An ontology-based spatial group decision support system for site selection application

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ABSTRACT

This paper presents a new ontology-based multicriteria spatial group decision support system (GDSS) dedicated to site selection problems. Site selection is one of the most complex problems in the construction of a new building. It presents a crucial problem in terms of selecting the appropriate site among a group of decision makers with multiple alternatives (sites); in addition, the site must satisfy several criteria. To deal with this, the present paper introduces an ontology based multicriteria analysis method to solve semantic heterogeneity in vocabulary used by participants in spatial group decision support systems. The advantages of using ontology in GDSS are many: i) it enables the integration of heterogeneous sources of data available on the web and ii) it enables to facilitate meaning and sharing of data used in GDSS by participants. In order to facilitate cooperation and collaboration between participants in GDSS, our work aims to apply ontology at the model's structuration phase. The proposed system has been successfully implemented and exploited for a personalized environment.

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1. INTRODUCTION

Recently, site selection has been a very active research field in building construction. The main problem in site selection is to find the appropriate site with some condition defined by criteria selection. In the last years, site selection was based essentially on economic factors. It appears that actually, to select an adequate site, we must take into consideration different criteria such as economic, social, technical, and, environmental. Keenan and Jankowski [1] define spatial group decision support system (SGDSS) as a computer based system that assist user or group of users more effectively and in interactive way in decision making process. spatial group decision-making to select the appropriate site is based on knowledge related to the problem and preferences of each decision-maker that participates in the group decision-making process.

In this paper, we focused on the structuration phase of the model presented in [2]. The structuration phase is very important in the group decision support system (GDSS). It consists of structuring the basic elements used in the site selection problem. In this kind of problem, a group of agents with different preferences, intentions, and interests, communicate and negotiate with each other to get the appropriate site for building construction. Creating a knowledge base as the same vocabulary for communication in GDSS can facilitate the information exchange between agents and therefore increase the collaboration process. To achieve our objectives in our work we ask the questions: i) are the agents need to have the same vocabulary for collaboration in group decision support? and ii) how we can represent this knowledge in a way that makes it more readable, structured, and shared by decision-makers? To deal with this, we propose to use ontology.

Ontology is defined as the conceptualization of a domain, in other terms, is an explicit formal specification of a shared conceptualization of a domain of interest [3].

The SGDSS, according to Keenan and Jankowski [1], is an interactive and computer-based tool created to assist a user or group of users in making decisions. In addition, Li *et al.* [4] suggest that the main concept of spatial decision support system (SDSS) is the interaction of users with a computer-based system, this interaction contain a number of tools for modeling spatial decision situations and evaluating geographical and non-spatial data. There are many different approaches and frameworks using the spatial decision support system in different fields. Among these works, we cite investigating knowledge and learning [5], medical emergency services [6], [7] ecological engineering [8], intercropping [9]. We can cite also, land use planning [10], Urban planning [11], [12], web-based intelligent SDSS [13], water management [14]. Recently, a lot of works have been interested by solving one of important and complex spatial decision problems, which is site selection. Current researches related to site selection problem implementing spatial decision support system are listed in Table 1.

Table 1. A literature review SDSS for selection problem

Fields	Approach/Model	Objectives	References
Parking site selection	Web 3.0-driven Collaborative SDSS	Integrate the Web2.0 community methods and the semantic web technologies for solving parking site selection.	[15]
	A group Web-based GIS and SDSS		[16]
Landfill site selection	GIS and SDSS	Support landfill site selection efforts in public health and physical environment.	[17]
	GIS and SDSS modeling	Employ methods of selection criteria concerning landfill geographic information system (GIS) modeling to clarifying its problems in this filed.	[18]
	GIS and Multicriteria analysis	Optimize number of potentials sites to reduce time in decision making process with desired conditions defined by selection criteria.	[19]
Site selection for facilities (airports, high ways and heavy industry, electronic and electricity)	Multicriteria decision analysis and AHP	Identify the most optimal location of facilities for the e-waste dismantling and sorting facility (DFS) in Indonesia using analytic hierarchy process (AHP).	[20]
Territory planning (TP)	Temporal distributed GDSS and PROMETHEE II	Propose a new model based on a multi-agent system and multi-criteria group decision support system modeling a spatial problem.	[21]
	Web-GDSS	Propose a multi-agent system and multicriteria analysis to help decision-makers in order to obtain a collective decision using monotonic concession protocol (CONDORCET and BORDA voting methods).	[22]

Use ontology in spatial decision support system is recent domain of interest. One of the most popular definitions of ontology refers to [23] in 1993, he was the first to employ the term of ontology in artificial intelligent (AI) field, and he suggests: an ontology is an explicit specification of a conceptualization. Knowledge is the base element of any decision support system (DSS), ontologies have been used in many DSS applications to give a structured and formal representation of this knowledge [24]–[27].

In [28] two ontologies are developed in air transport domain. The authors use decision making method for design stage of project delivery. These two ontologies provide heterogeneous decision preferences for evaluating sustainable infrastructure developments. Ontologies have been suggested in [29] to assist electronic air traffic management (ATM) operations. In this study, the authors demonstrate how air traffic controllers (ATCs) may interact with aircraft operators on physical airspace coordination using uncertainty representation and the reasoning evaluation framework (URREF). They employ the URREF-enabled avionics analytics ontology (AAO). The contribution of authors in [30] is an ontology-based system that provides the knowledge base for the subsea multiphase pump decision support system used in the oil and gas industry. The use of ontology in this study enhances the ability to suggest potential technologies based on the match algorithm and percentage comparator. The method suggested in [31] was a novel multi-objective holistic approach for designing energy pile systems using ontology-based multi-domain knowledge orchestration.

A large number of works used ontology and decision support systems in medical area. The analytic hierarchy process (AHP) technique was proposed in [32] as a multicriteria decision support service that support victims in their demand to identify the most suitable hospital. In [33], a decision support system based on ontology and hypothetical chemical hazard scenarios was built in goal to increase openness in catastrophe scenarios and disaster situations.

The study of related work in the field of ontology-based decision-making has shown that we can classify the related work into two different groups [3]: i) spatial decision support system in ontologies: approaches that use ontologies and ontology reasoning mechanisms to support decisions; and ii) spatial decision support system based partially on ontologies: approaches that use information from ontology as an input for decision-making, even though decision-making is not performed using ontology-based reasoning mechanisms.

