be categorized based on the end goal (classification or prediction), and the level of supervision provided during the training process (supervised learning, semi-supervised learning, unsupervised learning, reinforcement learning). The authors' goal in this study is to predict a scoring value for each of the alternatives in the dataset, with the end goal of obtaining an ascending ranking (from best to worst) based on the predicted scores, to accomplish this goal, and because of the nature of the territory planning problem (multi-criteria problem), the authors built a regression model trained to predict the output of a multi-criteria method (TOPSIS). The chosen regression model performed exceptionally well in the model selection process (training phase), accurately predicting the desired ranking, and exhibiting excellent resistance to changes in the number of alternatives (rows). However, the model was unable to predict if the number of criteria exceeded the model's dimension (it does not work on a dataset larger than the one used in training in number of criteria (columns)). The author chose the Linear Regression Model as the regression model to use because:

- The simplicity of the model.
- Ease of use and code.
- It shows great performance in accordance with TOPSIS behavior.

3) The Aggregation Module

This module is dedicated to the initiator role, and its main goal is to concatenate the goals vectors of the decision-makers involved to form a global matrix of results.

4) The Model Training Module

The administrator can train new prediction models in this module. There is only one case in which a new model is required: if the initiated problem has a higher dimensionality (number of criteria) than the model currently being used for prediction. A dataset is required to train a new model. The training procedure is depicted in Figure 2. This procedure consists of four steps:

- **Calculating criteria weights:** The AHP approach includes a matrix of criteria evaluations to assign weight to each criterion. This matrix comprises pairwise evaluations of the criteria.
- **Execute TOPSIS multi-criteria method:** This step consists of running the TOPSIS method to generate a score for each of the alternatives.
- **Form the labeled matrix of performances:** Following the completion of the above step, each alternative will be associated with its corresponding score (relative closeness) to form a labeled matrix, which will be used in the training process's next step.
- **Train a new model:** This step consists of training a new prediction model with the labeled matrix of performances from the previous step as input; the trained model is then saved for future use.

It is critical to note that in order to use this model, the dataset must be of the same dimension (number of columns); otherwise, the dataset will be adjusted to fit the model's dimension by filling the missing dimensions with 0 values.
Because the model used in this study was trained on a 7-dimensional dataset, it is applicable to all problems with dimensions less than or equal to that.

C. The Coordination Protocole

The aim of group decisional process is to find a compromise solution, satisfying the majority of actors involved in the problem. For this end, a collaboration between these actors is needed. A variety of techniques could be used to satisfy this objective (see section 3). In WIM-GDSS, a coordination protocol based mainly on PROMETHEE II GDSS method is used, to orchestrate the negotiation between the different actors involved, Figure 5 provide a global view of the latter protocol. The PROMETHEE II GDSS method was proposed in a three-phase procedure by Brans in [24], this method is an extension of PROMETHEE II method, developed to deal with group decision problems. The protocol proposed in this article, will follow the same logic in the PROMETHEE II GDSS method, by taking its three-phases procedure illustrated in Figure 4 and adapt it to fit the proposed system's needs, the phases are as follows (Figure 6):

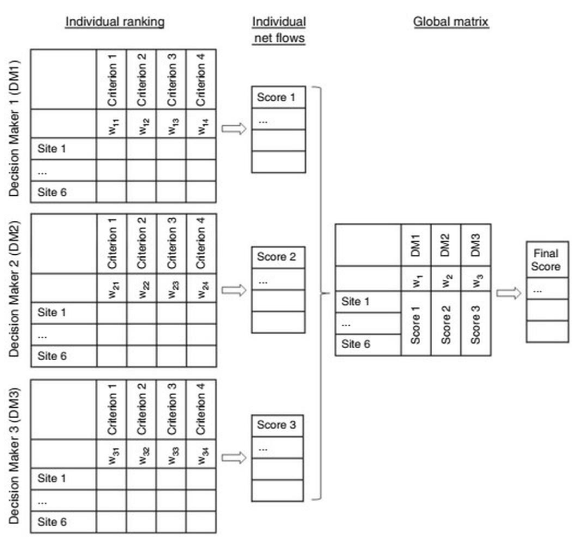


Figure 4. PROMETHEE GDSS procedure. Source([35])

- **Phase One:** The initiator generates a matrix of performances (alternatives, criteria, and evaluations) and then invites the decision- makers concerned, waits for their feedback, and determines whether or not the problem has been approved.
- **Phase Two:** After the problem has been approved (number of acceptances exceeds the acceptance threshold), the initiator sends a predicted order if the problem passed the verification process; otherwise, an executed order is sent. All decision makers resolve the given problem and send their final ranking along with the corresponding scores to the initiator.
- **Phase Three:** The initiator aggregates all of the decision makers' goals (rankings) and creates a global matrix to resolve it and come up with the final solution.

Table II provides a description of the acronyms in the sequence diagram in Figure 6.