In approaches that belongs to group: spatial decision support system in ontologies, the ontologies are used for two main objectives: firstly, it represents the knowledge of the spatial decision support system in a format that can be understood by both humans and machines, secondly the ontology reasoning mechanism is used in the process of making a decision. In this section, we discuss these approaches and compare them with our proposed system. In Table 2, we present other works that use decision support system in ontologies for the environment and spatial domain.

Table 2. Approaches use DSS in ontologies for environment and spatial domain

Fields	Approach/Model	Objectives	References
Land-use suitability	GIS and object-oriented programming	Propose a SDSS to support decision-making in land-use planning to enhances the strong trend towards using the advantages of knowledge-management.	[27]
City's social infrastructure	GIS and ontology	Develop a system to manage and monitor social infrastructure in the city.	[34]
Ecological networks	GIS and ontology	Develop an ontology that describe spatial constraints and their properties to automatically select the appropriate solution to a particular problem	[35]
Environment	Ontology and SPARQL	Develop a decision support system based on ontology and semantic sensor network (SSN) to allow developers to create rules for calculating fire weather indices.	[36]
Smart cities	Ontology	Propose an ontology modeling smart city knowledge (including visions, challenges, and solutions) aims to ensure sharing and reuse of the knowledge for informed planning decision making.	[37]
Health tourism	Collaborative Design Ontology	Develop an ontology-based decision support system for health tourism destinations. The goal of this system is to connect the available natural resources, the value offerings and the target groups of nature-based health tourism (NHT) destinations.	[38]

All these approaches use ontology to include all the group decision support system. The role of ontology in this kind of approaches is for two objectives: the first one is to represent the knowledge base of the system and the second objective is to use the inference system and reasoning techniques of ontology to get result and decision. On the contrary to our work, the ontology file represents data, suggestions/solutions and decisions related to the decision problem. The solution and final decisions can be obtained by using the reasoner engine included in ontology.

In approaches belongs to group: spatial decision support system based partially on ontologies, the knowledge base presented in ontology is used as input for decision-making model, which is performed in a separate tool. Our system belongs to this type of system. The approaches cited in Table 3 are examples of approaches that used ontology to represent data related to decision support system. Equivalent to our work, these approaches are based on the extraction of information from ontology to make decision with a separate decision model.

In this paper, we propose to develop a new system for site selection problem. Site selection problem is complex, multidimensional and interdisciplinary with multiple alternatives and multiple criteria. In order to select the appropriate site for building construction, different actors with different domains of interest can intervene in decision-making process. Each actor called participant (decision maker) is designed by his/her preferences. These preferences are list of criteria among his/her domain of interest and these criteria are represented in his/her own vocabulary.

By using ontologies in our system, the decision makers do not need to get the same vocabulary in the global knowledge base of decision-making process. The most significant advantage of using ontology is to facilitate communication and improve collaboration between participants, and therefore, reach a compromise in the decision-making process. Our proposed system is based on ontology and the multiple criteria decision analysis (MCDA) method. The goal of this system is to elaborate a spatial GDSS, which will be used to select the appropriate site for building construction. In the proposed system, we developed two ontologies: global ontology OG: to represent the global knowledge base of GDSS, and local ontology (OL) to describe the vocabulary of decision maker. By using a global ontology, a group of participants can reach a shared understanding by committing to the same ontology. To answer the questions presented in the introduction section, we focused on the participant's vocabulary and we suggest that they do not need to use the same vocabulary to describe the list of criteria. We also suggest that each participant represent his own preferences in local ontology as we named OL. Our methodology consists of using a linking method to link terms in the decision maker's ontology with their corresponding in a global ontology. From our point of view, there are two important functions of ontologies in our system: i) enable participants to work cooperatively and communicate with each other ii) make the available information in participant vocabulary comprehensive and more accessible and that by including ontologies and semantic web technologies.

On the contrary to our work, and in classic GDSS (GDSS does not integrate ontologies in the representation of the knowledge base of the site section problem) when specified terms in decision maker's vocabulary do not exist in the global knowledge base, this participant receives a reject and do not participate in decision making process. However, in the case of our system that integrates ontologies in structuration phase of GDSS, the participant can terminate the decision-making process by the corresponding terms (synonyms/factors: see uses cases). These corresponding terms are the result of semantic matching by the vocabulary of participant and the global knowledge base.

Our contribution consists of the following: firstly, we construct a global ontology (OG) for GDSS domain, which contains all basic elements, terms and synonyms, concepts, and relationships for the site selection problem. Secondly, local ontology OL is developed to represent the preferences of each participant (his/her own vocabulary). Thirdly, a linking method is employed to match participant's vocabulary in local ontology with their synonyms in a global ontology. Finally, a protocol of negotiation is applied to get the appropriate site.

The rest of the paper is organized as: in section 3, methodology is discussed. Section 4 contain results and discussion. In sections 5 conclusion, and future works are drawn.

Table 3. Approaches use ontology to represent data in DSS

Fields	Approach/Model	Objectives	References
Logistics Decision-making process	Ontology-based method	Propose a solution that uses ontology to describe the concepts, terms, knowledge and methods of logistics is constructed in a formal and specification way to improve the efficiency and accuracy of dynamic logistics decision-making procedure in enterprises.	[39]
Route planning system	GIS, ontology and AHP method	Improve an impedance model of road GIS for personalization route planning system, the use AHP method to evaluate multiple criteria resulting in hierarchical structure.	[12]
Electronic Product lifecycle management (PLM) systems	Ontology and ELECTRE IS Method	Measuring part Similarity based on ontology and multi-criteria decision making (MCDM) techniques by comparing users input data with part data stored. Semantic web rule language (SWRL) rules was used to validate uses' part preferences	[40]
Tender evaluation process	Ontology modeling	Assist decision makers to find principal data in order to automation transforming unstructured to structured data for decision-making analysis	[41]
Site selection process	Ontology, GIS and PROMETHEE II Method	Propose a spatial decision support system based on ontology and GIS to facilitate site selection negotiation process and reduce decision-maker conflict.	[42]

2. METHOD

In this section, we discuss the global architecture and basic components of our system Onto-GDSS. Figure 1 show essential elements of the system proposed. In this work, and to improve integration of ontologies in GDSS, the system architecture contains two essential components: ontology component and GDSS component. In the first subsection, we presented ontology component and in the second, we describe the GDSS component.