TABLE II. Acronyms

Acronym	Description
MP	Matrix of performances: it is A set of data describing the decisional problem, it is a 2 dimensions matrix where the columns are the criteria and the rows are the alternatives, and the content is the evaluations of alternatives against the criteria.
GMP	Global Matrix of Performances where the columns represent the decision makers, the rows represent the alternatives and the values are the score of each alternatives against each decision maker.
LD	List of decision-makers involved in the problem solving
CP	Criteria preferences: a linguistic evaluations of pairwise comparision of criteria
WD	Weights of the decision-makers: A list of decision-makers importance in the decisional problem
MD	Model Dimension (number of columns)
NC	Number of Criteria.
ACT	Acceptance threshold: the minimum number of decision maker involved to launch the problem.
Initiate-problem	Initiate the problem by the initiator decision-maker, he introduces all the necessary parameters to describe the decisional problem.
Count-agree	Count the number of responses: Count the number of decision-makers who agree to participate in the decisional problem.
Count-criteria	Count the number of criteria for a given problem.
Verify-model	verify if the prediction model could be used by Checking whether the problem's dimensionality(number of criteria) is less than or equal to model's dimensionality.
Aggregate	Aggregate the decision-makers vectors of preferences: to form the Global Matrix of Performances (GMP).
TOPSIS	Technique of order preference similarity to the ideal solution.
Data-preparation	Preparing the dataset for prediction if necessary, by adding the missing dimensions and scaling in order to feed it properly to the prediction model.

D. Communications

Communications in SPADE are handled internally through the XMPP protocol [30], the agents communicate with each other by exchanging messages(message to message) (Figure 6). Table III provides a description of the different messages exchanged.

E. Decision Making Process

As previously stated, WIM-GDSS integrates a multi-agent framework into the webserver level, with the primary goal of using virtual agents to model actual decision-makers in the system. There are two major roles that can be identified: administrator and decision-maker. The second role, which of decision maker, is of particular interest in this section. When a corresponding agent logs into the platform, it will be assigned two possible sub-roles to play in the decision-making process, which are as follows:

- If the decision-maker is the one who started the problem, his corresponding agent is an initiator.
- If the decision-maker is invited to take part in the decisional issue, the agent is a participant.

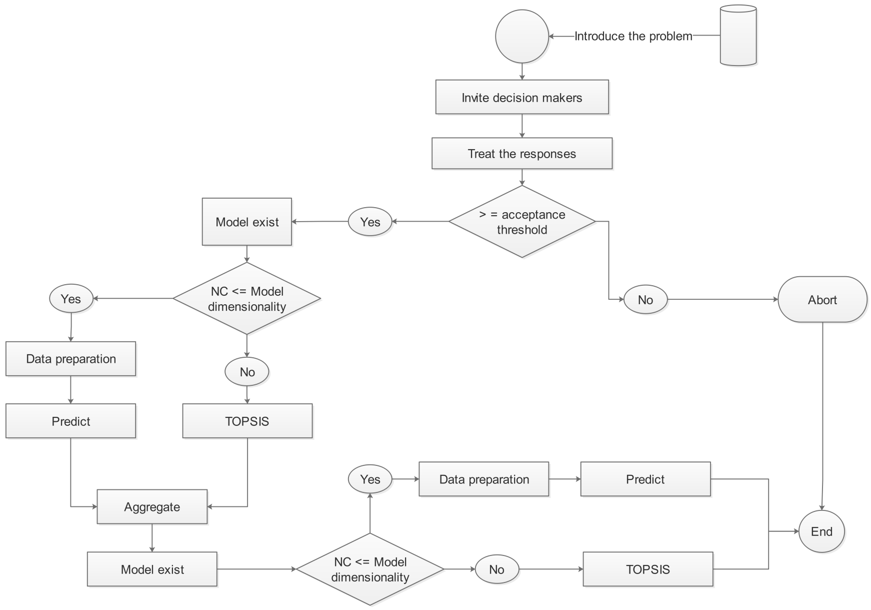


Figure 5. Flowchart of The coordination protocol

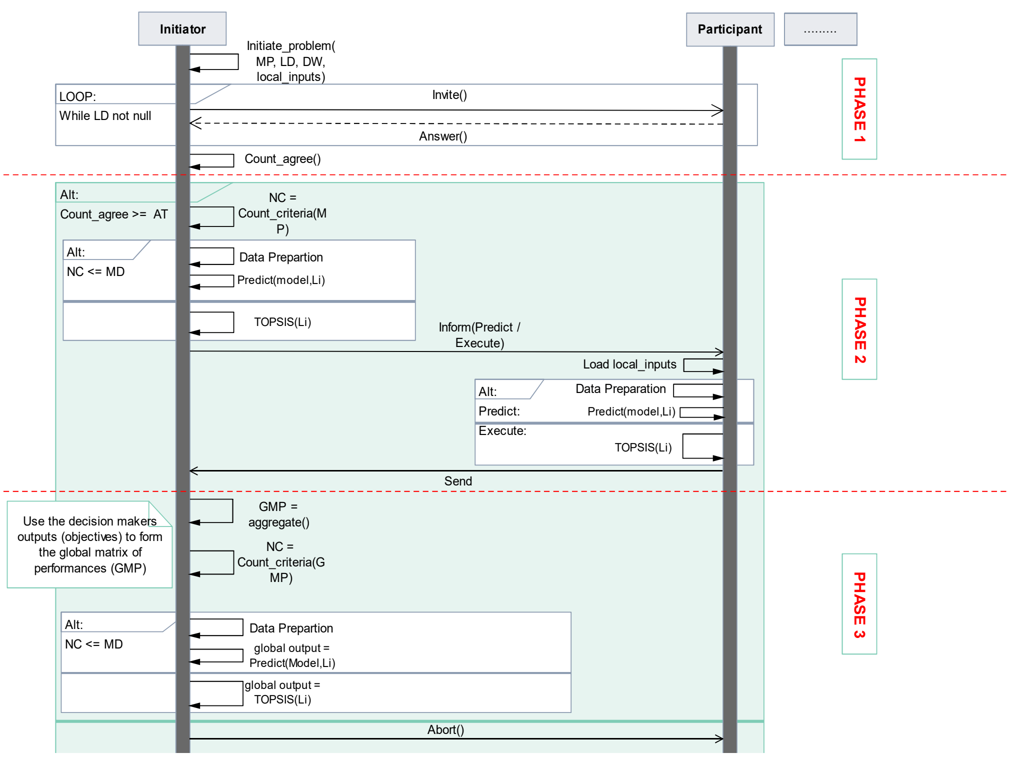


Figure 6. Sequence diagram of the coordination protocol

TABLE III. Primitives used in coordination protocol

Message	Description
Invite()	Send an invitation to the decision-makers to participate in the decisional problem.
Answer()	Send an answer (agree or refuse) to the initiator's invitation(whether to participate or not).
Inform()	Send an order to the decision- makers involved to begin their resolution, this order is either Predict for using the prediction model or Execute for using TOPSIS method.
Abort()	Send an order to the decision- makers to abort the decisional problem execution.
Send()	Send the result of the execution (objectives) to the initiator.

The pseudo algorithm below illustrate the difference and interaction between these roles in each phase of the decision-making process.

1) Pseudo Algorithm

In this section the pseudo algorithms for initiator role (2) and participant role (1) are presented. Refer to Tables II, III for acronyms and functions' descriptions.

Algorithm 1: Participant role

```
Input: CP
Output: Individual ranked alternatives vector
        (Individual-solution);
response = Answer():;
if response == "Accept" then
    WC = AHP(CP);
    Wait for initiator order;
    order = Receive initiator order;
    if order == "Predict" then
        PMP = Prepare-data(MP);
        Objectives = Predict(PMP);
        Send(Objectives);
    else Order == "Execute"
        Objectives = TOPSIS(MP);
        Send(objectives);
    end
else response == "Refuse"
    Abort the problem;
end
```

Algorithm 2: Initiator role

```
Input: MP, Description of the problem, LD, ACT,
       Deadline, CP
Output: Final ranked alternatives vector
        (Global-solution);
Initiate-problem(initiator-inputs in line 1);
WC = AHP(CP): Execute AHP method to calculate
  criteria weights;
Invite(LD,MP);
Wait for decider's responses;
if Deadline OR All responses received then
    number-A = Count-agree();
    if number-A ≧ ACT then
        p = Verify-model(MP);
        if p == True then
            foreach participant in LD do
                Inform(Predict);
            end
        else
            foreach participant in LD do
                Inform(Execute);
                Receive the participants objectives
                 O_1,O_2,...,O_n;
                GMP = Aggregate(O_1,O_2,...,O_n);
                p = Verify-model(GMP);
                if p == True then
                    PGMP = Prepare-data(GMP);
                    Global-solution = Predict(PGMP);
                else
                    Global-solution = TOPSIS(GMP).
                end
            end
        end
    else
        foreach participant in LD do
            Abort();
        end
    end
end
```

5. Case Study

WIM-GDSS is based on web architecture, which requires the use of a variety of tools at each level of the architecture in order to implement it: The authors in this study used a python web free open source framework called DJANGO [40] based on an MVT (Model View Template) architecture to handle WIM-GDSS. Many web browsers (Mozilla, chrome, opera, safari, explorer...) may be used as a web user interface at the client level, enabling the user to communicate with the platform's server level. The bootstrap frontend framework and JQuery libraries are used to design and view details. Users' queries and answers are processed on the server level (requesting and retrieving information from the database level). As previously mentioned, WIM-GDSS requires a multi- agent framework at this level; however, since designing such a tool is a difficult job, the authors chose to use an existing platform called SPADE (Smart Python Agents Development Environment) [29], which is a free and open-source multi-agent platform based on Python. This decision was based on the following criteria:

- The ease with which the platform can be integrated with the DJANGO framework (both using python).
- To take advantage of the Python programming language's ability when it comes to applying artificial intelligence methods.
- To take advantage of the Python programming language's ability when it comes to applying artificial intelligence methods.