2.1. Sub system ontology

In this subsection, we described the ontology component and we discus in details the ontology development process. Later, the developed ontology is used as input data for the GDSS system for the site selection problem. It represents the performance matrix exploited by the GDSS.

2.1.1. Ontology development process

We focus on ontology and semantic web technologies to represent basic elements in the formulation of decisional problem situations for example, site selection problems. The basic elements of GDSS are knowledge base and preferences of the participants. The role of using ontology in our work is to represent the knowledge base of the system, and the preferences of participants. In this sense, the ontology representation can facilitate the collaboration and cooperation between participant in the GDSS process. In our system, we use two ontologies global ontology OG for the knowledge base of GDSS and local ontology (OL), which contain the information about each participant and his preferences.

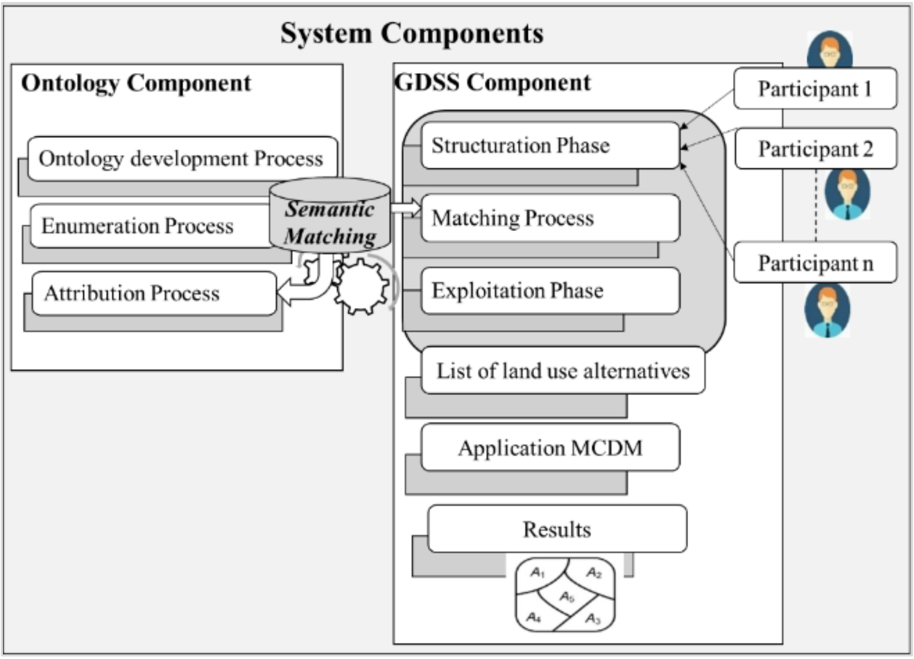


Figure 1. Global architecture of Onto-GDSS

From the previous works [43], many methodologies can be used for developing a new ontology, such as Uschold and King, Grüninger and Fox, Methontology, KACTUS, and ontology development 101 [44]. Each methodology has its advantages and drawbacks. In this work, ontology development 101 is chosen because of the following reasons: i) it is easy to use for beginners with no former experience in ontology development; ii) it provides guidance on how to implement the ontology step-by-step in the Protégé software environment; iii) it is suitable for development by reusing existing ontologies. Therefore, the following steps are used to construct the structural design ontology:
Step 1. Determine the domain and scope of the ontology,
Step 2. Consider reusing existing ontologies,
Step 3. Enumerate important terms in the ontology
Step 4. Define the classes and the class hierarchy,
Step 5. Define the properties of classes,
Step 6. Define the relations between classes,
Step 7. Create instances

We organize these seven steps in three (03) phases as shown in Figure 2. The following sections focused on the process to develop the two ontologies cited before; a global ontology to represent the performance matrix and local ontology to represent decision maker’s preferences. The same steps are used for the development of these two ontologies.
Phase 1. Problem formulation
Step 1. Defining domain and scope

In this step, we can start the development of our ontology by asking some basic questions. As examples: What is the domain that the ontology will cover? For what we are going to use the ontology? Who will use and maintain the ontology? By answering these questions, the essential information recovering the domain of use of ontology is presented as ontology file.

The domain of ontology determines all knowledge related to the site selection problem, which is a complex problem. This problem is recognized by set of multiple alternatives and set of multiple criteria and set of agents in order to reach an acceptable compromise. These elements constitute the decision matrix of the site selection problem. This phase involves collecting terms from other related studies and is based mainly on the systematic method and case studies proposed in the works of [2], [21], [22], [45], [46].

Inspired from previous work, we propose our global ontology OG as set of {*i*, *j*, *k*,*l* } where: *i*: number of alternatives, *j*: number of criteria, *k* number of factors and *l*: number of synonyms. Global ontology *OG* contain all basics elements for site selection problem such as:

– Alternatives that contain the *m* alternatives (sites) candidate noted by A_i *(i=1, 2, 3* [45] *…n)*.

– Criteria that contain the hierarchical structures of seven suitable criteria noted by C_j (j=1, 2, 3, 4, 5, 6, 7) where C_j={*Accessibility*, *Harm*, *Noise*, *Geotechnicals Naturals Risks*, *Impacts*, *Climate and Equipment*}, which are defined as a subclass of Criteria.
– Factors in this class, we collect list of terms, noted by F_k, which can be regrouped as semantic aggregation for criteria.
– Synonyms class contain different nomination of criteria, noted by S_l, in another language as example French language.

Step 2. Consider reusing ontologies

In ontology development process, using existing ontologies and extending another from external sources can be recommended for building a new ontology. In our case, we construct a new ontology of site selection problem. We develop a novel ontology that cover all basic elements of decisional problem such as set of alternatives and set of specific criteria.

Phase 2. Collect of information

Step 3. Enumerate important terms in the ontology

After defining the domain and scope of our ontology, the next step is to enumerate a list of terms and concepts cover the site selection problem. The development of the list of criteria consists of identifying all the factors influencing land habitat suitability. These terms are inspired from works [2], [21], [22], [45], [46]. Some of these factors can be regrouped in criteria by semantic aggregation as shown in Table 4. In our case, land suitability incorporates 650 alternatives A_i (i=1, 2, 3 …n) where n=650 described by seven criteria C_j (j=1, 2, 3, 4, 5, 6, 7) where C_j={*Accessibility*, *Harm*, *Noise*, *Geotechnicals Naturals Risks*, *Impacts*, *Climate and Equipment*}. Table 1 describes a set of various criteria considered in this study with set of factors and synonyms considered for each identified criteria.