A MYSQL server is used to manage the database at the database level.
The proposed system, in this article, aims to rank a set of alternatives (actions) from the best to the worst, that meets decision makers' requirements regarding several criteria, the ordering of the alternatives is associated with a score indicating the preference degree(how one action is preferred against another action).

A. The Adressed Problem

WIM-GDSS is adequate for all kinds of multi-criteria problems, however in this case study, the aim is to rank a collection of empty zones to assist decision-makers in choosing the best appropriate zone for the construction of a dwelling. The authors used an actual area as the basis of our analysis (with real data). The case used in this current study was brought up by Joerin [41] and treated also by [1]. The study area is located in the canton de Vaud in Switzerland, about 15 kilometers from Lausanne, and has an area of about 52 000 km2. Its geographical limits in the Swiss coordinating system are 532 750-532 500 (m) and 158 000-164 000 (m) (m). In addition to 650 empty lots (alternatives), seven criteria were defined based on a variety of factors (environmental, social, economic, etc.): harm, noise, impacts, geotechnical, and natural risks, equipment, accessibility, and climate. Figure 7 represent the matrix of performances of the problem described.

N°	ID_ZONE	HARM	NOISE	IMPACTS	GEOTECH	EQUIP	ACCESS	CLIMATE
1	202	1,00	0,68	0	1	816	8	0,92
2	209	1,00	0,45	0	1	1249	9	0,91
3	210	1,00	0,69	0	1	1165	9	0,89
4	211	1,00	0,48	0	1	1518	9	0,92
5	213	1,00	0,92	0	1	1356	9	0,89
6	215	1,00	1,00	0	1	1434	8	0,75
7	216	1,00	0,97	0	1	1490	10	0,83
8	218	1,00	1,00	0	1	1556	8	0,70
9	219	1,00	1,00	0	1	1638	12	0,68
10	220	1,00	1,00	0	1	1629	8	0,68
11	221	1,00	0,95	0	1	1641	10	0,84
12	223	1,00	1,00	0	1	1697	8	0,68
13	224	1,00	0,98	0	1	1758	10	0,70
14	225	1,00	1,00	0	1	1801	8	0,67
15	226	1,00	0,91	0	1	1809	10	0,84
16	228	1,00	1,00	0	1	1840	8	0,67
17	229	1,00	0,97	0	1	1870	10	0,68
18	230	1,00	0,09	0	1	1848	12	0,55
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:
644	9516	1,00	1,00	6	6	1568	6	0,69
645	9517	1,00	1,00	6	6	1569	8	0,67
646	9519	0,57	0,82	6	6	1589	10	0,47
647	9525	1,00	0,98	6	6	1766	12	0,07
648	9534	1,00	0,26	6	6	1912	11	0,39
649	9548	1,00	0,14	6	6	2240	12	0,66
650	9550	0,00	0,03	6	6	2012	10	0,54

Figure 7. Matrix of performances. Source([1])

B. Identification of The Actors Involved

The following decision-makers (actors) are involved in the current study:

- Decision maker 1: Environmental associations (EAss)
- Decision maker 2: Politician (Pl)
- Decision maker 4: Public (Pub)

Each one of these actors is represented by a virtual cognitive agent, created using the spade platform. The AHP approach is used to assign a weight to each decision-maker to represent their importance in the decision-making process. It should be noted that in this analysis, all decision makers are considered to be equally important.

C. Identification of Decision-makers' Preferences

Table IV shows the priorities of decision makers involved in the process; the ratings reflect the significance of the criteria to the decision maker; as shown, the values vary from one decision maker to the next; these values were determined using the AHP method.

TABLE IV. Criteria weights

	Harm	Noise	Impacts	Geotech	Equipment	Access	Climat
Pl	0.14285714	0.14285714	0.14285714	0.14285714	0.14285714	0.14285714	0.14285714
EAss	0.38397392	0.24243539	0.15307008	0.09664616	0.06102094	0.03852771	0.02432582
Pub	0.11128135	0.15447047	0.09385912	0.05900272	0.02912757	0.53175342	0.02050535

Table V illustrate the cost/benefit evaluation for each criterion, where Max represents a benefit criterion (the higher the better) and Min represents a cost criterion (the lower the better).

TABLE V. Cost/Benefit evaluations

	Harm	Noise	Impacts	Geotech	Equipment	Access	Climat
Evaluation	Max	Max	Max	Max	Max	Min	Max

D. Simulation of the decision making process

In WIM-GDSS there are two levels of system use (Figure 1), each with its own set of panels and activities; these levels are Administrator and Decision Maker, respectively

1) Administrator level

The administrator is responsible for managing the decision makers' accounts on the WIM-GDSS platform (Figure 8). To complete the decision maker's registration process, the administrator requires his XMPP credentials (JID and Password), for which the decision makers must have a valid XMPP account (refer to [30] for more details.)

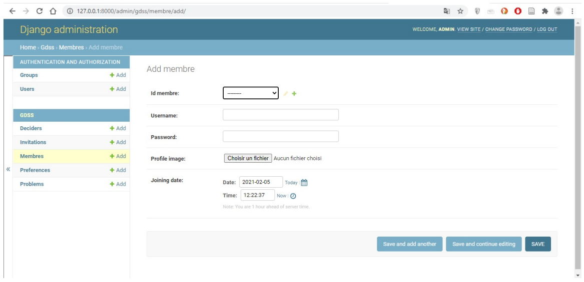


Figure 8. Panel of adding a new decision maker

2) *Decision maker level*

The decision makers has a separate panel of login and dashboard (Figure 9).

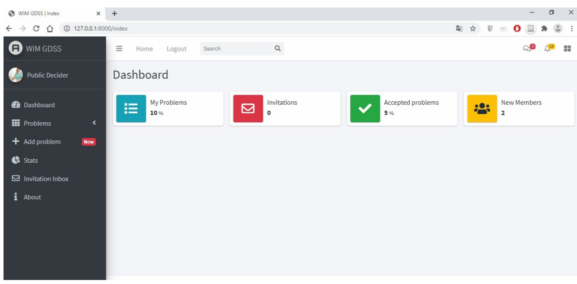


Figure 9. Decision maker's dashboard

When the decision maker logs in, the corresponding agent will automatically start having two FSM behaviors (Figure 10), each of which corresponds to a role (participant or initiator). The spade agent has its own web page that displays the agent's status and behaviors at all times (Figure 11).

Every decision maker in the system can initiate a new problem and select the decision-makers involved. The initiating agent is given the role of initiator and its corresponding behavior will be automatically triggered. After submitting, the agent will send an invitation to their agents to participate in the new decisional problem and await their responses. The participants have an invitation inbox panel (Figure 12) that contains the invitations received; in this panel, the decision-maker can view all of the problem's details (deadline, downloadable excel file, accept, refuse). When an invitation is accepted, the corresponding agent sends a response message to the initiator agent, who stores the responses for later use.

Following acceptance of an invitation, the participant must define their preferences (Figure 13), and then the AHP method is used to assign weights to the criteria. After all decision-makers have responded to their invitations or the deadline has passed, the initiator agent will compare the number of accepted invitations to the problem's acceptance threshold to determine whether to accept it or not. Following the acceptance of the problem, the agents involved (including the initiator) coordinate to carry out the execution phase of the coordination protocol in order to reach a compromise solution (see phase 2 and 3 in Figure 6).

When all of the agents have completed calculating and forming their objective vectors (ranked solutions), the initiator agent creates a global matrix by concatenating the objective vectors (Table VI) to serve as a global problem to be solved. Table VII depicts the final solution as an ordering of the problem zones.

TABLE VI. Group matrix of performances

Id-zone	C_1^*	C_2^*	C_3^*
202	0,122604373	0,060629518	0,061477084
209	0,122606179	0,060641976	0,061489357
210	0,122613016	0,060642142	0,061489318
211	0,122612792	0,060644348	0,061491521
213	0,122625516	0,060645201	0,061492005
⋮	⋮	⋮	⋮
9534	0,122687643	0,06064827	0,061492059
9548	0,122705964	0,060685866	0,061529502
9550	0,122651146	0,060637871	0,061476565

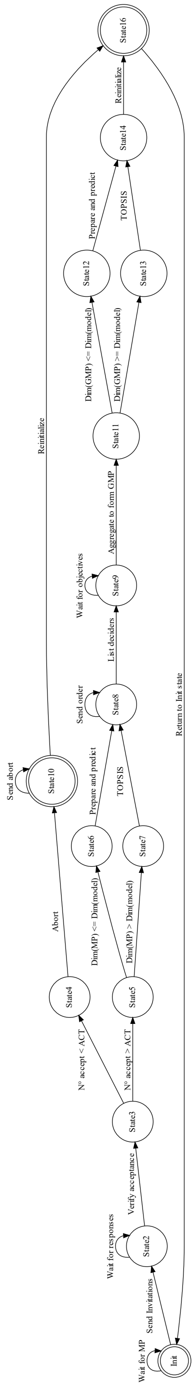
TABLE VII. Objective vector of the group problem

Rank	**ID zone**	**Score**
1	1045	0,000513351
2	3817	0,000513345
3	3820	0,00051328
4	3822	0,000513277
5	1049	0,000513253
6	6986	0,000513243
7	3701	0,000513235
8	5265	0,00051323
9	845	0,000513225
10	1050	0,000513217
⋮	⋮	⋮
648	7403	0,000512132
649	7402	0,000512131
650	7412	0,000512123