Phase 3. Creating ontology GDSS file

In this phase, we describe in detail two processes of creating two basic ontologies of our system, which are global ontology OG and local ontology OL. Figure 3 show the two processes: enumeration and attribution process. We use Protege1 tool to develop these ontologies.

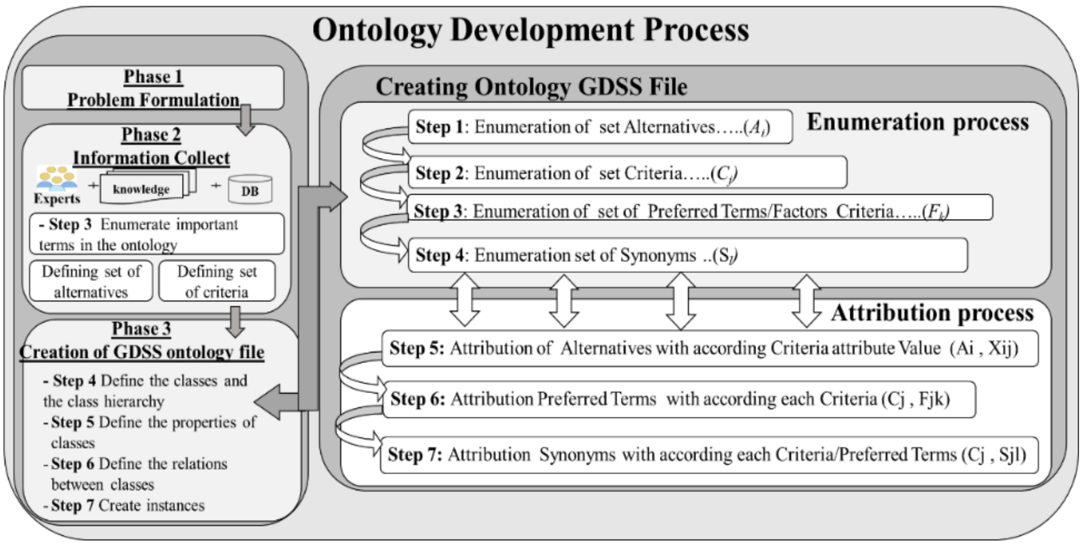


Figure 2. Ontology development process

Table 4. Identification of criteria

Criteria	Type	Scale	Factors	Synonyms (French)
1. Harm	Natural	[0,1]	Air pollution, Odors	Nuisance
2. Noise	Social	[0,1]	Motorways, Railways	Bruit
3. Impacts	Social	{0, ...,6}	Ground water, Sectorial plan	Impacts
4. Geotechnical and natural risks	Natural	{0, ...,6}	Constraints, Landslides, Flood, Seism, Firescriptsize	Géotechniques et risques naturels
5. Equipment	Economic	[0,2244]	Distance to: Gas, electricity, water, roads	Equipement
6. Accessibility	Social	[0,15]	The average time of trips between home and the workplace	Accessibilité
7. Climate	Natural	[0,1]	Sun, Fog, Temperature	Climat

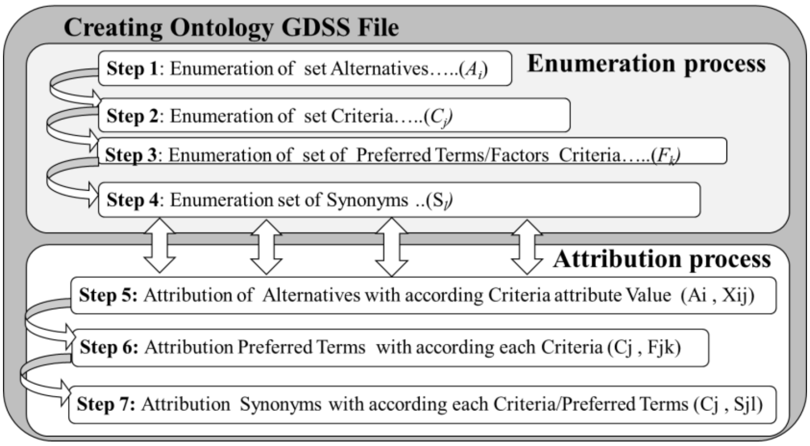


Figure 3. Creating ontology GDSS File

2.1.2. Enumeration process for creating global ontology

In this step, we enumerate the basic element of ontology file. Figure 4 represent these elements. Classes are shown in Figure 4(a), data properties are shown in Figure 4(b), object properties are shown in Figure 4(c) and annotations properties are shown in Figure 4(d). In following subsection, we detail the basic elements containing our global ontology.

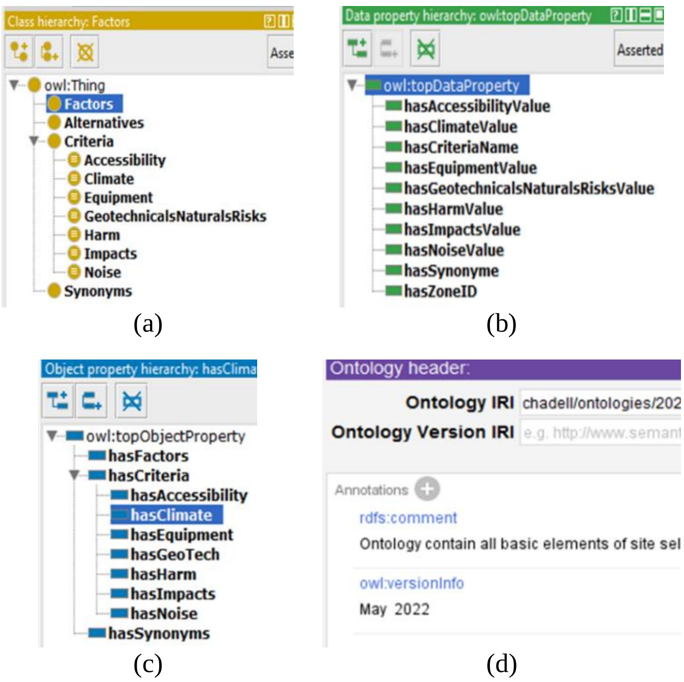


Figure 4. Classes and properties in global ontology (a) class view, (b) data property view, (c) object property and (d) annotation view

2.1.3. Define class and class hierarchy

We define four classes: alternatives, criteria, factors and synonyms as classes as shown in Figure 4(a). Alternatives class contain set of multiple solutions possible for site selection problem. Criteria class is a class that contain the hierarchical structures of seven suitable criteria: accessibility, harm, noise, geotechnical naturals risks, impacts, climate and equipment. Factors: in this class, we collect list of terms, which can be regrouped as semantic aggregation for criteria. Synonyms class contain different nomination of criteria.

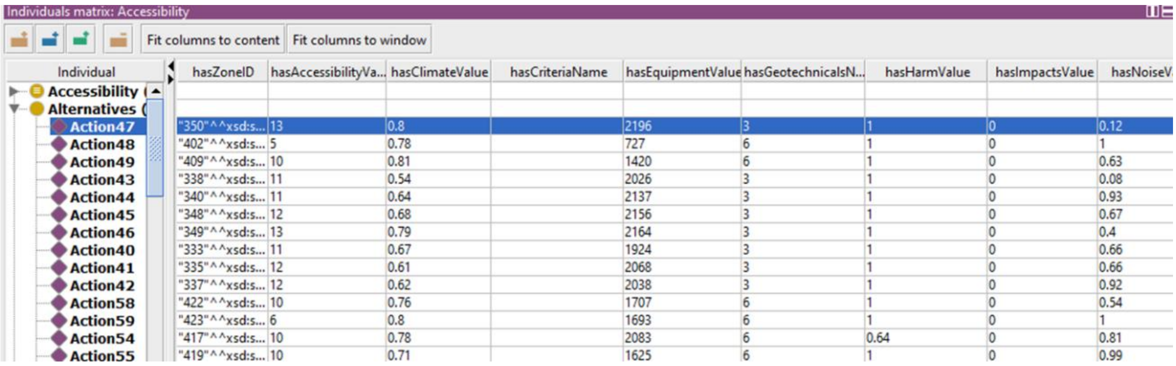
2.1.4. Define properties (attributes and relations)

There are three main types of properties: data-type property, object property and annotation property. Data-type property is a binary relation between instances of each class and their characteristic values. In our case, we define a list of datatypes that connect alternatives with their criteria attribute value, for example, "hasZoneID" in alternatives class describe the value of identity of each site as "integer" type. A data-type property can have a scale value as example data-type "hasHarmValue" in the "Harm" class as shown in Figure 4(b). Object property or relationships are binary relations that relates to individuals of classes. For example, "hasFactor" object property the relate climate instances with factors instances as shown in Figure 4(c). Annotation property is used as needed to enhance the ontology concepts with more human-friendly information as a comment, and version info as shown in Figure 4(d).

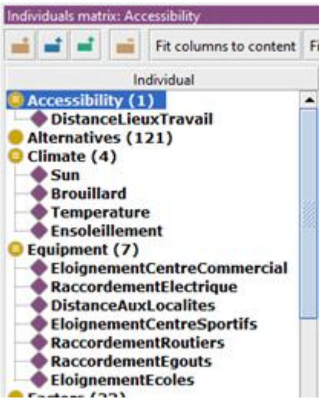
2.1.5. Attribution process for creating global ontology

a. Create instances

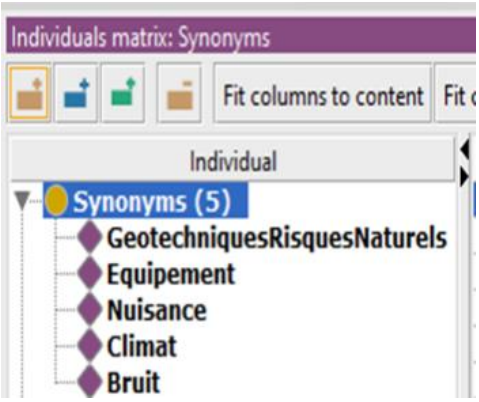
In this step, we define all evaluations of each alternative according to each criterion. Figure 5 shows the global performance matrix in the ontology file. Figure 5(a) show a set of alternatives instances with evaluation attributes X_{ij}. Example for $A_i = action\ 47$ and for $C_j = accessibility$ the $X_{ij} = 13$; Figure 5(b) shows the attribution of different criteria with their factors F_{jk}. For example, the criteria $C_j = accessibility$ and factors $F_k = DistanceLieuxTravail$ i.e., the term "*DistanceLieuxTravail*" is declared as factor of "Accessibility" criteria. Figure 5(c) shows the attribution of different synonyms with their criteria S_{jl}. For example, the criteria $C_j = accessibility$ and synonyms $S_l = accessibilit$é, then $S_{jl} = accessibilite$.



(a)



(b)



(c)

Figure 5. The global performance matrix in ontology file (a) individual of alternatives class, (b) individual of class factors, and (c) individual of class synonyms

The Figure 6 show the global ontology in graph representation powered by OntoGraph from protege. We can view all the instances containing in the ontology. All instances in class factors are presented in the view below. We can get a view of instances in alternative or in criteria class.