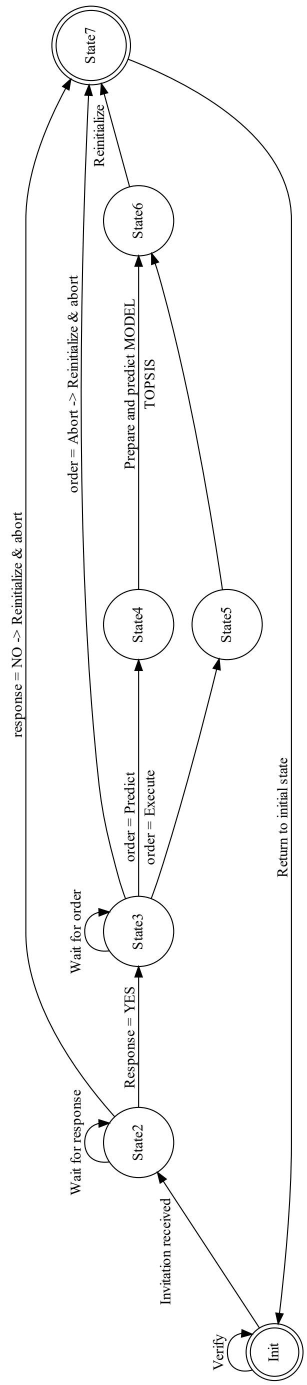
All of the results of the agents' executions (both local and global) are saved as excel files. Figure 14 illustrates a journal log of the various messages exchanged during the decision-making process between the initiator and participant agents.

E. Results and discussion

In this section, the authors provide a validation study for the model used in WIM-GDSS. As previously stated, a linear regression model was trained on a seven- dimensional dataset with real data. After the training process, the model gave an accuracy of 99% in the validation phase, The latter model was saved and used to predict any multi-criteria problem with seven or fewer dimensions (number of



(a) Finite state machine behavior of the initiator



(b) Finite state machine behavior of the participant

Figure 10. Agents behaviours

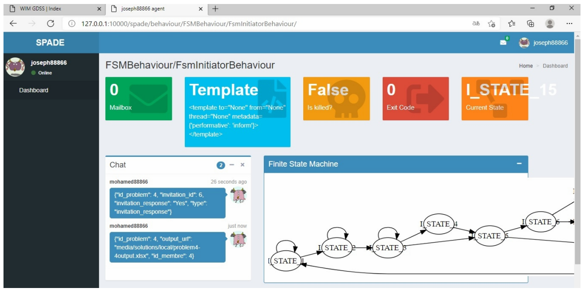


Figure 11. Spade's agent dashboard

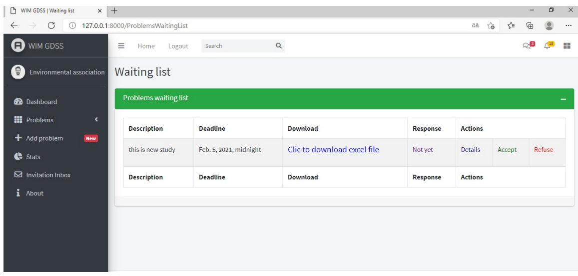


Figure 12. Decision-maker's invitation inbox

criteria). The trained model is used in the decision-making process at both the individual and group levels. Each decision maker expresses his or her preferences (Table IV), resulting in a difference matrix of performances for each of them, which is then fed into the model. Table VIII, Table IX and Table X show the predicted ranking compared with the measured ranking using the TOPSIS method to observe the model's performance in comparison with the TOPSIS method. As shown, the ranking of alternatives did not change, confirming the model's efficiency for a seven-dimensional problem.

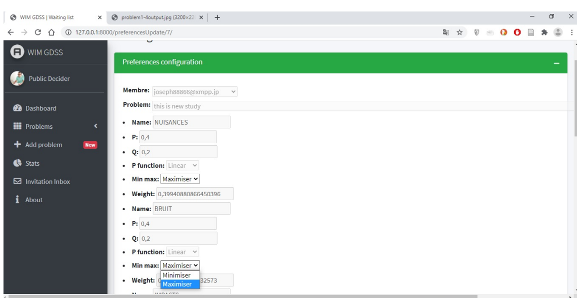
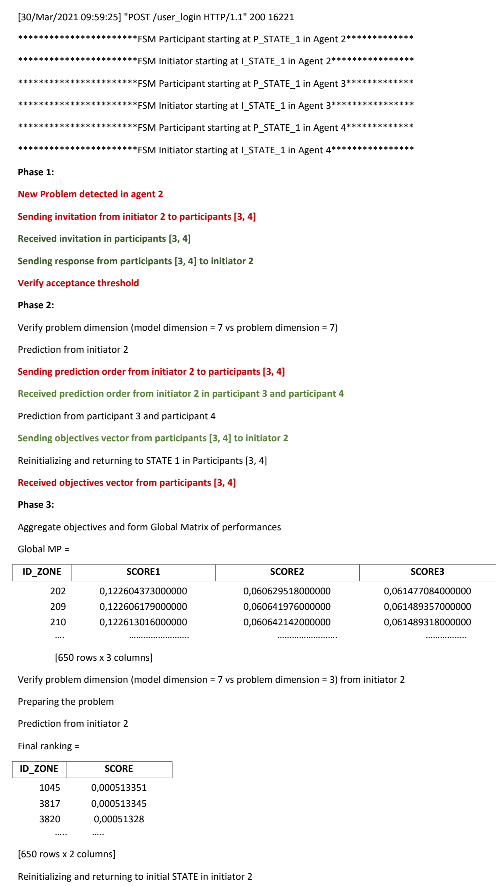


Figure 13. Criteria configuration panel


[30/Mar/2021 09:59:25] "POST /user_login HTTP/1.1" 200 16221

**********************FSM Participant starting at P_STATE_1 in Agent 2*************

**********************FSM Initiator starting at I_STATE_1 in Agent 2****************

**********************FSM Participant starting at P_STATE_1 in Agent 3*************

**********************FSM Initiator starting at I_STATE_1 in Agent 3****************

**********************FSM Participant starting at P_STATE_1 in Agent 4*************

**********************FSM Initiator starting at I_STATE_1 in Agent 4****************

Phase 1:

New Problem detected in agent 2

Sending invitation from initiator 2 to participants [3, 4]

Received invitation in participants [3, 4]

Sending response from participants [3, 4] to initiator 2

Verify acceptance threshold

Phase 2:

Verify problem dimension (model dimension = 7 vs problem dimension = 7)

Prediction from initiator 2

Sending prediction order from initiator 2 to participants [3, 4]

Received prediction order from initiator 2 in participant 3 and participant 4

Prediction from participant 3 and participant 4

Sending objectives vector from participants [3, 4] to initiator 2

Reinitializing and returning to STATE 1 in Participants [3, 4]

Received objectives vector from participants [3, 4]

Phase 3:

Aggregate objectives and form Global Matrix of performances

Global MP =

ID_ZONE	SCORE1	SCORE2	SCORE3
202	0,122604373000000	0,060629518000000	0,061477084000000
209	0,122606179000000	0,060641976000000	0,061489357000000
210	0,122613016000000	0,060642142000000	0,061489318000000
….	……………………	……………………	……………..

[650 rows x 3 columns]

Verify problem dimension (model dimension = 7 vs problem dimension = 3) from initiator 2

Preparing the problem

Prediction from initiator 2

Final ranking =

ID_ZONE	SCORE
1045	0,000513351
3817	0,000513345
3820	0,00051328
…..	…..

[650 rows x 2 columns]

Reinitializing and returning to initial STATE in initiator 2

Figure 14. Journal log of the decision making process

TABLE VIII. TOPSIS vs Model for Environnemental association agent

Rank	TOPSIS ranking	Model ranking
1	1345	1345
2	4142	4142
3	1343	1343
4	1340	1340
5	5557	5557
6	1337	1337
7	1326	1326
8	6956	6956
9	1045	1045
10	1321	1321
⋮	⋮	
648	8430	8430
649	230	230
650	3003	3003

TABLE IX. TOPSIS vs Model for Politic agent

Rank	TOPSIS ranking	Model ranking
1	3817	3817
2	1045	1045
3	3701	3701
4	3820	3820
5	3822	3822
6	1049	1049
7	845	845
8	6986	6986
9	1050	1050
10	649	649
11	3401	3401
12	943	943
13	945	945
⋮	⋮	
648	7402	7402
649	7412	7412
650	9203	9203

TABLE X. TOPSIS vs Model for Public agent

Rank	TOPSIS ranking	Model ranking
1	3817	3817
2	1045	1045
3	3701	3701
4	3820	3820
5	3822	3822
6	1049	1049
7	845	845
8	6986	6986
9	1050	1050
10	649	649
11	3401	3401
12	549	549
13	8747	8747
⋮	⋮	
648	7402	7402
649	7412	7412
650	9203	9203

At the group level, a new performance matrix is generated by aggregating the objective vectors of decision makers, resulting in a three-dimensional matrix. As previously stated, the number of dimensions must be adjusted to fit the model's dimensionality. The model on the resulting fitted matrix of performances is used to forecast the final ranking of the group decision-making problem (Table XI).