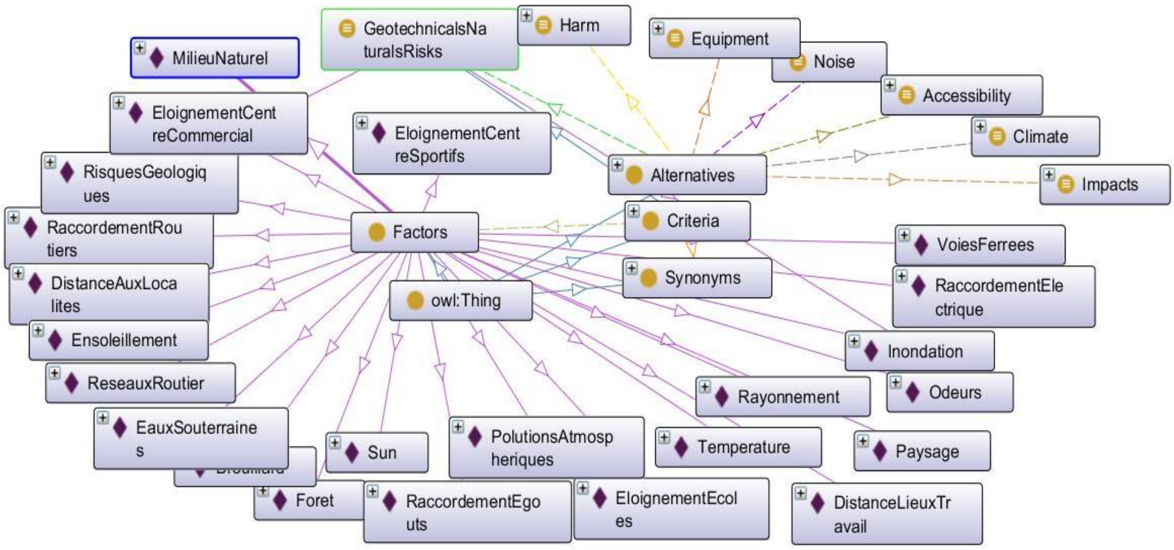


Figure 6. Global ontology in graph representation

b. Creating local ontology

The essential elements in a group decision support system are participants or decision-makers (DMs) or. each DM can be modelized by an agent. In our system, we describe ontology of each agent that contains agent vocabulary, which describe his/her preferences (specified criteria) and subjective parameters PS_i. This ontology which we named local ontology OL, facilitates communication and cooperation in the system define group of decision makers DM_i with ($i=1, ..., n$).

As same as the development of global ontology OG, we develop local ontology OL, which describes agent preferences and subjective parameters PS_i .We define classes: i) agent: class contains the information about the agent as his profile and his weight; ii) preferences: class contains the preferences of each agent; these preferences can be a set of criteria with the same nomination in global ontology or terms in his own vocabulary; iii) subjective parameters: in this class, we define the evaluation of each criterion among four parameters (weight, criteria indifference Q, criteria preference P and criteria Veto V).

Table 5 summarizes the various subjective parameters PS_i used in the multi-criteria method. They can be classified into two categories: "intercriteria parameters" and "intracriteria parameters". As same as creating OG ontology file, we use Protege to create OL ontology file. All information decision makers DM_i and their preferences, subjective parameters are defined by using enumeration and attribution process. The Figure 7 show an example of politic agent ontology with his preferences (specified criteria) value and subjective parameters values. The figure is obtained by protégé class matrix view.

Table 5. the subjective parameters Psi

Parameters	Symbol	Meaning
Weight	W_j	Qualifies the relative importance of a given criterion Cj with respect to the other criteria
Preference threshold	P_j	The threshold at which the difference between the two alternatives is perceptible and makes one preferable to the other.
Indifference threshold	q_j	This is the smallest significant difference. Below that threshold, it is impossible to separate the two actions.
Veto threshold	Vj	Allows fixing an additional notion. If this threshold is exceeded on a criterion, then the alternative cannot be taken into consideration. Thus, it defines an intolerable situation for one of the participants.

2.2. GDSS component-proposed negotiation model

The goal of this paper is to propose a multicriteria decision support system based on ontology. This system is based on the model in Figure 8. The model is composed by two main phases structuration phase and exploitation phase. These phases allow conception, structuration of all knowledge about agents of the system and exploitation of this knowledge to get the satisfaction result in goal of selecting the appropriate site in site selection problem. We inspired these phases from [2].

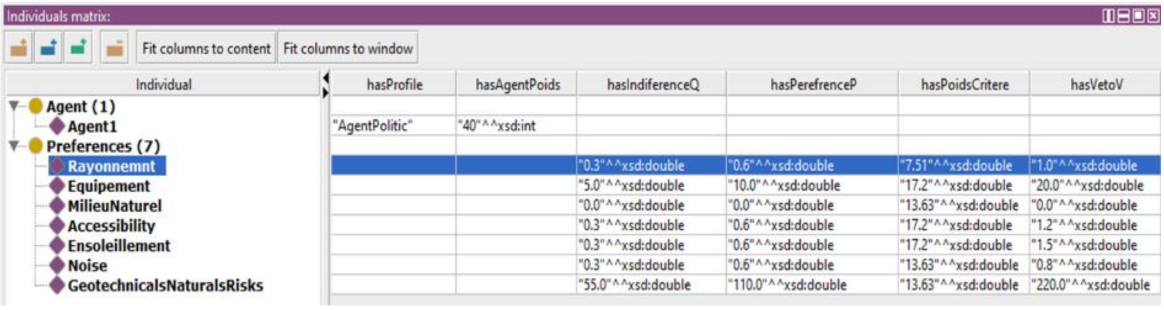


Figure 7. Politic agent local ontology view

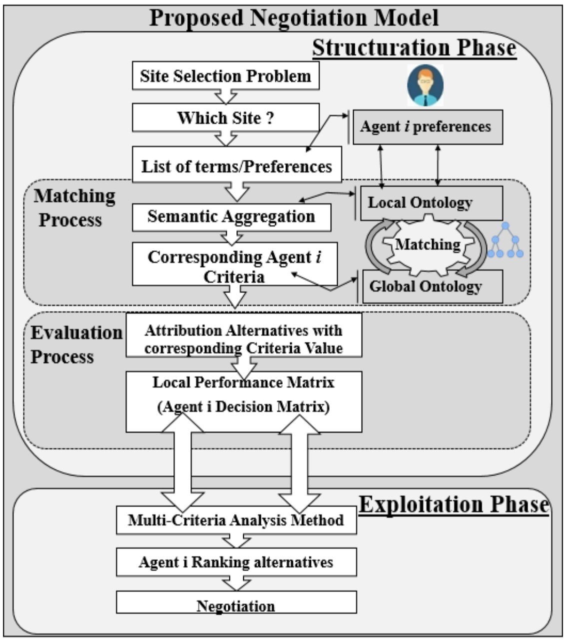


Figure 8. The proposed negotiation models

2.2.1. Structuration phase

In this phase, all information about agents are collected and structured in local ontologies (OL_1; OL_2…). The focus of our work is to get local performance matrix. Matrix that represents preferences of each agent by getting the corresponding set of criteria from the global performance matrix and ignoring criteria not employed by agent. To deal with this, we have two processes:

a. Matching process

Our objective in this process is to analyze agent ontology OL and extract the named criteria from his/her preferences by matching two ontologies OL_i and global ontology OG. We define similarity measure function $f(e_i,e_j)$ (1) to get correspondence value between two entities e_i and e_j where $e_i \in OL$ (we focused only on individuals of *Preferences* class entities), and $e_j \in OG$. Our process gets each individual of *Preferences* class in OL and compare it with all entities of OG. The output of this function is a score n_{ij}, $n_{ij}=0$ if there are not corresponding between entities, and $n_{ij}=1$ if the entity e_i can be matched with entity e_j.

$$f(ei\,, ej) = n,\ n = \begin{cases} 1 \\ 0 \end{cases} \quad (1)$$

To ensure semantic matching, the corresponding process has different types of relationships. The process consists of comparing each individual in *Preferences* class of agent ontology with all the entities in global ontology and the output of the process is list of corresponding criteria. We have tree axioms in our matching process: *owl:Class*, *rdfs:isDefinedBy* and *rdfs:synonyms*. More details in uses case section.

b. Evaluation process: generate the local ontology

The main goal of this process is to generate the corresponding decision matrix (as we named local performance matrix) for each agent according to his/her preferences criteria. The local performance matrix is decision maker matrix with same set of alternatives for each agent but these alternatives are evaluated on agent's criteria only. Each alternative in OG is evaluated with seven criteria. This process consists of selecting and extracting only the criteria that correspond (matched) with agent criteria to develop the corresponding decision matrix. The number of criteria extracted for evaluation is the *n* number issued from the semantic measure function in the above section. For example, the local performance matrix of agent 1 contain all alternatives with six criteria and not seven. Another example in local performance matrix of agent 3 contain all alternatives with four criteria and not seven.

2.2.2. Exploitation phase

When the structuration phase of GDSS is done. After the generation of local performance matrix, the next step is application of the MCDM method. In this process, each agent is invited to generate the appropriate decision matrix (local performance matrix) that contains a set of alternatives sites evaluated on the named criteria among his/her preferences and applicate the MCDM method. The output of this step is a ranking file of set of alternatives according to each agent.

The MCDM method used in this phase is PROMETHEE II (preference ranking organizational method for enrichment evaluation), which is a multi-criteria approach belonging outranking MCDM methods that provides the comparison of the alternatives for each separate criterion. PROMETHEE I was developed by [39] and allows a partial ranking obtained by the calculation of the positive and the negative outranking flows that can also give different results. PROMETHEE II was developed by [47] and provides a full ranking that can be more useful to communicate the results to decision-makers. New different versions of PROMETHEE were developed to solve the more complicated decision-making problems, also offering tools for sensitivity analysis to test the results while changing the weights [11]. Figure 9 present ranking file of each agent after the application of PROMETHEE II MCDM method.

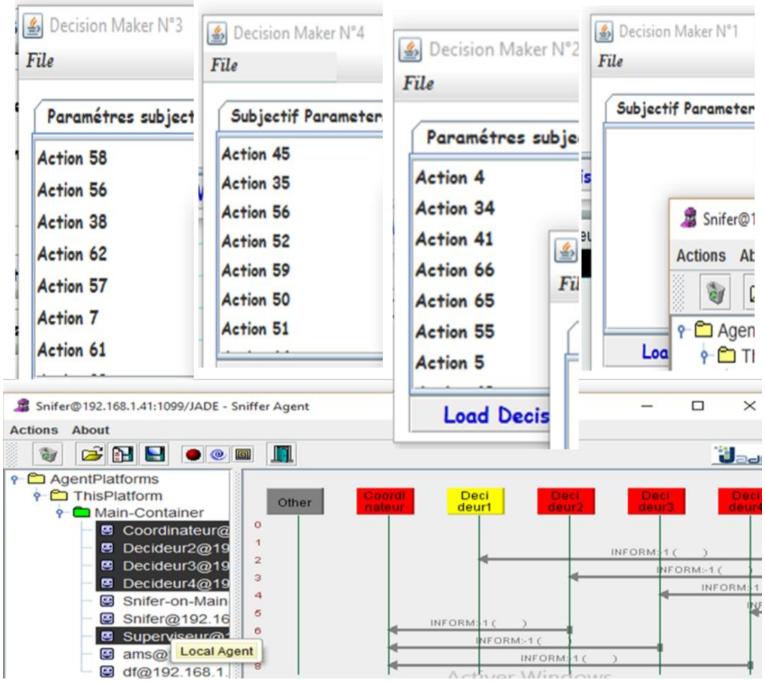


Figure 9. Ranking file of each participant (decision maker)

3. RESULTS AND DISCUSSION

In this section, we present an example of axioms used for semantic matcher. In the context of this paper, we suggest that each individual in OL_i has tree possibilities for semantic matching with entity in GO: *owl:class*, *owl:NamedIndividual* or *rdfs:synonyms*. The participants are the actors how participate in decisional situation for site selection situation. Each participant has a domain of interest which can be different to another. A semantic heterogeneity situation is created. We develop a local ontology specifying the vocabulary of each participant to deal with this.

The different decision makers involved in our study are inspired from Hamdadou and Bouamrane works [48]; We define four DM_i with ($i=1,2,3,4$):
- Decision maker 1: environmental associations representative
- Decision maker 2: politician
- Decision maker 3: economist
- Decision maker 4: public represent representative

3.1. First case: *owl:Class*

The entity e_i in OL_i is one of subclasses of C*riteria* entity in OG, in this case, we use *owl:Class* to get corresponding named Criteria. Figure 10 represent rdf/xml syntax for this example. For "Noise" individual of agent vocabulary (*Preferences* individual of OL), the corresponding entity in global ontology OG is the class with name *owl:Class*: "Noise". The named criteria is extract from *owl:Class* axiom.

```
<!-- http://www.semanticweb.org/aichadell/ontologies/2018/11/OntologyMPHamdadou#Noise -->
<owl:Class rdf:about="http://www.semanticweb.org/aichadell/ontologies/2018/11/OntologyMPHamdadou#Noise">
```

Figure 10. Matching of "Noise" in OL by *owl:Class* axiom in OG

3.2. Second case: *owl:NamedIndividual* of factors class

The entity e_i in OL_i is the same entity in Factors class in OG. We use *rdfs:isDefinedBy* axiom to get corresponding named criteria. Figure 11 represents rdf/xml syntax for this example. For the "Rayonnement" named individual of agent ontology OL, the corresponding named criteria is the class "harm" which is defined by *rdfs:isDefinedBy* axiom.

```
<hasFactors rdf:resource="http://www.semanticweb.org/aichadell/ontologies/2021/7/OntologyNewVersion#Rayonnement"/>
…..
<rdfs:isDefinedBy>Harm</rdfs:isDefinedBy>
```