TABLE XI. The fitted matrix of performances

Id-zone	C_1^*	C_2^*	C_3^*	Extra1	Extra2	Extra3	Extra4
202	0,122604373	0,060629518	0,061477084	0,0	0,0	0,0	0,0
209	0,122606179	0,060641976	0,061489357	0,0	0,0	0,0	0,0
210	0,122613016	0,060642142	0,061489318	0,0	0,0	0,0	0,0
211	0,122612792	0,060644348	0,061491521	0,0	0,0	0,0	0,0
213	0,122625516	0,060645201	0,061492005	0,0	0,0	0,0	0,0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
9534	0,122687643	0,06064827	0,061492059	0,0	0,0	0,0	0,0
9548	0,122705964	0,060685866	0,061529502	0,0	0,0	0,0	0,0
9550	0,122651146	0,060637871	0,061476565	0,0	0,0	0,0	0,0

The partial dependence plots shown in Figure 15 illustrates the relationship between the individual scores (preferences) of the decision-makers and the final (global) score. The rising lines indicate a direct linear relationship (as the individual score rises, so does the global score).

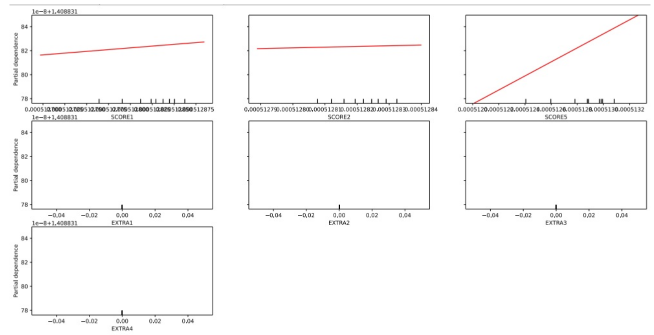


Figure 15. Partiel dependence plots for the reduced problem

The extra four plots represent the dimensions that were added to allow the model to predict; the latter plots are empty, indicating that they have no effect on the final result. The model's performance when changing the number of alternatives (increase or decrease) is the last thing to check; note that all of the matrices of performances used up to this point were composed of 650 alternatives; in the following example, the authors reduced the number of alternatives to 449 and changed the parameters (Table XII) to obtain a different matrix of performances.

TABLE XII. Criteria weights for reduced problem

	Harm	Noise	Impacts	Geotech	Equipment	Access	Climat
Weights	0.11128135	0.15447047	0.09385912	0.05900272	0.02912757	0.53175342	0.02050535

The previously trained model was used to predict each decision maker's individual ranking as well as the final compromise ranking that satisfied the majority of them. Following that, the TOPSIS method is used to calculate the solutions in order to conduct a comparison analysis to determine the model's reliability on the reduced problem. Table XIII shows the predicted and calculated ranking of alternatives. The model has an MSE (Mean Square Error) error of 0.00022, but it still predicts the ranking of the alternatives with high precision, (the exact same ordering was obtained in comparison to the result of the initial problem shown in Table XIV).

TABLE XIII. TOPSIS vs Model rankings for group decision

Rank	TOPSIS ranking	Model ranking
1	1045	1045
2	3817	3817
3	3820	3820
4	3822	3822
5	1049	1049
6	6986	6986
7	3701	3701
8	5265	5265
9	845	845
10	1050	1050
⋮	⋮	
648	7403	7403
649	7402	7402
650	7412	7412

TABLE XIV. TOPSIS vs Model ranking for reduced problem

Rank	TOPSIS ranking	Model ranking
1	1045	1045
2	943	943
3	3822	3822
4	4142	4142
5	1343	1343
6	1345	1345
7	1340	1340
8	1337	1337
9	1319	1319
10	845	845
⋮	⋮	
648	2402	2402
649	1002	1002
650	1001	1001

6. Limitations Of The Proposed System

The main limitations of the proposed WIM- GDSS are:

- The prediction model cannot be used on problems with more than seven criteria.
- The prediction model does not perform well when dealing with problems that have more than one cost criterion.
- The used multi-criteria method (TOPSIS) does not provide much flexibility to decision makers in terms of how deviations between alternatives are handled (only one subjective parameter).

7. Conclusion and Future Work

This paper proposed an innovative Web Intelligent Multi-criteria Group Decision Support System for land use management (WIM-GDSS).The latter incorporates four tools namely: multi-agent system, geographic information system, multiple criteria decision support, artificial intelligence. This system is dedicated to problems with the particularity of having multiple decision-makers with conflictual interests, and influenced by several criteria. The decision-makers in WIM-GDSS are modeled by virtual cognitive agents, using a multi- agent system, to assure a distributed environment, allowing the decision-makers to coordinate for choosing the alternative that best meets the given criteria. The latter agents are cognitive with a prediction capacity allowing them to predict the desired result taking into account decision makers' preferences, the prediction model fed to the agents is designed for problems with less than or equal to seven criteria, and it has proven to be as efficient and accurate as the TOPSIS method in terms of ranking. Like any research work, this paper's work has limitations and we are looking forward to exploring some of these limitations to get a better version of WIM-GDSS, below are some perspectives, which we are intended to resolve in the future:

- Fully integrate the GIS tool into WIM-GDSS
- Use fuzzy multi-criteria methods to deal with data uncertainties in the multi-criteria module
- Optimize the suggested model by using a larger dataset (more than seven criteria) in training than the one in use.
- Train non-supervised models.

Acknowledgment

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