Figure 11. Matching of "Rayonnement" in OL by *rdfs:isDefinedBy* axiom in OG

3.3. Third case: *rdfs:synonyms*

The entity e_i in OL_i is the same entity in synonyms class in OG, we use *rdfs:synonyms* to get corresponding entity. Figure 12 represents rdf/xml syntax for this example. For named invidual "Equipement" in OL file, the named criteria "Equipment" is extracted from ontology global *OG* as corresponding criteria with *rdfs:synonyms* axiom. Figure 13 show the corresponding between agent 1 criteria and global ontology OG. Table 6 summaries output named criteria after application of semantic matching process for corresponding each individuals in OL_1 with all entities in *OG*.

```
<owl:NamedIndividual
rdf:about="http://www.semanticweb.org/aichadell/ontologies/2021/7/OntologyNewVersion#Equipement">
…..
<rdfs:synonyms
rdf:resource="http://www.semanticweb.org/aichadell/ontologies/2021/7/OntologyNewVersion#Equipment"/>
```

Figure 12. Matching of "Equipement" in OL by *rdfs:synonyms* axiom in OG

As different from our work, in standard GDSS, where preferences of decision makers must be formulated in the same vocabulary as the knowledge base system, all decision maker can applicate MCDM method and give a list of the alternatives ranking. But if we modify the preferences of an agent by assigning terms in another vocabulary or synonyms; this agent cannot give the ranking list and he cannot participate in the negotiation process. Here we are in the situation of no corresponding knowledge is found. By using the ontology, which the main definition is: an explicit formal specification of the terms and relations between them in a domain of interest [23].

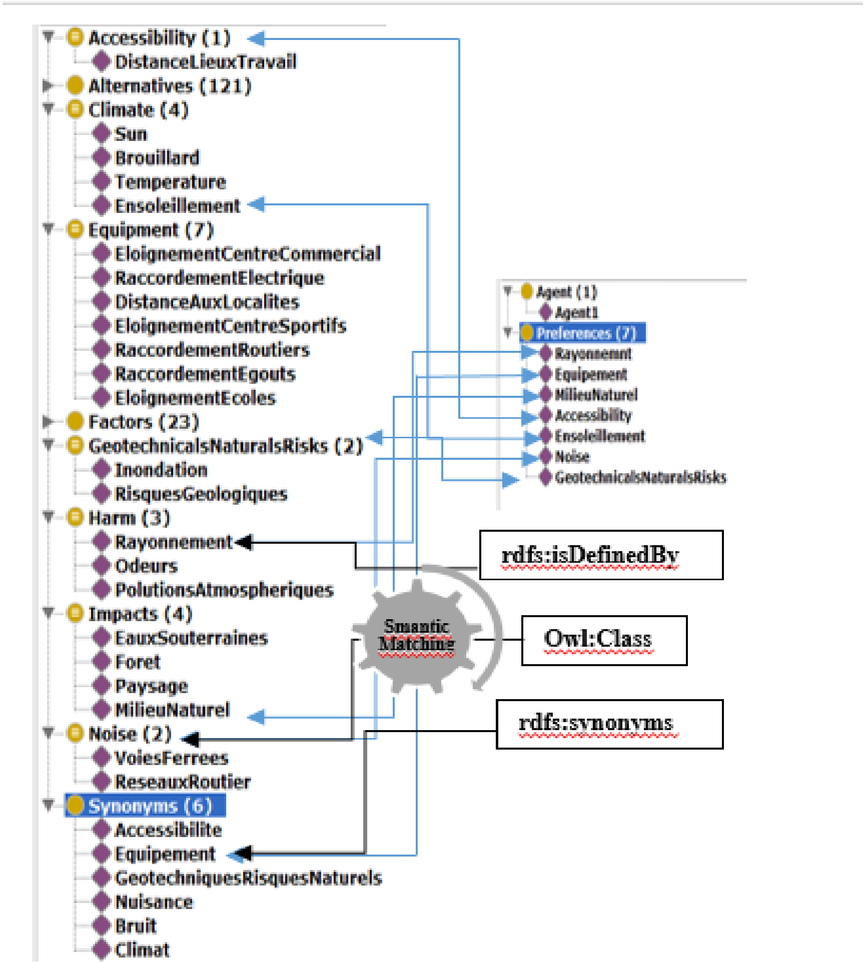


Figure 13. Semantic matching examples with agent 1 entities

Table 6. Matching axiom

Entities in OL_1	Corresponding named Criteria in OG	Axiom of Matching
Rayonnement	Harm	*rdfs:isDefinedBy*
Equipement	Equipment	*rdfs:synonyms*
MilieuNaturel	Impacts	*rdfs:isDefinedBy*
Accessibility	Accessibility	*owl:Class*
Ensoleillement	Climate	*rdfs:isDefinedBy*
Noise	Noise	*owl:Class*

In this work, we define a common vocabulary and a common understanding of information about GDSS domain in the site selection problem. This allows sharing of information between decision makers. To reach the long-term goal of this paper, enabling GDSSs to integrate ontology for representing the decision matrix as a reusable knowledge base can ensure interoperability in GDSS and solve semantic heterogeneity.

By building a global ontology as a common vocabulary for a collaboration set of criteria, alternatives and defining relations and dependencies between them, we enable information exchange between decision makers. The new vision of our system is when agents, and by sharing the global ontology, do not need to have the same knowledge base (preferences/criteria list); each agent knows facts the others do not know. This is in our opinion a great strength of an ontology approach for GDSS systems; each agent can receive a corresponding decision matrix that contains a set of alternatives evaluated on his preferences.

4. CONCLUSION

In this paper, we proposed a new ontology-based GDSS for the site selection problems that provides correspondences between terms in the knowledge base of the site selection problem and the decision maker's preferences. Semantic matching was used for two points: the first one is to connect the participant's vocabulary to the corresponding criteria in global domain vocabulary; the second point is to attribute the preferences of decision makers among the different a set of alternatives. As a result of this system, each participant applies a MCDM to get the ranking file of all alternatives based on their preferences and ignores the vocabulary of the global decision matrix. In addition, this was the main goal of integration ontologies in GDSS. After getting the ranking file, the important step in the site selection problem is negotiation. In this step, all the participants are invited to collaborate and cooperate to arrive at the best solution; a solution that satisfies all participants. This is the negotiation process. In future work, we aim to use ontology in the negotiation process. Our future goal is to develop a negotiation protocol based on an ontology that can extract and enrich the GDSS in its negotiation phase.

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